# Low Impact Development &

# Green Stormwater Infrastucture

# Construction, Inspection, Maintenance, and Monitoring Guidance Manual

Southern California Stormwater Monitoring Coalition
California LID Evaluation and Analysis Network

(SMC CLEAN)

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**Prepared by:**
**Daniel Apt (Olaunu)**
**J. Michael Trapp, PhD (Michael Baker International)**
**Matt Yeager (Riverside County Flood Control and Water Conservation District)**
**Jeanne BenVau (Michael Baker International)**

## EXECUTIVE SUMMARY

Numerous manuals have been developed to guide the implementation of Low Impact Development (LID) Best Management Practices (BMPs) in the Southern California region and nationwide in the past 10 – 15 years. These manuals provide information on site assessment, BMP selection and sizing, BMP designs, required/recommended materials, and recommended maintenance requirements. However, an evaluation of implementation of these BMPs suggests that LID BMPs are often constructed without due care with respect to siting, conformance with design standards, construction practices, materials used, and that inspection and maintenance are often not conducted as needed or required. In addition, it is challenging to conduct hydrologic and water quality monitoring for LID BMPs and Green Stormwater Infrastructure (GSI) features, and there are very few existing datasets representative of southern California.

This manual is a companion document to the LID Manual for Southern California and is designed to address these key implementation challenges in an effort to improve the effectiveness of LID BMPs and GSI as they are more widely implemented. Detailed design guidance for LID practices is included elsewhere (see LID Manual for Southern California or a manual developed for the local jurisdiction). Regulatory requirements for stormwater management vary somewhat across the state and are established in the Municipal Separate Storm Sewer System (MS4) Permits issued by the Regional Boards. Further design, operation, and maintenance information is included in technical design manuals that have been created by the MS4 permittees to guide land developers in compliance with the applicable MS4 permit.

The audience for this manual is intended to be LID/GSI practitioners, land development planners and engineers, staff responsible to manage municipal drainage infrastructure, regulatory agency staff, consulting designers and engineers, contractors, maintenance staff, and asset managers.

This guidance manual focuses on structural LID BMPs and Green Stormwater Infrastructure (GSI) with an emphasis on five key elements required to ensure effectiveness:

- Construction considerations.
- Visual inspections.
- Maintenance procedures.
- Tracking the locations.
- Condition and functionality of LID and GSI features over time through effective asset management, approaches and procedures to monitor their performance in removing pollutants and reducing changes in site hydrology.

Improper implementation of these elements may lead to improper construction or maintenance, which can have detrimental effects on the functionality of the LID/GSI facilities.

LID/GSI construction incorporates site management, planning and scheduling, safety, the use of proper LID/GSI materials, BMP protection, and inspections. Safety protocols must be developed and followed to ensure the safety of staff on-site. Materials used for the construction of LID/GSI facilities must be based on design specifications and stored correctly to prevent contamination or damage. The LID/GSI area must be protected from soil compaction and stormwater run-on during construction. Existing vegetation must be protected from damage from construction equipment. Ongoing construction inspections should be conducted to determine whether the above-mentioned requirements are being met.

The purpose of LID/GSI monitoring is to determine whether or not the implemented BMP provides hydrologic and pollutant reduction benefits as expected based on its design and application. Targeted research questions must be created to guide the creation of a sampling and monitoring plan. Monitoring plans must be designed specifically for each LID/GSI facility.

Periodic visual inspections of LID/GSI measures will confirm whether BMPs are adequately maintained and are functioning as designed. Inspections include assessing whether maintenance is needed, and if so, what type of maintenance is required. Photographs are taken, and field sheets are completed to document the inspections.

Proper maintenance of LID/GSI measures is vital to ensure that these systems continue to function as they were designed. Lack of maintenance may cause the systems to have reduced capacity, clogging, short circuiting, or complete failure. General maintenance includes the correction of: blockages to inlet and outlet structures, erosion on side slopes and bioretention inverts, burrows, emergence of excessive vegetation, graffiti or vandalism, and fence damage.

Verifying and tracking the design, proper installation, location and operating condition LID BMPs within a jurisdiction is crucial for managing maintenance and quantifying aggregate benefits. Maintaining records of BMP metadata is also central to providing background information to jurisdiction staff. Data on LID/GSI facilities is valuable in the long-term as it allows jurisdictions to gauge the effectiveness of LID/GSI infrastructure over time. Data includes water quality monitoring sat as well as meta data including design, inspection, maintenance data, and other data (see Section 6.3). GSI and publicly owned LID systems are a part of public infrastructure and so need to be properly managed as part of a public asset management systems. Effectively tracking private LID BMPs will help to understand the watershed area and volume of stormwater managed which will help with future stormwater management infrastructure planning and water quality standard compliance documentation. All current MS4 permits in Southern California require that post-construction BMPs be tracked and inspected. Development of an effective asset management program for LID BMPs therefore will be an essential part of ensuring LID BMPS are properly constructed and properly functioning.

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| BMP | best management practices |
| BSM | bioretention soil media |
| CASQA | California Stormwater Quality Association |
| CLEAN | California LID Evaluation & Analysis Network |
| EPA | United States Environmental Protection Agency |
| GSI | green stormwater infrastructure |
| LID | low impact development |
| MS4 | Municipal Separate Storm Sewer System |
| O&M | operations and maintenance |
| SMC | Southern California Stormwater Monitoring Coalition |
| SWRCB | State Water Resources Control Board |
| TKN | Total Kjeldahl Nitrogen |
| TPH | Total Petroleum Hydrocarbons |
| WQMP | Water Quality Management Plan |

## GLOSSARY

**Bioretention** – Structural stormwater control practices that biofilter and retain runoff using specific vegetation, mulch, bioretention soils media, aggregate rock, and some cases underdrains. Treatment occurs through filtration, biological uptake of pollutants, adsorption, ion exchange, infiltration and in some cases evapotranspiration.

**Biofiltration** – Structural stormwater control practices that detain and biofilter runoff using specific vegetation, mulch, bioretention soils media, aggregate rock, and underdrains. Treatment occurs through filtration, adsorption, ion exchange, biological uptake of pollutants, and in some cases evapotranspiration.

**Blue Roofs** – Serve as a rooftop storage designed to reduce runoff peaks and volumes, also known as rooftop detention systems. Captured stormwater is held on the rooftop until the water either evaporates or is slowly metered out via flow restriction valves.

**Evapotranspiration** – The loss of water from the soil by evaporation and by transpiration from the plants growing in the soil.

**Green Stormwater Infrastructure (GSI) -** Constructed structural systems that are used to infiltrate, evapotranspire, treat, detain, and/or reuse stormwater. Green Infrastructure uses natural processes for management of stormwater close to its source, thus reducing stormwater runoff and pollutant loading.

**Green roofs** - Vegetated roof systems that filter, absorb, and retain or detain the rain that falls upon them. Green roofs are composed of a layer of soil media planted with vegetation.

**Infiltration basins** - Basins designed to collect and infiltrate stormwater into the ground.

**Infiltration trenches** - Narrow trenches that have been back-filled with stone that allow for stormwater to infiltrate into the ground.

**Low Impact Development (LID)** – Storm water management practices in land development with the primary intent to mimic pre-development hydrology and minimize impacts on the natural environment. Low Impact Development techniques include conserving natural systems and hydrologic functions by managing rainfall at the source using design techniques that infiltrate, filter, store, evaporate, and detain runoff. LID is a comprehensive land development or retrofit approach that includes techniques to conserve and mimic natural hydrologic functions and reduce stormwater runoff and pollutants by managing rainfall, using a combination of LID site planning and LID site design techniques as well as LID structural systems or LID structural BMPs that infiltrate, filter, store, evaporate, and detain stormwater runoff.

**Low Impact Development Site Planning** - Evaluation and planning of a site with the primary planning principle of maintaining or restoring pre-development hydrology and minimizing the generation of runoff.

**Low Impact Development Site Design** – Design techniques to reduce and or disconnect impervious surfaces on a site including designing pervious functional surfaces such as green roofs and pervious pavement.

**Low Impact Development Structural BMPs** – Structural measures that retain or treat stormwater, usually the design capture volume.

**Municipal separate storm sewer system MS4**[1] – Conveyance or system of conveyances that is: owned by a state, city, town, village, or other public entity that discharges to waters of the U.S., designed or used to collect or convey stormwater (e.g., storm drains, pipes, ditches), not a combined sewer, and not part of a sewage treatment plant.

**Pervious pavement** - Pavement with voids that allow flows to be passed to a gravel/sand bed below the pavement for storage, treatment, or infiltration.

**Pervious pavers** - Interlocking units (often concrete) that provide some portion of surface area that may be filled with a pervious material such as gravel.

**Planter boxes** - "Green space" that provides a soil/plant mixture suitable for stormwater capture and treatment, usually associated with bioretention systems.

[1] The regulatory definition of an MS4 (40 CFR 122.26(b)(8)) is "a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains): (i) Owned or operated by a state, city, town, borough, county, parish, district, association, or other public body (created to or pursuant to state law) including special districts under state law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under section 208 of the Clean Water Act that discharges into waters of the United States. (ii) Designed or used for collecting or conveying storm water; (iii) Which is not a combined sewer; and (iv) Which is not part of a Publicly Owned Treatment Works (POTW) as defined at 40 CFR 122.2." (SWRCB 2013)

# 1 INTRODUCTION

The Low Impact Development (LID) land development approach aims to reduce stormwater runoff and pollutants by managing rainfall using a combination of site planning and design techniques and structural systems that infiltrate, filter, store, evaporate, and detain stormwater runoff. The LID Manual for Southern California (LID Manual) provides site planning and design guidance for land development projects for designers, engineers, planners, and municipal jurisdictions at different spatial scales. As a companion document to the LID Manual, this Construction, Maintenance, and Monitoring Manual includes methods and considerations beyond site planning and design of LID measures, with a focus on these critical implementation challenges:

- Proper construction of LID structural measures including considerations, challenges, and practices.
- Monitoring of LID features, including collecting and interpreting monitoring data, analyzing LID site performance with respect to effluent water quantity and quality.
- Performing visual inspections to confirm LID/green stormwater infrastructure (GSI) measures were built per plan requirements and are correctly maintained; and maintenance procedures.

LID Best Management Practices (BMP) siting and design guidance must be followed carefully when planning and constructing practices, including verifying use of specified materials and protecting soil infiltration capacity. Required inspection and maintenance procedures must be conducted throughout the life of the BMP. Where feasible, performance monitoring can demonstrate ongoing BMP effectiveness and achievement of regulatory and environmental protection goals. This guidance manual is focused on LID structural BMPs and is organized into five main elements:

- Construction considerations.
- Visual inspections.
- Maintenance procedures.
- Tracking of structural LID and GSI measures.
- Monitoring procedures.

## 1.1 Manual Overview

1. Introduction
2. LID Construction
3. LID Inspections
4. LID Maintenance
5. LID Asset Management
6. LID Monitoring
7. References

## 1.2 Importance of Proper LID Construction, Inspections, Maintenance, Asset Management and Monitoring

Correct design and construction of LID/GSI facilities is crucial for proper performance. Improperly constructed LID/GSI measures may result in a variety of problems, including poor stormwater infiltration, a reduction in the storage capacity of BMPs, and reduced efficiency in pollutant removal among other things. Poor drainage can result in flooding, standing water and mosquito breeding habitat as well as anoxic conditions that can lead to release of previously captured pollutants. Improper construction of curb cuts and other flow connectivity devices to the BMP may result in flows bypassing the BMP rendering them useless. Improperly constructed BMPs may even contribute pollutants to stormwater such as nitrate or phosphate from the improper use of compost or contribute sediment from BMP erosion (County of San Diego 2016).

Routine inspections of LID/GSI measures ensure that the measures function as designed and provide information on the type and frequency of necessary maintenance. Without routine inspection and maintenance, sediment, trash, and other debris can be trapped and accumulate in LID/GSI facilities, which can impede functionality and reduce capacity. Some LID/GSI measures may also have excess vegetation growth, which can block water from entering or infiltrating effectively. Overgrown vegetation, sediment, and other pollutants must be removed periodically throughout the life span of the BMP to maintain its capacity to process storm water and capture pollutants from every storm event. Alternatively, inadequate vegetation coverage can cause erosion issues in BMPs. Inspections are critical to identify potential problem areas and ensure the ongoing drainage and functionality of the facility (County of San Diego 2016).

Incorporating LID BMPs into a jurisdictional asset management plan is crucial for ensuring adequate tracking, inspection and maintenance. An asset management approach is also useful in documenting the costs, benefits and performance of LID systems, which can inform future stormwater management infrastructure planning. Water quality and hydrologic monitoring data for LID/GSI facilities is valuable in the long-term as it allows jurisdictions to gauge the effectiveness of LID/GSI infrastructure over time. GSI and publicly owned LID systems are a part of public infrastructure and so need to be properly managed as part of a public asset management systems. Effectively tracking private LID BMPs will help to understand the watershed area and volume of stormwater managed which will help with future stormwater management infrastructure planning and water quality standard compliance documentation. All current MS4 permits in Southern California also require that post-construction BMPs be tracked and inspected.

Accurate flow monitoring and water quality sampling data are vital to measuring the pollutant removal and hydrologic performance of LID/GSI measures. Monitoring flow at inlet, outlet and bypass points over time allows for the calculation of treated volume, volume reduction and bypass volume. Volume reduction through infiltration, evapotranspiration and harvest and use is a primary mechanism of LID/GSI measures and can be an important pollutant removal mechanism. The diverse shapes, sizes, and layouts of LID/GSI measures requires monitoring studies be site-specific and tailored to the configuration of the BMP and characteristics of the area. Monitoring studies and the development of targeted research questions help demonstrate whether a LID/GSI facility meets pollution or flow reduction requirements. Water quality sampling and flow monitoring are not typical requirements in MS4 permits so not all LID BMPs need water quality monitoring.

## 1.3 Training and Education

Training and education about different aspects of LID/GSI facilities are critical to proper BMP implementation and functioning. Site planning and design training are important as these inform proper selection, placement, and design of LID/GSI measures. Training for contractors will help ensure that contractors understand the purpose and intent of the LID/GSI measures and will guide the contractors on proper construction of structural LID/GSI measures. It is crucial to provide proper training and education to BMP maintenance staff since LID/GSI measures often require specialized maintenance to perform efficiently. Larger structural BMPs may be more complex to maintain and could require heavy equipment and special training (County of San Diego 2016).

Training is also required to properly perform both visual monitoring and water quality /flow monitoring of LID/GSI facilities. Training includes instruction on how to perform LID/GSI construction inspections, LID/GSI certificate of occupancy inspections, and the routine operations and maintenance inspections. For those performing water quality and flow monitoring of LID/GSI measures, training on monitoring protocols and specifics about LID/GSI monitoring will help ensure the data obtained during the monitoring process is effective.

