LAKE HAVASU CITY
LOW IMPACT DEVELOPMENT MASTER PLAN

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Prepared For:
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Parking Area Rainwater Harvesting Rendering

Executive Summary

Low Impact Development (LID) Practices and Benefits

Low Impact Development (LID) practices, sometimes referred to as Green Stormwater Infrastructure (GSI), manage stormwater runoff through decentralized, small-scale measures that are intended to mimic natural processes by capturing and controlling rainfall as close to the point of impact as possible. LID is an effective strategy for controlling urban runoff at a parcel-level by employing techniques that reduce the impact of development using multiple treatments that retain, detain, filter, treat, use, and reduce stormwater runoff. Direct, interrelated benefits from the use of LID include:

- Flood Damage Reduction.
- Water Conservation.
- Water Quality.
- Enhanced Community Space.
- Lower Temperatures.

LID Master Plan Purpose and Goals

The purpose of the *Lake Havasu City Low Impact Development Master Plan* (*LID Master Plan*) is to provide Lake Havasu City staff, residents, business owners, engineers, designers, landscape architects, contractors, and the development community proper guidance, specifications, standards, details, and direction for strategic implementation of LID Best Management Practices (BMPs), which can be implemented throughout the City to promote flood reduction, water conservation, and water quality. This document has been prepared with the following goals in mind:

- Resilient community development.
- Engaging developers, engineers, designers, City staff, etc.
- Practical, City-specific LID guidance and design principles.
- Recommendation of LID alternatives for City-identified locations experiencing routine flooding and maintenance needs.
- "Next step" guidance for embracing and implementing LID at a local-scale, development-scale, and City-wide-scale.
- Help achieve a broadening of the City's sustainability culture, including flood hazard/risk reduction, decreased maintenance, improved water conservation, improved water quality, and enhanced community gathering spaces.

LID Implementation for Types of Development

Considering the type of development is important to the successful implementation of LID. Retrofitting existing sites with LID can often be problematic and challenging, but if incorporated early into the new development and redevelopment process, LID implementation will have a high likelihood of success with a minimal increase in cost. To assist in successful implementation, it is recommended that LID practices be discussed in Pre-Application Meetings for new development and substantial redevelopment. The following table provides LID implementation considerations for new development, substantial redevelopment, non-substantial redevelopment, and existing development.

Development Scenario	Development Definition	LID Implementation Considerations
New Development	New commercial, industrial, residential, etc.	LID implementation **strongly recommended across full impervious area** per *LID Master Plan* guidelines.
Substantial Redevelopment	50% or more of impervious surface is altered.	LID implementation **strongly recommended across full impervious area** per *LID Master Plan* guidelines.
Non-Substantial Redevelopment	Less than 50% of impervious surface is altered.	LID implementation **strongly recommended within redeveloped incremental impervious area** per *LID Master Plan* guidelines.
Existing Development	Existing commercial, industrial, residential, etc.	LID implementation **encouraged** per *LID Master Plan* guidelines.

Prioritization of LID Selection

For Lake Havasu City, assuming the main goal of LID treatment is to reduce substantial flows and limit flooding, BMPs that capture stormwater should be prioritized over other BMP practices. Accounting for the site conditions during LID selection, the following is a prioritization of BMP practices:

1. *Stormwater Capture and Infiltration.*
2. *Stormwater Capture/Harvesting and Use*.
3. *Stormwater Capture, Detention and Metered Release*.
4. *Stormwater Conveyance via Biofiltration Systems*.
5. *Combination of Above Treatments 1 – 4*.

Hydrologic Design

Due to the relatively small size of Lake Havasu City, and little variation in rainfall, it was assumed the same LID design standard for capture volume and flow rate could be applied throughout the entire City. The approach presented below is for the effective sizing of LID facilities and should not be considered as a replacement for the *Drainage Design Manual for Mohave County*.

Design Capture Volume:

$$V = \frac{0.8}{12} * A = 0.0667 * A$$

Where: 0.8 inches = 75^{th} percentile design rainfall depth, capturing approximately 63% of rainfall volume

V = design capture volume, acre-feet (ac-ft)

A = contributing impervious area, acres (ac).

Design Flow Rate:

$$Q = 4A$$

Where: Q = design flow rate, cubic feet per second (cfs)

A = contributing impervious area, acres (ac).

LID BMPs for Lake Havasu City

The Low Impact Development (LID) Best Management Practices (BMPs) that are well suited for use within Lake Havasu City include, but are not limited to, the following:

- Bioswales
- Check dams
- Enhanced basins
- Curb openings
- Curb modifications
- Inverted Crown Roadway Variations
- Permeable hardscape
- Suspended pavement
- Soil modification
- Underground storage
- Cisterns
- Greywater collection
- Pretreatment practices

Cost-Benefit Analysis for LID Projects

Traditional cost-benefit analyses do not fully capture all of the benefits an LID project offers the City. Suitable cost-benefit analyses that recognize the range of LID benefits include:

- Triple Bottom Line
- Community Image
- Project Design Dividends

Implementation Strategies

Implementation strategies include adherence and adoption of LID policies, development of LID programs, and identification of future LID projects. These strategies are useful in guiding the City for setting priorities, allocating finances, and assessing achievements. Ultimately, the strategies should translate to specific actions.

When implementing LID strategies within a watershed, it is important to plan in an upstream-to-downstream manner before runoff turns into flooding and pollutants reach hazardous concentrations. LID practices should target identified issues or degradation before they occur. Therefore, implementation of LID BMPs should start in the upper watershed areas and work downstream as needed until the desired outcome is met.

ACKNOWLEDGEMENTS

The *Lake Havasu City Low Impact Development* (*LID*) *Master Plan* has been prepared with help from many diligent individuals, agencies, and organizations. Furthermore, this *LID Master Plan* rests on the foundation of past publications and contributions from others within the growing LID community. Partnering professionals providing key input and/or feedback are acknowledged below.

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DISCLAIMERS

This document serves as a guide for Low Impact Development planning for Lake Havasu City, Arizona. Selection and design of Low Impact Development Best Management Practices in any geographic area should be based on a thorough analysis of site conditions and awareness of local regulations.

Low Impact Development references and resources discussed throughout this document are intended to provide the reader with applicable, relevant information; however, Mohave County and Lake Havasu City do not officially endorse or cannot be held responsible for the Low Impact Development information and data developed or provided by others.

LOW IMPACT DEVELOPMENT REFERENCES & RESOURCES

Much of the information provided here within has been extrapolated from numerous Low Impact Development guidance documents that provide valuable, supportive information and data. The more relevant Low Impact Development references and resources reviewed and used for the development of this document are listed below.

- *Mohave County Low Impact Development Guide for Flood Protection and Water Sustainability* – Mohave County Flood Control District; December 2019.
- *Low Impact Development and Green Infrastructure Guidance Manual* – Pima County and City of Tucson, AZ; March 2015
- *Water Harvesting Guidance Manual* – City of Tucson, AZ; October 2005.
- *Plan Tucson: City of Tucson General & Sustainability Plan 2013* – City of Tucson, AZ; November 2013.
- *Greater Phoenix Metro Green Infrastructure Handbook: Low-Impact Development for Alternative Stormwater Management* – Scottsdale, Avondale, Gilbert, Peoria, AZ; January 2019.
- *Triple Bottom Line Cost Benefit Analysis of Green Infrastructure/Low Impact Development (GI/LID) in Phoenix, AZ* – City of Phoenix, AZ; June 2018.
- *Low Impact Development Toolkit* – City of Mesa, AZ; April 2015.
- *Planning and Land Development Handbook for Low Impact Development (LID): Part B, Planning Activities* – City of Los Angeles; 5th Edition; May 2016.
- *Innovative Drought and Flood Mitigation Projects* – Federal Emergency Management Agency (FEMA); January 2017.
- *Building Community Resilience with Nature-Based Solutions; A Guide for Local Communities* - Federal Emergency Management Agency (FEMA); June 2021.
- *National Management Measures to Control Nonpoint Sources Pollution from Hydromodification* - US Environmental Protection Agency (EPA); July 2007.
- *Benefits of Low Impact Development, How LID Can Protect Your Community's Resources (LID Barrier Busters Fact Sheet Series) Engagement* - US Environmental Protection Agency (EPA); March 2012.
- *Green Infrastructure in Parks: A Guide to Collaboration, Funding, and Community Engagement* - US Environmental Protection Agency (EPA); June 2017.
- *Improving the Resilience of Best Management Practices in a Changing Environment: Urban Stormwater Modeling Studies* – US Environmental Protection Agency (EPA); May 2018.
- *Green Streets Handbook* - US Environmental Protection Agency (EPA); March 2021.
- *Impacts of Grade Control Structure Installations on Hydrology and Sediment Transport as an Adaptive Management Strategy* – US Bureau of Reclamation; September 2020.

LOW IMPACT DEVELOPMENT DEFINITION

Federal Emergency Management Agency

Low Impact Development (LID) is a storm water management strategy that emphasizes conservation and the use of existing natural site features by integrating them with distributed, small-scale storm water controls to mimic natural hydrologic patterns…LID works best when used throughout a community or watershed, not just in the floodplain.

Environmental Protection Agency

Communities of all sizes and in all climates are using green infrastructure (Low Impact Development) to manage stormwater where it falls…Green infrastructure manages stormwater to control flooding from small storms and improve water quality. It also offers a wide range of other environmental, economic, public health, and social benefits.

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3PS	Three P's (People, Planet, Profit)
ADEQ	Arizona Department of Environmental Quality
AZPDES	Arizona Pollution Discharge Elimination System
BMP	Best Management Practice
CTP	Cooperating Technical Partners [program]
CWA	Clean Water Act (1972)
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GSI	Green Stormwater Infrastructure
LHC	Lake Havasu City
LID	Low Impact Development
MCM	Minimal Control Measure
MS4	Municipal Separate Storm Sewer System
MSGP	Multi-Sector General Permit
NOI	Notice of Intent
NFIP	National Flood Insurance Program
NPDES	National Pollution Discharge Elimination System
NPS	Non-Point Source [pollution]
SWPP	Surface Water Protection Program
SWMP	Stormwater Management Program
TBL	Triple Bottom Line
WOTUS	Waters of the United States

1 INTRODUCTION

1.1 Introduction to Low Impact Development

Low Impact Development (LID) practices, sometimes referred to as Green Stormwater Infrastructure (GSI), manage stormwater runoff through decentralized, small-scale measures that are intended to mimic natural processes by capturing and controlling rainfall as close to the point of impact as possible. LID is an effective strategy for controlling urban runoff at a parcel-level by employing techniques that reduce the impact of development using multiple treatments that retain, detain, filter, treat, use, and reduce stormwater runoff. Urbanized and developing communities, such as Lake Havasu City, are ideal places to benefit from LID implementation.

Both FEMA and EPA consider the use of LID as a cost-effective and resilient approach to stormwater management. According to the EPA, LID is "*a management approach and set of practices that can reduce runoff and pollutant loadings by managing runoff as close to its source(s) as possible. LID includes overall site design approaches…and individual small-scale stormwater management practices that promote the use of natural systems for infiltration, evapotranspiration and the harvesting and use of rainwater.*"

Direct, interrelated benefits from the use of LID include the following:

- **Flood Damage Reduction.** LID mitigates flood hazard/risk and alleviates local flooding by increasing the ability of the landscape to store and infiltrate water, which translates to a reduction in the number of costly flooding events.
- **Water Conservation.** LID practices improve rainwater infiltration (groundwater recharge) and promote stormwater use through rainwater harvesting.
- **Water Quality.** Stormwater runoff collects and transports pollutants such as oil, bacteria, sediments, metals, hydrocarbons, and nutrients. LID practices can reduce pollutant-laden stormwater currently being conveyed to natural washes and water bodies, such as Lake Havasu. By improving water quality, the cost of maintaining healthy waters is reduced.
- **Enhanced Community Space.** LID practices can incorporate vegetation and shade trees that enhance and beautify community spaces such as pathways, roadways, sidewalks, parks, commercial areas, and residential developments.
- **Lower Temperatures.** LID mitigates the urban heat island effect by minimizing hot, impervious surfaces through the increase of vegetative cover.

LID is a stormwater management approach that treats water as a resource, not a nuisance. It is typically not intended to eliminate or replace conventional stormwater management, but to supplement and enhance conventional stormwater management. As laid out by the EPA and Natural Resources Defense Council, LID principles include the following:

- Integration of stormwater management early in site planning activities.
- Use of natural hydrologic functions as the integrating framework.
- A focus on prevention rather than mitigation.

- An emphasis on simple, low-tech, and low-cost methods to manage urban runoff.
- Managing stormwater as close to the source as possible.
- Distribution of small-scale practices throughout the landscape.
- Reliance on natural features and processes.
- Development of multifunctional landscapes.

1.2 Current LID Practices in Lake Havasu City

Although LID practices may not be common in Lake Havasu City (City), they are not new to the City. Various applications have been incorporated and implemented on properties throughout the City for purposes of reducing erosion, promoting infiltration, and capturing non-potable water (rainwater, air conditioning condensate, etc.) for irrigation reuse. Examples of current LID practices include:

- Lake Havasu City Aquatic Center (Photograph 1-1). LID practices implemented: curb cuts, swales, check dams, and shallow basins.

Photograph 1-1. Curb cut with swale and check dams at Lake Havasu City Aquatic Center.

- Local Parking Area (Photograph 1-2) at Aquatic Center. LID practices implemented: grading to drain toward flush curbs and median basin.

Photograph 1-2. Parking lot draining to median basin with flush curbs at Lake Havasu City Aquatic Center.

- Lake Havasu City Street Maintenance Facility (Photograph 1-3). LID practices implemented: cisterns, rainwater harvesting and greywater collection.

Photograph 1-3. Cisterns capturing rainwater and greywater for irrigation reuse at Street Maintenance Facility.

- Rotary Community Park & Playgrounds (Photograph 1-4). LID practices implemented: soil modification (organic mulch).

Photograph 1-4. Organic mulch applied as ground cover either side of decomposed granite pathway at Rotary Community Park & Playgrounds.

- Commercial property near North Kiowa Boulevard and North Lake Havasu Avenue (Photograph 1-5). LID practices implemented: curb cuts and shallow basin.

Photograph 1-5. Curb cuts in parking lot to shallow basin.

The LID practices that have been implemented in the City are not limited to the examples shown above. Many others exist and some may have been implemented without the owners knowing that they were engaging in such practices. This document intends to help the reader understand what LID practices are and how to maximize their benefits.

1.3 *LID Master Plan* Purpose and Goals

1.3.1 Purpose

The purpose of the *Lake Havasu City Low Impact Development Master Plan* (*LID Master Plan*) is to provide Lake Havasu City staff, residents, business owners, engineers, designers, landscape architects, contractors, and the development community proper guidance, specifications, standards, details, and direction for strategic implementation of LID Best Management Practices (BMPs), which can be implemented throughout the City to promote flood reduction, water conservation, and water quality.

The *LID Master Plan* is a planning-level document that can be used to advance the City's future master planning efforts by promoting resilient community development. As LID implementation provides a multitude of benefits, the *LID Master Plan* is a resource for practical use by several City Departments, such as Public Works, Parks & Recreation, and Development Services.

By providing standards and guidance for design and implementation of LID BMPs, the *LID Master Plan* is a tool to facilitate the transition away from full reliance on traditional, centralized, grey stormwater infrastructure through the inclusion of multi-beneficial, sustainability-focused, decentralized LID infrastructure.

The *LID Master Plan* is a resource that provides technical information and details, but also encourages readers to embrace and promote LID practices.

1.3.2 Goals

As highlighted throughout the *LID Master Plan*, this document has been prepared with the following goals in mind:

- Resilient community development.
- Engaging developers, engineers, designers, City staff, etc.
- Practical, City-specific LID guidance and design principles.
- Recommendation of LID alternatives for City-identified locations experiencing routine flooding and maintenance needs.
- "Next step" guidance for embracing and implementing LID at a local-scale, development-scale, and City-wide-scale.
- Help achieve a broadening of the City's sustainability culture, including flood hazard/risk reduction, decreased maintenance, improved water conservation, improved water quality, and enhanced community gathering spaces.

1.4 LID Master Plan Origins

The *LID Master Plan* was prepared under the FEMA Cooperating Technical Partners (CTP) Program, which is a program that creates partnerships between FEMA and communities participating in the National Flood Insurance Program (NFIP). The Mohave County Flood Control District (County) and FEMA first entered into a CTP agreement in December 2003, with the intent to continue proactive floodplain and stormwater management activities within Mohave County.

As part of the County-FEMA CTP agreement, the County prepared the *Mohave County Low Impact Development Guide for Flood Protection and Water Sustainability* (*County LID Guide*). The *County LID Guide* was the first County-sponsored document of its kind to discuss the benefits of Low Impact Development and to provide practical LID alternatives that may be implemented to improve local flood protection and advance water sustainability.

As a proactive stormwater management community that promotes water conservation and water quality initiatives, Lake Havasu City partnered with the County to obtain CTP grant funding in order to build-upon the *County LID Guide* by preparing this City-focused *LID Master Plan*. The *LID Master Plan* was in large part funded through CTP Grant No. EMF-2020-CA-0010 and conducted as a FEMA Risk MAP Project.

1.5 *LID Master Plan* Overview and Development

1.5.1 Overview

The *LID Master Plan* is arranged as follows:

- Section 1. Introduction.
- Section 2. Stormwater Management Considerations
- Section 3. LID Selection and Design Factors for Consideration
- Section 4. Hydrologic Design Analysis
- Section 5. Low Impact Development BMP Details
- Section 6. Rethinking Cost-Benefit Analysis
- Section 7. Implementation Strategies
- Section 8. Site-Specific Examples of Future Applications of LID BMPs
- Section 9. References

1.5.2 Development

The *LID Master Plan* was developed in partnership with the City, County, FEMA, and the Consulting Team of Holistic Engineering and Land Management, Inc. (HELM) and WERK | urban design (WERK). The *LID Master Plan* development efforts included the following:

- Regular coordination between County, City, FEMA RIX, and Consultant Team to define the evolving *LID Master Plan* purpose, need, goals, and deliverable.

- Review of the *County LID Guide* to maximize compatibility and capture applicable LID guidelines and applications.
- Review of LID information from LID-focused agencies, such as the City of Tucson, City of Phoenix, City of Los Angeles, County of Los Angeles, Urban Drainage and Flood Control District (Denver, CO), and Riverside County (California). Much of the valuable information provided in the *LID Master Plan* has been obtained from LID guidance and design manuals and policy documents made readily available by the LID community. A list of the collected LID resource material is provided in Section 9: References.
- Compilation and evaluation of readily available hydrologic data and drainage information, such as rainfall records, current modeled drainage analysis of the City, and roadway drainage characteristics. This data and information were the basis for engineering calculations used to determine LID BMP sizing/design guidance specific to the City.
- Identification of LID BMPs most appropriate for use within Lake Havasu City. Preparation of LID BMP details for inclusion in the *LID Master Plan*.
- Consideration of various LID BMPs for the following two demonstration sites:
  - Demonstration Site 1 - General area in vicinity of McCulloch Boulevard between South Smoketree Avenue and Querio Drive.
  - Demonstration Site 2 - Island Ball Fields adjacent to City's wastewater treatment facility.
- Preparation of *LID Master Plan* document.

The *LID Master Plan* is intended to build upon the *County LID Guide*, while providing more local guidance applicable to the City. Therefore, the reader is strongly encouraged to investigate and employ the foundational concepts outlined in the *County LID Guide*.

1.6 Need for an LID Master Plan

Three important, relevant issues currently being addressed by the City are flood hazard reduction, increased water conservation, and improved surface and reservoir water quality. Employing LID in existing and future development will provide benefits to these three critical issues.

1.6.1 Need for Flood Hazard Reduction

City spending on flood hazard reduction projects and flood-related maintenance needs is significant. Furthermore, transportation corridors throughout the City are designed to convey a substantial volume of stormwater. Stormwater within streets adversely impacts travel, presents risk to residents, and delays emergency response timing. Strategic implementation of LID BMPs will reduce stormwater runoff discharge, volume, and velocity – particularly within roadways.

Smaller, more frequent storm events cause costly maintenance issues; therefore, a one-time investment in LID is more prudent than relatively routine maintenance costs.

1.6.2 Need for Water Conservation

Water conservation has been identified as a key issue for the City of Lake Havasu, which is embodied in the City's most recent *Water Conservation Plan*. According to the *Water Conservation Plan*:

"*The overall goal of the 2020-2025 water conservation plan cycle is to continue to decrease Lake Havasu City's per capita water consumption…*"

"*A number of activities ranging from an increased education/outreach component to converting more potable water irrigation customers to effluent are proposed over the next five years…*"

"*Even small reductions in consumption spread out over such a large user base can potentially realize significant savings.*"

"*With drought conditions remaining relatively unscathed in the last two decades, future water supply availability is more uncertain than ever.*"

"*Lake Havasu City would like to continue a program to install or give incentives to install rainwater harvesting systems on city, school, and commercial roofs and parking lots adjacent to irrigable landscaping.*"

The *Water Conservation Plan* can be viewed and obtained from the City's website (https://www.lhcaz.gov/docs/default-source/department-documents/waterconservationplan.pdf?sfvrsn=ad2b2f7c_28).

1.6.3 Need for Water Quality

As Lake Havasu City is so close to, and relies so heavily on, the Colorado River, water quality enhancements are critical.

Runoff pollution is conveyed by rainwater that washes off roads, bridges, parking lots, rooftops, and other impermeable surfaces. As rainwater flows over these surfaces, it picks up dirt and dust, rubber and metal deposits from tire wear, antifreeze and engine oil that has dripped onto the pavement, pesticides and fertilizers, and discarded litter. When left unaddressed, resulting outcomes lead to regular and often expensive maintenance and potential lost revenues due to impaired waters. For Lake Havasu City, these contaminants are ultimately carried to the Colorado River; and therefore, improving water quality is critical for maintaining Lake Havasu as a tourist destination and economic driver.

LID practices encourage infiltration and decrease flow velocity, thereby reducing the amount of erosion and pollutants deposited in roadways, stormwater facilities, washes and the Colorado River. Since the highest pollutant loads occur at the initiation of the runoff event, even relatively minor implementations of LID practices can have a significant improvement on water quality by both capturing and limiting the concentration of pollutants.

2 STORMWATER MANAGEMENT CONSIDERATIONS

Stormwater management is an increasingly important issue for Lake Havasu City staff, residents, and business owners. This section provides an overview of urban stormwater issues, centralized vs. decentralized stormwater management approaches, stormwater regulatory frameworks, site development LID considerations, and other means for addressing urban runoff impacts.

2.1 Urban Stormwater Overview

Urban stormwater is any runoff that occurs from impervious surfaces that are introduced to an environment through development. Impervious surfaces are commonly associated with roads, rooftops and parking lots and interrupt the infiltration process that typically occurs in the natural, undeveloped environment. This loss of infiltration, which is critical to the hydrologic cycle, results in undesirable environmental consequences such as:

- Increased and more frequent runoff events.
- Erosion and degradation of receiving streams and washes.
- Reduced groundwater recharge.
- Greater downstream pollutant loading.

Specifically, for Lake Havasu City, impervious surfaces generate substantial runoff from storm events that impact property, transportation corridors, and public safety. This is largely an unfortunate byproduct of design as many City streets, in lieu of dedicated channels or storm drain systems, are the primary means to convey stormwater. After collecting, concentrating, and conveying urban runoff, the streets often discharge directly to washes in the larger historic flow corridors. The introduction of increased runoff to these larger flow corridors often results in the need to improve the washes to prevent degradation. Stabilizing features such as grade control structures or other features are then necessary to compensate for the rapid change in flow conditions.

The Environmental Protection Agency (EPA) has identified runoff from urbanized areas as a significant source of water quality impairments for downstream bodies of water. The EPA refers to urban stormwater runoff as a type of nonpoint source (NPS) pollution. Such pollutants typically include sediment, oil/grease from motor vehicles and heavy metals that can harm fish/wildlife, contaminate drinking water supplies, and make recreational areas unsafe or unpleasant.

Urban stormwater management challenges for the City include, but are not limited to, the following:

- Streets conveying substantial runoff.
- Steep terrain with runoff-induced erosion.
- Expensive maintenance (e.g., removal of sediment within streets and roadways) resulting from nuisance flows.
- Infrequent runoff events resulting in high pollutant buildup during dry conditions.
- Areas of inadequate draining or infiltration, resulting in excessive ponding.

2.2 Centralized vs. Decentralized Stormwater Management

The goal of urban stormwater management is to prevent excessive runoff from impervious surfaces. When implementing permanent stormwater BMPs, it is important to understand how they are implemented. As discussed below, urban stormwater is managed in either a centralized or decentralized fashion. The challenge of the *LID Master Plan* is to show how decentralized LID opportunities can be successfully integrated with the more traditional, centralized stormwater management scenarios typical of the land development approach at the time of this document. Often, urban communities in the arid southwest are best served by implementing a combination of both centralized and decentralized stormwater management practices.

2.2.1 Centralized Stormwater Management

Centralized stormwater management typically considers stormwater a nuisance and employs storm drain systems, channels, and basins to collect and remove (centralize) the stormwater as quickly as possible. Centralized stormwater management is commonly regional in nature and requires relatively expensive, large-scale infrastructure projects. Regional flood control is best planned/implemented regionally by starting at the bottom of the watershed and working up. Such facilities are designed for the larger, less frequent storm events that can overwhelm smaller, local LID BMPs.

Centralized stormwater management can be implemented on a regional level, but the benefit of water as a resource typically diminishes as centralization of runoff increases. This is because water is not being captured on-site and runoff travel time is condensed, reducing infiltration capability.

Water quality also tends to decrease as runoff (and pollutants) accumulates in regional facilities, leading to greater pollutant loading. To achieve water quality goals, on-site LID BMPs may still be necessary, regardless of the existence of regional, centralized stormwater management structures.

2.2.2 Decentralized Stormwater Management

Decentralized stormwater management, such as LID, considers stormwater a resource that can be infiltrated back into the ground, stored for later use, or used for routine needs such as landscape irrigation. To achieve this, rain is captured as close as practical to where it falls, much like the hydrologic cycle in the natural environment. Therefore, LID BMPs tend to be smaller and distributed throughout a site, in parallel or series, rather than a single (centralized) collection point. When considering smaller, more frequent storm events and arid-compatible plants, LID BMPs can be sized to sustainably support some vegetation without the use of regular potable irrigation.

Decentralized stormwater management takes advantage of the cumulative impact of relatively inexpensive, local, small-scale features. Implementing LID BMPs on-site helps to capitalize on stormwater as a resource, and depending on the size of a site, multiple LID BMPs may be needed to effectively decentralize stormwater. Generally, when addressing stormwater in a watershed, LID BMPs are best implemented by starting at the top of the watershed and working down with dispersed treatments throughout.

The goal of decentralized stormwater management is to prevent the concentration of runoff by minimizing velocity and thereby, eliminating the energy required to erode, generate sediment, and transport sediment and other pollutants. In general, as the percentage of pervious surface (capable of retaining water) increases, infiltration becomes more effective as stormwater is spread over a larger area reducing flow depths and shortening the drawdown time.

In some cases, traditional landscape planting can serve as the LID BMP as it slows runoff and absorbs water through plant uptake. This is effective for locations where runoff is still under sheet flow conditions. For example, a vegetated strip placed along the edge of a parking lot. Decentralized stormwater management BMPs suitable for implementation within Lake Havasu City are presented in Section 5.

2.3 Stormwater Regulatory Framework

The following section provides a brief overview discussion of the common federal, state, county and local regulatory frameworks pertaining to urban stormwater management. Prior to any construction of stormwater management facilities, the reader is strongly encouraged to identify and adhere to applicable regulatory permitting requirements.

2.3.1 Federal

2.3.1.1 Clean Water Act

The Clean Water Act (CWA) is the principal regulatory law for stormwater pollution prevention and control. The goal of the CWA is to set water quality standards and make it unlawful to discharge any pollutants from a point source (pipes, constructed channels, etc.) to navigable waters without a permit. The U.S. Environmental Protection Agency (EPA) is responsible for administering and enforcing the requirements of the CWA. Under section 402(b), all urban and industrial stormwater must be controlled through the National Pollutant Discharge Elimination System (NPDES) program with respect to both construction and post-construction phases of development. In Arizona, the NPDES permitting program is referred to as the Arizona Pollutant Discharge Elimination System (AZPDES) program and is administered by the Arizona Department of Environmental Quality (ADEQ).

2.3.2 State

2.3.2.1 Arizona Pollutant Discharge Elimination System (AZPDES) General Permit

The AZPDES General Permit is the state-level regulatory law for stormwater pollution and covers small Municipal Separate Storm Sewer Systems (MS4s) in Arizona for cities, towns, counties and state/federal properties. It specifically authorizes stormwater discharges from MS4s in Arizona to Waters of the United States (WOTUS) per the terms and conditions of the permit. It is eligible to permittees that are located fully or partially within urbanized areas as determined by the Bureau of Census. To obtain coverage under the general permit, the permittee must submit a Notice of Intent (NOI) and develop a stormwater management program (see Section 2.3.4.1) that meets the minimum requirements of the permit. The AZPDES MS4 General Permit and fact sheet can be viewed and obtained from ADEQ's website (https://azdeq.gov/node/520).

2.3.2.2 AZPDES Industrial Stormwater Multi-Sector General Permit (MSGP)

Under certain circumstances, on-site activities are not eligible under the MS4 General Permit. These activities are generally considered industrial in nature with a higher potential of adversely impacting water quality to WOTUS. Types of activities include, but are not limited to, warehousing, manufacturing, landfills, water/wastewater treatment, and airports. For these industrial activities, permittees are covered under the AZPDES Industrial Stormwater MSGP and must adhere to its conditions. The only exception is for industrial activities related to certain types of mining, which are covered under a separate permit. In addition to obtaining a NOI for coverage under the industrial general permit, the permittee must develop a stormwater pollution prevention plan documenting both water quality monitoring and mitigation of potential pollutants. Industrial Stormwater MSGP and fact sheet can be viewed and obtained from ADEQ's website (https://azdeq.gov/node/685).

2.3.2.3 Construction General Permit (CGP)

The ADEQ 2020 Construction General Permit (CGP) was issued on March 27, 2020, and became effective on July 1, 2020, replacing ADEQ's 2013 CGP. The 2020 CGP was modified to include non-WOTUS protected surface waters. This modification was necessary to incorporate Arizona's new Surface Water Protection Program (SWPP). The CGP and fact sheet can be viewed and obtained from ADEQ's website (https://azdeq.gov/node/524).

2.3.2.4 Arizona Administrative Code (AAC) Title 18, Chapter 9, Article 7 – Part D (Greywater)

Since this document refers to the use of greywater for the purposes of irrigation reuse, it is important for the reader to understand Arizona's rules for greywater use. In general, greywater is any wastewater with a low risk of contamination by bacteria, viruses, and other pathogens. Examples include wastewater from clothes washers, bathtubs, showers, and sinks (not kitchen), as well as air conditioning condensate. Restrictions include a household limit to 400 gallons a day and irrigation use only for non-food producing plants (except for citrus and nut trees). The greywater rule can be viewed and obtained using this link: https://apps.azsos.gov/public_services/Title_18/18-09.pdf.

2.3.3 County

2.3.3.1 Mohave County Stormwater Management Ordinance - 2018

The Mohave County Stormwater Management Ordinance – 2018 was adopted to ensure Mohave County meets the minimum federal requirements for designation by the EPA as a small Municipal Separate Storm Sewer Operator (MS4). As a small MS4, Mohave County is required by the CWA to implement and enforce a program to improve, to the maximum extent practicable, the quality of stormwater in the County's stormwater conveyance system with the unincorporated urbanized areas of the County. The ordinance is intended to protect WOTUS by improving the quality of stormwater runoff from urbanized areas through the use of BMPs by the County and its residents. The Mohave County Stormwater Management Ordinance – 2018 can be viewed and obtained from Mohave County's website using this link: http://stormwater.mohavecounty.us/pdf/MCStormwaterOrdinance.pdf.

2.3.3.2 Low Impact Design Guide for Flood Protection and Water Sustainability

As discussed in Section 1.4, Mohave County has taken steps to address the integration of LID principles and practices with the Mohave County Flood Control District's *Low Impact Development Guide for Flood Protection and Water Sustainability* (Mohave County Flood Control District, December 2019). The *County LID Guide* can be viewed and obtained from Mohave County's website using this link: https://resources.mohave.gov/File/DevelopmentServices/FloodControl/LID/20191202_Mohave_County_LID_Guide_Flood_Protection_Water_Sustainability.pdf.

2.3.4 Municipal

2.3.4.1 Lake Havasu City Stormwater Management Program

The 2014 Lake Havasu City Stormwater Management Program (SWMP) is the current program covered under the AZPDES General Permit. In general, to achieve compliance, the program presents Best Management Practices (BMPs) to address the Minimum Control Measures (MCMs) appropriate for the City's stormwater system. As stated in the document, the goal of the program is to protect water resources so current and future residents can enjoy fishing, boating and the aquatic/wildlife of the area. The SWMP provides BMPs for the following MCMs:

- Public Education & Outreach
- Public Involvement/Participation
- Illicit Discharge Detection & Elimination
- Construction Site Runoff Controls
- Post-Construction Site Runoff Control
- Pollution Prevention/Good Housekeeping

For each MCM, the applicable activities are defined with associated objectives, schedule to conduct, and measurable goals.

According to the SWMP, technical guidance for the design and maintenance of post-construction (permanent) BMPs should refer to the *Drainage Design Manual for Mohave County*. In addition, sites using permanent BMPs shall provide the City a "Stormwater Management/BMP Facilities Maintenance Agreement" identifying parties responsible for operation and maintenance of the BMPs. The agreement also grants the City access for inspection of the facility. Refer to Appendix A for the City's maintenance agreement template.

The City's Stormwater Management Program document can be viewed and obtained using this link: http://www.lhcaz.gov/docs/default-source/department-documents/swmpupdate2014.pdf?sfvrsn=55952b7c_6.

2.3.4.2 Lake Havasu City Ordinance No. 14-1105

Ordinance No. 14-1105 is Lake Havasu City's current stormwater ordinance adopting the requirements of the CWA, AZPDES and SWMP. The City's Ordinance No. 14-1105 can be viewed and obtained using this link: http://www.lhcaz.gov/docs/default-source/department-documents/signedordinance14-1105.pdf?sfvrsn=27952b7c_6.

2.3.4.3 Lake Havasu City Code Chapter 8.28

City Code Chapter 8.28 is Lake Havasu City's current code related to stormwater, with the intent of setting the minimum standards under federal and state laws. Under the regulations section, the *Drainage Design Manual for Mohave County* is considered a reference guide for stormwater management activities and design. The City's Code Chapter 8.28 can be viewed and obtained using this link: http://www.lhcaz.gov/docs/default-source/department-documents/stormwaterchapter828.pdf?sfvrsn=21952b7c_6.

2.4 LID Considerations for New Development, Substantial and Non-Substantial Redevelopment, and Existing Development

The *LID Master Plan* presents opportunities to treat water as a resource, rather than a nuisance, for new development and existing sites. Although the *Drainage Design Manual for Mohave County* states that stormwater storage facilities should not be allowed on residential lots smaller than one acre, it is encouraged that permanent LID BMPs be installed for development sites of any size. At the time of this *LID Master Plan*, there is no City ordinance or code that defines a minimum area threshold for the application of LID BMPs.

Considerations for LID implementation for new development, substantial redevelopment, non-substantial redevelopment, and existing development are provide in Table 2-1. Except for industrial sites that are already required to address stormwater, these LID implementation considerations may be applicable to any development regardless of the land use type (commercial, public, residential, etc.). It is imperative to understand that implementation of LID BMPs is not intended to replace the minimum stormwater management requirements prescribed by the County; but rather, LID BMPs are intended to offset and/or supplement the minimum requirements outlined in the *Drainage Design Manual for Mohave County*.

Table 2-1. Considerations for LID Implementation.

Development Scenario	Development Definition	LID Implementation Considerations
New Development	New commercial, industrial, residential, etc.	LID implementation **strongly recommended across full impervious area** per *LID Master Plan* guidelines.
Substantial Redevelopment	50% or more of impervious surface is altered.	LID implementation **strongly recommended across full impervious area** per *LID Master Plan* guidelines.
Non-Substantial Redevelopment	Less than 50% of impervious surface is altered.	LID implementation **strongly recommended within redeveloped incremental impervious area** per *LID Master Plan* guidelines.
Existing Development	Existing commercial, industrial, residential, etc.	LID implementation **encouraged** per *LID Master Plan* guidelines.

To assist in the successful implementation of LID, it is recommended that LID considerations be discussed in Pre-Application Meetings for new development and substantial redevelopment.

2.5 Other Means to Address Urban Runoff Impacts

2.5.1 Source Control BMPs

Stormwater management practices can be implemented as structural (engineered) or source control (planned strategies) BMPs, whether it is a new site or a redevelopment project. Source control BMPs vary significantly in size, type, configuration, and operation. Source control BMPs focus on the “source” of urban runoff, essentially addressing stormwater before it becomes runoff. In general, source control BMPs address water quality issues, but can also reduce runoff volume and sediment loads if site-dependent considerations are made. Source control BMPs are strongly encouraged when practical and include structures or operations that prevent pollutants from contacting stormwater through physical separation.

The typical LID practices discussed throughout this *LID Master Plan* are considered structural measures and require design/engineering and construction. Source control BMPs minimize the need for structural LID measures through strategic site planning. Source control BMPs include the following:

- Minimizing land disturbance and reducing clearing of land.
- Protecting natural drainage patterns.
- Avoiding soil compaction where appropriate.
- Limiting the amount of proposed impervious surface area. This can be done by removing impervious areas where they are not needed or installing less impervious area for new development.

- Good housekeeping, such as removal of trash, covering stockpiles, cleaning up toxic spills (e.g., oil from vehicles), and limited use of fertilizers and pesticides. Properly designed trash storage areas reduce the potential for loose trash and pollutants to be transported by stormwater runoff. Preventative measures include enclosures, containment structures, and impervious pavements where groundwater contamination may result from pollutant spills.
- Storm drain signage to inform residents that waste dumped into storm drain inlets can adversely impact receiving and ground waters.
- Efficient landscape irrigation that minimizes runoff excess.
- Outdoor material storage areas should be properly designed to reduce the opportunity for toxic compounds, oil and grease, heavy metals, nutrients, suspended solids, and other pollutants to enter the stormwater conveyance system. Infiltration potential is eliminated, and pollutant containment is maximized, with properly designed outdoor storage areas.
- Outdoor work areas and vehicle washing areas that are properly designed to direct runoff directly to a sanitary sewer, if possible, not a storm drain system.

2.5.2 Stream Stabilization

As in the case of most cities, existing streams, washes, and other natural conveyances serve as the outfall for much of the urban stormwater runoff. This is no different for Lake Havasu City. By changing how stormwater enters the drainageway, either through increasing the inflow rate, moving the location of the inflow, or changing the timing of the inflow, that drainageway will fundamentally be altered. This is because the natural drainageway is trying to find a new equilibrium within the altered environment (see below Figure 2-1). For natural washes, this often results in some level of erosion and incision of the stream bed. Such erosion not only places adjacent development at risk but it also transports and deposits sediment downstream. This sedimentation can be significant and can potentially result in unintended downstream environmental degradation. For Lake Havasu City, sediment laden flows into Lake Havasu contributes to the reduction of the reservoir capacity and adversely impacts the aquatic environment and habitats.

Stream stabilization can come in many forms, from providing drainage easements for washes to readjust and function naturally to the construction of concrete-lined channels. Typically, a fully lined, hardened channel as a means for channel stability proves to be expensive, undesirable with the public, and damaging to the environment. Within the City, strategically placed grade control structures are commonly used to flatten channel slopes and prevent stream degradation. In some cases, bank protection with a cutoff wall may be needed if lateral migration of the stream becomes an issue on tighter bends.

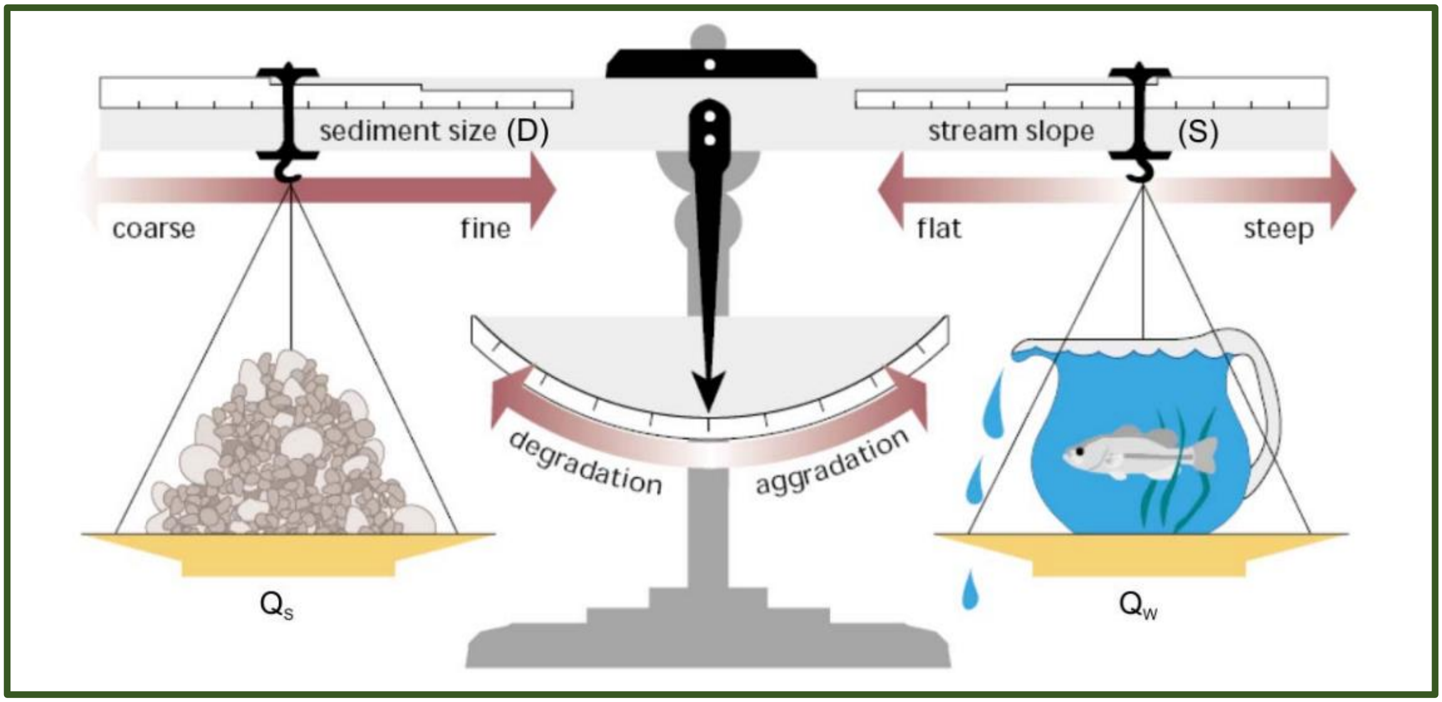


Figure 2-1. Factors affecting channel degradation and aggradation (EPA, National Management Measures to Control Nonpoint Source Pollution from Hydromodification, July 2007)

For additional discussion on stream modification, please refer to the hydromodification discussion in Section 3.9.

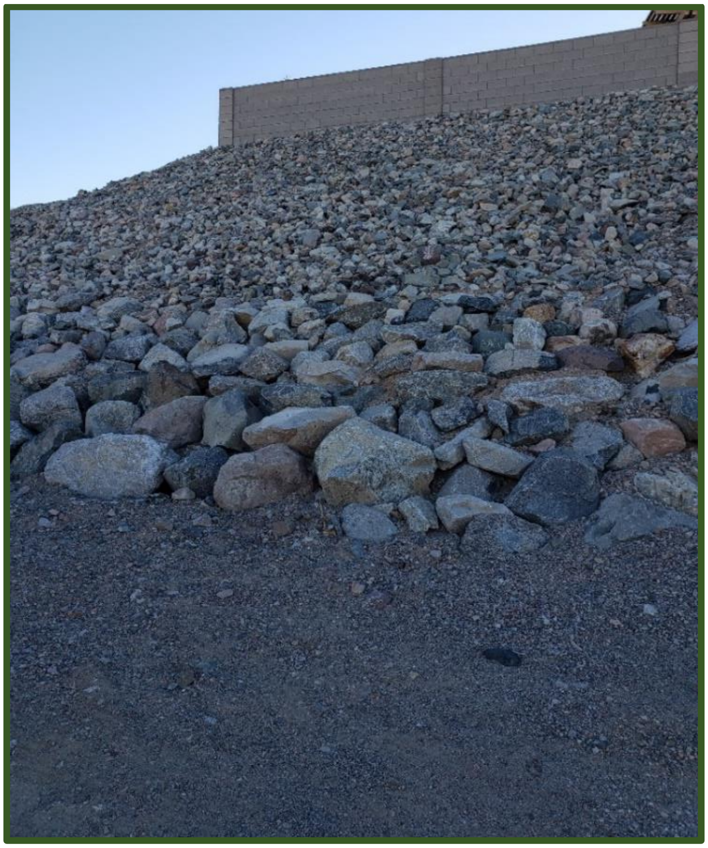
2.5.3 Terracing and Brow Ditches

Within Lake Havasu City the topographic relief has resulted in construction of residential properties on steep slopes that have been disturbed and/or cleared/grubbed (see below Photograph 2-1). Site conditions such as this often result in local erosion and the transport of sediment to streets where it is eventually deposited. City Maintenance Staff have identified sediment deposited on streets as a significant, costly issue. For steep slope site conditions within Lake Havasu City, rock/rip rap is a common slope erosion mitigation measure (see below Photograph 2-2).