LID/GSI education and training programs should identify the target audiences. Any LID/GSI training that is completed should be documented. LID/GSI training should integrate adult learning principles and be interactive with exercises and quizzes to engage the trainees. The effectiveness of training should also be evaluated with pre- and post- training surveys (County of Los Angeles Department of Public Works 2014).

# 2 LID CONSTRUCTION

This section identifies considerations that will help ensure LID/GSI structural measures are constructed per the design and perform as intended. Even minor modifications to the design or small elevation changes in elements of a LID/GSI measure can have significant effects on the overall performance and function of the system. Many contractors and subcontractors in California may not be familiar with LID/GSI measures and may inadvertently implement design and/or material modifications that affect overall function and performance. Construction inspections are a significant part of LID construction and details regarding construction inspections are provided in Section 3.1 below. It should be noted that there are also other programs and initiatives that provide guidance regarding the construction of LID and GSI including the San Francisco Public Utilities Commission Green Infrastructure Construction Guidebook (SFPUC 2018) and the National Green Infrastructure Certification Program (NGICP, 2019).

## 2.1 LID/GSI Site Management, Planning, & Scheduling

The development of site management goals is an essential step in the planning of a LID or GSI site. Site management goals are specific to each site but should evaluate the sections identified below including:

1. Protection of existing vegetation and trees.
2. Protection of LID system locations from construction activities and offsite stormwater run-on.
3. Effective erosion and sediment controls.
4. Identification and protection of existing utilities.
5. Protection of LID/GSI construction materials.
6. Protection of LID/GSI vegetation until established, and any other issues specific to the site.

The site management goals and the construction sequencing/schedule should be developed prior to the pre-construction coordination meeting(s) with the contractor and subcontractor(s) (Riverside County Flood Control and Water Conservations District 2015).

### *2.1.1 Construction Sequencing and Scheduling*

Construction sequencing and scheduling is a critical component for the effective implementation of properly performing LID/GSI structural measures. Construction sequencing and scheduling will be different based on whether the LID/GSI site is a retrofit or new construction. With retrofits, in most cases only LID or GSI measures are newly constructed; therefore scheduling is not dependent on completion of other elements of construction.

For new developments construction, sequencing is essential; LID/GSI features should be installed at the end of construction when the surrounding site is complete to avoid the potential for construction materials to contaminate a newly constructed LID/GSI feature. If construction of LID/GSI features are not possible at the end of construction when the surrounding site is complete measures should be implemented to protect the LID/GSI measure locations including conveying stormwater around the

LID/GSI measure locations. Additionally, sequencing construction of LID/GSI BMPs at the end of new development construction tends to cause less conflict with other aspects of construction (Ventura Countywide Stormwater Quality Management Program 2011).

Construction scheduling of LID/GSI measures must consider lead times on specialized LID/GSI BMP materials including:

- Bioretention soil mix.
- Bioretention stone aggregate.
- Plants and Mulch.
- Impermeable liners.

### *2.1.2 Pre-Construction Coordination*

Coordination prior to commencing construction of LID/GSI measures is critical to ensure proper installation and protection of LID/ GSI BMPs during construction. Pre-construction coordination meetings should cover in general all of the information provided in the LID Construction chapter of this manual, however the following subjects should be covered in detail:

- Safety and site management goals for the project.
- Construction documents (design plans) for the LID/GSI measures to be constructed.
- Proper construction sequencing and schedule for the project.
- Critical path/item checkpoints and verification.
- LID construction materials and process for substitutions.
- Communication protocols.

Consistent communication between the construction and design teams is essential for the successful implementation of LID/GSI projects. The contractor, subcontractors, and the designer should all be present in the pre-construction coordination meeting(s) and protocols for communication and for submitting and answering Requests for Information should be discussed during the pre-construction coordination meeting. The construction documents (design plans) should also be reviewed in detail during the pre-construction coordination meeting to allow the contractor or subcontractor to ask questions of the designer.

### *2.1.3 Construction Documents*

The construction documents include the design plans that identify what to build and the specifications that identify how to build it. Construction documents may include the following, however critical must include items have been identified below:

1. Title page that includes the project name, location and designer information (must include).
2. Plan view sheet providing a geographical reference looking down on the project site (must include).

3. The plan view sheet should include a legend, topographic contours, and locations of existing features, proposed LID/GSI measures, utilities, vegetation, and property lines; and in some cases proposed erosion and sediment control BMPs.

4. Section view, also known as cross-sections, of each LID/GSI feature, which provide an overall view of all critical elements and detail views of the LID/GSI measure as seen if viewed across the critical elements (must include).

5. Longitudinal profiles may be provided in some cases to offer.

6. Longitudinal section pertains to a section along the long axis of a structure.

7. Standard details provide a detail view of critical elements such as a LID/GSI measure, and the appurtenant details such as a curb cut or overflow riser (must include).

8. Specifications provide written detailed information on materials used on a construction project as well as the proper technique required for installation/construction (must include).

## 2.2 Safety in and Around LID/GSI

Safety is of concern in the construction of LID/GSI measures, as many elements of construction of LID/GSI systems have hazards associated with them. Safety should be discussed as part of the pre-construction coordination meeting. Safety protocols should include:

- Plans to ensure the site is protected and secured with effective perimeter controls during and after site work hours.
- Traffic safety plan including vehicular, bicycle, and pedestrian plans as appropriate.
- Protocol directing staff to call "Dig Alert" before digging to locate utilities.
- Existing utility protection and marking.
- Identification and safety procedures for overhead power lines.
- Confined space identification, and procedures ensuring workers have proper training before entering.
- Protocols for all workers to wear Personal Protective Equipment (PPE) appropriate to their duties and proximity to other work.
- Schedules for frequent safety meetings to inform workers of and coordinate upcoming construction activities.
- Proper implementation of erosion and sediment controls including dust controls.
- Protocol that calls for the use of trench boxes or shoring in trenches over 4 feet deep.
- Instructions to divert stormwater away from trenches and around the site.

## 2.3 LID/GSI Materials

Use of the specified materials in the construction of LID/GSI measures is essential to LID/GSI performance and durability. It is important to source material before construction begins to ensure that the materials specified in the design plans are available. Lead times may affect the availability of materials such as bioretention soil, non-standard over flow structures, and trench drains. Any proposed changes to the specified materials should be coordinated with the designer (e.g. design engineer) of the project as identified in the pre-construction meeting. LID/GSI materials and a process for substitution of materials should be discussed in the pre-construction meeting. As part of the process the regulatory document such as a Water Quality Management Plan (WQMP) should be reviewed if changes of materials would deem the project non-compliant.

LID/GSI facilities in most cases infiltrate or filter stormwater; therefore, it is essential that the materials used for construction of LID/GSI facilities are clean. Using clean materials such as aggregates will help prevent pollutant export from LID/GSI facilities and prevent the potential for clogging from increased fine particles. All materials should be inspected prior to installation in a LID/GSI system.

Typical materials associated with construction of LID/GSI facilities include:

- Aggregate: Aggregate is washed to remove finer particle sizes. The American Associate of State Highway and Transportation Officials aggregate is used in permeable pavement systems for the aggregate base that provides structural support (particularly for flexible systems such as porous asphalt, pavers and grid systems) and water storage. The aggregate is also used as a drainage/water storage layer under bioretention media. Sand is classified as mineral aggregate ranging in size from 0.0625 mm to 2 mm. Sand is used as a typical component of bioretention media, drainage layers, filter layers under permeable pavement and other LID/GSI practices.

- Bioretention soil media (BSM): Many BSM specifications have been developed but they usually consist of fine sand and compost and sometimes sandy loam.

- Riprap: A mixture of rock sizes and is angular (fractured). Rip rap is used for energy dissipation.

- Mulch: Cover to prevent erosion and support soil retention, retain moisture, reduce weeds, and enhance plant growth. When used in ponding zones, mulch should be aged, stabilized, and non-floating, such as a specified composted wood mulch or coconut fiber. Gravel mulch may also be used when high flow velocities through the system are expected.

- Geotextile fabrics: Used for separation of adjacent native soils from a subgrade of LID/GSI systems. Geotextile fabrics should not be used in the invert of LID/GSI systems.

- Liners and Waterproofing membranes: Thin sheets of synthetic material that do not allow water to pass through. Liners and waterproofing membranes are used in biofiltration systems, bioretention planter boxes, green roofs, blue roofs, and to protect adjacent structures.

All GSI materials should be protected at the construction site prior to installation. Protection includes covering and perimeter control around stockpiles of LID/GSI construction materials. LID/GSI materials should not be delivered to the site until just before their construction: this will reduce the incidence of contamination of the LID/GSI system materials. Avoid placing LID/GSI construction materials in concentrated flow paths and or near catch basins.

## 2.4 Site Layout Survey and Utility Location

Site layout survey and utility locating is primarily associated with LID/GSI retrofit projects and re-development sites. Site layout survey and utility locating is often the first construction activity on site. Verification of how the proposed construction layout interacts with existing infrastructure is essential to efficient construction. Utilities should have been identified and located during the design process through several methods: record plans collected from utility providers, surveys providing locations of utility surface indications, and potholing to determine locations and depths of known critical utility lines that could significantly impact the project design (SFPUC 2018). Overhead, surface, and underground utilities should be evaluated for conflicts with the proposed LID/GSI features. Construction should not commence without a clear understanding of how utility conflicts are to be addressed. Locations of existing or unknown utilities should be identified with the use of as-builts, potholing, ground penetrating radar, or other similar method.

## 2.5 Geotechnical Investigations

Geotechnical investigations to determine infiltration rates, substrate composition, and depth to groundwater should be completed as part of the design phase of any LID/GSI feature. Accurate geotechnical investigations to understand infiltration rates are critical to those LID/GSI measures relying upon infiltration. Once excavation of the location of the LID/GSI features is complete infiltration testing should be completed to confirm the design infiltration rates. Infiltration tests should be performed at the depth of the invert of the LID/GSI system using an approved methodology by the approving jurisdiction. Common infiltration tests include a double ring infiltrometer test and a single ring infiltrometer test, or in drill hole permeability test. A factor of safety should be applied to all infiltration rates when determining the design infiltration rate. The factor of safety is at the discretion of the engineer and/or local jurisdiction based on the underlying soil type and expected sediment loading to the BMP.

## 2.6 Existing Vegetation and Tree Protection

Existing vegetation and trees provide hydrologic benefits by retaining stormwater discharge on site. It is therefore essential to protect existing vegetation and trees outside the area of disturbance of the project, especially since vegetation takes time to regrow. Trees are susceptible to damage from soil compaction near the root zone that may be caused by construction equipment. Tree branches may also be damaged by large overhead equipment such as excavators. Construction stormwater should be routed away from existing vegetation with gravel bags to avoid impacts to vegetation. Trees should be taped off at the drip line to warn on-site workers to avoid using construction equipment or storing equipment or materials too near the trees.

## 2.7 BMP Area Protection

As the surrounding site is constructed, it is critical to protect of the on-site locations where the LID/GSI measures will be implemented. It is important to protect the LID/GSI areas from compaction, sedimentation, and pollutants. Areas where LID/GSI measures will be constructed should be taped off and surrounded by gravel bags to prevent sedimentation and deposition of other pollutants.

LID/GSI locations should only be excavated when the site is ready for construction of the LID/GSI measure. If excavation of LID/GSI areas is necessary, a 6-inch layer of soil above the excavation depth should be left in place to help protect the future system. Whenever possible, machinery performing excavation for LID/GSI measures should be located adjacent to, not inside of, the LID/GSI BMP when in operation. When machinery must operate in the LID/GSI BMP due to size or location, the soils engineer should be consulted for strategies to minimize compaction and implement re-scarification of the compacted area.

Locations of future LID/GSI measures in many cases are in low depressed areas where stormwater naturally flows. These areas should not be used as temporary sediment basins during construction and construction stormwater should be conveyed around these areas if possible. Construction stormwater flows may carry fine sediment into the LID/GSI area which may reduce or eliminate the ability of these locations to infiltrate stormwater, negatively affecting the overall LID approach for the site. Additionally, the weight of the water may result in compaction of the area including the substrate, which would reduce or eliminate the infiltration capacity of the future LID/GSI measure.

## 2.8 Erosion and Sediment Controls

An effective combination of erosion and sediment controls are needed for construction sites, especially for the protection of future and existing LID/GSI measures. Erosion BMPs are designed to keep sediment from being mobilized by runoff, whereas sediment BMPs are designed to capture sediment from discharge off-site. The Erosion and Sediment Control Plan for the site should include specific protections for future locations of LID/GSI measures. The California Stormwater Quality Association (CASQA) Construction BMP Manual should be consulted for a full suite of construction site stormwater management BMPs (CASQA 2018a).

## 2.9 Bioretention Specifics

Although all of the above construction sections apply to bioretention systems, there are construction considerations specific to bioretention systems:

- Filter fabric is not to be used in the invert LID/GSI landscape features as it may cause long-term clogging and system failure.
- Ensure that the bioretention soil mix used is per the design specification and is not mixed on-site using native soils.
- Compaction of the bioretention soil mix should adhere to the compaction procedures identified in the BSM specifications. Do not use mechanical compaction equipment for BSM compaction.
- Verify BSM elevations per the design plans.
  - Ensure final grades are maintained upon completion of plant and mulch installation (if used).
  - Excess soil from planting should be exported or reincorporated to meet design contouring.
- Ensure bioretention plants adhere to the planting plan.
- Ensure bioretention plantings are protected until established enough to endure stormwater flows.

- Ensure a non-floating mulch is used such as aged compost or coconut fiber. Wood mulch will float and clog overflows.
- Ensure that overflow risers are not at the elevation of the bioretention system. They need to be raised to allow for ponding, otherwise stormwater will discharge out of the riser and not filtrate into the BSM.
- Ensure structural capacity of bioretention systems adjacent to streets and parking lots or other areas that have potential structural issues.
  - Because bioretention soil is not compacted, planter walls require proper structural support such as continuous footings or lateral bracing to maintain the structural integrity required for adjacent use loadings.
  - For side sloped-style bioretention systems maintaining a native soil bench adjacent to the bioretention system can help maintain structural support.
- For bioretention systems on greater than a 2% slope check dams should be integrated into the system. Check dams can be made of concrete, rock, or steel.
- Ensure energy dissipaters are integrated into the bioretention system at the inlets so that erosion does not occur. Concrete splash pads and cobble are effective energy dissipaters.