In addition to the use of rock/rip rap, site development grading and drainage strategies to minimize local erosion of residential sites include terracing (Figure 2-2) and construction of brow ditches. Terracing involves defined swales constructed at regular intervals along the face of a slope designed to reduce erosive energy by capturing surface runoff and directing it to an adequate, stable outlet (such as a lined swale or pipe). A brow ditch is a ditch constructed at the top of slopes to intercept and direct minor surface drainage runoff away from steeper slopes, thereby, preventing erosion.

Terraces are typically constructed to manage sheet flow runoff and should not be constructed in sandy or rocky soil. Terraces limit runoff energy by reducing the length stormwater can move down a slope; thus, terracing can reduce erosive cutting of the slope. Terracing of a site may require retention walls where slopes are too steep, even for soil stability. If stabilization of terraced slopes is required, it should be limited as much as possible to maximize pervious area.

Photograph 2-1. Residential property, steep slope erosion.



Photograph 2-2. Residential property, rock/rip rap to mitigate steep slope erosion.

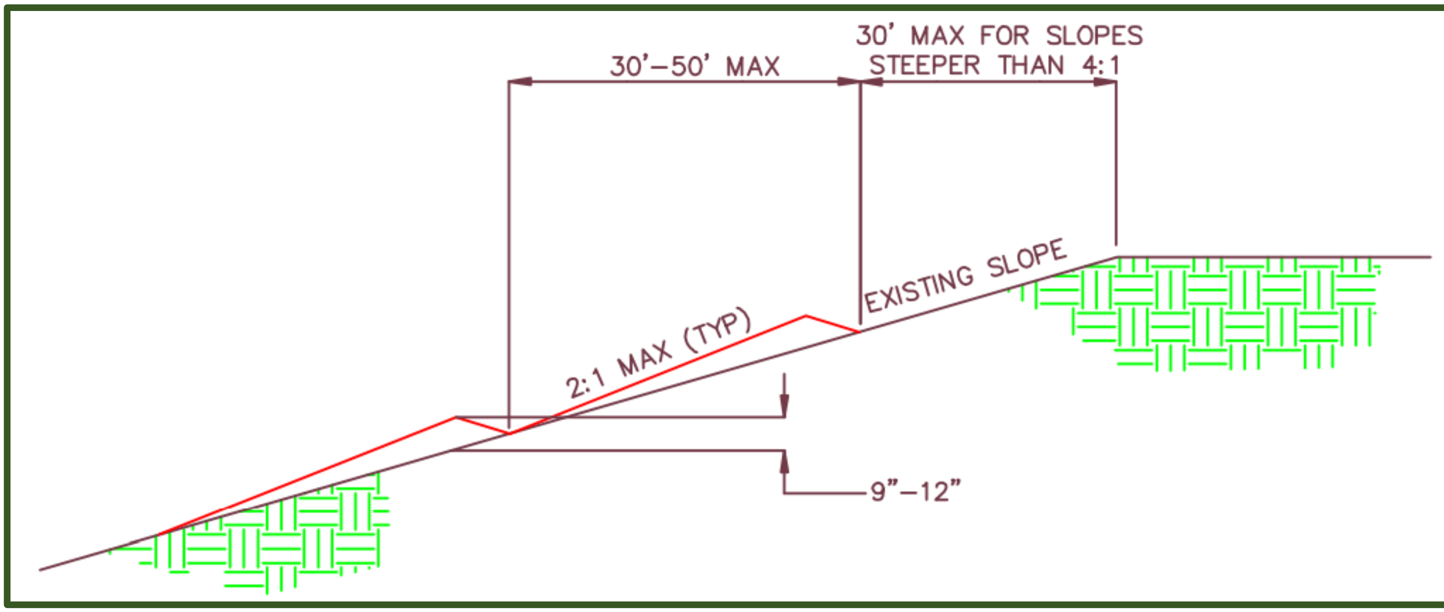


Figure 2-2. Example terracing construction detail.

3 LID SELECTION AND DESIGN FACTORS FOR CONSIDERATION

There are numerous factors to consider when selecting and designing an LID BMP. Several LID factors to consider are discussed below, and include arid climate, LID practice prioritization, site characteristics, flow regimes, pretreatment, targeted pollutants, maintenance, avoiding design flaws, Mohave County standards versus *LID Master Plan* guidance, and hydromodification design.

It is important to note that this *LID Master Plan* is not intended to be a fully detailed design manual; therefore, the reader is encouraged to utilize the references and resources provided in Section 9: References when selecting and designing LID practices.

3.1 Arid Climate Design

3.1.1 Infrequent, "Flashy" Storm Events

Arid regions, such as Lake Havasu City, experience a low amount of annual precipitation as storm events are typically infrequent. Despite their infrequency, these storm events are often "flashy," characterized by high intensity rainfall, which is conducive to soil erosion and increased sediment transport. Given the low frequency of annual storm events within Lake Havasu City (see Section 3.3), pollutants accumulate within roadways and parking lot areas during prolonged dry conditions. When designed appropriately, LID practices may serve as first flush treatments to help capture a large portion of these accumulated pollutants. The cumulative effect of LID practices will both slow the flow of water and provide locations specifically designed to capture sediment and other pollutants. Due to these pollutant accumulations, LID BMPs should be designed with sediment traps (Section 5.14.1) or similar pretreatments to promote longevity and reduce maintenance needs.

3.1.2 Native and Drought-Tolerant Plants

If possible, LID facilities should encourage more plant growth without the need for potable water irrigation. The use of drought tolerant and/or native plants in these conditions will improve the chances of plant survival and health. If the water provided to the plants through LID-based means is insufficient for plant survival, supplemental irrigation or alternative water sources such as reclaimed water, household greywater, or air conditioning condensate should be explored. Supplementing irrigation enhances plant growth, increases canopy size, encourages root development, all of which help an established site meet the intent of implementing LID. Native plant selection resources include the Lake Havasu City Recommended Landscaping Plant List (provided in Appendix A) and the Arizona Municipal Water Users Association's website (https://www.amwua.org/plants), which provides information on Arizona desert plants and strategies for successful landscapes. When selecting vegetation to enhance LID treatments in an arid climate, the designer should consider the following:

- Use of native and drought-tolerant plants.
- The type of plant species and the number of plantings should be conducive to the available water supply. If irrigation is required, group plants based on water needs and adjust irrigation schedules according to seasonal weather.
- Plants should be able to tolerate inundation.

3.2 Prioritization of LID Practices

As discussed throughout Section 3, the selection of an appropriate LID practice is dependent on several factors. For Lake Havasu City, assuming the main goal of LID treatment is to reduce substantial flows and limit flooding, BMPs that capture stormwater may be prioritized over other BMP practices. Below is a prioritization of BMP practices for consideration during the BMP selection process:

1. *Stormwater Capture and Infiltration*: Promotes flood reduction, improved water quality, and groundwater recharge.
2. *Stormwater Capture/Harvesting and Use:* Potential use such as landscape irrigation.
3. *Stormwater Capture, Detention and Metered Release:* Capture of stormwater, but infiltration is infeasible; therefore, stormwater released at a reduced rate to a viable designated outfall like a street gutter or natural watercourse.
4. *Stormwater Conveyance via Biofiltration Systems:* Pass-through systems that address water quality but may not reduce flow rate.
5. *Combination of Above Practices 1 – 4*: Any combination of the four methods listed above. This method is generally appropriate where available storage has been maximized but the BMP has not achieved the design volume capture.

3.3 Site Characteristics

The first step in selecting the appropriate LID BMP(s) is identifying and understanding the characteristics of the site. The purpose of LID is to reintroduce and/or maintain the natural processes that constitute the hydrologic cycle - including infiltration and flow patterning consistent with the natural surrounding area.

3.3.1 General Site Considerations

Inadequate assessment of site conditions and potential constraints can lead to improperly designed and poorly functioning LID BMPs. Even though LID BMPs are intended to only address site-specific conditions, there may be scenarios where the off-site conditions need to be considered. For example, the site may have a contributing drainage area that generates larger flows than what is anticipated from on-site conditions. Larger flows, if not considered, may damage the BMP or the BMP may adversely impact other on-site or off-site features. The LID BMP would then need to be designed to adequately pass the larger flows without sacrificing the intended function of the BMP. Such scenarios would be more typical of street rights-of-way where the adjacent properties represent the contributing drainage area. In most cases, commercial and residential sites would likely not need to consider contributing areas as they are typically designed as high points where runoff drains away to streets and/or washes. Desktop reconnaissance and site visits can help identify various site constraints, and even site opportunities, that influence the selection of an appropriate LID practice. Common site considerations to be assessed are listed in Table 3-1.

Table 3-1. Common site considerations to assess when selecting appropriate LID BMP.

General Site Considerations
Drainage area and flow paths
Topographic relief and flow paths
Existing vegetation
Soils – description, infiltration rate
Possible sources of pollutants and sediment
Existing stormwater infrastructure
Existing utilities
Street LID Site Considerations
Likely travel use – vehicles, pedestrians, bicycles
Lane widths and sidewalk configuration
Traffic patterns and volume
Parking demands
Pedestrian access points
Rights-of-way and easements
Visibility constraints that LID features may cause
Context-Sensitive Site Considerations
Neighborhood characteristics
Existing and proposed land use
City Master Plan objectives for the area/site
Expected urbanization in upper watershed.

3.3.2 Topography

Lake Havasu City exhibits steep topographic relief throughout the City, which presents both challenges and opportunities. In steeper terrain, BMPs will likely need to be more frequent or designed to limit runoff over surfaces where erosion is more likely to occur. Steeper terrain also limits grading for BMPs where volume capture is intended and could create space constraints at optimal locations for BMP implementation. In this case, underground storage becomes more advantageous than surface storage. On steep terrain, the erosion and flow patterning are typically observable, making the location of BMPs obvious with the ability to easily target the issues.

3.3.3 Larger Site Area

Larger sites tend to translate to larger on-site contributing areas for LID BMPs. The BMP's contributing drainage area affects the size of the BMP - larger contributing areas require larger BMPs. In general, the goal is to decentralize stormwater flow to maximize the benefits. This usually results in multiple, smaller BMPs placed in a distributed pattern throughout a site. With larger contributing drainage areas, there is more stormwater to manage, and infiltration drain times become more challenging, pollutant loading increases, and environmental benefits diminish. BMPs for smaller contributing areas tend to be easier to implement, with simpler approaches and the ability to integrate with traditional landscaping maintenance.

3.3.4 Soils

Like much of Arizona, most of the soils in Lake Havasu City are well graded loams, which typically experience low to moderately low infiltration rates. This tends to limit the depth of BMPs to achieve target drain times. According to the *Drainage Design Manual for Mohave* County, basins are intended to drain no less than 36 hours after the storm ends, which is half the time needed to generate vectors (i.e., mosquitos). For example, if considering an 0.5-inch per hour infiltration rate, the BMP depth would be limited to 18 inches of depth to meet the required drain time. In most cases, this is a good maximum depth for a BMP since deeper depths create longer side slopes that are more likely to erode. Soils information for Lake Havasu City can be obtained from the USDA NRCS website at https://websoilsurvey.nrcs.usda.gov/app/.

3.4 Flow Regimes

It is critical that LID BMPs are selected and designed to adequately intercept and capture the runoff approaching the BMP (Section 4); therefore, it is essential to understand the flow regime(s) impacting a site. Within Lake Havasu City, the two predominant flow conditions relevant to LID design are concentrated runoff and sheet flow runoff. For example, flow within a curb-and-gutter roadway concentrates as it is conveyed downstream; however, flow within a large parking area will be less confined and tend to exhibit more sheet flow characteristics. Curb cuts are an obvious BMP technique (Section 5.5) to capture concentrated roadway runoff, while vegetated swales (Section 5.2) or permeable hardscapes (Section 5.8) may be appropriate BMP techniques to capture sheet flow runoff. Section 5 provides details on several LID practices for both concentrated and sheet flow runoff conditions.

3.5 Pretreatment

Pretreatment practices can trap sediment or debris suspended in the runoff before it enters the LID BMP; therefore, during the selection and design of any BMP, pretreatment should be strongly considered for ease of maintenance and extending the service life of the BMP.

Since sediment in runoff is widespread and ongoing in Lake Havasu City, sedimentation of BMPs will be an ongoing concern. Over time, sedimentation reduces storage capacity and infiltration rates, thereby diminishing the effectiveness of the BMP. Use of sediment traps (Section 5.14) as a pretreatment will help intercept sediment before runoff enters the BMP. The size of the pretreatment facility should be proportional to the expected sediment load to ensure there is enough capacity to contain the sediment during a single storm event. Ease of access and maintenance should be a consideration for sediment traps since the removal of captured sediment is likely to be required after most storm events.

If underground storage is planned for the BMP, sediment traps or similar pretreatments must be included to prevent sedimentation in the storage facility due to the difficulty and cost of maintenance. Depending on the design of a basin BMP, pretreatment may not be needed. If regular maintenance (i.e., landscaping) is occurring for the BMP, then sediment might be easily removed through that process, reducing the reliance on sediment traps.

According to the EPA's *Green Streets Handbook* (https://www.epa.gov/nps/green-streets-handbook), common pretreatment practices include the following:

- **Sediment Trap (Forebay).** Sediment traps are placed before a LID BMP, such as a bioswale or enhanced basin. Sediment traps may be constructed as earthen pits/basins or a concrete structure. Weirs may be used in conjunction with a sediment trap to slow incoming flow. Sediment traps minimize, but may not eliminate, the amount of sediment entering an LID BMP. It is imperative that sediment removal is a regularly planned maintenance activity, particularly after a storm event.
- **Vegetated Filter Strip.** Vegetated filter strips are gradually sloped, densely vegetated areas designed to receive and treat sheet flow. They are designed as flow-through devices to slow down and infiltrate runoff and to remove sediment before it reaches a downstream BMP. Note: This pretreatment option is generally not recommended for Lake Havasu City due to the low likelihood of achieving the appropriate level of vegetative density to be effective without significant irrigation.
- **Swale.** Pretreatment swales are shallow, vegetated channels that capture runoff and slowly convey it along the swale while infiltrating and filtering coarse sediment. Although swales are typically designed to account for sedimentation, pollutant removal will vary with type and density of vegetation used. Swales are commonly applicable in parking lots and along roadways.
- **Modified Catch Basin.** Storm drain catch basins can be modified with a deep sump to provided extra storage for the accumulation of sediment.
- **Flow-Through Structures.** Flow-through structures are subsurface structures that include a settling or separation unit that improves water quality by removing coarse sediments, floatables, oils, and other toxic pollutants from runoff. These types of structures include vortex separator systems, oil and grit separators, and proprietary devices.

3.6 Targeted Pollutants

In urban areas, water quality is a concern and is often addressed through the application of LID BMPs, which can remove pollutants from runoff through physical, chemical, and biological processes. These pollutants are generally referred to as nonpoint source (NPS) pollution, which includes, but is not limited to, fertilizers, oils, sediment, and bacteria associated with human activities. As it relates to Lake Havasu City, sediment is the most significant NPS pollutant followed by general urban runoff (oil, grease and toxic chemicals). BMPs can intercept sediment and prevent downstream sedimentation. Certain types of soil media and/or vegetation in the BMP can be used to address urban runoff through adsorption/absorption and biological uptake.

When selecting a BMP, it is important to determine if these pollutants are present and need to be addressed. Due to the steep topography and relatively minimal vegetative cover throughout the region, it is assumed that sediment will be present everywhere within the City. Pervious areas (i.e., residential) will likely generate more sediment than impervious areas (i.e., commercial). This means considerations should be made for: 1) the ability of the BMP to trap/capture sediment; and 2) the ease of maintenance for the BMP. There are many types of BMPs that can intercept sediment but if they are difficult to maintain, then the effectiveness of that facility will be brief. Pretreatment (Section 3.5) can resolve some of these issues.

Oils, greases, and fuels may accumulate within commercial areas, industrial parks and institutional lots (e.g., hospitals, schools, etc.). These areas generally include parking lots and other large impervious areas that handle significant vehicular traffic. Vehicle-related pollutants will also tend to accumulate within large transportation corridors, such as the US95 and McCulloch Boulevard corridors. Due to the infrequency of runoff-producing storm events in the region, these pollutants tend to accumulate and buildup on these impervious services in large concentrations. When they finally do runoff, those high concentrations can have acute and damaging adverse impacts to downstream water quality and sensitive environments.

Onsite BMPs can limit those downstream urban runoff concentrations by containing the pollutants to the site itself. At these lower onsite concentrations, engineered soil media filters can be designed to capture and/or breakdown pollutants through adsorption/absorption. Through biological uptake, plants can address many of these pollutants as well improve water quality.

The EPA's *Green Streets Handbook* provides an overview of the potential pollutant removal capability of common LID practices (see below Table 3-2), which should be considered when the primary goal of the project is improving water quality – particularly for roadway and parking area runoff.

Table 3-2. Excerpt from EPA's *Green Streets Handbook* showing potential pollutant removal capability of common LID practices with a focus on water quality.

Table 4-2. Relative effectiveness of green infrastructure practices for various constituents based on pollutant-removal efficiencies when practices are properly maintained

	Total Suspended Solids	Total Nitrogen	Total Phosphorus	Fecal Coliform	Total Zinc	Total Copper	Total Lead
Bioretention	●	○	●	–	●	–	◉
Bioswale	◉	○	○	○	–	–	–
Stormwater curb extension	●	○	●	–	●		◉
Stormwater planter	●	○	●	–	●	–	◉
Street trees	●	◉	◉	●	◉	◉	◉
Infiltration trench	●	○	●	●	●	–	–
Subsurface infiltration and detention	●	◉	◉	●	●	●	●
Permeable pavement	●	–	◉	–	●	◉	◉
Permeable Friction Course	●	–	–	–	●	◉	●

Note: The values for subsurface infiltration and detention were considered equivalent to those for sand filters. Stormwater curb extension and stormwater planters were considered bioretention devices.

For all constituents, ○ = 0-30%, ◉ = 31-65%, ● = >65%, – = no data

3.7 Maintenance

Because LID practices are designed as small-scale treatments distributed throughout a drainage area, implementing an LID approach to help with stormwater management implies the City or private property owner/manager will be responsible for an increase in the number and type of facilities to maintain. As it pertains to maintenance, LID program challenges include:

- Funding mechanisms.
- Dedicated maintenance staff.
- Tracking BMP locations and responsible parties.
- Poorly designed BMPs that are not conducive to access or ease of maintenance.
- Private landowners not aware of maintenance responsibilities and/or requirements.
- Administering compliance and enforcement procedures.
- Integrating LID BMPs into conventional stormwater infrastructure asset management programs.

As discussed in the *County LID Guide*, overlooked and/or underfunded maintenance activities can be a significant detriment to LID performance. Because LID maintenance can go beyond typical stormwater management activities, education and training programs are critical for ensuring success. For example, common landscaping practice includes use of chemicals to kill vegetation; however, using herbicides may also kill native vegetation and soil health, both of which can be key components of a functioning LID BMP. Physical removal of unwanted plants, which assumes knowing which plants are unwanted, is an example of proper LID maintenance.

An LID Maintenance Plan is a tool to help ensure the effectiveness of installed LID practices and the overall success of the City's LID program. The plan would be submitted as part of the "Stormwater Management/BMP Facilities Maintenance Agreement" to the City for future inspectors to verify expected BMP performance, if needed. Recommended information to be included in an LID Maintenance Plan includes the following:

- A site map (or GIS database) to include location and type of LID BMPs; parcels, rights-of-way, and/or easements; locations of upstream pollutant sources; locations of downstream receiving waters; and locations where LID practices may reduce the need for routine maintenance activities (e.g., removal of sediment accumulation within roadways).
- Type and schedule of maintenance activities. Inspection and maintenance activities should be conducted after each significant storm event and as specified with a long-term schedule.
- Equipment and resources necessary to operate and maintain LID BMPs.
- Identification and contact information of responsible party for operation and maintenance of LID BMPs.
- Inspection and maintenance log.
- Maintenance activity checklists.
- Pollutant spill plans.
- Training documentation.
- As-necessary, water quality testing results.

It is important to reiterate that poorly maintained facilities may lead to reduced infiltration potential and/or reduced volume capacity. Failure to maintain LID BMPs can lead to flooding, erosion, runoff pollution, and threats to public safety. Recommended maintenance activities for specific LID BMPs are discussed in Section 5.

For LID program success, routine inspections of installed facilities are important to maintain and understand overall LID effectiveness. Initially, City inspectors should verify the LID BMP(s) was built per plan as part of the City's typical construction approval process. After that, ongoing inspections should be conducted on a limited basis due to the infrequency of storm events in Lake Havasu City. Visual inspections on a 1- to 2-year (or longer) cycle would be sufficient for most surface BMPs. The LID Maintenance Plan, if available, should be utilized to supplement the visual inspection process.

Generally, the time after storm events serves as the best opportunity to inspect the effectiveness of the LID BMPs. Many of the facilities will be required to drain or drawdown within a specified amount of time. Simple observation ports (i.e., small, perforated PVC pipes) can be installed with infiltration BMPs to quickly observe if the facility is meeting its drawdown requirements. Such observation features are critical for underground facilities where direct visual inspection may be impractical. Post-storm inspections should occur after storms that are at least considered moderate (1-inch or more) in nature.

3.8 Avoiding Design and Installation Flaws

As discussed in Section 3.3, improperly designed and installed LID practices can lead to poorly functioning or non-functioning BMPs, from both runoff quantity and runoff quality perspectives. With the risk of BMP failure ranging from catastrophic to diminishing function, key design and installation flaw takeaways include:

- BMPs should be constructed as designed and with specified materials.
- BMPs located directly within flow paths face a greater risk of failure, particularly during large storm events.
- Installation of an upstream sediment trap significantly reduces the potential for volume reduction due to sediment accumulation.
- Erosion is most likely to occur where runoff enters and exits the BMP.
- An undersized and/or ineffective placement of a BMP inlet will lead to an unplanned reduction in runoff volume capture and an undesired increase in flow downstream.
- Established, native vegetation and soil health are key components of an effectively functioning BMP. Non-native plants are difficult to establish and will likely require costly, supplemental irrigation.

3.9 Hydromodification

According to the EPA's *National Management Measures to Control Nonpoint Source Pollution from Hydromodification* (https://www.epa.gov/nps/hydromodification-and-habitat-alteration-national-management-measures), hydromodification is defined as "alteration of the hydrologic characteristics of coastal and non-coastal waters, which in turn could cause degradation of water resources." The EPA groups hydromodification into the following three categories:

1) Channelization and channel modification – includes activities such as straightening, widening, deepening, and clearing channels of debris and sediment.
2) Dams – includes artificial barriers on waterbodies that impound or divert water and are built for a variety of purposes, including flood control, power generation, irrigation, navigation, and to create ponds, lakes, and reservoirs.

3) Streambank and shoreline erosion – the wearing away of material in the area landward of the bank along non-tidal streams and rivers.

In general, hydromodification refers to activities that alter the natural landscape. Such activities increase runoff volume, frequency of runoff events, and concentration of flows that result in degradation as the environment attempts to establish a new equilibrium to meet the flow alterations. In urban environments, such as Lake Havasu City, this is typically a result of increased imperviousness (i.e., asphalt, concrete, buildings, etc.) and channelization of flows in wash and street corridors. Degradation takes the form of erosion in the upper watershed where loss of soil results in loss of vegetation, which further results in more erosion. With removal of most topsoil, the organic matter content in soil is reduced, preventing the establishment of new vegetation. In the lower watershed, sediment from upstream results in sedimentation, which reduces downstream flow capacities and impacts animal habitat in and near receiving waters.

Regarding hydromodification, when planning any new development activities or restoration/improvement of already developed areas, it is important to mirror predevelopment or natural conditions as much as possible. Goals of maintaining natural conditions include protecting, maintaining, and restoring water resources, based on the geomorphology, ecology, and other natural characteristics of the watershed. The intent of hydromodification is to maintain existing flow conditions (i.e., magnitude, patterning, etc.) to prevent unintended degradation from environmental alterations. Implementation of LID BMPs can assist in returning site outflows, altered by development, to their predevelopment or natural flow conditions.

4 HYDROLOGIC DESIGN ANALYSIS

Due to the relatively small size of the City, and little variation in rainfall, it was assumed the same LID design standard for capture volume and flow rate could be applied throughout the entire City. The guidance presented in this section is only meant for sizing of LID facilities and should not be considered as a replacement for the *Drainage Design Manual for Mohave County*.

4.1 Design Capture Volume

The purpose of implementing LID measures is to offset the effect of urbanization within a given watershed. Increases of impervious surfaces (buildings, roadways, parking lots, etc.) due to urbanization prevent natural infiltration and increase runoff, which often results in substantial flow and/or flooding. By capturing additional runoff produced by impervious surfaces, LID can reintroduce the natural function of infiltration and ultimately reduce flooding, promote vegetation, and replenish groundwater.

The recommended design capture volume was based on an analysis accounting for the City's rainfall and runoff characteristics to determine an optimal design volume. For the analysis, the following goals were considered:

- Maximize the volume capture throughout the year to reduce excessive flows.
- Sustainably support vegetative growth with LID facility.
- Prevent the violation of applicable water rights laws.

To understand storm events within the City, rainfall data was obtained from several rain gauges around the City with periods of record ranging from less than a year to more than 50 years. Of those gauges, six (6) were determined to have record data useful for this analysis (see Figure 4-1). Although three (3) other gauges were identified, the record data was either not available or too brief for this analysis. Rainfall gauge data is provided in Appendix B.

The rainfall analysis centered around estimating storm volumes, percentile distribution, and annual/monthly averages. Generally, storms were simple, distinct and easy to quantify, but there were cases where back-to-back storms occurred. For these cases, it was assumed that if these storms occurred within 24 hours of each other, then they would be considered the same storm and the total volume of both events would be calculated. Storms separated by more than 24 hours would be considered distinct and separate. Once the storm volumes were generated, they were broken down based on their percentile distribution. Any storm totals equal to 0.05 inches or less were removed from consideration since it was assumed that no runoff would occur based on the surface retention loss criteria set by the *Drainage Design Manual for Mohave County* in Table 7.7 for "Pavement and Rooftops." The percentile distribution of storms recorded by the gauge located at the Lake Havasu City Airport is presented in Figure 4-2.

To interpret Figure 4-2, percentile is a function of the number of storm events that produce up to a specific depth divided by the numbers of storm event that occur in a given year represented by the blue line. For example, the 80^{th} percentile captures all storm events that produce a rainfall depth (storm total) up to 0.78 inches. Due to the extreme nature of storms that occur in the City, 80^{th} percentile does not correlate directly with 80 percent volume captured throughout the year. The extreme events tend to skew the data in a way that captures less annual volume than what the percentile would suggest. To understand this phenomenon, the percent annual capture volume was compared to the percentile represented by the orange line. This is important because it helps understand the effectiveness of LID facilities in terms of both the effectiveness of reducing overall runoff and the ability to sustain vegetation. If the LID facility is too small, then it may be ineffective for runoff reduction and if it is too large, the facility may not be able capture enough runoff throughout the year to sustain plant life. Finding a balance between reducing runoff and sustaining vegetation will maximize the benefits the LID facility can provide.

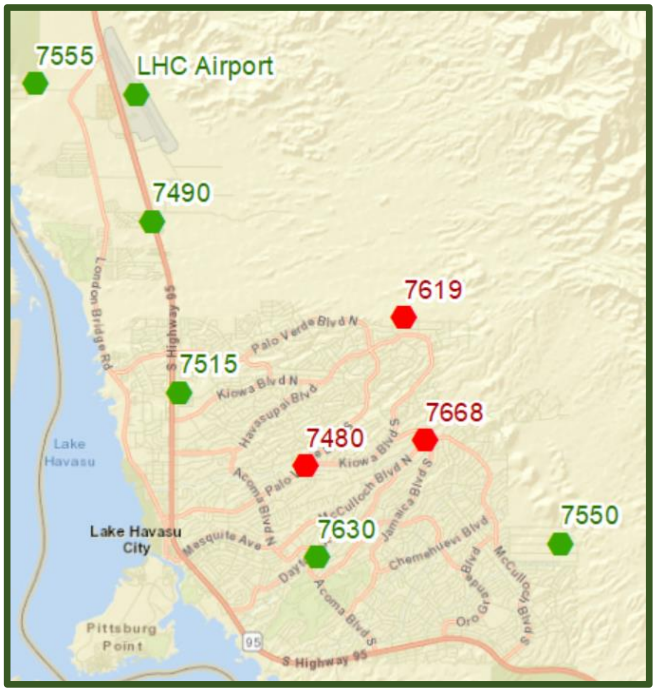


Figure 4-1. Locations of Lake Havasu City rain gauges. Gauges shown in green were used for rainfall analysis.

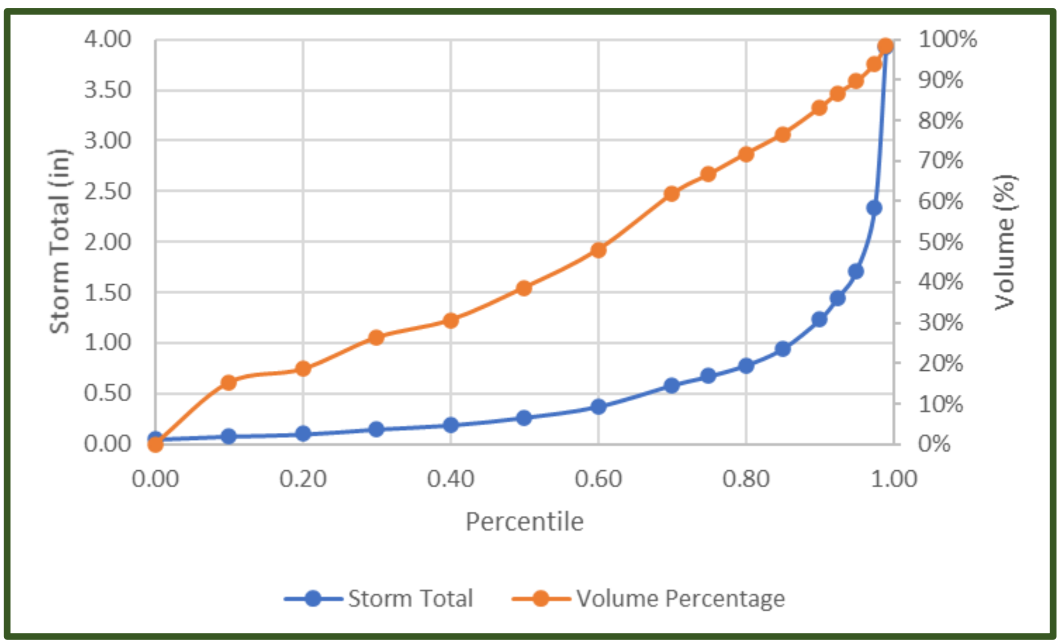


Figure 4-2. Percentile distribution of rainfall for storms recorded at Lake Havasu City Airport.

For the purpose of finding that balance for sizing LID facilities, LID documentation from other agencies throughout the western United States was reviewed. From this review, it was determined that the target rainfall percentiles from runoff-producing storm events ranged from 80% to 95%. To estimate the most appropriate design percentile for the City, an aggregate percentile distribution for the rain gauges was utilized for this analysis. On average for the City, the aggregate percentile distribution is presented in Table 4-1.

Table 4-1 – LHC rainfall aggregate percentile distribution.

Percentile	Rainfall Depth (in)	Volume Capture (%)
0%	0.05	0.0
20%	0.12	18.8
40%	0.24	30.9
50%	0.31	36.6
60%	0.45	46.7
70%	0.66	56.6
75%	0.81	62.9
80%	0.93	66.8
85%	1.25	74.2
90%	1.78	82.8
95%	2.50	89.7
100%	5.62	100

As expected, aggregate rainfall data shows that most storms are relatively small. However, the City also experiences extreme storm events that tend to skew the volume data as mentioned in the above discussion for the Lake Havasu City Airport gauge (refer to Figure 4-2). Rainfall data shows that smaller storms, though relatively frequent, produce very little runoff while the larger storms produce the majority of runoff generated in a given year. This suggests that selecting a rainfall percentile directly from another agency may not be appropriate since it is unlikely to achieve the City's LID goals and could be cost-prohibitive.

Another approach to evaluate design capture volume is to understand how urbanized impervious areas directly influence runoff in the City. To do this, the difference in runoff volume was estimated between imperviousness and natural terrain. Using the rational method as defined by the *Drainage Design Manual for Mohave County,* the runoff volume was calculated for a range of storm frequencies and durations to understand the runoff characteristics for different storms. Since LHC is primarily hillslopes, the Sonoran Desert land use category was used to represent natural conditions for the runoff calculation. On average, an impervious area generates approximately 60 percent additional runoff over a natural pervious area, which is roughly 40 percent of the total volume generated from impervious area. Therefore, an LID facility would need to capture at least 40 percent of the impervious runoff that drains to the facility in order to offset the overall additional runoff volume.

Assuming the Mohave County's 100-year, 2-hour rainfall requirement for storage facilities of 2.34 inches for the downtown McCulloch Boulevard area with runoff coefficients of 0.60 (Sonoran Desert) and 0.95 (Pavement and Rooftops), the required LID rainfall capture depth is calculated to be 0.86 inches. Considering an infiltration rate of 0.5 inches/hour for an 18-inch ponding depth based on a 36-hour vector criterion, the area of the LID facility would be roughly 5 percent of the contributing impervious area. Assuming the rainfall duration is two (2) hours based on the County storage requirement, infiltration loss by the time the facility is at capacity would be one (1) inch. Extrapolating to the larger contributing area, one inch of infiltration in the LID facility translates to 0.05 inches of rainfall contributing to the facility. Subtracting from the required rainfall capture depth of 0.86 inches, the LID facility would only need to be sized for 0.81 inches of rain. Understanding there is some variability throughout the City in terms of rainfall and infiltration, the design volume capture was rounded to **0.8 inches** for simplicity.

Corresponding 0.8 inches to Table 4-1, this rainfall depth falls roughly in the 75th percentile category, which is expected to capture 63 percent of the annually generated runoff. With surface retention loss and infiltration factored into the design rainfall depth, the following design capture volume calculation becomes relatively straight forward and is only a function of the contributing impervious area:

$$V = \frac{0.8}{12} * A = 0.0667 * A$$

Where: 0.8 inches = 75th percentile design rainfall depth, capturing approximately 63% of rainfall volume

V = design capture volume, acre-feet (ac-ft)

A = contributing impervious area, acres (ac).

Calculations supporting the determination of LID capture volume are provided in Appendix B.

4.2 Design Flow Rate

In some cases, capturing some or all of the required runoff volume (Section 4.1) may not be feasible. This could be due to limited space, poor infiltration, conflicts with utilities, etc. Regardless of the LID configuration, facilities should allow flow-through capabilities to address urban runoff water quality and to prevent damage to any of the components, such as vegetation.

Since LID addresses urban runoff associated with impervious areas, a typical and highly efficient location for LID is within or adjacent to streets where runoff collects and concentrates. When retrofitted into streets, LID facilities should consider typical street drainage design criteria so they do not interfere or adversely impact potential flow within the streets. As a result, facilities should accept and adequately convey the flow it receives whether it is gutter flow or other low point in the street. Therefore, LID facilities should be designed for the 10-year storm event in accordance with the *Drainage Design Manual for Mohave County*, which states that for a 10-year design flow rate within the street, flow depths should not exceed the curb height and maintain a dry lane in each direction. This design criteria holds true regardless of the street section (normal crown, inverted crown, W-section, or otherwise).

If correctly implemented, a single LID facility should address no more than a few acres of contributing impervious area. This typically results in time of concentrations of five (5) minutes or less. Since the highest intensity of rainfall for the 10-year storm event is no less than four (4) inches per hour (five-minute duration) for the City, the design flow rate is assumed to be four cubic feet per second per acre (cfs/ac) using the rational method; and therefore, the following design flow rate calculation becomes relatively straight forward and is only a function of the contributing impervious area:

$$Q = 4A$$

Where: Q = design flow rate, cubic feet per second (cfs)

A = contributing impervious area, acres (ac).

When planning/designing the placement of an LID facility within a street, the following should be considered:

- *Inline with existing flow* – the facility must be designed for the full four cfs/ac to pass through. Examples include curb extensions and chicanes (see Section 5.6) for normal crown streets and medians for inverted crown streets.
- *Offline to existing flow* – the facility can be designed for less than four cfs/ac as long as the facility capacity and bypass flow equal to four cfs/ac. Examples include curb cuts (see Section 5.5) and parkway swales for normal crown streets and catch basin inlets for inverted crown and W-section streets.

4.3 Mohave County Stormwater Standards vs. *LID Master Plan* Guidance

As previously discussed, the approach for developing the design capture volume and flow rate for LID facilities relied heavily on existing drainage policy as outlined in the *Drainage Design Manual for Mohave County.* By taking this approach, LID facilities can be designed under existing policies and in some cases, provide an alternative, less expensive approach to the traditional drainage design options discussed in the County's *Drainage Design Manual*. Differences between LID design and the County's more traditional roadway drainage design approach are highlighted in Table 4-2.

Table 4-2. Key differences between LID design and the more traditional roadway drainage design approach.

Characteristic	Mohave County Manual	LID Master Plan
Contributing Area	Varies; generally applicable to larger watersheds	Small; typically a few acres or less
Approach	Systemic, centralized, downstream to upstream	Independent, decentralized, upstream to downstream
Purpose	Mitigate flooding caused by either urbanization or natural conditions	Reintroduce natural hydrologic cycle interrupted by urbanization
Volume Design	100-year, 2-hour for new development regardless of pervious or impervious areas	100-year, 2-hour difference between natural and impervious areas; 0.8 inches
Flow Rate Design	Method varies depending on watershed size	4 cfs/ac; 10-year storm event based on 5-minute duration
Stormwater Disposal	Discharge to outfall	Infiltration, capture and storage
Maintenance	Varying costs; typically infrequent	Minimal cost if part of regular maintenance plan; frequent
Lifespan	Varies; 30 to 60 years for hardened structures	10 years on average; typically soil media or vegetation needs to be replaced to maintain infiltration
Public Risk	High	Low

As seen in Table 4-2, LID is not directly correlated to traditional drainage design as defined in the County's *Drainage Design Manual*, but it does provide another solution to the same problem of mitigating excessive flows and flooding. Depending on the type of site - developed, redeveloped or already existing - LID may serve as a viable alternative where traditional design may be infeasible or cost prohibitive.

5 LOW IMPACT DEVELOPMENT BMP DETAILS

The Low Impact Development (LID) Best Management Practices (BMPs) discussed within this section are well suited for use within Lake Havasu City and include the following: bioswales; check dams; enhanced basins; curb openings; curb modifications; inverted crown roadway variations; permeable hardscape; suspended pavement; soil modifications; modular underground storage; cisterns; greywater collection; and pretreatment practices.

In support of the LID BMPs discussed below, general stormwater management considerations are discussed above in Section 2; LID selection and design factors are discussed in Section 3; and hydrologic design considerations are discussed in Section 4.

As noted in Section 2.5.1, source control BMPs vary significantly in size, type, configuration, and operation. Source control BMPs prevent pollutants from contacting stormwater through physical separation. Although source control BMPs are strongly encouraged when practical, given the wide variety of potential alternatives and approaches, source control BMPs are not discussed below. Source control BMPs should be considered a first step, before permanent BMPs.

The design details described and provided within the *LID Master Plan* are meant to be conceptual and not final design specifications. Prior to selection and design of an LID BMP, designers should thoroughly assess site and drainage conditions and revise, modify, or amend BMP details as necessary. Standard details for the LID BMPs discussed below are provided in Appendix C. As discussed in Section 1.5.2, much of the valuable information provided in the *LID Master Plan* has been obtained from LID guidance and design manuals made readily available by the LID community. The reader is encouraged to review the collected LID materials and resources – listed in Section 9 - for additional design guidance, specifications, details, and maintenance needs.

5.1 Low Impact Development BMP Matrix

The below LID BMP Matrix (Figure 5-1) is a reference guidance tool that can be used to help determine BMP applicability for various site or development conditions. The BMPs referenced in the LID BMP Matrix are discussed in the following sections. Site or development conditions highlighted in the LID BMP Matrix include the following:

New Development. New development describes development activity that is customarily on undeveloped or cleared land, which may have pre-exiting vegetation and natural characteristics. New development may consist of residential, commercial, or transportation related projects, and is assumed to have been designed by a professional and permitted or reviewed by the City. Integrating LID into new development can be relatively straight forward when compared to implementation of LID into redevelopment.

Existing Development. Existing development describes development activity on sites that are in part or fully developed, such as residential, commercial, or transportation projects, which are undertaking redevelopment, renovation, addition, or simply adding LID BMPs to aid in stormwater management and/or water quality improvement. Existing development may have a high degree of impermeable surfaces, such as rooftops and pavement. The open areas may also be more compacted; and therefore, the site may have relatively low infiltration rates. Implementation of LID BMPs within existing development may not require professional design or City review, depending on the extent of the improvements.

Roadways. Roadways are broken into four different site condition applications including three for normal crown street sections (no, attached, and detached sidewalk) and one for inverted crown (and "W") sections. Roadways are identified as a unique development type due to the large number of potential BMPs available for implementation. Roadways are also challenging due to the impermeable nature of their construction (both paved surfaces and highly compacted soil beds) and therefore, BMPs may need to account for lower infiltration rates or considerations for over excavation to improve infiltration.

LEGEND
- FULLY APPLICABLE
- PARTLY APPLICABLE
- NOT APPLICABLE

BMPs	SITE OR DEVELOPMENT CONDITIONS: NEW DEVELOPMENT – RESIDENTIAL	NEW DEVELOPMENT – COMMERCIAL	NEW DEVELOPMENT – INDUSTRIAL	NEW DEVELOPMENT – PARKING	EXISTING DEVELOPMENT – RESIDENTIAL	EXISTING DEVELOPMENT – COMMERCIAL	EXISTING DEVELOPMENT – INDUSTRIAL	EXISTING DEVELOPMENT – PARKING	ROADWAY – NO SIDEWALK	ROADWAY – ATTACHED SIDEWALK	ROADWAY – DETACHED SIDEWALK	ROADWAY – INVERTED CROWN ROAD
BIOSWALES	Partly	Fully	Partly	Not	Partly	Partly	Partly	Partly	Fully	Fully	Fully	Not
CHECK DAM	Fully	Partly	Partly	Fully	Partly	Partly	Fully	Partly	Fully	Partly	Fully	Partly
ENHANCED BASINS	Fully	Partly	Fully	Fully	Partly	Partly	Not	Partly	Fully	Fully	Partly	Partly
CURB OPENING	Partly	Partly	Partly	Fully	Partly	Partly	Partly	Fully	Partly	Not	Fully	Not
CURB MODIFICATION	Fully	Partly	Not	Fully	Partly	Partly	Not	Partly	Not	Partly	Fully	Not
PERMEABLE HARDSCAPE	Partly	Fully	Partly	Fully	Partly	Partly	Partly	Not	Not	Fully	Fully	Fully
SUSPENDED PAVEMENT	Partly	Partly	Partly	Fully	Partly	Partly	Partly	Fully	Not	Fully	Fully	Fully
SOIL MODIFICATION	Partly	Partly	Fully	Fully	Partly	Partly	Fully	Fully	Partly	Partly	Partly	Partly
MODULAR UNDERGROUND STORAGE	Partly	Fully	Fully	Fully	Partly	Fully	Fully	Fully	Fully	Fully	Fully	Partly
CISTERNS	Fully	Partly	Partly	Not	Partly	Partly	Partly	Not	Not	Not	Not	Not
GREYWATER COLLECTION	Fully	Partly	Partly	Not	Fully	Partly	Partly	Not	Not	Not	Not	Not
TRAFFIC CIRCLE	Partly	Partly	Not	Partly	Partly	Not	Not	Partly	Partly	Partly	Partly	Fully
MEDIAN	Fully	Not	Not	Partly	Partly	Partly	Not	Partly	Partly	Partly	Partly	Fully

Figure 5-1. LID BMP Matrix.

5.2 Bioswale

5.2.1 Description

As described in the *Greater Phoenix Metro Green Infrastructure Handbook* (Scottsdale, AZ; January 2019), a bioswale is an open shallow channel that may have trees, grasses, and other low-lying vegetation covering the swale bottom and side slopes, with pervious surface plating materials such as decomposed granite, larger rock, and/or mulch. Bioswales are designed to slow the flow of runoff to downstream discharge points and/or infiltrate stormwater runoff as it moves downstream. Bioswales are water quality BMPs when designed having sufficient length and vegetation.