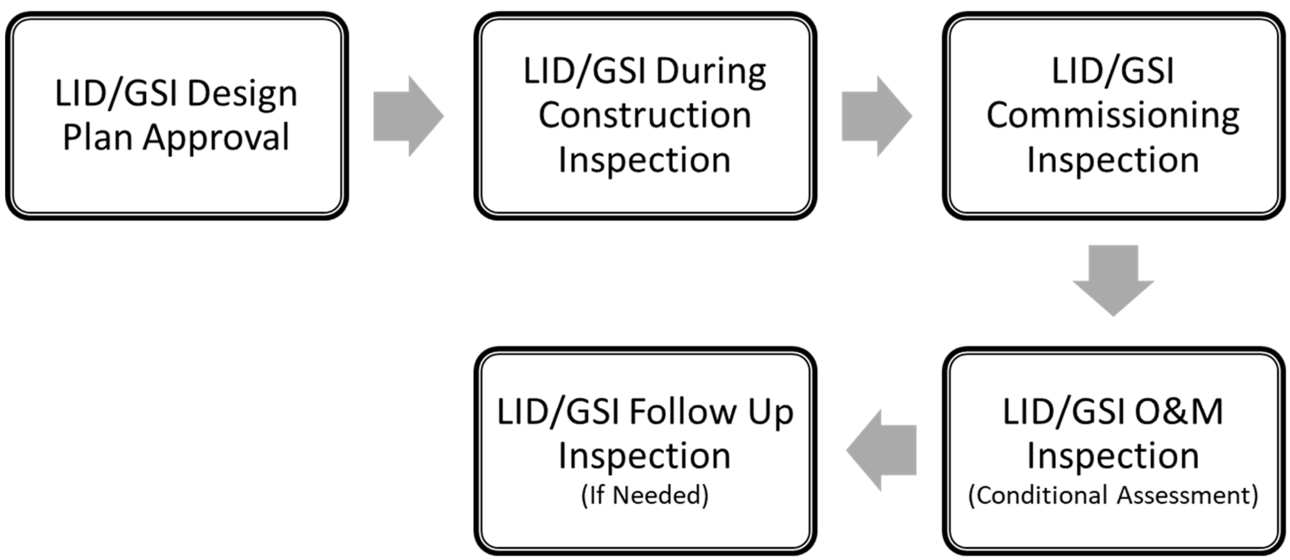
# 3 LID INSPECTIONS

Visual monitoring of LID/GSI measures in the form of inspections is an important element to ensure that LID/GSI measures have been constructed per the design plans and are effectively being maintained to ensure their proper function and performance. The following are the three types of inspections associated with LID/GSI measures:

- **During Construction –** Verify BMPs are being constructed in accordance with the approved design plans.
- **Commissioning/Construction Complete** - Verify BMPs were constructed in accordance with the approved design plans.
- **Operations and Maintenance (O&M) Inspections/Conditional Assessments** – Verify BMPs are present and functional, and that the area is well maintained.

Figure 3-1. LID/GSI Measures Process of Inspections below identifies the process of inspections for LID/GSI measures.

**Figure 3-1. LID/GSI Measures Process of Inspections**




## 3.1 Construction Inspections

Inspections during the construction of structural LID/GSI projects are critical to ensure that the LID/GSI measures are constructed per the approved design, with acceptable materials, and that proper construction procedures are implemented. BMP inspections are recommended at each stage of construction. At least one inspection should take place, but several inspections are optimal to observe the various stages of construction of a LID/GSI measure. The following are the stages of construction where construction inspections should occur using bioretention as an example:

1. Completion of initial excavation.
2. Placement of aggregate layer.
3. Placement of bioretention soil media.
4. Planting of bioretention plants.

Any changes or modifications to the BMPs that occur during construction should be documented as part of the as-built drawings for the project. LID/GSI projects construction inspections should:

- Verify the presence, location, footprint, type and configuration of each LID/GSI measure.
- Evaluate if the LID/GSI measure is built per the approved design plans including all constructed elements based on the stage of construction completion.
- Verify that the LID/GSI measure inlets, outlets, and invert are at the elevations identified in the design plans to ensure conveyance of inflows and outflows.
- Evaluate if the correct BMP materials are used for the LID/GSI measure and installed correctly.
- Identify if machinery performing excavation is adjacent to, and not inside of the LID/GSI measure footprint.
- Evaluate if the LID/GSI BMP area is being protected from construction traffic and debris to prevent compaction, sedimentation, and construction pollutants.
- Confirm the drainage area contributing runoff to the LID/GSI measure and evaluate the condition of the drainage area; including the land use and use intensity, status of surrounding construction, and the surface cover condition.
- Evaluate if proper construction sequencing is being implemented:
    - The LID/GSI BMP measure is one of the last items constructed onsite.
    - Excavation for LID/GSI BMPs is completed after adjacent construction is complete.
- Photographs of the LID/GSI measure.

## 3.2 Commissioning Inspections

After construction of a LID/GSI structural measure is complete, a commissioning inspection is performed as a final check to ensure the measures were built per design plans and, if any modifications occurred, that the changes are documented. This final check is similar to the commissioning of other infrastructure or buildings. The verification of structural LID/GSI measures, updates to reports, and records of a maintenance agreement may occur concurrently with project closeout or may be required prior to final construction completion based on local requirements.

Project close-out procedures for new and redevelopment sites typically include field verification that site design, source control and treatment control BMPs are designed, constructed and functional in accordance with the approved site plans. Documentation is submitted of the field verification, including tracking number, if applicable, and information on the type, location and maintenance responsibility of the BMPs.

Commissioning inspections should:

- Verify the LID/GSI measure existence, location, footprint, type and configuration.
- Evaluate if the LID/GSI measure is built and sized per the approved design plans including all constructed elements.
- Identify conveyance to the LID/GSI measure and that LID/GSI measure inlets, outlets, and invert are at the elevations identified in the design plans.
- Confirm the drainage area contributing runoff to the LID/GSI measure and evaluate the condition of the drainage area; include the land use and use intensity, if the surrounding construction is complete, and the surface cover condition in the drainage area.
- Identify if the overflow structure/outlet is at the proper elevation.
- Take photographs of the LID/GSI measure areas mentioned above.

Vegetation condition is assessed during commissioning inspections since plant installation is usually the last step in LID/GSI measures construction. The condition of the plants in bioretention, biofiltration, and bioswale type LID/GSI measures must be evaluated and documented, including observation of the following:

- If vegetation is planted per the specifications or an identified plant list.
- If the vegetation percentage coverage, placement, and spacing is consistent with the planting plan.
- If the proper mulch has been used.
- Whether the BMP is offline until vegetation is established.
- If the irrigation system is installed per the irrigation plan and is functioning properly.

## 3.3 Operation and Maintenance Inspections (Conditional Assessments)

Operations and maintenance (O&M) inspections also called conditional assessments, are typically performed on an annual basis to ensure the LID/GSI structural measures are adequately maintained and functioning. Additionally, some LID/GSI BMPs are required to be inspected after significant storm events, with a significant storm event varying by the location of the LID/GSI measure. LID/GSI structural measures are subject to sediment, trash, and other debris build up which can impede infiltration or biofiltration. Excess vegetation can reduce infiltration or biofiltration, while LID/GSI structural measures lacking proper vegetation density can cause erosion of sediment.

LID/GSI structural measures maintenance requirements are included in the LID/GSI O&M plan that is usually attached to the approved water quality compliance plan [e.g. WQMP, Standard Urban Stormwater Mitigation Plan]. Operation and maintenance inspections/conditional assessments should:

- Verify the existence, location, footprint, type and configuration of the LID/GSI measure.
- Evaluate if the LID/GSI measure is built and sized per the approved design plans including all constructed elements.
- Identify conveyance to the LID/GSI measure and verify LID/GSI measure inlets, outlets, and invert are at the elevations identified in the design plans.
- Confirm the drainage area contributing runoff to the LID/GSI measure and evaluate the condition of the drainage area; including the land use and use intensity and the surface cover condition in the drainage area.
- Identify if the overflow structure/outlet is at the proper elevation.
- Identify if any short circuiting is occurring.
- Identify if maintenance is needed per maintenance triggers in the O&M plan including:
    - Visible erosion, which may require energy dissipation or the addition of vegetation.
    - Vegetation
        - Observe if plants installed are per the specifications or from an identified plant list.
        - Observe if the vegetation percent coverage, placement, and spacing is consistent with the planting plan.
        - Observe if the proper mulch has been used and whether it needs replacement.
        - Observe if vegetation removal is required, such as invasive, woody, or dead vegetation.
    - Sediment accumulation in inlets and in the LID/GSI measure.
    - Presence of trash and/or debris.
    - Whether the capacity of the LID/GSI measure is reduced by sediment and vegetation.
    - Check infiltration rates with simple tests.
- Photographs of the LID/GSI measure.

A number of jurisdictions have created fact sheets that outline schedules for inspection activities for LID/GSI measures such as infiltration trenches, permeable pavement, and bioretention. O&M inspection activities during dry weather of common LID/GSI measures are listed below.

### 3.3.1 Permeable pavers/pavement

- Ensure the design infiltration rate is maintained for the majority of the BMP.
- Ensure sediment and debris have not accumulated and caused surface sealing.

### 3.3.2 Bioretention basin

- Ensure BMP is free of damage. Vegetated BMPs should be free of erosion or scouring.

- Remove significant sediment, trash, and/or debris accumulation.
- Ensure BMP inlets and outlets are free of obstructions. Obstructions may be caused by sediment, trash, and debris, or by excessive vegetation.
- Ensure BMP is free of standing water and unpleasant odors.
- Ensure vegetated BMPs maintain sufficient ground cover per the design. Vegetation should be healthy, but not overgrown.
- Infiltration Basin.
- Maintain vegetation, avoiding fertilizers, pesticides and herbicides.
- Remove debris and litter from basin.
- Check for ponding water, odor, and insects.
- Check for erosion and sediment accumulation in the basin.

## 3.4 Inspection Protocols

For all LID/GSI facility inspections, the following is a list of what can be completed in the office prior to a field inspection:

- Review water quality plan, design plans, specifications, and O&M plan.
- Determine the contributing drainage area of the BMP.
- Identify BMP type, configuration, location, and footprint.
- Review design specifications for BMP materials (construction inspection).
- Review plant specifications (certificate of occupancy/O&M inspection).
- Identify the O&M requirements and triggers (O&M inspection).

## 3.5 Inspection Checklists

Accurate and complete LID/GSI inspection forms are vital to maintaining precise LID/GSI maintenance and performance data over time. Example LID/GSI inspection and verification forms are included in Appendix A.

# 4 LID MAINTENANCE

Proper maintenance of LID/GSI measures is important to ensure that these systems continue to function as they were designed. Lack of maintenance may cause the systems to have reduced capacity, clogging, short circuiting, or complete failure. Performing effective maintenance of LID/GSI measures on a regular basis ensures they will continue to function properly, meet performance standards associated with their design, and provide pollutant removal and hydrologic benefits (Riverside County Flood Control and Water Conservation District 2011). This section identifies types of maintenance and some maintenance challenges associated with commonly implemented LID/GSI measures. It should be noted that there are also other programs and initiatives that provide guidance regarding the maintenance of LID and GSI including the San Francisco Public Utilities Commission Green Infrastructure Maintenance Guidebook (SFPUC 2018) and the National Green Infrastructure Certification Program (NGSICP 2019).

## 4.1 Maintenance Challenges

Maintenance of LID/GSI measures can present significant challenges that should be considered with the installation of LID/GSI measures and in planning for maintenance of existing measures. Some of these challenges are more overarching and others are more specific to certain LID/GSI measures and their associated elements.

<u>Maintenance Training</u>: Proper education and training of maintenance staff and crews is essential to proper function of LID and GSI systems and continues to be a significant challenge as some maintenance staff and crews may not be familiar with LID/GSI measures. In some cases, if LID/GSI measures are not maintained correctly, the performance of these systems can be diminished greatly. Effective and consistent training of maintenance personnel will help ensure long term functionality of LID/GSI measures.

<u>Distributed BMPs</u>: Another maintenance challenge is related to the nature of LID/GSI measures as distributed systems. As opposed to regional or centralized structural BMPs, LID/GSI measures are designed to manage stormwater at its source. Because of the LID/GSI approach, a larger number of smaller systems are integrated in specific drainage areas. An increased number of smaller LID/GSI systems results in an increased amount of maintenance responsibility and an increased cost associated with that maintenance. Additionally, more LID/GSI measure inspections need to be performed, which also results in higher costs. An increased number of LID/GSI measures within a jurisdiction can strain existing municipal budgets for both maintenance of LID/GSI measures in the public right-of-way and on inspections of LID/GSI measures in both the public right-of-way and for private developments.

<u>Inspection Training</u>: Education and training of inspectors is yet another challenge, as some inspectors may not be familiar with LID/GSI BMPs and need to be trained for different levels of inspections (identified in Section 3.7). Untrained inspectors may not be able to identify different types of LID/GSI measures and how they function. If inspectors cannot understand the LID/GSI BMPs during construction, the LID/GSI measure may not be identified as incorrectly constructed. Additionally, some inspectors may not understand different LID/GSI maintenance triggers which results in ineffective inspections and poorly maintained LID/GSI systems.

Some specific challenges associated with maintenance of LID/GSI systems include the following (Orange County Public Works 2011):

- Vegetation management
    - Overgrowth
    - Barren areas
    - Dying or dead vegetation
    - Vegetation identification
- Erosion issues
    - Lack of energy dissipation
    - Replacement or addition of plants
    - BMP brought online before plants became established
- Sediment and trash accumulation
    - Blocking inlets
    - Capacity reduction and clogging

Maintenance Information Tracking: As the number of constructed LID/GI measures increases and the resulting maintenance requirements also increase, the time and effort needed to adequately track LID/GI maintenance can become more time-intensive and challenging. Tracking of maintenance should include 1) the maintenance action that was performed (e.g. vegetation removal); 2) quantification of maintenance action (e.g. volume of sediment removed); and 3) costs to perform the maintenance including labor costs (e.g. labor hours) and other costs (e.g. hauling and dumping fees). Maintenance tracking is also identified in the Section 5 Asset Management under subsection 5.1 Record Keeping.

## 4.2 Bioretention Maintenance

Bioretention systems are the most common type of LID/GSI measure as they are versatile and can be implemented with many different configurations. Bioretention systems slow, clean, and infiltrate stormwater, which reduce the volume of stormwater runoff and its associated pollutants. Bioretention systems are composed of:

1. Aggregate layer at their base to allow for storage of stormwater.
2. Engineered BSM that helps to remove pollutants and provides a growing media for the plants.
3. Specific bioretention plants that are selected based on the climate zone and the ability to be inundated with stormwater.
4. Non-floating mulch layer to protect the soil and keep it moist, which helps with plant health.

Additionally, depending upon the configuration, bioretention systems may have structural components such as overflow risers, curbs, inlets, energy dissipaters, and other appurtenant elements.

Some bioretention systems may have underdrains and so function as more of a biofiltration system. These bioretention systems with underdrains biofilter stormwater and then discharged the water to the storm drain system. Some bioretention systems are designed with side slopes and others are designed as concrete bioretention planter boxes. The following sections address the maintenance triggers and tasks associated with bioretention systems.