A bioswale can be designed to slow and infiltrate stormwater flows through different design approaches. Meandering to lengthen the flow path; including check dams to slow water so debris can settle out; and/or the addition of beneficial grasses, forbs, or shrubs are some potential ways to slow the flow. Water infiltration can support an abundance of plants, which can be designed to provide an attractive, shady landscape. The selection of landscape plants for use in bioswales must prioritize the plant's ability to withstand periodic inundation between long dry periods.

A bioswale can be built in a naturalistic or in an urban context. A naturalistic design style will allow for a wider, possibly deeper channel, but does not accommodate pedestrian or urban activity as well as a constrained swale.

Examples of bioswales are shown in Photograph 5-1, Photograph 5-2, and Figure 5-2. A bioswale standard detail is provided in Appendix C.

5.2.2 Benefits

Bioswale implementation provides the following benefits:

- Provides an attractive asset to the landscape.
- Increases infiltration due to slowing of water.
- Improves water quality.
- Enhances the landscape plantings.
- Simple to construct.
- Low construction costs.

5.2.3 Application

Bioswales can be used along roadways, pathways, or linear areas with adequate topography to allow water to be directed and consolidated into a channel. Swales can be short or long and similar to bioretention planters (Section 5.4.1). Check dams (Section 5.3) may be required when the swale slope is in excess of 5%. Check Dams will control erosion and slow water and will help the long-term stability of the swale. Sediment traps (Section 5.14) may be necessary if incoming stormwater contains suspended fine material. Sediment Traps will help keep sediment out of the channel, which will ease long term maintenance requirements.

5.2.4 Maintenance

Bioswales will require occasional maintenance. Perform the following actions on a regular basis to maintain the swale's effectiveness and visual appearance:

- Remove settled sediment from bottom of channel.
- Prune landscape plants.
- Repair erosion.

Photograph 5-1. Bioswale example – campus, large area.
(Mesa Community College Bioswale, Author & Source: Jesse Westad)

Photograph 5-2. Bioswale example – campus, small campus.
(University of Arizona Bioswale, Author & Source: AAA Landscape)

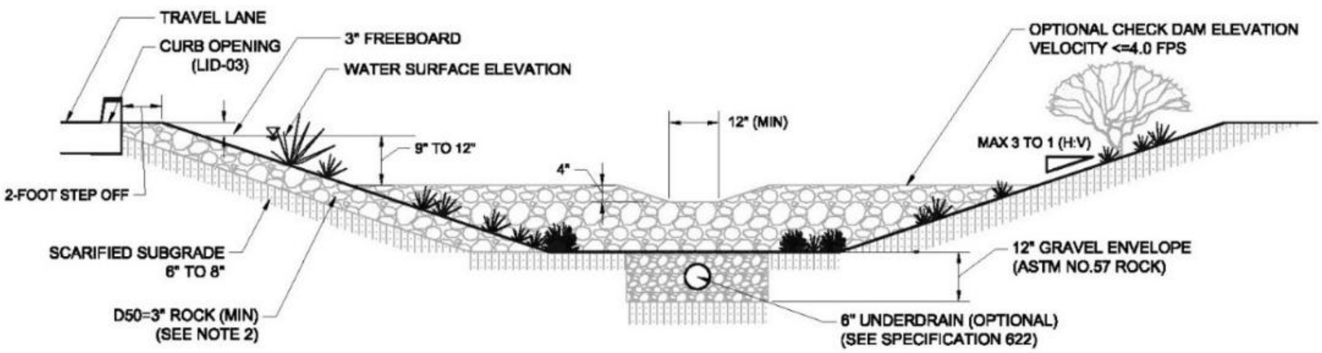


Figure 5-2. Bioswale Section Example

5.3 Check Dam

5.3.1 Description

A check dam is a raised earth berm, rock berm, or concrete curb constructed within a drainage way. Check dam examples are shown in Photograph 5-3 and Photograph 5-4. A check dam standard detail is provided in Appendix C.

5.3.2 Benefits

Check dams slow the rate of water flow, providing multiple stormwater management benefits, which include the following:

- Reduces erosion due to slowing of water.
- Improves downstream water quality.
- Increases water infiltration.
- Reduces total runoff downstream.

5.3.3 Application

Check dams are typically associated with swales, channels, or bioswales (Section 5.2). They are used to slow and spread the flow of water, increasing infiltration. In addition, check dams may be constructed horizontally, perpendicular to the slope, to slow the rate of sheet flow. Check dams should be implemented in swales with slopes at 5% or greater and spaced so that the toe of the uphill dam is level with the crown of the downhill dam.

5.3.4 Maintenance

Check dams will require routine maintenance, including sediment removal, repair of erosion on downside of check dam, and repair of adjacent swale/channel side slopes.

Photograph 5-3. Check dam example - upstream view
(City of Tucson Check Dam, Author: C Vargas Photography, Source: Wheat Design)

Photograph 5-4. Check dam example, Yavapai County roadway swale.
(Source: HELM)

5.4 Enhanced Basin

An enhanced basin is a constructed basin that utilizes a structured base and soil material, or other underground elements, meant to facilitate the infiltration of water while providing bioretention and biofiltration. Bioretention and biofiltration refer to a treatment process that reduces stormwater volume and pollution - removing pollutants by filtering runoff through a vegetated and engineered soil media while promoting evapotranspiration.

5.4.1 Bioretention Planter

5.4.1.1 Description

A bioretention planter utilizes underground flow regulating underdrains, allowing water to pass through a constructed soil media that functions as a filter, collecting pollutants while allowing the cleaner water to drain into the subsoil.

5.4.1.2 Benefits

Benefits of employing bioretention planters as LID include:

- Flexible sizing.
- Reduces pollutants.
- Reduces total runoff downstream.
- Enhances landscape health.
- Relatively low maintenance costs.
- Low construction costs.
- Low likelihood of failure.
- Improves air quality.
- Reduces urban heat island.
- Improves site aesthetics.
- Increases property values.

5.4.1.3 Application

Bioretention planters can be utilized in commercial, industrial, and residential contexts, and are flexible in size and depth. They are useful when engineering standards require stormwater to drain within a certain time frame, and can support trees and vegetation, provided that adequate clearances and tree size are considered.

5.4.1.4 Maintenance

Bioretention planters require routine maintenance. Perform the following actions routinely to maintain the feature’s effectiveness: remove settled particulates and fine materials from the surface; and check infiltration rates and replace filtration media when infiltration slows or stops.

Photograph 5-5. Bioretention basin example
(Arizona State University Orange Mall, Author: Marion Brenner, Source: AZASLA)

Photograph 5-6. Bioretention basin example - healthy trees shading pedestrians.
(Arizona State University Orange Mall, Author: Marion Brenner, Source: AZASLA)

Photograph 5-7. Bioretention basin example – captured water creating lush vegetation. (Arizona State University Orange Mall, Author: Cindy Quinn, Source: AZASLA)

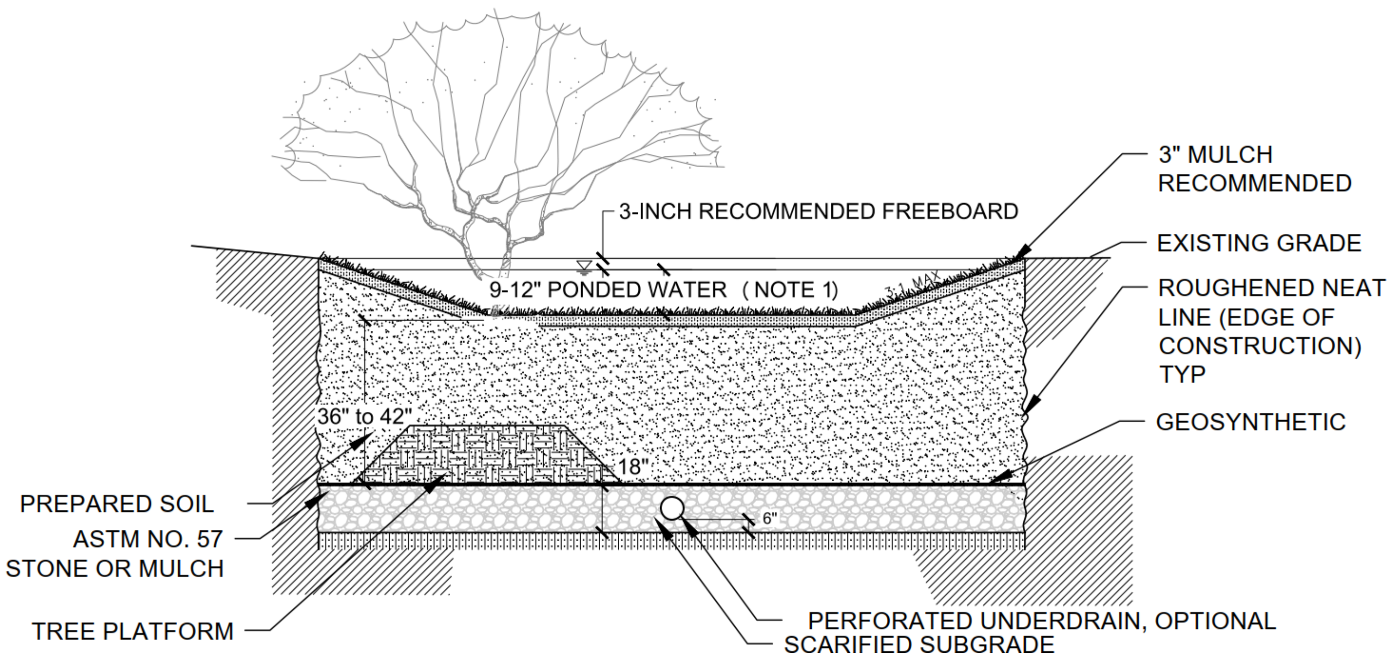


Figure 5-3 Bioretention system section example

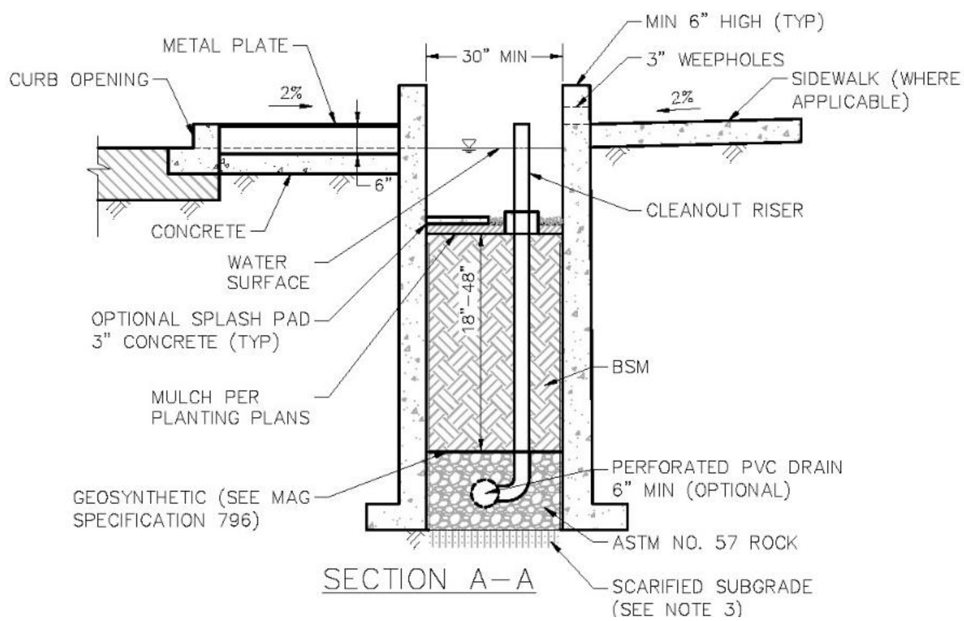


Figure 5-4 Bioretention planter cell section example

5.5 Curb Opening

5.5.1 Description

Curbs contain surface flows within streets (normal crown), parking areas, etc. A curb opening allows water to enter the adjacent landscaped areas. Curb openings (also known as curb cuts) can direct water to many of the other BMPs discussed herein. A curb cut can be implemented when a project is constructed, or after construction as a retrofit. They can vary in size and should be designed to capture an appropriate flow rate (Section 4).

Curb opening examples are shown in Photograph 5-8, Photograph 5-9, Figure 5-5, and Figure 5-6. A curb opening standard detail is provided in Appendix C.

5.5.2 Benefits

Curb openings provide the following benefits:

- Enhance application of other BMP components, such as sediment traps, bioswales, or enhanced basins.
- Direct the flow of water into other BMPs.
- Control sedimentation.

5.5.3 Application

Cut existing curbs or construct low portions of new curb near landscape beds, LID BMPs, and other areas that can receive stormwater and allow for infiltration. As water passes through the cut, a sediment basin is helpful to aid the water quality within the BMP.

Water will be moving parallel to the opening of the curb cut; therefore, directional baffles may be necessary to redirect water from the gutter flow line into the curb cut.

Adjacent paved areas should be designed to move water towards the curb opening. Curb openings built on the high side of a parking lot or road shoulder will not receive sufficient runoff water and are discouraged. Those on the runoff path and at the bottom of the slope will be more successful. Further, the grade of the planting bed or basin behind a curb cut must be lower than the street grade, or water will not enter or stay behind the curb cut.

5.5.4 Maintenance

Curb openings/cuts will require routine maintenance, including removal of waste and debris caught within the curb cut, visual inspection of the curb cut for cracking or curb rolling, and removal of fines trapped in sediment trap, if used.

Photograph 5-8. Curb opening along a city street to allow for stormwater capture.
(Pima County Public Works, Author: Sheila Cook, Source: Brian Sager)

Photograph 5-9. Curb opening above grade of adjacent landscape.
(Source: City of Phoenix, AZ).

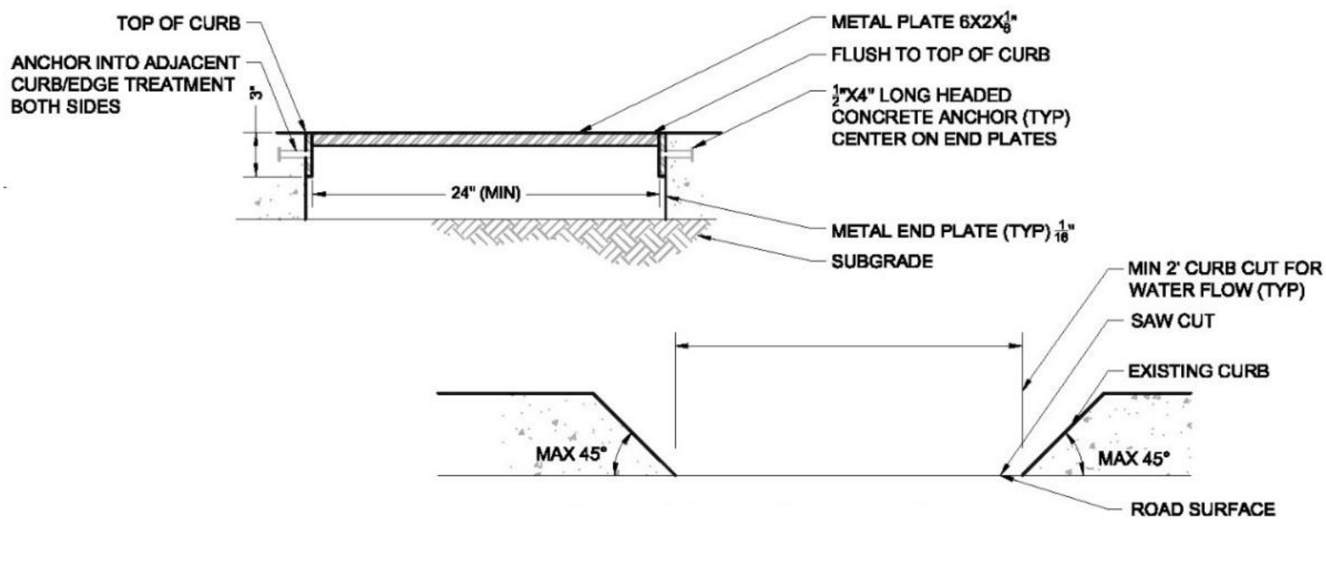


Figure 5-5 Curb opening example – vertical and horizontal cuts on existing curbs

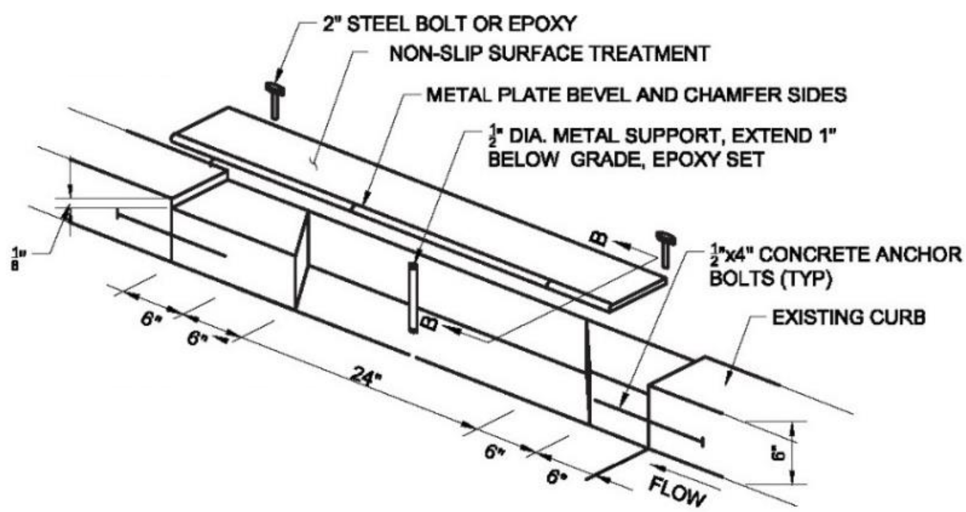


Figure 5-6 Curb opening example – concentrated flow inlet with metal plating

5.6 Curb Modification

5.6.1 Description

A curb modification is created to accept street runoff and can be placed in a variety of locations along new and existing (normal crown only) streets. Curb extensions, chicanes, and bulb-outs are considered curb modifications, which are distinguished by their street location and desired traffic-related outcomes. Curb modifications are best paired with vegetation, with space added for trees. Sediment traps (Section 5.14) are typically included as a beneficial element to all categories of curb modification.

A curb extension physically and visually narrows the roadway width. Curb extensions have the added benefit of increasing pedestrian safety through traffic calming when used to narrow vehicular lane widths. The space created by a curb extension can be utilized by layering additional BMP components, including a bioswale or enhanced basin, along with street trees and active street amenities. A bulb-out is a curb extension that is applied at the mouth of an intersection or crosswalk of the street, which typically creates an aesthetic gateway.

A chicane is a curb extension that extends into a travel lane on one side or alternating sides, creating a non-linear route for vehicular traffic. A chicane on a residential or low volume downtown street can slow traffic speeds considerably. Like a curb extension, the space created by a chicane can be utilized by layering components including a bioswale or enhanced basin, along with street trees and active street amenities.

A curb extension example is shown in Photograph 5-10. Curb extension details are provided in Appendix C.

5.6.2 Benefits

The many benefits of a curb extension include the following:

- Increases pedestrian mobility when paired with end crosswalks or mid-block cross walks.
- Increases traffic calming by narrowing street.
- Increases pedestrian safety and visibility by aligning with the parking lane and reducing cross walk length.
- Increases public space available for streetscape amenities.
- Increases commercial space available for adjacent property owners.
- Flexible sizing.
- Reduces pollutants.
- Reduces runoff when paired with other BMP components.
- Improves air quality.
- Reduces urban heat island.
- Improves site aesthetics.
- Increases property values.
- Simple to construct.
- Low construction costs.

- Low likelihood of failure.
- Relatively low maintenance costs.

5.6.3 Application

Curb extensions are versatile and can be located at curbed roads, driveways, parking lots, and pedestrian and vehicular intersections. A curb extension can be paired with additional BMP components, but it is not required. They should be constructed in a location upstream of a grey infrastructure stormwater inlet. The curb returns to the original curb line should be designed to enable street sweeping along an angled edge. Curb extension inlets should include a pre-settlement treatment along the soil edge to prevent erosion and excess settling. Utilities located in curb extensions can be sleeved to minimize conflict.

5.6.4 Maintenance

Routine maintenance of curb extensions includes removal of particulates and fines. Infiltration rates should be periodically checked, and if necessary, filtration media should be replaced.

Photograph 5-10. Curb extension example in Buckeye, AZ.
(City of Buckeye Monroe Avenue Curb Extension, Author & Source: Jesse Westad)

5.7 Inverted Crown Roadway Variations

5.7.1 Median

5.7.1.1 Description

A median can be an effective BMP on inverted crown roadways, where the street geometry predictably directs flows along, or near, the centerline. Medians may or may not require vehicular protection, dependent upon the roadway travel speed. Medians are recommended to have vertical curbing along their length, but flush curbs at each end to allow for stormwater entry and exit. Medians do not require overflow piping, but can be an effective location for a drain inlet that would convey surplus water to a nearby roadside BMP. The materials of and approaches to a median are similar to those for curb modification treatments, such as the use of arid-adapted trees and native plants. Medians width can vary depending on the roadway width but should allow for a full travel lane on each side of the median for vehicular traffic mobility. When planted with trees, attention shall be paid to tree species selection, as the ultimate size of a tree's crown should not encroach a travel lane.

Medians can be used singularly or in a series if the roadway width can accommodate it. Medians should be designed to allow for left-turning movements on higher volume streets, and should not block access to driveways, alleys, or adjoining streets. If used in a series, the effectiveness of water catchment and slowing will be enhanced.

A median example is shown in Photograph 5-11. A median detail is provided in Appendix C.

5.7.1.2 Benefits

The benefits of a median include the following:

- Capitalizes on inverted crown roadway geometry.
- Increases traffic calming by narrowing streets.
- Increases public space available for streetscape amenities.
- Flexible sizing.
- Reduces pollutants.
- Reduces runoff.
- Improves air quality.
- Reduces urban heat island.
- Improves site aesthetics.
- Increases property values.
- Simple to construct.
- Low construction costs.
- Low likelihood of failure.
- Relatively low maintenance costs.

5.7.1.3 Application

Medians can be located on inverted crown roadways that have sufficient width to accommodate two full-width roadway lanes after implementation of the BMP. The size of the median should accommodate the passing of larger vehicles and should anticipate recreational vehicles, boats in tow, and buses.

5.7.1.4 Maintenance

Routine maintenance of medians includes removal of waste and debris caught within the median, tree trimming and plant management, and verification that any overflow piping (if used) is functional and not clogged. Occasion maintenance resulting from vehicular contact may include replacement of trees or barricades, and regrading tire ruts that may result from careless drivers.