### *4.2.1 General Maintenance*

General maintenance includes inspection or observation of inlet and outlet structures, side slopes and bioretention inverts, erosion, burrows, emergence of trees or woody vegetation, graffiti or vandalism, and fence damage. Inspections or observations performed by maintenance staff are critical as the operations and maintenance manual for a site should identify maintenance triggers that can be observed by maintenance staff to identify when certain types of maintenance are needed. General maintenance should consider the following:

- Proper and timely maintenance is essential to continuous and effective operation.
- All structural components must be inspected, at least once annually, for cracking, subsidence, spalling, erosion and deterioration.
- Components expected to receive and/or trap debris and sediment must be inspected for clogging annually prior to the wet season, as well as after every storm exceeding 1 inch of rainfall.
- Sediment removal should take place when all runoff has drained, and the basin is dry.
- Disposal of debris, trash, sediment and other waste material must be done at suitable disposal or recycling sites and in compliance with all applicable local, state and federal waste regulations.
- Maintenance frequency: Annually or after rain events of 3 inches or more.
- Maintenance indicators: Standing water 96 hours after a storm event; burrows, holes, or mounds; debris or trash present; sediment depth exceeds 10% of the facility design; erosion.
- Recurring conditions in a bioretention system after significant storm events such as sediment accumulation that may indicate an issue with the bioretention system or the drainage area to the bioretention system.

### *4.2.2 Drainage Time*

Effective drainage of bioretention systems is essential to their proper function. Drainage time provides a good trigger to identify if a bioretention system is functioning properly. Specifics about drainage time include the following:

- The bioretention system must be inspected at least annually to determine if the infiltration or biofiltration capacity of the basin has decreased.
- Ponded water and drawdown failure can be caused by the following:
    - Crusting or sealing of the soil surface via accumulation of fine-grained soil, organic matter, etc.
    - Heavily compacted soil.

- Large amounts of sediment accumulation in the soil.
- Blocked or clogged overflow structures.

- If the bioretention system fails to drain the design storm within 96 hours, consider the following:
  - Remove excess sediment.
  - Remove dead and excess vegetation.
  - If bioretention system continues to fail to drain after removal of excess sediment and excess vegetation:
    - Pump water and use for non-potable use (i.e. dust control). Do not discharge pumped water downstream.
    - Flush bioretention system cleanout ports if available.
    - If the bioretention system does not drain, evaluate replacement of top 2-3 inches of BSM for the entire bioretention area and replace if necessary. Typical replacement method to avoid compaction consists of removing the top 2-3 inches of BSM by hand with shovels, properly disposing of the BSM at an approved facility, and then shoveling by hand 2-3 inches of new BSM to replace the removed BSM.

### *4.2.3 Trash / Debris Accumulation*

Excessive trash or debris accumulation causes problems that extend beyond poor aesthetics. Trash and debris accumulation can clog or inhibit the infiltration or biofiltration capacity of the BSM, and clog overflow structures of bioretention systems. Clogged or inhibited infiltration or biofiltration capacity could lead to extended drawdown times and unwanted ponding. Additionally, clogged overflow structure grates can lead to overflowing and flooding.

- All trash and debris should be removed from bioretention systems before the start of the rainy season (October 1) or as frequently as site conditions dictate. All material should be discarded at an appropriate facility.
- Maintenance Indicator: Excessive debris or trash present, where trash could inhibit the capacity or the function of the bioretention system.

### *4.2.4 Sediment Management*

Some sediment accumulation in bioretention systems is normal and expected; however excess sediment in bioretention systems will reduce their capacity and could clog the basin in its entirety.

- Steps must be taken to remove sediment accumulation on an annual basis (or more often, depending on site conditions) to keep the bioretention systems functioning properly. This built-up sediment must be removed to ensure water can flow freely into and through the bioretention systems, as well as to maintain the BSM filtration and infiltration capacity. Typical removal methods consist of removing sediment with shovels and properly disposing of the sediment at an approved facility.
- Replace any damaged vegetation as a result of removal of sediment in bioretention system.
- Investigate the source of excess sediment in the drainage area to the bioretention system.

- Maintenance Indicator: Sediment depth exceeds 10% of the bioretention system design or drain time exceeds 96 hours.

### 4.2.5 Bioretention Soil Media Repair/Erosion

Inflow and water movement through bioretention systems may cause erosion and scouring of the BSM surface over time, or immediately after construction during the plant establishment period. Erosion and subsequent sediment deposition can be detrimental to the BSM filtration capacity, cause damage to plants, and create clogging in overflow structures.

- Repair measures must include identifying and correcting the cause of the erosion by repairing the erosion damage and removing any sediment created by the erosion process.
- Identify if erosion is caused by lack of energy dissipation, or damaged energy dissipation in the bioretention system. If necessary add energy dissipation and flow dispersal measures to reduce channelized flow (rock cobble or rip-rap level spreader, etc.).
- Reseed and/or revegetate barren spots as appropriate for the area.
- Re-mulch as necessary.
- Maintenance Indicator: Erosion on the side slopes or invert of the bioretention system, rilling on the side slopes of the bioretention system, and/or erosion near inlet or outlet riser.

### 4.2.6 Vegetation Management

Since vegetation plays an important role in treatment processes and supports infiltration or biofiltration capacity, healthy and well-established vegetation is essential for bioretention systems. Thus, vegetation replanting and removal of weeds and dead plants are important, especially in the first one -year establishment period. Vegetation also helps to stabilize side slopes, prevent erosion, and enhance filtration into the engineered soil media by creating pathways for water to infiltrate along plant root structures. In addition to supporting evapotranspiration, plant roots help aerate the soil, minimize soil compaction, replenish organic materials in the soil, and provide a habitat for beneficial bacteria that aid in the biological breakdown and mitigation of pollutants deposited by stormwater into the facility.

Excessive vegetation can degrade bioretention systems by taking up basin capacity and blocking of overflow risers. Poorly-sited, spreading or overgrown plant material can create blockages at the inlet point of bioretention systems. Overgrown vegetation can block stormwater flows from entering the facility, potentially causing stormwater to pond upstream of the inlet or bypass the unit entirely. If only a portion of the design capture volume of stormwater can enter the bioretention system, the facility function will be significantly diminished. Maintenance practices associated with LID/GSI facility vegetation include the following:

- Cutting or removing vegetation and clippings as appropriate.
- Removal of any emergent trees, or woody vegetation.
- Any plant material that blocks the inlet of a facility must be pruned, thinned, or be removed and disposed of.

- Removal of excess vegetation that reduces the capacity of the bioretention system.
- Dead, diseased, dying, or missing plants must be replaced. If many plants have died, consult with a horticultural expert on the cause of the die-off, and remedy the cause before replanting.
- Maintenance Indicator: Emergence of trees or woody vegetation; average plant height is greater than 12 inches.

### *4.2.7 Rodent Damage and Burrowing*

Rodent damage and animal burrows in bioretention systems can cause structural, landscape, and stormwater flow-based issues. Burrows can undermine structural components, leading to unwanted settlement. Burrows may also create preferential flow paths through the section of the berm, causing piping and erosion problems in the berms. Rodents can also damage plants and plant root systems.

- If rodent or other animal damage is observed, consult a licensed professional pest control service for eradication, or trapping and relocation, as appropriate.
- Where burrows cause seepage, erosion, or leakage, backfill firmly.
- Maintenance Indicator: Visible borrows, holes, or mounds.

### *4.2.8 Structural Damage*

Minor damage to structural components such as bioretention system edges or overflow structures should be repaired on a yearly basis. More significant structural damage must be repaired as soon as possible.

- Minor repairs can consist of, but are not limited to, patching chips and cracks to concrete structures and resetting outlet structure frames and grates. Major repairs can consist of removal and replacement of damaged overflow risers, or structural bracing and supplemental reinforcement of failing structural components.
- Maintenance Indicator: Minor or major structural damage. Inspect after all large earthquakes (Magnitude 5.0 or higher) or other incidents that may affect the bioretention system.

### *4.2.9 Life Span*

The life span of bioretention systems can be up to 20 years and potentially longer if properly maintained. Bioretention life span depends significantly on the maintenance of the bioretention system and the stabilization of the bioretention system drainage area. More sediment entering the basin equates to a reduction in the bioretention system life span.

## 4.3 Permeable Pavement

Permeable pavement includes a range of different types of systems that allow stormwater to drain through the pavement surface and into its base. Permeable paving consists of a porous surface layer and an underlying clean aggregate layer. The aggregate layer provides temporary storage until stormwater infiltrates into the soil below or in some cases flows to a perforated pipe underdrain. General types of permeable pavement include permeable pavers, pervious concrete, and porous asphalt.

### 4.3.1 General Maintenance

General maintenance includes inspection of the pavement surface, the surrounding areas of the pervious pavement, and the upstream drainage area of the permeable pavement. General maintenance and inspection should consider the following:

- Proper and timely maintenance is essential to continuous and effective operation of permeable pavement and to prevent clogging.
- Maintenance Indicator: Standing water visible on the pavement more than 48 hours after the most recent rainfall; structural damage to the pavement, or broken pavers; weed growth, sediment, vegetation, or other material clogging the permeable pavement surface; signs of contamination on the pavement surface.

### 4.3.2 Trash / Debris Accumulation

Excessive trash or debris accumulation causes problems that extend beyond poor aesthetics. Trash and debris accumulation can clog or inhibit the infiltration or filtration capacity of the permeable pavement system. Clogged or inhibited infiltration or filtration capacity could lead to unwanted ponding.

- All large trash and debris should be removed from the permeable pavement system before the start of the rainy season (October 1st) or as frequently as site conditions dictate. All material should be discarded at an appropriate facility.
- Large trash and debris should be removed before sweeping or vacuuming the permeable pavement.
- Smaller trash and debris can be removed by routine vacuuming.
- Rakes and leaf blowers can be used to remove leaves.
- Maintenance Indicator: Excessive debris or trash present, to where the function of the permeable pavement could be affected.

### 4.3.3 Vacuuming

- Sediment and smaller debris accumulated on the permeable pavement can clog the surface and prevent stormwater infiltration or filtration. After large trash and debris have been removed, permeable pavement should be vacuumed to clear all sediment and other debris from the pavement surface. (SFPUC 2018). The following are considerations for vacuuming: Prior to vacuuming, remove bulky debris and waste materials from pavement surfaces that are too large to be picked up by vacuum hose (e.g., litter, tree branches, wire, car parts).
- Vacuum sediment and debris from the entire surface area of the permeable pavement installation using a dry vacuum.
- Give extra attention to pavement edges and areas where sediment has accumulated.
- Sweep up sediment and debris from surrounding surface areas, especially those that slope toward the permeable pavement.

- Note and report damage in pavement, including holes, cracks, excessive scuffing, settlement, and areas of standing water.
- It is important to vacuum the sediment and debris from upstream, or highest point, to downstream, or lowest point, to prevent any sediment from being carried back onto the vacuumed surface.
- Maintenance Indicator: Surface Ponding (> 48 hours after rainfall), excessive sediment or other material logged in the voids of the permeable surface.

### *4.3.4 Pressure Washing and Restorative Vacuuming*

Permeable pavement is intended to let water pass through its surface into the aggregate base and soil below or into underdrains. Over time, deep cleaning and unclogging of permeable pavement may become necessary and is best accomplished by simultaneous pressure washing and restorative vacuuming. (SFPUC 2018). The following are the considerations for pressure washing and restorative vacuuming:

- Do not use extremely high pressures with a pressure washer. High pressures can dislodge joint aggregate in unit pavers or damage pervious concrete and porous asphalt surfaces.
- Prior to vacuuming or pressure-washing, remove bulky debris and waste materials from pavement surfaces that may be too large to be picked up by a vacuum hose (e.g., litter, tree branches, wire, car parts).
- Vacuum and pressure wash impacted areas of the permeable pavement.
- Dispose of the sediments and debris at an appropriate facility.
- Note and report any damage in the pavement, including holes, cracks, excessive scuffing, settlement, dislodged aggregate, and areas of standing water.
- After vacuuming and pressure washing permeable pavers, re-joint the pavers with the appropriate aggregate based on the original design or the paver manufacturer's recommendation.
- Maintenance Indicator: Extended Surface Ponding (> 48 hours after rainfall), excessive sediment or other material logged in the voids of the permeable surface.

# 5 LID/GSI BMP Asset Management

Effective asset management and tracking LID/GSI facilities within a jurisdiction is crucial for managing maintenance and quantifying aggregate benefits. First, it is important to identify where LID/GSI measures are located within the jurisdiction and in which watershed they are located. LID/GSI facility owners must report changes in ownership and responsibility for the operation and maintenance of post-construction LID/GSI measures to the corresponding jurisdiction to ensure the changes are properly recorded in public records. LID/GSI facility ownership and operation change information must be conveyed to all appropriate parties when there is a change in project or site ownership (County of San Diego 2016). LID/GSI facility owners must at least provide the following information to the jurisdiction:

- Local project identifier and description of the project (such as application number, tentative tract number, review number, etc.).
- Type of structural treatment control BMPs.
- Location of BMPs.
- Parties responsible for construction and, operation and maintenance (SARWQCB 2011).

## 5.1 Recordkeeping

Maintaining records of BMP metadata is also central to providing background information to jurisdiction staff. For example, a new inspector performing operation and maintenance LID/GSI facility inspections would need to have several pieces of information before being able to properly perform a maintenance and operation BMP inspection, such as:

- BMP site and maintenance plan or as-built construction plans.
  - Location of the BMP.
  - Owner contact information.
  - Type of BMP.
  - BMP dimensions and functionality.
  - How the BMP must be maintained and how often.
- Inspection history.
  - Past inspector(s).
  - Frequency of inspection.
  - Past inspection results.
  - Historical issues.

Additionally, record keeping can help with future planning for maintenance of LID/GI BMPs. Tracking of maintenance performed is critical to being able to forecast future operation and maintenance costs of LID/GI BMPs. Tracking of maintenance performed should include:

- Maintenance activity
- Quantification of maintenance action
- Costs to perform the maintenance

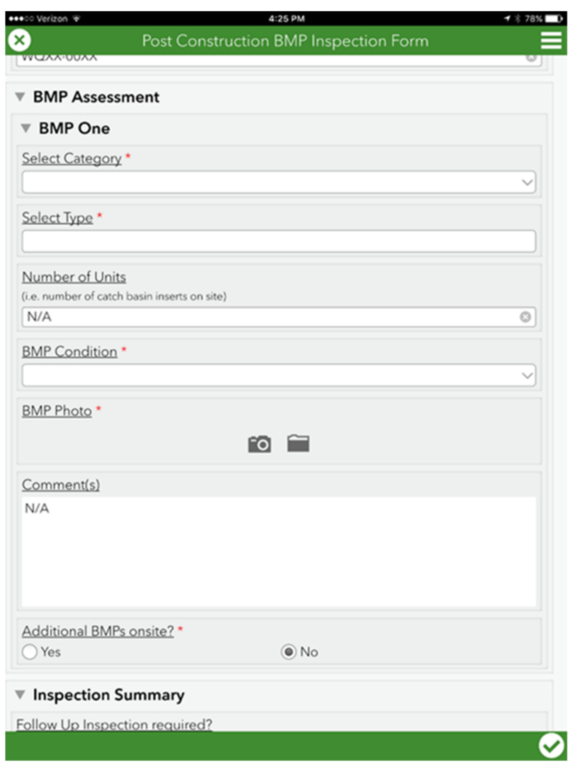
Maintenance tracking can be integrated into an electronic form so that as maintenance is performed photos can be taken and quantities and labor hours spent can be entered into the electronic form in the field.

## 5.2 Electronic forms

Hard copy inspection forms may be used for LID/GSI facility inspections and tracking, but paper copies may be completed incorrectly, fields may be skipped, and pages may be misplaced or lost. Many jurisdictions are moving towards web-based inspection forms that can be completed in the field via tablet. Using tablets in the field reduces the extra time that would be required to scan, and hand enter hard copy data into computer databases.

Online tools such as Survey123 for ArcGIS can be used to develop electronic LID/GSI inspection forms that link directly to a jurisdiction database. Survey123 allows users to easily design forms which are accessible via a mobile app for data entry in the field. The program integrates into ArcGIS to enable spatial analysis and other data analysis (Law 2017). Figure 5-1 shows a screenshot of the County of Orange BMP inspection form through the Survey 123 app (County of Orange 2018).

**Figure 5-1. County of Orange BMP Inspection Form Survey 123**



Data on LID/GSI facilities is very valuable in the long-term as it allows jurisdictions to gauge the effectiveness of LID/GSI infrastructure over time. Limited data has been collected thus far on LID/GSI measure effectiveness in Southern California because the implementation of LID/GSI measures is relatively new to the region (Haan-Fawn Chau 2009). Also, data from LID/GSI measures in Southern California cannot be compared to other LID/GSI facilities in the United States since BMPs are designed based on the Mediterranean climate, which is distinctly different from other regions of the country. LID/GSI BMP monitoring data is vital to the progress of regional regulations, organizations such as Southern California Stormwater Monitoring Coalition (SMC) California Stormwater Quality Association (CLEAN), and BMP functionality in the Southern California region.

# 6 LID MONITORING

## 6.1 Monitoring Purpose

The primary goals of LID/GSI facilities are to remove pollutants from stormwater runoff and infiltrate, retain, and/or treat runoff. The purpose of a monitoring study is to establish that the implemented BMP provides the hydrologic and pollutant reduction benefits as expected based on its design and application. There is a need to establish performance metrics and ranges of acceptable performance for LID BMPs in Southern California and throughout the rest of California.

The initial step in creating a monitoring program is to create targeted research questions that guide the creation of a sampling and monitoring plan, which provides pertinent and useful data. The following process can be used to develop targeted research questions:

- Background planning:
  - Who - are the stakeholders, involved parties?
  - What - are the issues, problems, needs?
  - Where - is the focus of the study/interest? Are there single or multiple locations?
  - When - will changes be implemented, have related events or studies taken place?
  - Why - is this problem, need, issue being addressed; why is this study critical to addressing it?
  - How - will possible solutions, interventions, other aspects of the study be assessed for effectiveness; how will results be delivered and/or implemented?
- Development of specific questions:
  - Problem - what is the main problem you are addressing, what are the characteristics of the LID/GSI BMP site? Of the surrounding area? Of the watershed? Of similar sites?
  - Method – what to implement to address the problem of interest?
  - Comparison – compare methods from other studies. In your context, is it important to review studies that have addressed similar problems, methods, or measured outcomes?
  - Outcome of interest - what are the measurable outcomes (standardized measures if possible) that would demonstrate effectiveness of the study?
  - Time frame - are there are specific time frames of interest for your study? (Virginia Tech 2018).

## 6.2 Southern California Stormwater Monitoring Coalition (SMC) California LID Evaluation & Analysis Network (CLEAN) Monitoring Protocol

This section outlines the process of data collection for a specific LID or GSI project. It provides project management information, specific project information (meta data) to be collected, monitoring plan review recommendations, specific details on the data acquisition process including monitoring equipment, site set-up guidance, monitoring parameters for hydrology and water quality, and describes the intended use of the data collected. As much as possible, sample collection and analysis methods are standardized for comparability. However, due to different study needs, the recommended sampling frequency and schedule may vary substantially. Consequently, sampling schedules are included for three identified project types: Basic BMP Performance Verification; BMP Performance over Time, and Special BMP Studies (Table 6-1, Table 6-2, and Table 6-3 respectively).

Basic BMP Performance Verification—for new BMP installations:

- To establish that the implemented BMP provides the hydrologic and pollutant reduction benefits as expected based on its design and application.
- To fulfill effectiveness assessment requirements for grant-funded BMPs.
- To support quantitative BMP effectiveness inputs to watershed management plans and impacts on receiving water quality.
- To support regional studies of bioretention BMP performance (such as the SMC CLEAN Project).

BMP Performance over Time:

- To evaluate the lifespan of bioretention media, both hydraulic performance and water quality performance, or otherwise predict major maintenance needs (e.g., media replacement) for common bioretention installations.
- To evaluate the performance implications of plant conditions and maintenance.
- To support cost-benefit evaluations.

Special BMP Studies:

- Proof-of-concept to evaluate new bioretention soil media types, new designs, or unique BMP arrangements[2].
- To evaluate the performance impacts of specific factors such as plant palette; construction practices; rainfall characteristics, or other.
- To evaluate pollutant fate and transport.

This data collection protocol is designed to ensure that monitoring data are adequate to evaluate the effectiveness of the aggregate of LID/GSI measures and are collected in a consistent manner to ensure that data from different LID/GSI measures installations will be comparable. Improved understanding of the hydrologic and water quality benefits of LID/GSI measures will improve efforts to modify LID/GSI designs, specifications, and maintenance measures to optimize performance. Many individual LID/GSI measures should be monitored throughout regional watersheds. Collectively, such data can be used to determine how effectively each class of LID/GSI measures reduce runoff volume and maintain or restore pre-project hydrologic parameters; how effectively they reduce pollutant loads and concentrations in runoff; what maintenance is required to ensure BMP performance over time; and what is the typical lifespan of bioretention media. Monitoring data collected, depending on the protocol options selected, will support evaluations of LID performance for individual projects, for multiple projects at small and large scales, and for various LID design

[2] The focus of the SMC CLEAN has been field testing of BMPs however innovative designs could also benefit from bench scale lab testing with synthetic stormwater.

approaches and implementation conditions. For example, monitoring for Basic BMP Verification or proof-of-concept studies for new designs or new bioretention media should be designed to stand alone since conclusions must be drawn from a single (or very few) installations.

This protocol is an integral part of a comprehensive project evaluation process. The process requires a complete project description and implementation records; stated objectives and management questions; a monitoring/sampling protocol; laboratory test methods, analytical procedures, and Quality Assurance/Quality Control procedures; data evaluation methods; and reporting specifications. The LID/GSI monitoring is part of an iterative process as identified in **Error! Reference source not found.** on the following page. The effectiveness evaluation should be scaled to the scope and life expectancy of the project. Most LID/GSI facilities are expected to function effectively for 20 years or longer if adequately maintained. If possible, prior to investing in full water quality monitoring, perform visual monitoring of at least one storm to identify any functional defects that may need to be corrected. A comprehensive evaluation will include documentation and evaluation of maintenance and performance over the life of the project BMP.

### *6.2.1 Pre-Monitoring Check*

Before monitoring is scheduled to commence the basic functionality of the BMP must be checked. This pre-monitoring check should verify:

- BMP is built and sized per design.
- Preferred construction practices were used to minimize soil compaction or contamination.
- Correct BSM materials used and installed correctly.
- Correct elevations to ensure functionality.
- Inlet and outlet in good condition.
- Hydraulic connectivity between BMP and inlet/outlet conveyance.

### *6.2.2 Contributing Area Condition Evaluation*

The condition of the area contributing runoff to the BMP must be evaluated initially and periodically to verify the size of the area, the land use and use intensity, and the surface cover condition.

### *6.2.3 Plant Condition Assessment*

The condition of the plants in the bioretention BMP must be periodically evaluated and documented, including consideration of the following parameters:

- Planted per Design
  - Plant type
  - Placement/spacing
- % Cover
- Irrigation system observations
- Maturity
  - Plant establishment date
- No plants by design

**Table 6-1. Monitoring/Sampling Frequency Options - Basic**

<table>
<tr><th colspan="3">Table 1: Basic BMP Performance Verification</th></tr>
<tr><th>Year 1</th><th>Year 2</th><th>Year 3</th></tr>
<tr><td>Pre-monitoring check</td><td rowspan="4">3 events; early, mid, late season:<br>• Influent, effluent, hydrology<br>• Contributing area observations<br>• Plant condition observations<br>• Maintenance condition tracking</td><td rowspan="2">1 event:<br>• Influent, effluent, hydrology<br>• Contributing area observations<br>• Plant condition observations<br>• Maintenance condition tracking</td></tr>
<tr><td rowspan="2">2 events; early and mid/late season:<br>• Influent and effluent samples;<br>• hydrology;<br>• contributing area observations;</td></tr>
<tr><td rowspan="2">2 additional events required if significant BMP changes occur:<br>• Influent, effluent, hydrology<br>• Visual monitoring of contributing area<br>• Plant condition observations</td></tr>
<tr><td>Monthly plant condition observations</td></tr>
</table>

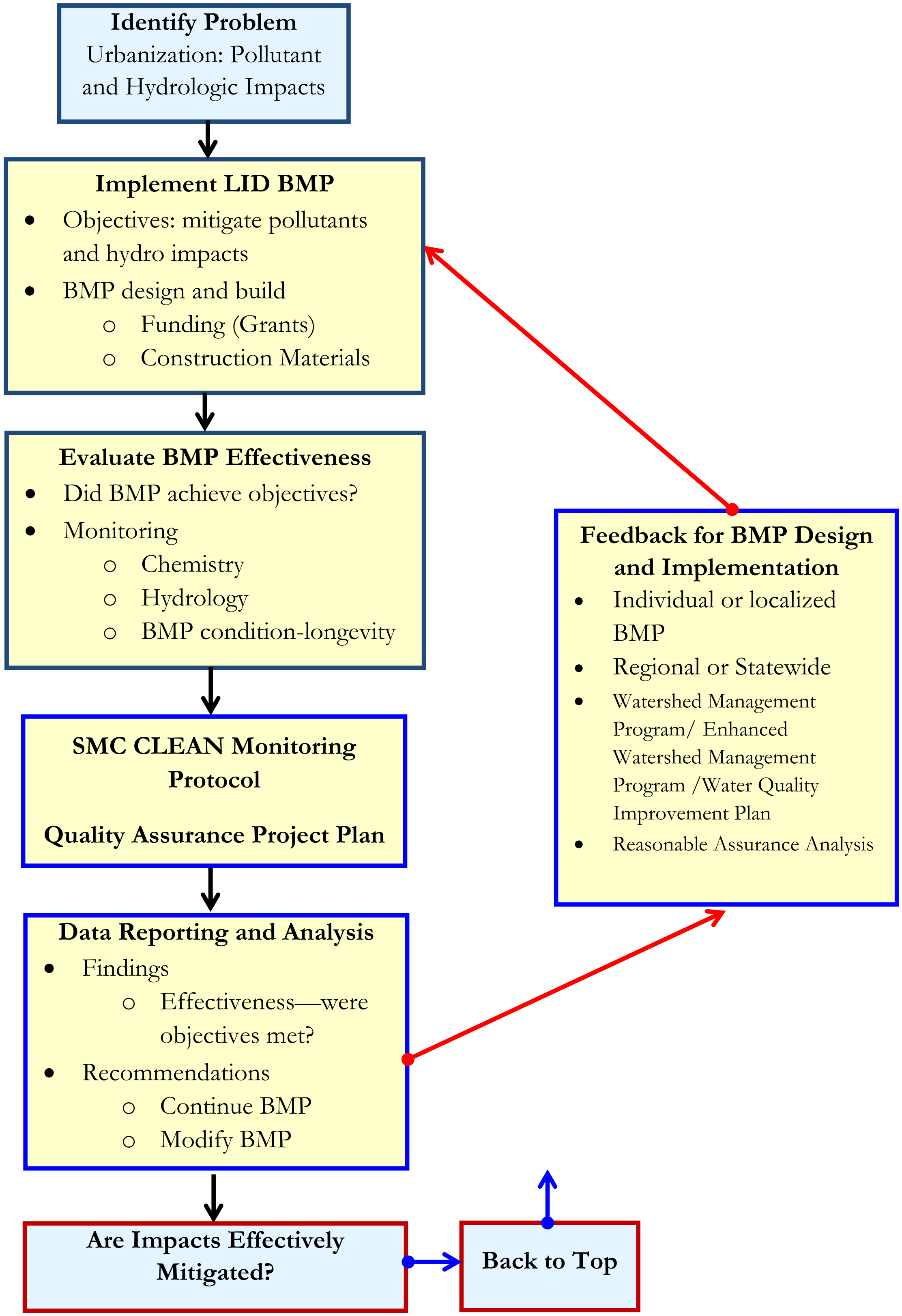
## Table 6-2. Monitoring/Sampling Frequency Options – Performance over Time

<table>
<tr><th colspan="4">Table 2: BMP Performance over Time</th></tr>
<tr><th>Year 1</th><th>Year 2</th><th>Year 3 - 10[1]</th><th>Year 11 - 20[1]</th></tr>
<tr><td>Pre-monitoring check</td><td rowspan="2">3 events; early, mid, late season:<br>• Influent, effluent, hydrology<br>• Contributing area observations;<br>• Plant condition observations<br>• Maintenance condition tracking</td><td rowspan="2">2 events; early and mid/late season:<br>• Influent, effluent, hydrology<br>• Contributing area observations;<br>• Plant condition observations<br>• Maintenance condition tracking</td><td rowspan="2">2 events; early and mid/late season:<br>• Influent, effluent, hydrology<br>• Contributing area observations;<br>• Visual hydrologic function verification<br>• Plant condition observations<br>• Maintenance condition tracking</td></tr>
<tr><td rowspan="2">2 events; early and mid/late season:<br>• influent and effluent samples;<br>• hydrology;<br>• Contributing area observations;</td></tr>
<tr><td rowspan="4">3 events required after significant BMP changes occur:<br>• Influent, effluent, hydrology<br>• Contributing area observations;<br>• Plant condition observations<br>• Maintenance condition tracking</td><td>3 events required after significant BMP changes occur:<br>• Influent, effluent, hydrology<br>• Contributing area observations;<br>• Plant condition observations<br>• Maintenance condition tracking</td><td>2 events required after significant BMP changes occur:<br>• Influent, effluent, hydrology<br>• Contributing area observations;<br>• Plant condition observations<br>• Maintenance condition tracking</td></tr>
<tr><td>Monthly plant condition observations</td><td>[1]Evaluate data after year 5 and confirm or revise sampling frequency.</td><td>[1]Evaluate data after year 10 and confirm or revise sampling frequency.</td></tr>
<tr><td>First event after plant establishment:<br>• Influent, effluent, hydrology<br>• Contributing area observations<br>• Plant condition observations</td><td colspan="2" rowspan="2">Evaluate and revise schedule in response to any significant changes to BMP, major plant or structural failure, change, or replacement;<br><br>Evaluate and revise schedule with any significant changes in contributing area condition.</td></tr>
<tr><td rowspan="2">Maintenance condition tracking<br>(develop protocol with CWH)</td></tr>
<tr><td colspan="3">Older, established BMPs can begin monitoring using the Year 2 schedule.</td></tr>
</table>