Photograph 5-11. Median example with flush curbs at ends and vertical curb along edges in Tucson, AZ. (North Palo Verde Road, Tucson, AZ, Author & Source: Google Maps)

5.7.2 Drain Inlet Capture and Distribution System

5.7.2.1 Description

On narrower roads where a median may not be practical, a drain inlet capture and distribution system may be more appropriate. This feature utilizes a traffic rated drain inlet along the drainage path of an inverted crown roadway or a W-section roadway to capture flows. Water is captured into a small basin, and when the water level reaches the height of the distribution pipes, it is conveyed out of the basin to roadside bioswales. The depth of the collection basin provides pretreatment for the settlement of silt and suspended fines. This BMP functions well within a roadway and will not create a negative impact to vehicular movement.

Drain Inlets can be used singularly or in a series. If used in a series, the effectiveness of water catchment and slowing will be enhanced.

A drain inlet capture and distribution system example is shown in Figure 5-7. A drain inlet capture and distribution system detail is provided in Appendix C.

5.7.2.2 Benefits

The benefits of a drain inlet and distribution system include the following:

- Capitalizes on inverted crown roadway geometry.
- Does not impact vehicular travel.
- Flexible sizing.
- Reduces pollutants.
- Reduces runoff.
- Reduces urban heat island if coupled with bioswales
- Low likelihood of failure.
- Relatively low maintenance costs.

5.7.2.3 Application

Drain inlet and distribution systems can be located on inverted crown roadways that are narrow, or on W-section roadways where drainage is conveyed off the center of the road but not along the curb line. The full application of the system will also need roadside bioswales or vegetation to fully realize the benefits.

5.7.2.4 Maintenance

Routine maintenance of Drain Inlet features includes removal of waste and debris caught on top of the grate, removal of silt from the bottom of settling basin, and maintenance of the roadside BMP vegetation.

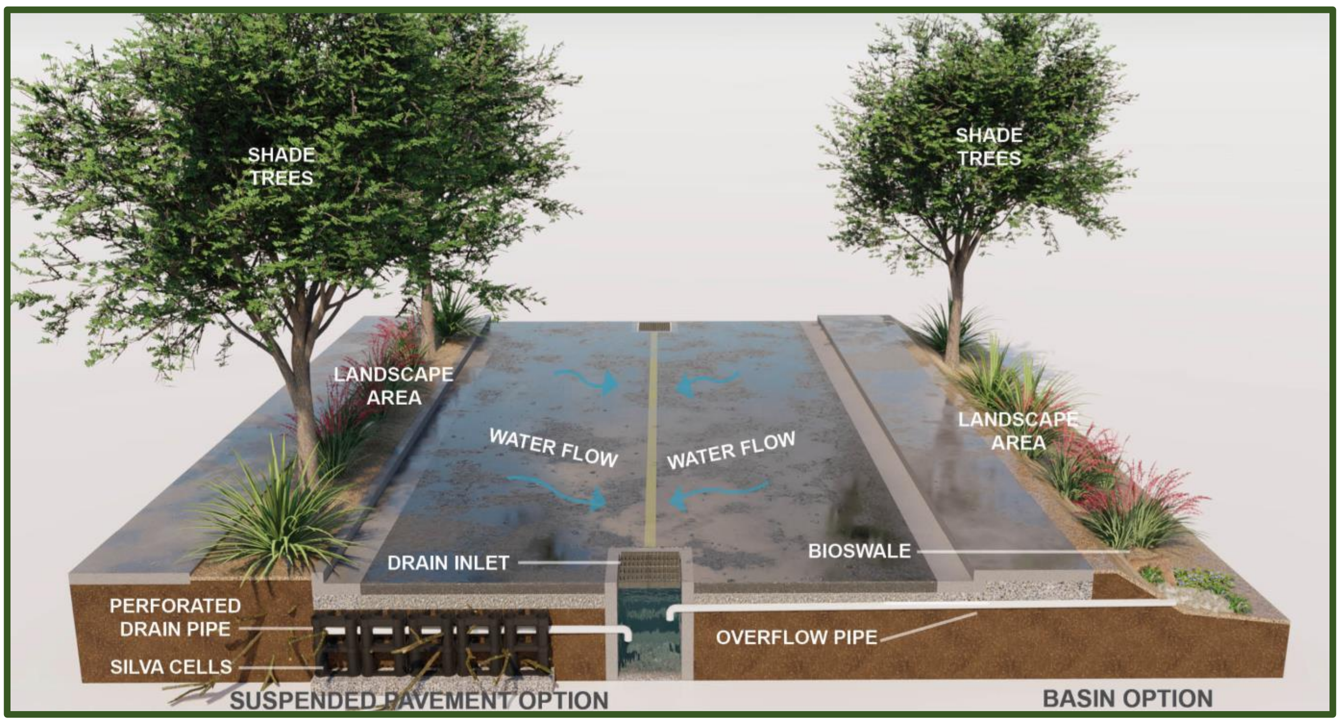


Figure 5-7. Drain inlet capture and distribution example.

5.7.3 Traffic Circle

5.7.3.1 Description

A traffic circle is another roadway BMP that is effective on inverted crown roadways, where the street directs flows down the centerline, or other non-gutter flow line, towards a roadway intersection. Traffic circles will have vehicular protection such as bollards or curbs, but will allow for stormwater to pass through the barriers and enter the landscape area, where the water can be slowed and infiltrated. The materials of and approaches to a traffic circle are similar to median treatments, such as the use of native vegetation and organic groundcover. However, traffic circles cannot create impediments to safe movement of vehicles; and therefore, traffic circles should use overflow piping to direct impounded water away from the intersection to prevent any impounded water from encroaching on a vehicular travel lane.

Traffic circles can be used singularly, or in a series, if the inverted crown roadways are wide enough to safely pass vehicles, and if the travel speeds are slow enough, such as in a neighborhood street network or a network of local roadways. If used in a series, the effectiveness of water catchment and slowing will be enhanced.

Traffic circle examples are shown in Photograph 5-12 and Photograph 5-13. A Traffic circle detail is provided in Appendix C.

5.7.3.2 Benefits

The many benefits of a traffic circle include the following:

- Capitalizes on inverted crown roadway geometry.
- Increases traffic calming by narrowing streets.
- Increases public space available for streetscape amenities.
- Flexible sizing.
- Reduces pollutants.
- Reduces runoff when paired with other BMP components.
- Improves air quality.
- Reduces urban heat island.
- Improves site aesthetics.
- Increases property values.
- Simple to construct.
- Low construction costs.
- Low likelihood of failure.
- Relatively low maintenance costs.

5.7.3.3 Application

Traffic circles can be located at traffic intersection points where one or both roadways have inverted crown sections. They can also be utilized in wide portions of roadways that do not have crossing streets, or in three-way or multiple leg intersections if space allows for it and if visibility is accommodated. These are generally low-speed neighborhood intersections, or four-way stop intersections. The size of the traffic circle should accommodate turning radius of larger vehicles and should anticipate recreation vehicles, boats in tow, and buses.

5.7.3.4 Maintenance

Routine maintenance of traffic circles includes removal of waste and debris caught within the traffic circle, tree trimming and plant management, and verification that the overflow piping is functional and not clogged. Occasional maintenance resulting from vehicular contact may include replacement of trees or barricades, and regrading tire ruts that may result from careless drivers.

Photograph 5-12. Small traffic circle example in Tucson, AZ.
(Dunbar Springs Neighborhood, Tucson, AZ, Author & Source: Nolan Bade)

Photograph 5-13. Large traffic circle example in Tucson, AZ.
(Tucson, AZ, Author & Source: Nolan Bade)

5.8 Permeable Hardscape

Permeable hardscapes are a diverse group of materials with varying applications, but generally described as porous urban surfacing composed of an underlying stone reservoir. Permeable pavement captures precipitation and surface runoff, storing it while slowly allowing it to infiltrate into the soil below, or discharge through a drain tile below.

In general, the benefits of implementing permeable hardscape LID include the following:

- Applicable options when hardscapes are necessary, and landscaping is not practical.
- Runoff volume reduction is achieved when permeable hardscapes are placed over a permeable stone/aggregate bedding layer and permeable soils, allowing infiltration of water into the subgrade. Significant runoff volume reduction can be achieved if coupled with underground storage (Section 5.11).
- Peak runoff rate reduction is achieved when water is detained within the subgrade beneath the permeable hardscape.
- Increased runoff capture and infiltration translates to less runoff downstream. Less runoff downstream reduces nuisance drainage issues, reduces pollutant conveyance, and reduces the potential for erosion of adjacent landscape.
- Permeable hardscapes are durable and resist erosion.
- Low maintenance costs.
- Decreases urban heat gain.

The dominant types of permeable hardscapes include stabilized aggregate, permeable pavers, permeable block, permeable concrete, and permeable asphalt.

5.8.1 Stabilized Aggregate

5.8.1.1 Description

As described in the *Greater Phoenix Metro Green Infrastructure Handbook* (Scottsdale, AZ; January 2019), stabilized aggregate is a mixture of compacted stone aggregate and a binder. A compacted and graded sub-base, consisting of porous stone layers, can be utilized for additional storage volume. Examples of stabilized agregate are shown below in Photograph 5-14. A stabalized aggregate standard detail is provided in Appendix C.

5.8.1.2 Application

Commonly, stabilized aggregate is used to pave driveways, footpaths and other accessible landscape areas. If necessary, it can be ADA compliant, with correct specification. It should be used in areas that do not have high volumes of vehicular or pedestrian traffic.

5.8.1.3 Maintenance

Stabilized aggregate maintenance includes routine inspection for settlement, fissuring or ponding; periodic raking to remove weeds; and periodic redressing and reapplication of binder material to maintain level grade.

Stabilized aggregate reduces storm runoff from low-traffic paving areas.

Photograph 5-14. Example of stabilized aggregate.
(Source: Greater Phoenix Metro Green Infrastructure Handbook)

5.8.2 Permeable Pavers

5.8.2.1 Description

As described in the *Greater Phoenix Metro Green Infrastructure Handbook* (Scottsdale, AZ; January 2019), permeable pavers are comprised of precast concrete unit pavers designed to be set on a stone aggregate base and highly permeable setting bed with joints filled with sand or fine gravel. Water enters the joints between the unit pavers and flows through an open-graded base, to infiltrate into the subgrade. The sand joints provide surface permeability and help filter stormwater sediments and pollutants. The void spaces in the aggregate base store water and infiltrate it back into the subgrade. An example of permeable pavers is shown below in Photograph 5-15. A permeable pavers standard detail is provided in Appendix C.

5.8.2.2 Application

Permeable pavers can be used for vehicular and pedestrian applications and are a decorative permeable hardscape option. They can be used for parking lot, sidewalk, and street applications and in areas of high travel.

5.8.2.3 Maintenance

Maintenance of permeable pavers includes periodic inspection for settlement and cracking; routine inspection for visible clogging; periodic clearing of leaf and soil/sediment accumulation; and joint clear-out if regular clogging exists.

Photograph 5-15. Patio constructed with permeable pavers.
(Author & Source: Unknown)

5.8.3 Permeable Block

5.8.3.1 Description

Permeable block, such as PaveDrain (www.pavedrain.com), is an effective hardscape alternative comprised of a unique precast arch block design that allows water to be taken up rapidly on site through a highly permeable infiltration path. The precast blocks include spacers that allow for a vertical infiltration path for precipitation and runoff, with a reported infiltration rate of more than 1,000 in/hr. Examples of PaveDrain installation are shown in Photograph 5-16, Photograph 5-17, and Photograph 5-18. PaveDrain standard details are available at https://www.pavedrain.com/design-assistance.

A permeable block system promotes significant infiltration, primarily due to the ADA-compliant space between the blocks being void of any filler material. Given the high rate of infiltration, rainfall is captured close to the point at which it falls, and runoff is substantially reduced. Reduced runoff translates to flood mitigation and increased water quality.

The precast arch block design and stone bedding layer provide significant storage capacity for captured runoff. Storage capacity can be substantially increased when the overall LID system includes underground storage (see Section 5.11).

5.8.3.2 Application

Permeable block systems are applicable where hardscape is necessary, and landscape is not practical. Permeable block systems are scalable, used for both small and large site applications. Permeable block systems have been employed for parking lots, driveways, streets, and pathways.

5.8.3.3 Maintenance

Maintenance is relatively straightforward, performed with street sweeping/vacuum equipment. In addition, because blocks are placed with no filler material necessary, individual blocks can be easily removed and reset during maintenance. Routine maintenance should include inspection for visible clogging, vacuuming of leaf and soil accumulation that deposit from surrounding landscape areas, and inspection for settlement.

Photograph 5-16. PaveDrain system at Franciscan Renewal Center, Paradise Valley, AZ – spacers, mesh, rock bedding. (Source: Holistic Engineering and Land Management, Inc.)

Photograph 5-17. PaveDrain system at Franciscan Renewal Center, Paradise Valley, AZ – installation and arch design. (Source: Holistic Engineering and Land Management, Inc.)

Photograph 5-18. PaveDrain system installation at Franciscan Renewal Center, Paradise Valley, AZ. (Source: Holistic Engineering and Land Management, Inc.)

5.8.4 Permeable Concrete

5.8.4.1 Description

Single size aggregate, also known as permeable concrete or porous concrete, consists of a special concrete mix design with void spaces that make it highly permeable. Aggregates are normally screened to provide particles that can fall within narrow limits to ensure porosity. A typical permeable concrete pavement cross-section is shown below in Figure 5-8. A permeable concrete standard detail is provided in Appendix C.

5.8.4.2 Application

Permeable concrete can be used for vehicular and pedestrian applications, such as parking lots, sidewalks, trails, and streets. It is suitable in areas of low to high travel.

5.8.4.3 Maintenance

Permeable concrete requires routine maintenance, such as sweeping and vacuuming to ensure pavement is clear from sediment fines and debris. Deep cleaning or unclogging (typically simultaneous power wash and vacuum) may become necessary without routine maintenance. Periodic inspection for settling and cracking should take place.

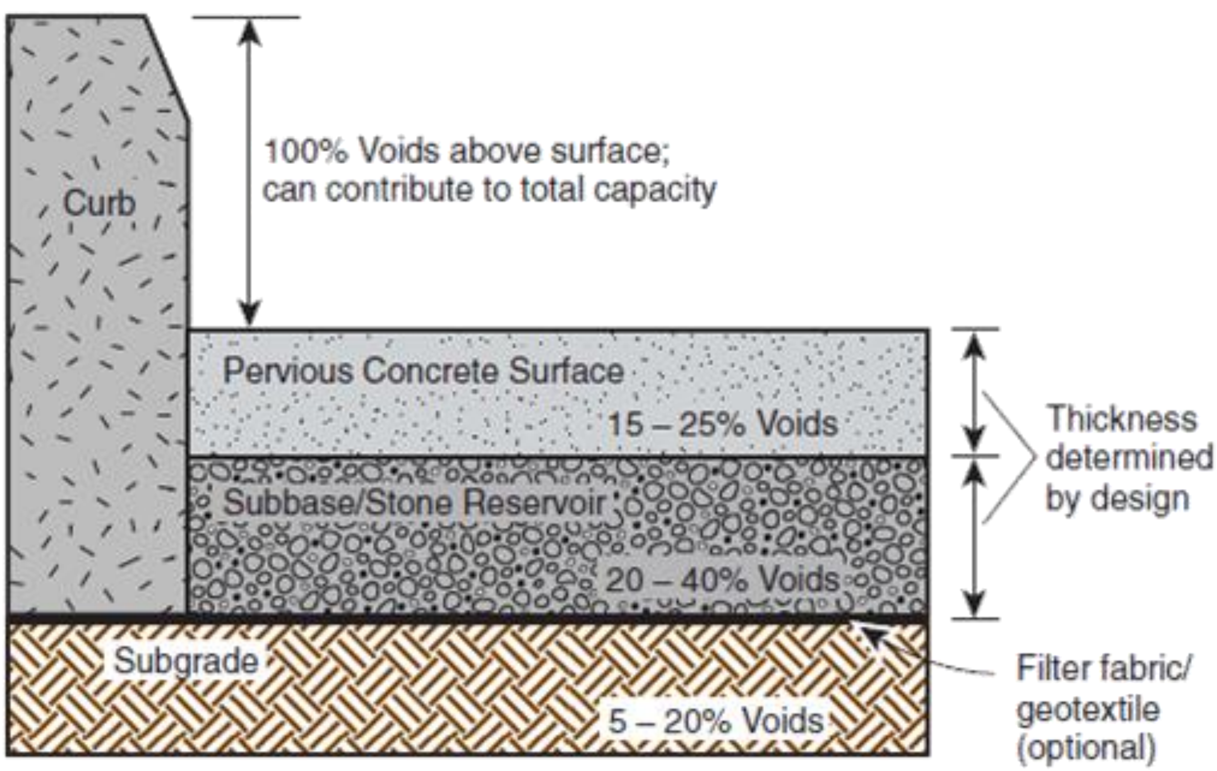


Figure 5-8. Typical cross-section of permeable concrete pavement.
(Source: ACPA Concrete Pavement Wiki, https://wikipave.org/index.php?title=Pervious_concrete_pavement).

5.8.5 Permeable Asphalt

5.8.5.1 Description

Permeable Asphalt, also known as Porous Asphalt, consists of standard asphalt pavement in which the fines have been screened and removed, creating void spaces that make it highly permeable to water. An example of permeable asphalt is shown below in Photograph 5-19. A permeable asphalt standard detail is provided in Appendix C.

5.8.5.2 Application

Permeable asphalt is used in areas that do not have high volumes of traffic. A compacted and graded sub-base, consisting of porous stone layers, can be utilized for stormwater storage.

5.8.5.3 Maintenance

See routine maintenance discussion in Section 5.8.4.3.

Photograph 5-19. Permeable asphalt parking lot.
(Author & Source: Sustainable Building Initiative, https://sustainablebuildingsinitiative.org/).

5.9 Suspended Pavement

Suspended pavement is any technology that supports the weight of paving. This tactic creates voids space below the paving that can be filled with soil or amended soil, and then paved over as it would be normally, with pervious or impervious pavement. Suspended pavement is advantageous for stormwater control but also supports healthy tree rooting when planted near functional hardscapes. Types of suspended pavement technology include pervious storage media and structural soil.

5.9.1 Pervious Storage Media

5.9.1.1 Description

A pervious storage media, such as the Silva Cell system, is a modular suspended pavement that uses soil volumes to support large tree growth and provide powerful on-site stormwater management through absorption, evapotranspiration, and interception. Stormwater can access the system through permeable hardscape, soil media filters within planters/basins, or directly through catch basin inlets. Due to sedimentation and clogging concerns with directly introducing stormwater, pretreatment (Section 5.14) is highly recommended to prolong the life of the system. Examples of previous storage media are shown in Photograph 5-20, Photograph 5-21, Figure 5-9, and Figure 5-10. A pervious storage media standard detail is provided in Appendix C.

5.9.1.2 Benefits

Pervious storage media provides the following benefits:

- Reduces stormwater runoff volume and peak flow rate.
- Improves water quality and pollutant control.
- Increases tree growth rate, health, and longevity.
- Compatible with any soil type.

5.9.1.3 Application

Pervious storage media is used on almost any type of site involving pavement, including streets, sidewalks, parking areas, and over-structure decks. It is ideal for dense urban applications where pavement is required, and landscape area is limited. It is highly recommended in areas where tree root growth is limited by impermeable pavement and soil compaction.

5.9.1.4 Maintenance

Pervious storage media units themselves have little to no maintenance required. Maintenance is primarily required for the auxiliary components, such as inlet/outlet, piping, trees, and pavement surfacing. Routine maintenance should include inspecting for clogging, standing water, sediment, trash, and debris. Pretreatment through temporary erosion and sedimentation control measures in the tributary drainage basin should be implemented during construction.

Photograph 5-20. Silva Cell system installation.
(Silva Cell Trenching, Author & Source: Deeproot)

Photograph 5-21. Street catch basins connected to pervious storage media.
(Queensway Sustainable Sidewalk Pilot Project, Author: City of Toronto, Source: Sustainable Technologies)

Figure 5-9 Silva Cell water flow diagram.
(Lake Havasu City, Author & Source: WERK)

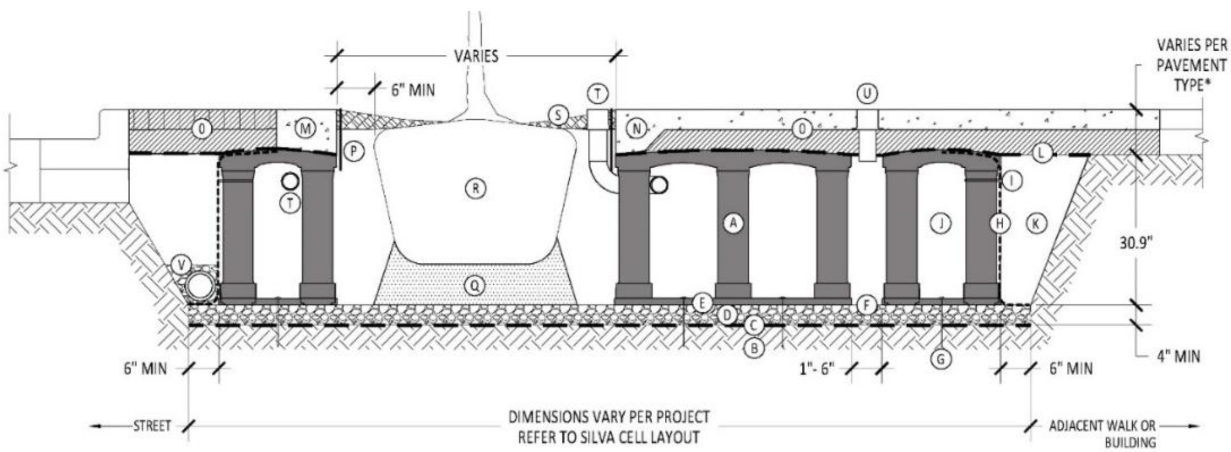


Figure 5-10. Silva Cell section detail example – 2X System.
(Silva Cell Resources, Author & Source: Deeproot)

5.9.2 Structural Soil

5.9.2.1 Description

CU-Structural Soil® is a proprietary soil system that creates a suspended pavement. The two-part system includes a rigid stone "lattice" that meets engineering requirements for a load-bearing paving base. Large voids between the stones provide room for an uncompacted clay loam soil and allow for root growth and aeration of the root zone, supporting vigorous tree development and health. The CU-Structural Soil® is shown in Figure 5-11. Examples of suspended pavement technology are shown in Photograph 5-22 and Photograph 5-23. Suspended pavement standard details are provided in Appendix C.

5.9.2.2 Benefits

This structural soil technology provides deep tree root growth into the base course material, helps reduces urban heat island stress on tree roots, increases infiltration rates, and reduces cracks and heaving in pavement caused by tree roots.