**Table 6-3. Monitoring/Sampling Frequency Options – Special Studies**

| Table 3: Special BMP Studies | | | |
|---|---|---|---|
| **Year 1** | **Year 2** | **Year 3** | **Beyond Year 3** |
| **Pre-monitoring check**<br><br>**2 events; early and mid/late season:**<br>• influent and effluent samples;<br>• Hydrology;<br>• Soil moisture;<br>• Contributing area observations;<br><br>**In addition:**<br>For studies requiring pollutant removal data to evaluate performance of bioretention soil media:<br>• Collect effluent samples;<br>For studies where pollutant removal is determined by volume of retention;<br>• Ensure flow monitoring equipment is functional prior to each event<br><br>**Monthly plant condition observations** | **3 events; early, mid, late season:**<br>• Influent, effluent, hydrology<br>• Soil moisture<br>• Contributing area observations<br>• Maintenance condition tracking<br>• Monthly plant condition observations | **3 events; early, mid, late season:**<br>• Influent, effluent, hydrology<br>• Soil moisture<br>• Contributing area observations<br>• Maintenance condition tracking<br>• Monthly plant condition observations<br><br>**2 additional events required if significant BMP changes occur:**<br>• Influent, effluent, hydrology<br>• Soil moisture<br>• Contributing area observations<br>• Monthly plant condition observations | **Evaluate study objectives and existing data; confirm or revise sampling frequency.**<br><br>• Evaluate and revise schedule in response to any significant changes to BMP, major plant or structural failure, change, or replacement.<br><br>• Evaluate and revise schedule with any significant changes in contributing area condition. |

**Figure 6-1. Iterative Process & LID/GSI Monitoring**



### 6.2.4 Integration of Monitoring into LID/GSI BMP Design

LID/GSI BMPs are inherently challenging to monitor due to their design as part of the landscape. LID conveyance features are subtler and distributed when compared to conventional BMPs which have defined inlet and outlet structures. Therefore, monitoring approaches should be considered and monitoring features should be integrated as part of the BMP design. LID/GSI measure designs should be modified based on the type of monitoring that will be performed. Monitoring details of specific design plans are discussed in Section 6.3 below.

### 6.2.5 Project Description and Implementation[3]

- Site drawings – Design plans, specifications, As-builts.
- Design storm, drainage area size, and sizing calculations.
- Drainage area land uses and percentages.
- Historic site information.
- Native soils information (including analysis of all inorganics measured in the water quality protocol), geotechnical report, infiltration tests.
- Engineered soil matrix information, soil matrix source.
- Plant information/list, plant source.
- Mulch information/source.
- Construction records, contractor information.
- Maintenance protocols.
- Maintenance records, maintenance contractor information.
- Inspection records.
- Data tracking protocols.
- Data access information.
- Data reporting protocols.
- Other information being collected for each site and why it is being collected.

### 6.2.6 Monitoring Plan Review and Reporting

LID project monitoring plans should be consistent with the requirements of the agency requesting/requiring project monitoring and should be reviewed before being implemented. Some projects may have a monitoring plan review requirement imposed by the jurisdiction where the project has been implemented or by a regulatory agency (i.e. State Water Resources Control Board (SWRCB))

[3] The international BMP database provides guidance for collecting data. http://www.bmpdatabase.org/data-entry.html

for a grant funded project or as part of a 401 Water Quality Certification or other regulatory requirement (SWRCB 2012). For projects in the geographic scope of the SMC, projects can submit their LID monitoring plan to the SMC CLEAN project for review.

Monitoring data should be reported as specified by the jurisdiction approving the project and per applicable regulatory reporting requirements (e.g. California Environmental Data Exchange Network/ Surface Water Ambient Monitoring Program). For LID/GSI projects in the geographic region of the SMC, LID monitoring and meta data will be submitted to the SMC CLEAN Data Submittal Tool.

### 6.2.7 Measurements

Monitoring will include these measurements:

- Rainfall depth
- Influent and effluent flow rate (used to calculate flow volume)[4]
- Bypass Occurrence and/or Flow Rate
- Influent and effluent pollutant concentration
- Soil moisture (optional)

### 6.2.8 Site Setup

Develop BMP configuration schematic including:

- Contributing drainage area(s)
- Influent sampling point(s)
- Underdrain/effluent sampling point (s)
- Overflow/bypass sampling point(s)

Flow rate of water into and/or out of the selected LID/GSI measure and pollutant concentration should ideally be measured during runoff events at relevant site-specific points which could include:

- Inflow
- Overflow
- Underdrain/Effluent
- Bypass
- Vadose zone or within the bioretention soil media or gravel reservoir (optional)

[4] See flow monitoring guidance: http://www.openchannelflow.com/blog/isco-releases-7th-edition-of-its-flow-measurement-handbook

If all inlet/outlet points cannot be monitored, representative sites should be selected that allow for scaling or modeling of the entire BMP. Monitoring of flow from the underdrain (if present) and overflow/bypass is preferred to monitoring of the overflow/bypass alone.

If possible, projects should collect hydrologic and water quality data at the proposed BMP location before the BMP is installed. These projects should characterize the pre-BMP drainage area, for stormwater volume and project specific water quality parameters to provide baseline conditions.

Each sampling point should be instrumented with a data logger, autosampler, and flow measurement devices. Site specific considerations should be taken into account for public safety and equipment security which could include placing equipment in lockable security enclosures to deter theft and vandalism and protecting tubing lines and data cables with PVC conduit. Additional sampling information can be found in the Urban Stormwater BMP Performance Monitoring report (Geosyntec and Wright Water Engineers, Inc. 2009).

### *6.2.9 Event Mobilization*

Prior to mobilization for a sampling event, weather/storm events should be tracked using multiple weather sources such as National Oceanic Atmospheric Association National Weather Service and Accuweather to estimate the event rainfall amount and arrival time of the storm event. Rainfall estimates should equal at least the project specific threshold to ensure adequate runoff to sample (0.25 inches suggested over 24 hrs.), and for effluent sampling, the antecedent dry period should be sufficient so that the BMP has completely drained water from previous rain events.

When event conditions are met, the sampling team should conduct a pre-event site visit to ensure the site is prepared for monitoring and the equipment remains properly installed and begin sampling preparation procedures.

### *6.2.10 Sampler Programming*

#### 6.2.10.1 Composite samples

Minimum: collect a single volume-adjusted or time-weighted composite sample at the inlet and outlet/overflow which will represent the influent and effluent event mean concentrations for the storm event. Flow-weighted composite sampling is strongly encouraged as it provides a more representative event mean concentration.

Enhanced: collect a flow weighted composite sample representing the "first flush" or rising limb of the hydrograph, and a composite sample representing the remaining flow for the event at the inlet and outlet/overflow. This requires using an autosampler equipped with multiple bottles or switching out the composite sample over the course of the storm. These samples would be analyzed separately. Composite sampling methods are discussed in Section 6.2.10.2 through 6.2.10.4.

#### 6.2.10.2 Time-based

Based on the duration of the forecasted storm event autosamplers should be programmed to sample for up to 24 hours, or for the full duration of the storm if shorter than 24 hours, to provide a composite sample to represent the event mean concentration for the event. For a 24-hr. storm, tiered programming is recommended; where the first 12 discrete auto samples are collected every 30 minutes and the final 12 samples are collected at 1.5 hrs. For a storm event shorter than 24 hours the program should be appropriately scaled so that at least 75% of the storm is sampled. Time-based composite sampling is a straightforward sampling method that can be used for new sites where the hydrograph is not known. However, time-based sampling will not provide an accurate or representative event mean concentration since the sample pacing will not match the flow hydrograph shape. Also, sample volume and timing set before the storm can cause too many or too few samples to be collected if the rainfall patterns differ significantly from the forecast.

If multiple bottles are used to collect samples on a time-based schedule, these samples can be composited by hand on a flow-weighted basis, otherwise known as volume-adjusted composite sampling. A volume-adjusted composite sample is typically collected as many discrete time-paced samples over the course of the storm. After the storm, a portion of each discrete sample is combined to create the volume adjusted composite sample. The amount of each discrete sample added is proportionate to the volume of the storm represented by the time interval associated with the discrete sample.

#### 6.2.10.3 Volume-based

Preferably, autosamplers will be programmed for volume-weighted sampling by triggering samples based on a user-defined volume-to-sample quantity. This method produces the most accurate event mean concentration estimation. This method requires a good estimate of flow rate and shape/timing of the hydrograph. Adjustments are usually required based on experience from initial storm events. Underestimation of runoff will result in collection of additional samples and increased sample pacing which can backlog the autosampler tubing rinse/purge routine; backlogged samples then become time-weighted. Overestimation of runoff will result in collection of fewer samples and reduced representation of the event. Estimation of storm volumes and hydrographs can be improved by observing the monitoring site and instrumentation during the sampling event and adjusting pacing if needed. Hydrologic response of the BMP contributing area can also be better understood by monitoring and evaluating rainfall and flow only during storm event(s) prior to initiation of water quality sampling. Volume-based sampling provides a more representative event mean concentration since sample volume is directly linked to flow measurement and matched the hydrograph shape. However, volume-based sampling can be more complicated to implement in the field as the storm size and hydrograph need to be anticipated in order to set the correct flow pacing. Incorrect flow pacing could result in the collection of either too small of a sample volume or too large of a sample volume that is collected during only a portion of the storm.

#### 6.2.10.4 General setup

The autosampler should be programmed to conduct a triple rinse of the line, take a water sample of a predefined volume, and then purge the line.

The auto sampler/bubbler should be programmed to trigger sample collection based on a minimum flow/water level when water begins to overflow the weir. This can be done by setting a zero-water level at ambient atmospheric pressures and setting the trigger to be the elevation of the top of the weir. Sample bottles should be then loaded into the auto sampler and iced for sample preservation prior to setting the sampler to standby.

Finally, all field meters should be calibrated/checked per manufacturer's instructions for in-situ instructions.

#### 6.2.10.5 Grab Samples

Grab sampling may be required to collect samples for a specific parameter such as oil and grease or bacteria. Such grab samples should be collected during the estimated peak of a storm event in an area with representative flow. Collect water grab samples using a clean high-density polyethylene bottle (or a glass bottle for hydrocarbon analysis). If possible, avoid reusing sample bottles to minimize the risk of contamination. Once bottled, water samples are to be put on ice for rapid cooling to reduce biological activity. See United States Environmental Protection Agency *Industrial Stormwater Monitoring and Sampling Guide* (EPA-832-B-09-003; 2009) for grab sampling procedure.

### *6.2.11 Field Water Quality Monitoring*

Use field meter to measure temperature, pH, electrical conductivity, dissolved oxygen, turbidity and other parameters at selected times during the storm event.

### *6.2.12 Sample Collection*

Multiple trips to collect or retrieve the composite / grab samples may be required to ensure hold times are met (sampling collection times should be calculated based on the final sample of the composite). Discrete samples for the rising, peak, and declining limbs of the hydrograph should be composited together in a clean vessel and homogenized prior to subsampling into containers for sample analysis. Personnel should wear disposable gloves to prevent sample contamination. One subsample should be used to collect in-situ measurements such as temperature, conductivity, pH, and dissolved oxygen.

### *6.2.13 Laboratory Preparation and Submittal*

Transport samples to a safe, dry, and clean area for preparation to ship to a certified contract laboratory for processing. Alternatively subsamples for dissolved species should be filtered using a 0.45-micron filter in the field where possible using a syringe filter to ensure hold times are met for these parameters. Samples requiring acid preservation should then have their pH adjusted to $<2$ as required.

Prepare Chain of Custody and field sheets for accurate documentation of the collection and processing of samples. Chain of Custody forms must accompany samples to the analytical laboratory as per Environmental Protection Agency (EPA) guidelines. All samples should be transported and stored on ice or with gel-based ice packs to ensure samples stay at our below the 6°C sample preservation requirement.

#### 6.2.13.1 Recommended Constituent Sampling

Common parameters that the certified contract laboratory should test for are listed below with their typical units and reporting limits from the 2015 Surface Water Ambient Monitoring Program (**Error! Reference source not found.**Table 6-4). A prioritized list of pollutants should be developed for each project in the event this is so that in the event that adequate sample volume cannot be collected, the bottles for the highest priority pollutants will be filled.

**Table 6-4. Recommended Constituent List**

| Parameter | Analysis Method | Volume Requirement [a] | Preservation Requirements [b] | Common Units | Target Detection Limit |
|---|---|---|---|---|---|
| **Conventional** | | | | | |
| pH | SM 4500-H+ | N/A | N/A | s.u. | N/A |
| Conductivity | SM 2510 | 250 mL | Cool, ≤6°C | µS/cm | 2.5 |
| Turbidity | EPA 180.1 | 100 mL | Cool, ≤6°C | NTU | 1 |
| Total Suspended Solids (TSS) | SM 2540-B | 250 mL | Cool, ≤6°C | mg/L | 2.0 |
| Suspended Solids Concentration (SSC) | ASTM D3977 | 250 mL | Cool, ≤6°C | mg/L | 1.0 |
| Total Hardness | SM 2340-B | 250 mL | $NHO_3$ or $H_2SO_4$ to pH<2 | mg/L | 1 |
| **Bacteria** | | | | | |
| Fecal Coliform [c] | SM 9221-E | 100 mL | Cool, 10°C; 0.0008% $Na_2S2O_3$ | MPN/100 mL | 2 |
| Enterococcus [c] | EPA 9000-1600 | 100 mL | Cool, 10°C; 0.0008% $Na_2S2O_3$ | Colonies/100 mL | 1 |
| **Nutrients** | | | | | |
| Total Phosphorus | SM 4500 – P E | 250 mL | Cool, ≤6°C; $H_2SO_4$ to pH <2 | mg/L | 0.5 |
| Total Kjeldahl Nitrogen (TKN) | SM 4500-N | 250 mL | Cool, ≤6°C; $H_2SO_4$ to pH <2 | mg/L | 0.5 |
| **Metals – Total** | | | | | |
| Cadmium | EPA 200.8(m) | 250 mL | Cool, ≤6°C; $HNO_3$ to pH <2 | µg/L | 0.03 |
| Copper | EPA 200.8(m) | 250 mL | Cool, ≤6°C; $HNO_3$ to pH <2 | µg/L | 0.10 |
| Lead | EPA 200.8(m) | 250 mL | Cool, ≤6°C; $HNO_3$ to pH <2 | µg/L | 2 |
| Zinc | EPA 200.8(m) | 250 mL | Cool, ≤6°C; $HNO_3$ to pH <2 | µg/L | 0.70 |
| **Metals - Dissolved** | | | | | |
| Cadmium | EPA 200.8 | 250 mL | Cool, ≤6°C; filtration, 0.45µm; $HNO_3$ to pH <2 | µg/L | 0.03 |
| Copper | EPA 200.8 | 250 mL | Cool, ≤6°C; filtration, 0.45µm; $HNO_3$ to pH <2 | µg/L | 0.10 |
| Lead | EPA 200.8 | 250 mL | Cool, ≤6°C; filtration, 0.45µm; $HNO_3$ to pH <2 | µg/L | 2 |
| Zinc | EPA 200.8 | 250 mL | Cool, ≤6°C; filtration, 0.45µm; $HNO_3$ to pH <2 | µg/L | 0.70 |

| Parameter | Analysis Method | Volume Requirement [a] | Preservation Requirements [b] | Common Units | Target Detection Limit |
|---|---|---|---|---|---|
| **Organics** | | | | | |
| Pesticides | EPA 625(m) | 1-L (glass) | Cool, ≤6°C | μg/L | 0.005 - 0.2 |
| **Hydrocarbons** | | | | | |
| Total Petroleum Hydrocarbons (TPH) [c] | EPA 625(m) | 1-L (glass) | Cool, ≤6°C; HCL to pH <2 | mg/L | 0.5 |
| a: Volume requirements may vary depending on specific laboratory used for analysis<br>b: Source- 40 CFR Part 136.3, Table 2<br>c: Grab sample only | | | | | |

## 6.3 SMC CLEAN Standard Data and Information List

The following is the list of data/information that will be requested and compiled for each of the LID projects data/information is being obtained for the SMC CLEAN project. The list comprises monitoring data as well as meta data so that analysis can be performed to answer the proposed SMC CLEAN targeted research questions. Based on coordination with the SWRCB this list may serve as a preliminary list of data-information required to be gathered associated with future LID grant projects.

- Monitoring Data
  - Monitoring protocol
  - Monitoring parameters
  - Research question parameters (common 303-d constituents)
    - Bacteria – Fecal coliform, Enterococci
    - Pesticides
    - Nutrients – TKN, Total Phosphorus
    - Metals – Cadmium, Copper, Zinc, Lead
  - Water chemistry,
    - Total suspended solids / turbidity
    - Field parameters - pH, total hardness, Conductivity
    - TPH
  - Monitoring elements integrated into LID feature.
  - Water quality data – inlet/outlet.
  - Whole-storm water flow data – inlet/outlet.
  - Draw down time/volume.
  - Precipitation data.

- Meta Data
    - Design plans and specifications.
    - As-builts.
    - Design storm, drainage area size, and sizing calculations.
    - Drainage area land uses and percentages.
    - Native soils information (including analysis of all inorganics measured in the water quality protocol), geotechnical report, infiltration tests.
    - Engineered soil matrix information, soil matrix source.
    - Plant information/list, plant source.
    - Mulch information/source.
    - Construction records, contractor information.
    - Maintenance protocols.
    - Maintenance records, maintenance contractor information.
    - Inspection records.
    - Data tracking protocols.
    - Data access information.
    - Data reporting protocols.
    - Other information being collected for each site and why it is being collected.

## 6.4 Alternative LID GSI Testing

### *6.4.1 Synthetic Stormwater Testing*

LID/GSI effectiveness monitoring has historically been performed during storm events to measure in situ conditions during natural wet weather events. Wet weather monitoring is based on changing weather predictions and occurs in a non-controlled environment, which can result in unexpected field conditions (i.e. large sediment loads, higher or lower than expected flow rates, equipment malfunction, etc.). Wet weather monitoring study results can be uncertain due to poor characterization of discharge into and out of the LID/GSI or due to pollutant sampling issues (Gulliver and Anderson 2008).

Synthetic stormwater can be used in certain situations to simulate stormwater runoff by controlling flow discharge and pollutant concentrations for accurate evaluation of LID/GSI effectiveness. Synthetic runoff consists of potable or deionized water and may contain targeted pollutants at predetermined concentrations or loads. Smaller-scale, lined LID/GSI, such as small biofiltration basins and filtration tree boxes, are ideal for synthetic stormwater testing because smaller volumes are required to simulate a storm event. In larger LID/GSI measures synthetic stormwater testing is less feasible due to the large volumes needed to produce outlet runoff well in excess of LID/GSI retention volume. A higher ratio of outlet runoff to retention volume is required to ensure that biases resulting from small-scale effects such as first flush pollutant release from LID/GSI media is not introduced. needs to be sustainably larger than the retention that could be caused by wash off from the media.

For synthetic runoff testing to be feasible, the following conditions must be met:

1. There must be an available water supply to provide sufficient volume for flow measurement and sample collection at the LID/GSI outlet.
2. All synthetic stormwater effluent must be contained and properly disposed of. The nearest downstream catch basin can be temporarily blocked to prevent synthetic stormwater from reaching the downstream MS4.
3. Flow into the LID/GSI must be able to be measured from one concentrated inlet. The inlet must be accessible for water quality samples and hydraulic flow measurements. Alternatively, for lined or small-scale LID/GSI measures surface water elevations in the LID/GSI can be measured to estimate inlet flow. Infiltration can be assumed to be negligible if the stormwater LID/GSI is filled rapidly with synthetic stormwater and the infiltration rate into the soil media is relatively slow or infiltration below the LID/GSI is blocked by a liner. LID/GSI infiltration testing should be conducted prior to using this method.
4. Flow out of the LID/GSI, other than infiltration, must be able to be measured from one concentrated outlet. The outlet must be accessible for water quality samples and hydraulic flow measurements (Gulliver and Anderson 2008).

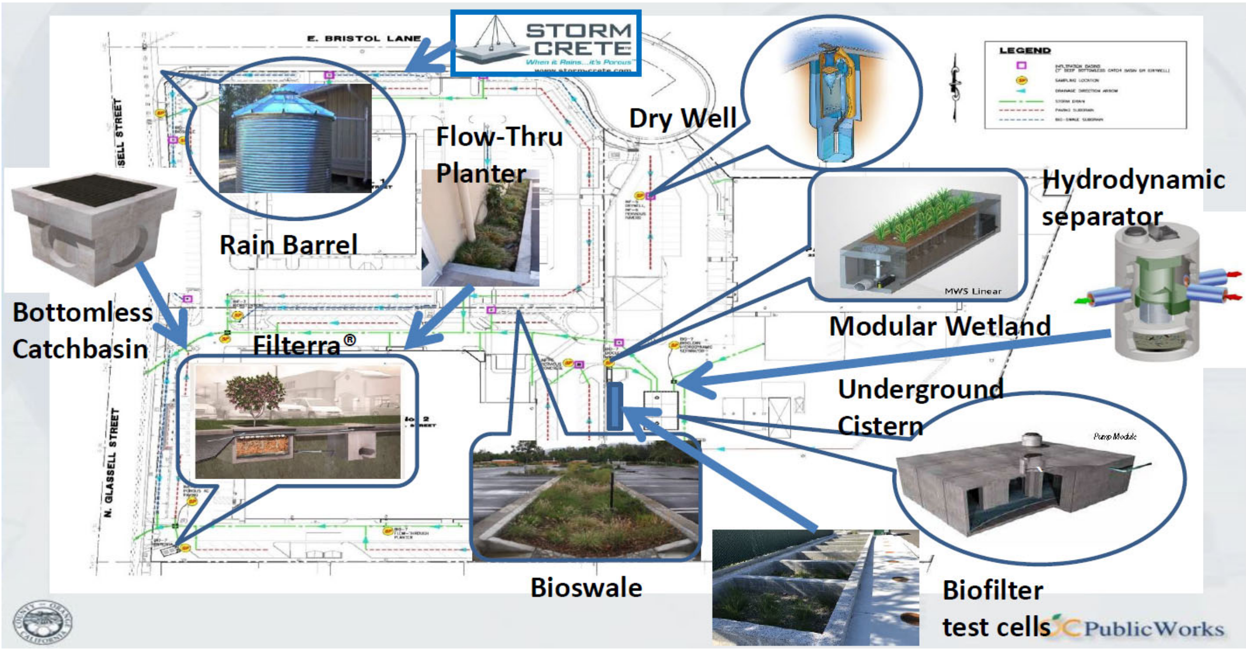
The necessary permits must be obtained and associated regulatory agencies notified prior to performing synthetic stormwater testing. Synthetic stormwater testing is only feasible for small-scale LID/GSI that are small enough to be filled with synthetic stormwater and meet the above qualifications. Gulliver and Anderson (2008) provide information on synthetic stormwater testing and assessing LID/GSI filtration retention times.

### 6.4.2 Multiple LID/GSI Testing

Conventional monitoring protocols may not be able to be applied to locations with multiple LID/GSI measures that are designed to work in concert. A parking lot with bio-swales and permeable pavement that overflow into a downstream biofiltration basin is an example of a multiple LID/GSI system. The LID/GSI testing facility located in Orange County is a constructed example of multiple LID/GSI measures working in tandem (

Figure 6-2) (Peng 2019). Because the LID/GSI measures now represent an entire system, it is not possible to isolate the separate parts and the LID/GSI are assumed to be working together as one unit.

**Figure 6-2 Orange County Public Works Glassell Campus LID Project.**




In these situations, a mass-emission cumulative effect approach can be utilized. A mass-emission approach measures pre-construction and post-construction water quality and hydraulic conditions for the entire site rather than the conventional method of monitoring individual LID GSI inflow and outflow. The mass-emission approach would require pre-site or pre-development monitoring to establish baseline conditions before the LID GSI were installed. Pre- and post-development monitoring results are compared to measure site effectiveness. The mass-emission approach measures storm water site characteristics on a larger scale and considers improvements to the entire project site, such as improvement to inflow prior to LID GSI treatment, which may not be captured using only individual LID GSI testing.

## 6.5 Standard Design and Monitoring Plans

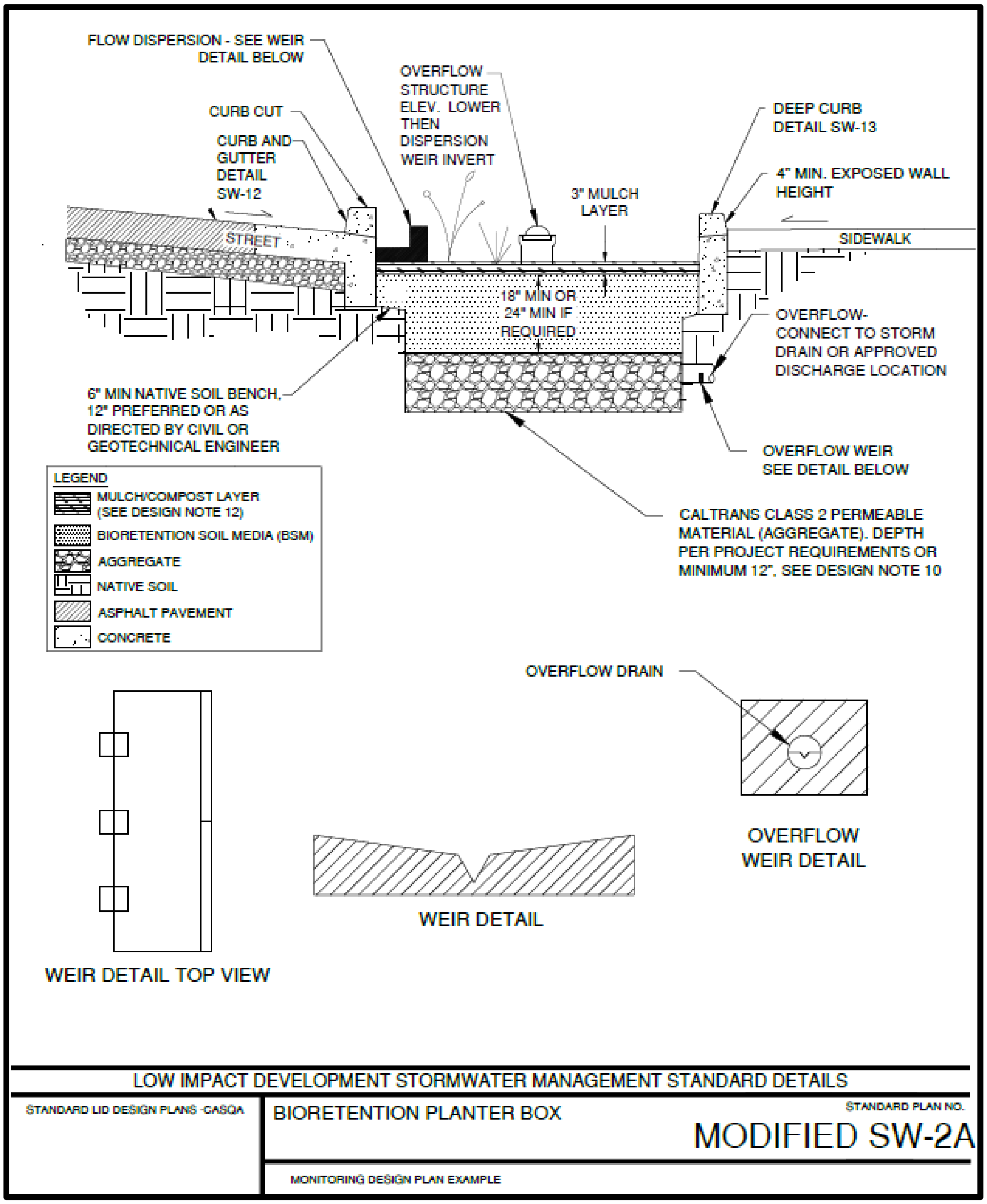
Standard monitoring design plans are outlined below to demonstrate in detail how LID/GSI facilities may be configured to accurately measure flow and to collect representative water quality samples. The design plans below are provided as examples only, LID/GSI facility monitoring plans must be designed based on individual BMP configurations. Examples of LID/GSI facility monitoring procedures are also included to provide additional information on how flow could be measured, and samples collected.

### *6.5.1 Standard Design Plan 1. Street Biofiltration Planter Box with Underdrain*

The following standard design plan example outlines a biofiltration planter box LID/GSI facility with an underdrain in between a sidewalk and street (Figure 6-3). The below design plan was adapted from the CASQA standard design plans as an example (CASQA 2018b). The example biofiltration planter box receives sheet flow from an adjacent street or pavement through curb cut inlets. A large square flow monitoring container is set just inside the biofiltration planter such that the stormwater flow from the street collects in the container and then flows over a triangular, v-notch weir into the biofiltration area. The flow monitoring container must be wide enough to collect all sheet flow into the LID/GSI measure and is expected to span multiple curb cut inlets. The flow monitoring container must be tall and deep enough to allow flow to settle, turbulence to subside, and for flow to steadily overtop the weir. The flow monitoring box dimensions must be sized based on the characteristics of flow to the LID/GSI measure and the size and configuration of the LID/GSI measure. The flow monitoring container is installed only for monitoring purposes and is not part of the LID/GSI measure. Inside the biofiltration area stormwater either infiltrates through the soil media or flows into the overflow structure and out into the MS4 system.