5.9.2.3 Application

Structural soil technology can be used in many applications involving site pavement, including streets, sidewalks, and parking areas. It is ideal for dense urban applications where pavement is required and landscape area is limited, as it provides a high strength pavement system that shifts design away from individual tree pits.

5.9.2.4 Maintenance

Like pervious storage media (Section 5.9.1.4), maintenance requirements are not directly associated with structural soil, but rather for the auxiliary components, such as inlet/outlet, piping, trees, and pavement surfacing. Pre-treatment through temporary erosion and sedimentation control measures in the tributary drainage basin should be implemented during construction.

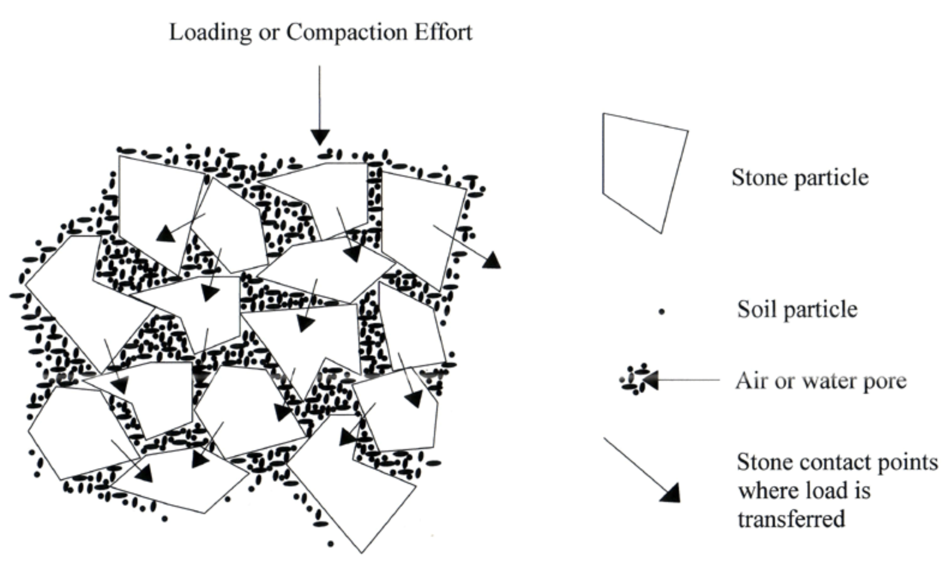


Figure 5-11 CU-Structural Soil® composition.
(CU Structural Soil, Author & Source: Cornell University)

Photograph 5-22. Installing structural soil prior to paving.
(New York City Plaza, Author: Nina Lauren Bassuk, Source: Urban Horticulture Institute – Cornell University)

Photograph 5-23. Structural soil application in tandem with pervious storage media.
(Stratavault, Author & Source: Citygreen)

5.10 Soil Modification

Soil modification treatments provide effective ways to maximize infiltration in poorly draining soils, while also maximizing the effectiveness of connected LID applications. Soil modification treatments that are increasingly being employed include energy-passive groundwater recharge systems, biochar, and organic mulch (Sections 5.10.1, 5.10.2, and 5.10.3, respectively).

5.10.1 Energy Passive Groundwater Recharge (EGRP®)

5.10.1.1 Description

The Energy-Passive Groundwater Recharge Product (EGRP®), developed by Parjana (www.parjana.com), *is a device designed to increase the infiltration of surface water into near-and-sub-surface soils, providing subsequent benefits to groundwater recharge, runoff mitigation, water quality, and vector control*. The EGRP® system works by using fundamental physical properties of capillary action, water pressure, and soil moisture content in conjunction with how water interacts with soil to create a pathway for water molecules traveling through the soil. EGRP® has been proven to increase native soil infiltration rates by up to seven to ten times in areas with poor soil aggregation and impervious surfaces. It is important to note that the EGRP® system improves infiltration without disturbing the soil's ecological balance, as the devices do not encourage water to flow straight down to the bottom of the device like a pipe; but rather, the devices enhance horizontal distribution of water through the soil matrix, as well as vertical distribution. The EGRP® is shown below in Photograph 5-24, Figure 5-12, and Figure 5-13. EGRP® standard detail is provided in Appendix C.

5.10.1.2 Benefits

As discussed above, the EGRP® system promotes infiltration in poorly draining soils, which translates to groundwater recharge, runoff mitigation, pollution mitigation, improved soil productivity, and vector control.

5.10.1.3 Application

The EGRP® system can augment traditional stormwater practices by increasing the infiltration rate and management capacity of systems that capture peak volumes – such as ponds, swales, or other storage treatments. Often the system can be paired with filtration/biofiltration systems to improve the water quality of volumes being infiltrated.

5.10.1.4 Maintenance

Once installed, the EGRP® system is maintenance free.


**Photograph 5-24. Excerpt from Parjana presentation showing technology testing site.
Control site after rain shown in left photograph. EGRP® (test) site after rain in right photograph.**

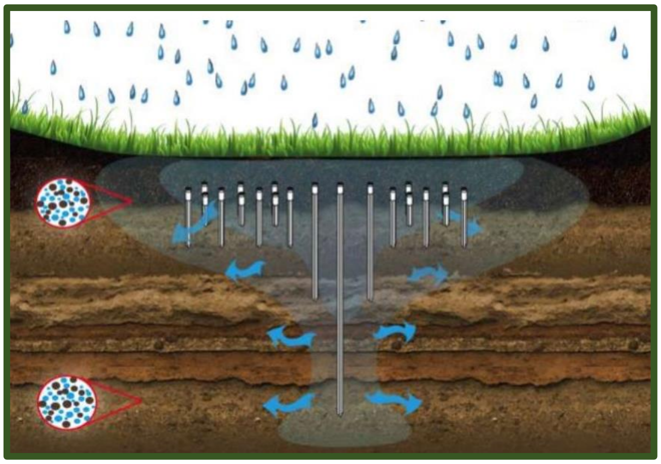


Figure 5-12. EGRP® horizontal and vertical infiltration. (Source: www.parjana.com)

Figure 5-13. EGRP® 5-chamber, hydrophobic device. (Source: www.parjana.com)

5.10.2 Biochar

5.10.2.1 Description

According to a Colorado State University fact sheet (https://extension.colostate.edu/docs/pubs/crops/00509.pdf), "*Biochar is a charred organic matter used deliberately as a soil amendment, with the intent to improve soil properties. Biochar is made by heating biomass to high temperatures (480-1800°F) in the absence of oxygen through pyrolysis.*" Examples of biochar are provided in Photograph 5-25, Photograph 5-26, and Photograph 5-27.

5.10.2.2 Benefits

As a soil amendment, biochar is a porous material that increases a soil's water-holding capacity, thereby reducing runoff and promoting water use and/or infiltration. It has been reported that the water-holding capacity in sandy soils can be increased over 20 percent when biochar is used as a soil amendment. By increasing water retention in soil, biochar can be used to decrease irrigation demands for landscaped areas, golf courses, and recreational fields, which is particularly important in arid regions such as Lake Havasu City.

The physiochemical properties of biochar improves soil nutrients and provides physical protection to beneficial microorganisms within the soil matrix. These healthy soil conditions, coupled with significant water-holding capacity, results in enhanced vegetation growth.

In terms of water quality, biochar has significant adsorption ability, which in turn immobilizes heavy metals, pesticides, herbicides, hormones, and other chemicals/pollutants that adversely impacts waterways and groundwater.

Various biochar benefits are summarized graphically in Figure 5-14.

5.10.2.3 Application

Biochar can be used as a soil amendment for numerous LID BMPs, including tree beds, bioswales, bioretention planters, and biofiltration planters. To enhance tree growth, it is most effective when the biochar is worked into the plant's root zone. As mentioned above, biochar may be used as a water conservation tool to decrease irrigation demand within regularly irrigated landscapes. Finally, biochar use is applicable in urban environments where non-point source pollution runoff is an issue.

5.10.2.4 Maintenance

As a soil amendment, biochar is added as needed per manufacturer's recommendations. No further maintenance is required once biochar has been applied.

Photograph 5-25. Biochar soil amendment.
(Source: unknown)

Photograph 5-26. Layer of biochar added to topsoil.
(Biochar & Urban Soils, Author & Source: ARTi)

Photograph 5-27. Preparing a biochar bed for urban tree.
(Planting Urban Trees with Biochar, Bjorn Embrén, The Biochar Journal)

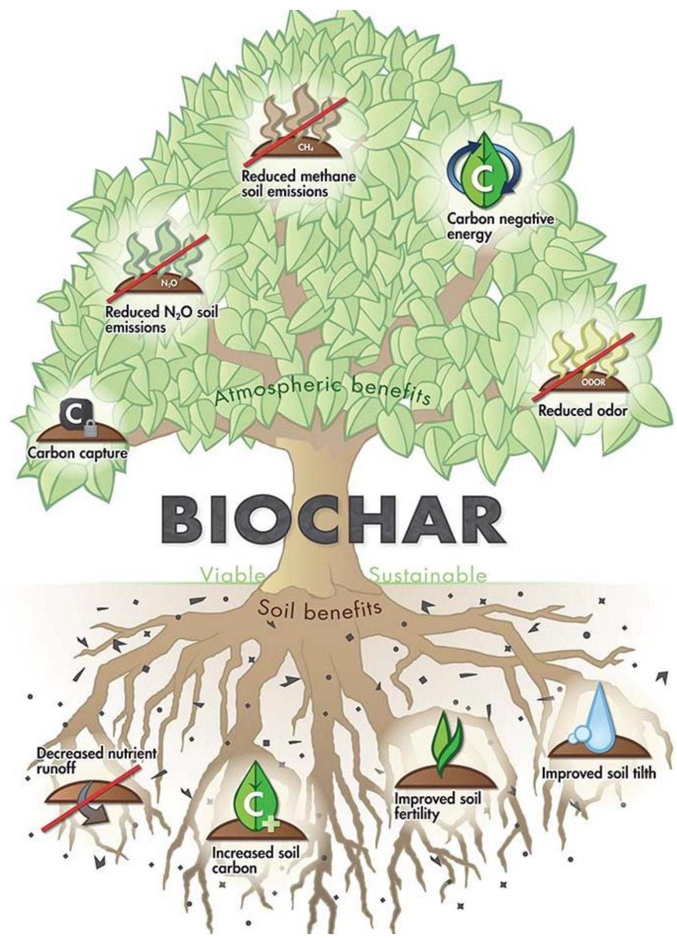


Figure 5-14. Biochar benefits.
(Biochar Benefits, Author & Source: Biochar Institute)

5.10.3 Organic Mulch

5.10.3.1 Description

Organic mulch is a topdress material composed of shredded or chipped wood, bark, or similar materials. Organic mulch can be used in place of inert groundcover materials like decomposed granite. Generally, wood chip mulch is the most common organic mulch material. It is readily available, decays relatively slowly, and is aesthetically attractive. Examples of organic mulch are shown in Photograph 1-4 (above), Photograph 5-28 and Photograph 5-29.

5.10.3.2 Benefits

The use of organic mulch offers many benefits to soil quality and resulting plant health, which beneficially impacts localized air quality and surface temperatures. Benefits of employing organic mulch include the following:

- Improves dust control and air quality.
- Improves soil nutrient content.
- Improves soil structure.
- Retains water and soil moisture.
- Inhibits weed growth.
- Aids in erosion mitigation.
- Retains a lower temperature than decomposed granite.
- Reduces urban heat island effect.
- Helps create localized microclimates.
- Improves soil microbiology.
- Increases plant vigor.
- Increases plant evapotranspiration (ET) rate.
- Reduces pollutant loading.
- Low application costs.
- Low maintenance costs.

5.10.3.3 Application

Organic mulch can be used in planter beds, residential yards and gardens, and associated BMP bioswale and planter components. A four-to-five-inch layer of organic mulch is placed on native or amended topsoil after planting and installing irrigation. The mulch is commonly produced by chipping wood from tree trimming and maintenance, and therefore this is a local material, which reduces the amount of material imported onto the site and reduces cost.

5.10.3.4 Maintenance

Organic mulch will decompose and will require annual toppings on top of the previous course. Add two to three inches of organic mulch topping annually. Remove weeds as needed but minimize the use of glyphosate (commonly used herbicide). If used in bioswales or bioretention planters, sediment traps or erosion control will reduce erosion and shifting of mulch and generally minimize the required maintenance.

Photograph 5-28. Mulch combined with passive rainwater harvesting (City of Buckeye Monroe Avenue, Author & Source: Jesse Westad)

Photograph 5-29. Native plant and mulch garden renovation (Grass to Raingarden, Author & Source: Watershed Management Group)

5.11 Underground Storage

5.11.1 Infiltration Trench

5.11.1.1 Description

The *Green Streets Handbook, Section 6.6*, identifies infiltration trenches as "*excavated linear areas that are filled with layers of stone and sand wrapped in geotextile fabric. The trench is covered with stone, gabion, sand, or grassy surface with surface inlets. Stormwater is stored in the stone reservoir and slowly infiltrates … thereby reducing stormwater volume and peak discharge*". Typically, soil media is placed over the stone storage layer to allow for stormwater to be filtered, but infiltration trenches can be modified to be placed entirely under an impervious surface (e.g., parking lot) in combination with a modified catch basin as discussed in Section 5.14.3. Infiltration trenches can provide improvements to stormwater volume reduction, water quality, and groundwater recharge without negatively impacting surface use. An infiltration trench schematic is shown in Figure 5-15.

5.11.1.2 Benefits

Benefits of employing infiltration trenches include the following:

- Reduces total stormwater runoff.
- Aids in erosion mitigation.
- Removes fine sediments, trace metals, and particulates from storm water (soil media application only).
- Reduces the size and cost of downstream stormwater control facilities.
- Allows for surface use such as parking and pedestrian movement.
- Compact size allows for easy retrofit and use in smaller sites
- Can direct water towards vegetation which improves shade cover and reduces urban heat.
- Low maintenance costs.

5.11.1.3 Application

Infiltration trenches can be used in new construction or as a retrofit upstream of flood prone areas. They can vary in size depending on the storage needs and infiltration capacity of the native soil. Typical applications backfill the trench with rock mulch or rip rap (40% void space for storage capacity) and covered with geotextile fabric below a topping layer of earth or pervious pavement. Alternatively, if a modified catch basin is used, the stone storage layer can be placed directly under a standard pavement section with a perforated pipe distribution system similar to a leach field (see Photograph 5-30). The flexible size and simple construction allow for this technique to be used in many different situations.

5.11.1.4 Maintenance

Infiltration trenches are low maintenance features but do require occasional maintenance. Sediment can accumulate in both soil media and modified catch basin applications and should be inspected and removed when infiltration is compromised or fills the catch basin sump. If landscaping is used, vegetation management and replanting may be necessary. An observation port will enable visual inspection of infiltration time within the stone storage layer, which should occur within 72 hours (36 hours for any surface ponding).

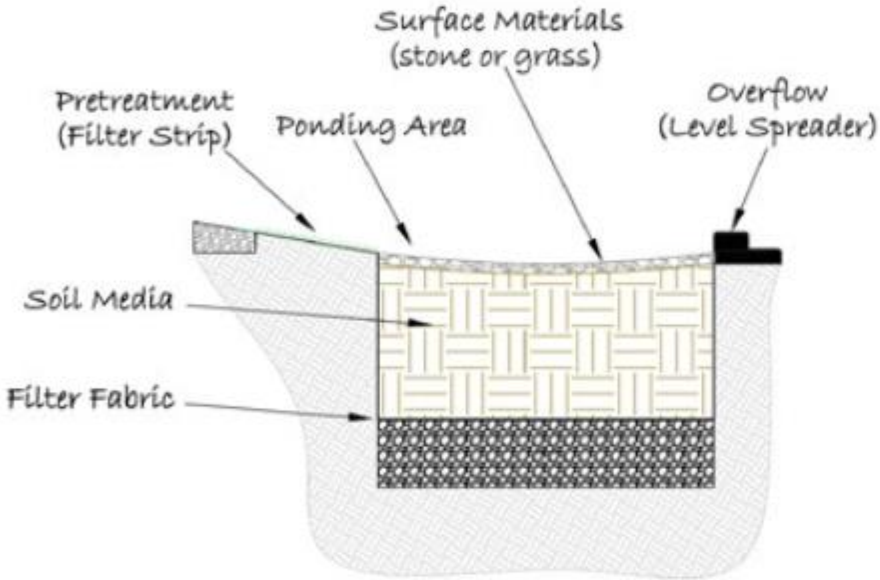


Figure 5-15. Stormwater infiltration trench schematic.
(Author: EPA/Tetra Tech, Inc. & Source: Figure 6-8 from the Green Streets Handbook)

Photograph 5-30. Perforated pipe distribution system example.
(Author & Source: Wikipedia/Nonztp)

5.11.2 Modular Underground Storage Systems

5.11.2.1 Description

There are many types of modular underground storage systems and applications, which produce varying degrees of capacity and complexity. In modular systems, porous cells are placed inside an excavated pit and wrapped in geotextile fabric. Stormwater is routed into the underground storage area through inlets. Overflow and outlet piping is optional and may protect the facility. Once filled with stormwater, the system can route stormwater to a drainage system, recycle stormwater for irrigation, or infiltrate it into the ground.

R-Tank® Stormwater Modules (https://acfenvironmental.com/products/engineered-applications/stormwater-management-lid/space-efficient-storage/r-tank/) are an efficient and versatile modular underground stormwater storage system. Modules are equipped with 95 percent void space, allowing for substantial water harvesting potential and capable of supporting HS-20 and HS-25 traffic loads. The system is scalable with many options for modular size and system size. Examples of the R-Tank® modular system are shown in Photograph 5-32 and Photograph 5-31. An R-Tank® standard detail is provided in Appendix C.

5.11.2.2 Benefits

Benefits of using modular underground storage with LID include:

- Provides cost-effective alternative to other underground systems.
- Reduces underground stormwater storage system footprint.
- Provides more site development area by reducing surface basin area.
- Encourages additional infiltration compared to traditional pipe and stone system.
- Moves water slowly, increasing time of concentration.
- Maximizes storage potential of other green infrastructure systems.
- Construction is simple.
- Construction cost is comparable to traditional systems.
- Low maintenance costs.

5.11.2.3 Application

Modular underground storage systems are diverse and beneficial for large residential, commercial, or industrial sites that store rainwater for irrigation, vehicle washing, dust control, or other outdoor, non-potable uses, and sites where additional infiltration is needed. They are beneficial when underground storage size is an issue. The smaller footprint can potentially resolve utility conflicts or free up space for a future expansion or more intense development. Because of their loading strength, modular underground storage systems can be installed beneath sidewalks, streets, and parking areas.

5.11.2.4 Maintenance

A modular underground storage system is fully accessible for maintenance, with one maintenance port installed within 10 feet of each inlet and outlet connection. Systems can be backflushed once sediment accumulation has reached six inches or 15 percent of the total system height. Any contaminated water needs to be properly disposed of as part of the routine maintenance process.

Photograph 5-31. R-Tank® modular system being constructed.
(R-Tank, Author & Source: ACF Environmental)

Photograph 5-32. R-Tank® modular system before backfilling.
(R-Tank, Author & Source: ACF Environmental)

5.12 Cisterns

Rainwater harvesting cistern systems intercept, divert, store, and release rainwater for future use. Rain is a free source of relatively clean, soft water. As rain falls onto surfaces such as concrete, pavement, and grass it contacts more contaminants than it would from dry fallout on a roof. Harvesting rainwater from roof runoff is an easy, inexpensive way to capture water before it has contacted many potential contaminants. In addition, greywater (Section 5.13) can be collected and stored in the same cistern if the intent is to only use the water for irrigation. In general, cisterns fall into two categories – aboveground and belowground cisterns (Sections 5.12.1 and 5.12.2, respectively). As highlighted below in Figure 5-16, based on an annual precipitation of 4.38 inches, a single-family home with a 1,000 square-foot roof may be able to harvest approximately 2,600 gallons of rooftop runoff.

5.12.1 Aboveground Cistern

5.12.1.1 Description

An aboveground cistern can be made from concrete, metal, polyethylene (plastic), or fiberglass. Aboveground cisterns are typically located close to the building and collect water through a roof drain and gutter system, where individual cistern size and water collection volume is determined based on the roof watershed area. If located on the roof or in the attic, air conditioning (AC) condensate can be plumbed to drain to the cistern to collect water between storm events. Additional components such as exact overflow location, connection to automated irrigation system, and connection to a master control system are add-ins and customizable. An example of an aboveground cistern is shown above in Photograph 1-3 and below in Photograph 5-33. An aboveground cistern standard detail is provided in Appendix C.

5.12.1.2 Benefits

Benefits of aboveground cisterns include:

- Aboveground cisterns reduce local runoff and drainage issues by capturing the rainfall that would typically cascade from the roof of a structure. This capture also mitigates local erosion caused by cascading roof runoff.
- Aboveground cisterns are ideal for water collection, water storage, and eventual water reuse for a variety of purposes, including outdoor landscape irrigation. According to the conservation campaign Water – Use It Wisely (www.wateruseitwisely.com), up to 70 percent of water use is outdoors. Using cistern-stored water for landscape irrigation promotes water conservation and reduces monthly water costs.
- Aboveground cisterns are relatively inexpensive to construct and have relatively low maintenance costs. Furthermore, aboveground cisterns can be planned and installed as aesthetic features.
- Many hobbyists find the capture and use of rainwater and/or greywater to be engaging and fun.

5.12.1.3 Application

Aboveground cistern systems range from small, pumpless rain barrels for residential usage, to large, pumped, irrigation-equipped cistern systems for commercial/industrial buildings.

Large residential or commercial aboveground cistern systems can store rainwater for irrigation, vehicle washing, dust control, or other outdoor, non-potable uses. If greywater is collected in the same cistern, then the water can only be used for irrigation.

5.12.1.4 Maintenance

Aboveground cistern systems should be regularly inspected and maintained. Components to inspect on a routine basis include the cistern, first flush diverter, screen, pump, irrigation piping and/or other conveyance components. In general, an aboveground cistern system is relatively easy to inspect for possible damage.

Photograph 5-33. Residential, aboveground cistern, 1,000 gallons.
(Author & Source: Texas Tank)

5.12.2 Underground Cisterns

5.12.2.1 Description

Underground cisterns function similarly to aboveground cisterns (Section 5.12.1), and can be made of concrete, metal, or reinforced polyethylene. The shell materials are more durable and reinforced for underground application. They are more expensive to install than aboveground cisterns due to site excavation and the need for a pump. Underground cisterns can capture roof runoff, water collected from parking and roadway surfaces and greywater. If runoff is anticipated to contain contaminants or suspended particulates, filtration and cleaning may be necessary if the water will be utilized for irrigation. Underground cisterns are installed in the ground, with an earth layer of cover, and may require anchorage if installed in an area with high ground water levels or installed within a surface stormwater basin. Harvested water is piped into the tank. An overflow pipe is necessary and can direct surplus water to a designated area on the site. All underground tanks require a pump to evacuate water out of the tank. Examples of underground cisterns are shown in Photograph 5-34 and Photograph 5-35. A belowground cistern standard detail is provided in Appendix C.