It is assumed for design purposes that stormwater can only flow into the BMP through the curb cuts. It is also assumed that the BMP is contained such that all flow within the BMP either infiltrates into the soil or flows into the overflow structure.

### Figure 6-3. Standard Design Plan 1 Biofiltration Planter Box

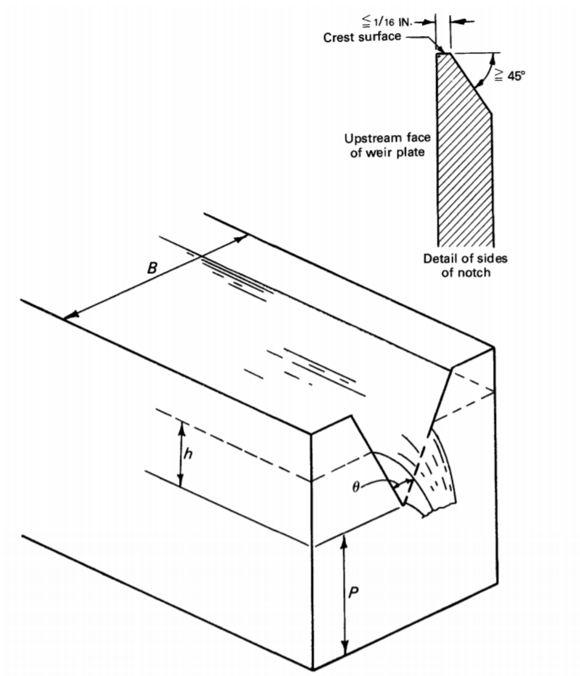



#### 6.5.1.1 Flow measurement

The flow monitoring container would be installed against the curb cuts and sealed. The monitoring container is a temporary installation and is not part of the BMP design. A flow bubbler is installed inside the monitoring box to measure the height of the water as it flows over the weir into the BMP. Weir equations use the area of a known geometric shape to estimate the volume of water traveling over time, which results in a flow rate (

Figure 6-4) (USGS 1981).

**Figure 6-4. USGS V-notch weir schematic**




The Triangular Weir (V-Notch Weir) equation below can be used to calculate flow in cubic feet per second:

$$\boldsymbol{Q} = \boldsymbol{K_u}\,[\tan\left(\frac{\theta}{2}\right)]H^{2.5}$$

Where: Q = Discharge ($m^3/s$), θ = Angle of v-notch (degrees), H = head on apex of v-notch (m), $K_u$ = 1.38 (USDOT, 2009).

For flow heights above the capacity of the triangular notch, a modified version of the Triangular Weir equation could be used.

$$\boldsymbol{Q} = \boldsymbol{K_u}\,[\tan\left(\frac{\theta_a}{2}\right)]\,{H_{max}}^{2.5} + \boldsymbol{K_u}\,[\tan\left(\frac{\theta_b}{2}\right)]H^{2.5}$$

Where: Q = Discharge ($m^3/s$), $\theta_a$ = Angle of lower v-notch (degrees), $\theta_b$ = Angle of upper v-notch (degrees), $H_{max}$ = height of lower v-notch (m), H = head on apex of upper v-notch (m), $K_u$ = 1.38

To measure output flow from the BMP, the nearest downstream stormwater catch basin would need to be accessed and a weir installed in the underdrain conveyance as it connects to the catch basin. Portable volumetric weirs can be purchased or made by cutting plastic sheeting (such as plastic marine board), as seen in

Figure 6-5 (Michael Baker International, 2018).

**Figure 6-5. V-Notch Weir with Sampler and Bubbler Installation in Underdrain**

The conveyances would need to be investigated to ensure no additional stormwater connections are contributing to flow at the downstream flow monitoring location. Water quality samples would be collected at the input and output weir locations.

#### 6.5.1.2 Pollutant loading

Calculating pollutant load is a primary objective to determine LID/GSI facility performance. Pollutant load is defined as the mass of a substance that passes a particular point of a LID/GSI measure (for example at the inlet or outlet) in a specified amount of time (e.g., daily, annually). Pollutant load is essentially the product of water discharge and the concentration of a substance in the water (Meals et al. 2013). Pollutant loads can be calculated using the below equation:

$$Load\ \left(\frac{lbs}{day}\right) = Concentration\ x\ Discharge\ Volume\ x\ Unit\ Conversion\ Factor$$

The pollutant load reduction is calculated using the below equation and is expressed as a percentage. A negative pollutant load percentage indicates a reduction in the effluent sample pollutant load.

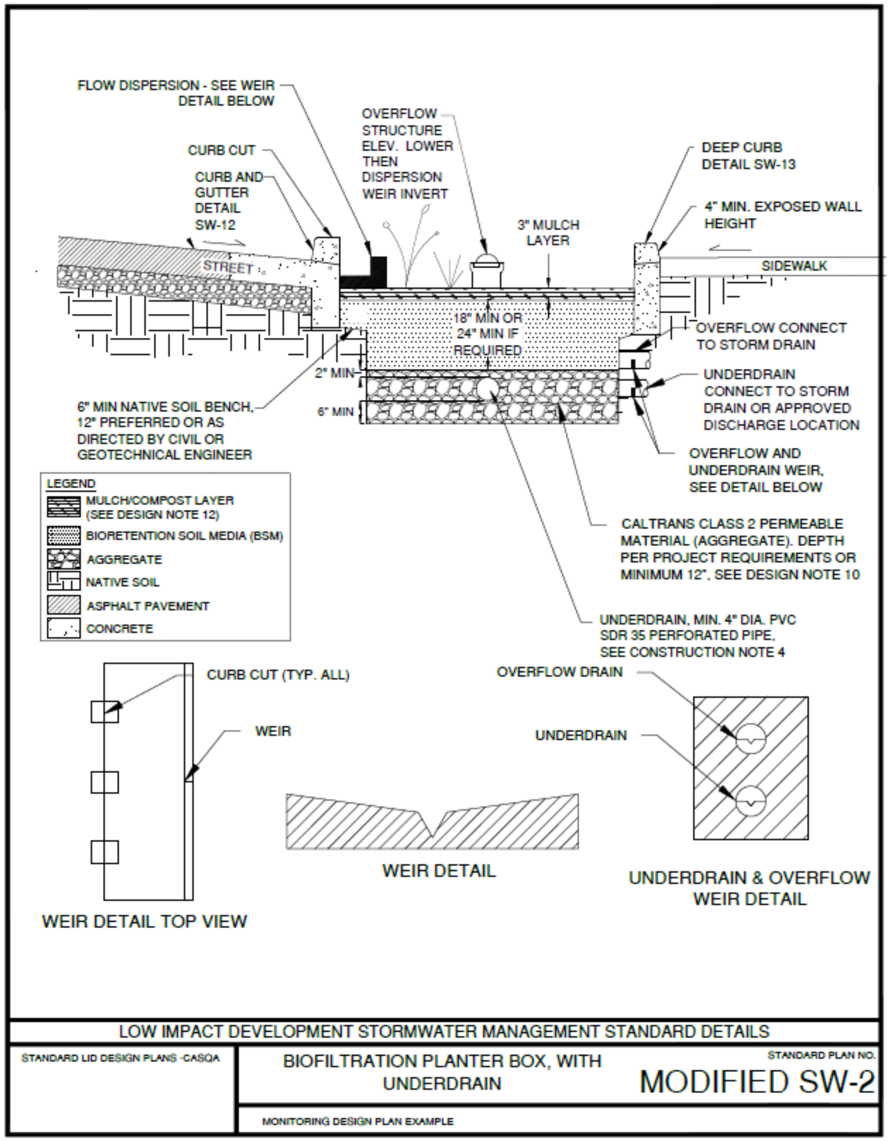
$$Percent\ Load\ Reduction = \frac{(Outlet\ Load - Inlet\ Load)}{Inlet\ Load}\ x\ 100$$

### *6.5.2 Standard Design Plan 2. Street Biofiltration Planter Box with Underdrain*

The following standard design plan example has the same layout as Plan 1, outlined above, with the exception that Plan 2 incorporates an underdrain (

Figure 6-6) (CASQA 2018b). Stormwater infiltrates through the soil media and flows into an underdrain. As water fills the biofiltration planter box, water would overtop the overflow structure and flow into the overflow pipe. A weir and flow meter would be installed in both the underdrain and overflow pipes as described in Design Plan 1 to measure flow into the BMP. This design plan assumes that the underdrain and overflow pipes are separated, and no other pipe junctions contribute flow.

## Figure 6-6. Standard Design Plan 2 Biofiltration Planter Box with Underdrain




### 6.5.3 Weir installation

Successful weir installation depends on several factors. Note that the below weir installation guidelines may need to be modified based on constraints of the LID/GSI measure configuration.

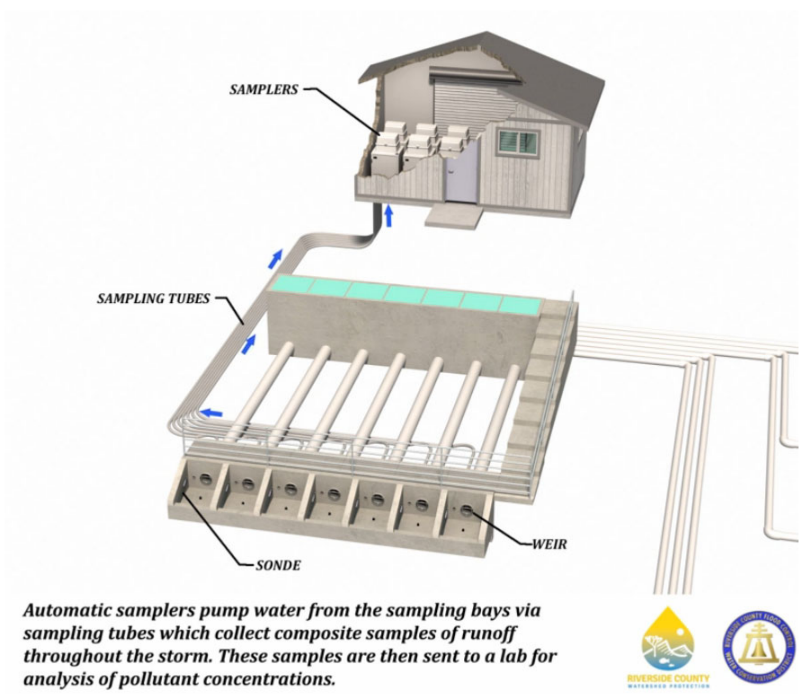
- Approach channel should be straight and of uniform cross-section for a distance of 15 to 20 times the maximum anticipated water depth (head) (h) upstream of the weir.
- The approaching flow should be sub-critical, tranquil, and be uniformly distributed across the width of the channel.
- Center the weir in the flow stream.
- Weirs must be level from front-to-back and from side-to-side. No deviation is allowed.

- Set the lowest point of the crest (the edge of the weir over which flow passes, (P) at least 2-3 times (h) above the channel floor.
- At full flow, the sidewalls on each side of the weir should extend 2- times water depth (h) on either side of the maximum width of the flow over the crest to the channel sidewalls.
- The lowest point of the crest should be at least 2 inches (5 cm) above the downstream water level.
- The point of measurement is 3-4-times water depth (h) upstream of the weir. Any closer and the head reading is affected by drawdown as the flow approaches the weir.
- The zero elevation for the point of measurement is the same elevation as the lowest point of the weir crest – this is the same as the water surface being the weir once flow over the weir has ceased (Open Channel Flow 2018).

### 6.5.4 Porous Pavement and Pervious Areas

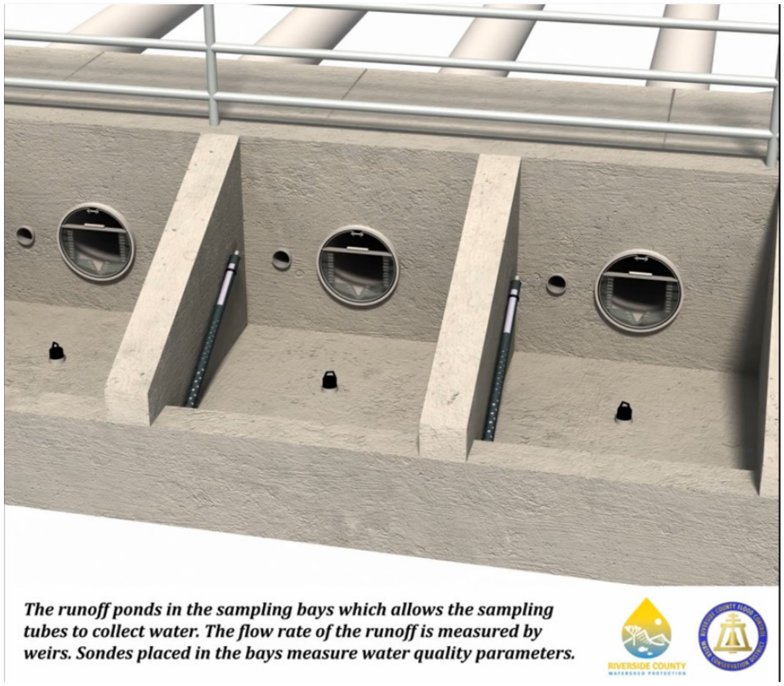
Flow monitoring and sampling for porous pavement and pervious area LID/GSI measures can be difficult to perform due to the large surface area and multiple inflow and outflow points. Riverside County and the Riverside County Flood Control and Water Conservation District (RCFC & WCD) built the Low Impact Development Testing and Demonstration Facility, that is dedicated to the long-term study of LID BMPs. LID planter boxes and multiple types of pervious pavement were installed on-site. Each BMP was built with a separate underdrain and outflow samples are collected from each BMP, as seen in Figure 6-7 below (RCFC & WCD, 2018).

**Figure 6-7. Riverside County Low Impact Development Testing and Demonstration Facility Water Quality Sampling Graphic Overview**



BMP flow is measured using weirs installed in the downstream conveyances, as seen below (Figure 6-8. ) (RCFC & WCD 2018).

**Figure 6-8. Riverside County Low Impact Development Testing and Demonstration Facility Flow Monitoring Outlet Weir Graphic**




## 6.6 Other Monitoring Resources

In addition to the SMC CLEAN monitoring protocol there are other monitoring protocols and monitoring resources available including:

- Technology Assessment Protocol - Ecology Protocol: See: http://www.wastormwatercenter.org/tape-program
- San Diego Stormwater BMP Design Manual
  - See: https://fortress.wa.gov/ecy/publications/documents/1810038.pdf.
- Caltrans Stormwater Program: See http://www.dot.ca.gov/env/stormwater/
- Sacramento Stormwater Quality Partnership: See: http://www.beriverfriendly.net/
- International Stormwater BMP Database Monitoring Guidance
  - See: http://www.bmpdatabase.org/Docs/2009%20Stormwater%20BMP%20Monitoring%20Manual.pdf

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