5.12.2.2 Benefits

In addition to the benefits discussed for aboveground cisterns (Section 5.12.1.2), belowground cisterns can save valuable space within a site and preserve a site's visual appearance.

5.12.2.3 Application

Belowground cisterns can save space on site and can be installed on smaller properties where the size of the property prohibits aboveground tanks. At the residential level, they are often installed underneath driveways and are a popular choice for new home developments. As with aboveground cisterns, large residential or commercial belowground cistern systems can store rainwater for irrigation, vehicle washing, dust control, or other outdoor, non-potable uses. If greywater is collected in the same cistern, then the water can only be used for irrigation.

5.12.2.4 Maintenance

Belowground cistern systems should be regularly inspected and maintained. An inspection checklist should include water pressure, change in water color, air in water supply, and unaccounted loss of storage volume. Tanks should be washed out and inspected as needed, and at least once every three years.

Photograph 5-34. Commercial, underground fiberglass cistern, 10,000 gallons.
(Underground Fiberglass, Author & Source: National Storage Tank)

Photograph 5-35. Underground steel-reinforced polyethylene cistern backfilled with 50 percent stone.
(Author: Greg Kowalsky and Kathryn Thomason, Source: Contech Engineered Solutions)

5.13 Greywater Collection

Water that has been used in non-food production or waste removal applications, such as from residential bathing, can be suitable for a second use as landscape irrigation. This water is commonly known as "greywater", as it is non-potable and carries some particulates, but is still substantially clean and useful. Sources of greywater include air conditioning (AC) condensate water, shower water, and laundry water. Greywater is diverted to irrigate landscape areas and create landscape features and microclimates such as ponds, among other uses. An estimate of residential greywater capture is shown below in Figure 5-16. Examples of greywater system components are shown in Photograph 5-36 and Photograph 5-37. AC condensate, shower water, and laundry water as greywater sources are discussed below in Sections 5.13.1, 5.13.2, and 5.13.3, respectively.

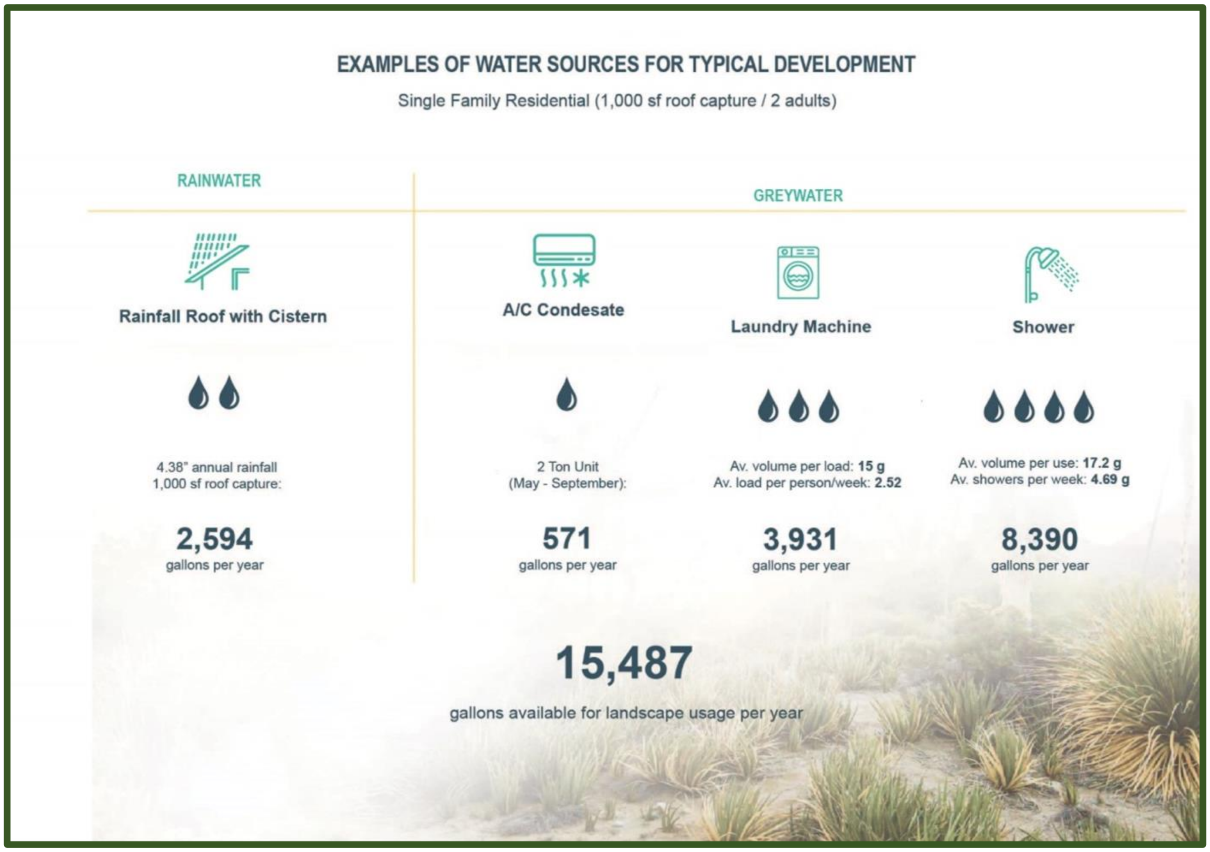


Figure 5-16. Water savings chart assuming single family residence, 1,000 sf roof capture, and 2 adults.

The use of greywater falls under the Arizona Administrative Code (Section 2.3.2.4), which defines the conditions to meet the requirements of the General Permit. Per the General Permit, there are two types of greywater use. The first type (Type 1) allows up to 400 gallons per day of greywater use without the need to inform ADEQ of the intent. The second type (Type 2) allows up to 3000 gallons per day but a Notice of Intent (NOI) is required to be filed with ADEQ. Type 2 refers to reclaimed water and does not pertaining to greywater use in this section. According to ADEQ's website (https://www.azdeq.gov/GrayWater), to comply with the General Permit, residential greywater use should follow these best management practices:

1. Your greywater must only be used for household gardening, composting, or landscape watering at your home, where it cannot be accessible by the public or run off your property.
2. Greywater flow must be less than 400 gallons per day.
3. Greywater may only be used in locations where groundwater is at least 5 feet below the surface throughout the year and cannot be in a floodway (e.g., wash or drainage way).
4. Do not use greywater on any plants that produce food, except trees, and shrubs with edible portions that the gray water does not touch.
5. Avoid overwatering and incorporate practices to increase filtration and minimize standing water, such as using mulch cover.
6. Use only flood or drip watering methods. Spraying greywater is prohibited due to the potential for inhalation or drifting off-site.
7. Avoid contact with greywater or soil irrigated with gray water as much as possible.
8. Greywater cannot contain hazardous chemicals such as antifreeze, mothballs or solvents. Do not include wash water from greasy or oily rags in your gray water.
9. Greywater must not contain water used to wash diapers or other infectious garments. This water must be discharged to a residential sewer line.
10. Label pipes carrying gray water under pressure to eliminate confusion between greywater and drinking water pipes.
11. Cover, seal and secure any surge tanks to restrict access by small rodents and to control disease-carrying insects, such as mosquitoes. Also, minimize the time water is held in surge tanks to avoid any unpleasant odors.
12. Should a blockage, backup or overload occur, greywater use must cease until the problem is corrected. The greywater system may include a means of filtration to reduce plugging and extend system lifetime.
13. If you have septic or other on-site wastewater treatment and disposal system for black water, your greywater use must not change the system’s design requirements for capacity and reserve areas.

Photograph 5-36. Example greywater irrigation system.
(Settling Tank and Components, Author & Source: Renew Organization)

Photograph 5-37. Surge tank and greywater filer.
(Flotender greywater system, Author & Source: Flotender)

5.13.1 AC Condensate

5.13.1.1 Description

Central air conditioning (AC) systems cool warm air, which creates water vapor that consolidates into water. This water, known as condensate, must be drained away from the mechanical systems to prevent water damage to buildings or systems. The amount of condensate produced by an air conditioner can range from five to 20 gallons per day for a house to millions of gallons per year for large structures such as apartment buildings, schools, and businesses. Condensate recovery is included in the International Code Council's International Green Construction Code and other major codes. As this water is generated through a mechanical process, it may contain residual metals or contaminants. Therefore, the holding tank or cistern should be drained and cleaned occasionally. An elaborate example of AC condensate capture and reuse is shown below in Photograph 5-38. An AC condensate capture standard detail is provided in Appendix C.

5.13.1.2 Benefits

The benefits of harvesting AC condensate include the following:

- Provides an available, diverse option for residential, commercial, and industrial buildings.
- Reduces demand for potable water.
- Provides relatively clean, versatile water.
- Can create cooler microclimates.
- Can be installed as a component in new construction, or as a retrofit on an existing building.
- Can contribute to green building certifications.
- Low maintenance costs.

5.13.1.3 Application

Condensate production and payback is dependent on many variables, including building size and number, new or retrofitted building type, air-handling load, and quantity of condensate produced. Residential systems mainly reuse water for irrigation, swimming pools, and pond water. Commercial systems mainly reuse water for irrigation. Industrial systems can reuse water for irrigation, cooling tower makeup, and industrial process makeup.

AC condensate systems can be developed as a hybrid system that routes the greywater into a storage reservoir, holding tank, or cistern along with rainwater and other greywater components, for a more synergistic irrigation system. Water can also be re-routed for toilet flushing applications to further reduce potable water consumption.

5.13.1.4 Maintenance

AC condensate systems with pumps need to be well maintained to ensure success. A dual plumbing component to the system may be required (recycling back into the building), which also requires routine inspection and maintenance. While AC condensate is essentially distilled water, there is potential for contamination when water sits in a warm environment. Chlorine may be used to treat condensate if required. Further, draining and cleaning the holding tank or cistern is an important annual activity.

Photograph 5-38. AC condensate refilling pond and infiltrating into aquifer (CAPLA Underwood Garden, Author: Bill Timmerman, Source: Green Infrastructure Digest)

5.13.2 Shower Water Recycling

5.13.2.1 Description

Showers are a large source of greywater in the average single family residential structure (see Figure 5-16). Recycled shower water is often abundant and relatively clean water. Shower water can be stored in aboveground or belowground cisterns and is typically used for irrigation water. A shower greywater standard detail is provided in Appendix C.

5.13.2.2 Benefits

In addition to the AC condensate harvesting benefits discussed above in Section 5.13.1.2, shower water reuse provides a consistent source of water throughout the year. Because reused shower water is not diverted to a centralized system for treatment, there is a saving in water treatment costs.

5.13.2.3 Application

Shower water recycling is typically utilized in residential applications, where water is reused for irrigation, but can be applied to any application where normal shower applications exist. Like AC condensate, shower water recycling can be developed as a hybrid system that routes the greywater into a storage reservoir or holding tank along with rainwater and other greywater components, for a synergistic irrigation system. Shower water can also be re-routed for toilet flushing applications to further reduce potable water consumption.

5.13.2.4 Maintenance

Shower water systems with pumps and plumbing need to be regularly inspected and well maintained to ensure success. Shower greywater requires specific measures for its safe reuse for irrigation, such as using biocompatible detergents and products that are free of salts or sodium compounds; boron, borate, or borax; and chlorine bleach.

5.13.3 Laundry Water Recycling

5.13.3.1 Description

Laundry machines are a large source of greywater in the average single family residential structure (see Figure 5-16). As water is jettisoned from a washing machine, it can be diverted from the sewer or septic line to a greywater irrigation system. Laundry water recycling is commonly used when greywater systems are installed.

5.13.3.2 Benefits

The benefits of recycling laundry water include the following:

- Reduces demand for potable water.
- Provides a consistent source of water throughout the year.
- Can be installed as a component in new construction, or as a retrofit on an existing building.
- Simple to use.
- Easy to install.
- Low construction costs.
- Low maintenance costs.

5.13.3.3 Application

Laundry water recycling can be applied to new and retrofitted residential applications where water is typically reused for irrigation. The system requires a diverter or bypass valve, allowing dirty water to be drained into the municipal sewer system if the water is expected to contain fecal or biological contaminants. Like AC condensate and shower water reuse, laundry water recycling can be developed as a hybrid system that routes the greywater into a storage reservoir or holding tank along with rainwater and other greywater components for use as irrigation. Laundry greywater requires specific measures for its safe reuse for irrigation, such as using biocompatible detergents and products that are free of salts or sodium compounds; boron, borate, or borax; and chlorine bleach.

5.13.3.4 Maintenance

Laundry water recycling systems may require pumps and plumbing, which will require routine inspection and as-needed maintenance.

5.14 Pretreatment Practices

5.14.1 Sediment Trap (Forebay)

5.14.1.1 Description

Accumulation of sediment within an LID BMP is a considerable threat to BMP function and may lead to failure. A sediment trap should be installed at curb openings and/or inlets to BMPs that receive concentrated stormwater flows. A sediment trap provides a collection point for sediment and other debris before runoff enters a LID facility. It can take the form of a pit or check dam (Section 5.3) to dissipate enough runoff energy for sediment to drop out. Sediment traps decrease maintenance of other BMP components, especially when paired with a bioswale or enhanced basin.

Sediment trap examples are shown in Photograph 5-39 and Figure 5-17. A sediment trap standard detail is provided in Appendix C.

5.14.1.2 Benefits

Sediment trap installation includes the following benefits:

- Improves function and longevity of other BMP components.
- Simple to construct and retrofit.
- Low construction costs.
- Low likelihood of failure.
- Relatively low maintenance costs.

5.14.1.3 Application

Sediment traps should be used at a BMP inflow location. They should be designed to allow water to pool momentarily allowing course sediment to drop out of stormwater runoff before continuing to the downstream BMP component(s).

5.14.1.4 Maintenance

Sediment traps, by design, are meant to collect sediment and other debris; and therefore, sediment traps should be maintained routinely. This includes removing blockages and accumulated sediment. Sediment trap apron, slopes, and edges should be routinely checked for erosion and repaired as needed. In some cases, if rock check dams are implemented for the purpose of trapping sediment, simply removing and replacing the same check dam rocks to clean out sediment may be an easier option during maintenance.

Photograph 5-39. Sediment trap at roadway curb cut.
(Author & Source: NACTO)

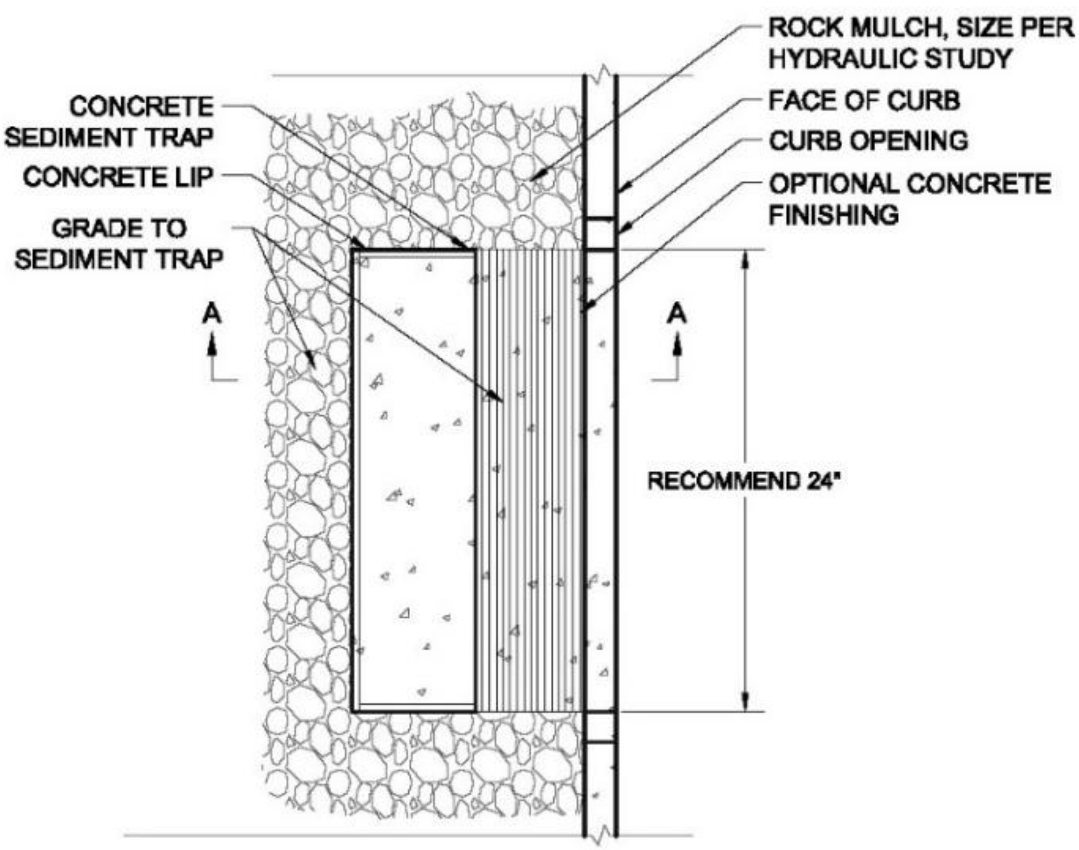


Figure 5-17 Sediment Trap Plan View Example

5.14.2 Swale

5.14.2.1 Description

Similar to bioswales in Section 5.2, pretreatment swales are open shallow channels that may have trees, grasses, and other low-lying vegetation covering the swale bottom and side slopes, with pervious surface plating materials such as decomposed granite, larger rock, and/or mulch. The difference is that pretreatment swales are designed to capture sediments and debris to reduce maintenance on downstream BMP component(s). They purposely exclude the enhanced infiltration/filtration components typical of bioswales to facilitate the ease of maintenance.

The pretreatment swale should be designed to slow stormwater runoff enough to dissipate enough runoff energy for sediment to drop out. This can be done with vegetation or check dams as long as maintenance is easily accessible. Like bioswales, pretreatment swales can be built in a naturalistic or in an urban context.

Because of their similarity to bioswales, examples of pretreatment swales are shown in Photograph 5-1, Photograph 5-2, and Figure 5-2. A bioswale standard detail is provided in Appendix C.

5.14.2.2 Benefits

Pretreatment swale installation includes the following benefits:

- Improves function and longevity of other BMP components.
- Provides an attractive asset to the landscape.
- Enhances the landscape plantings.
- Simple to construct and retrofit.
- Low construction costs.
- Relatively low maintenance costs.

5.14.2.3 Application

Pretreatment swales, like bioswales, can be used along roadways, pathways, or linear areas with adequate topography to allow water to be directed and consolidated into a channel. Swales can vary in length depending on the site conditions or potential sediment loading. Check dams (Section 5.3) are recommended to trap sediment for ease of maintenance or if the density of vegetation is insufficient.

5.14.2.4 Maintenance

Pretreatment swales are designed to collect sediment and other debris; and therefore, pretreatment swales should be maintained routinely. This includes removing blockages and accumulated sediment. Swale bottom, side slopes, and check dams (if used) should be routinely checked for erosion and repaired or replaced as needed. In some cases, if rock check dams are implemented for the purposes of trapping sediment, simply removing and replacing the same check dam rocks to clean out sediment may be a relatively easy option during maintenance.

5.14.3 Modified Catch Basin

5.14.3.1 Description

Where space is limited or a sediment trap (Section 5.14.1) is infeasible, a standard catch basin can be modified to capture sediment, debris, and other pollutants that pose a considerable threat to downstream BMP components. The threat of clogging or loss of function are especially high for underground storage systems (Section 5.11) where maintenance can be a challenge. Catch basin modifications include a deep sump with storage for the accumulation of sediment and a hood or inverted pipe elbow to minimize floatables into the downstream components. Depending on the site conditions, the bottom of the catch basin can remain impervious and converted to drain water into the surrounding soils. A sediment trap can be installed in parking lots, street gutters, and in the flow line of inverted crown streets where stormwater flow concentrate.

Modified catch basin examples are shown in Figure 5-18 and Figure 5-19. A modified catch basin standard detail is provided in Appendix C.

5.14.3.2 Benefits

Modified catch basin installation includes the following benefits:

- Improves function and longevity of other BMP components.
- Can be placed in locations with vehicular traffic.
- Capitalizes on inverted crown roadway geometry.
- Utilizes existing standard details familiar with contractors.
- Simple to construct and retrofit.
- Low construction costs.
- Low likelihood of failure.
- Relatively low maintenance costs.

5.14.3.3 Application

Modified catch basins should be used at a BMP inflow location. To maintain stability for traffic loading and public safety standards, the modified catch basin may generally adhere to the Maricopa Association of Governments (MAG) Standard Details 535 and 537. Modifications should be limited to placement of the outlet pipe, depth of the sump, and removal (or partial removal) of the catch basin floor. The outlet pipe should positively drain to the downstream BMP to prevent backup and clogging within the pipe itself.

5.14.3.4 Maintenance

Modified catch basins are designed to collect sediment and other debris; and therefore, modified catch basins should be maintained routinely and after runoff-producing storm events. This includes removal of accumulated sediment and debris from the sump. Routine maintenance includes vacuuming sediment and water (if the floor is solid) from the sump and removing any debris blockages from the outlet pipe.

Image: University of NH Stormwater Center

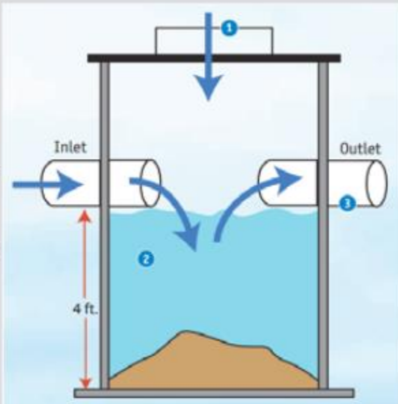


Figure 5-1. Simple modified catch basin

Deep Sump Catch Basin Operation Steps:

- Runoff flows into the deep sump catch basin typically through an inlet or surface grate on the street (1) and drops into the sump (2).
- The sump provides a deep collection area (2) between the incoming flow (1) and outgoing flow (3), which allows coarse sediments and trash to drop out of suspension. Trash grates, hoods (4), or filter skirts can enhance performance by preventing floatables from entering outflow pipes.
- Outgoing flows (3) continue to a centralized drainage network or can be designed to discharge to a surface or subsurface green infrastructure practice.

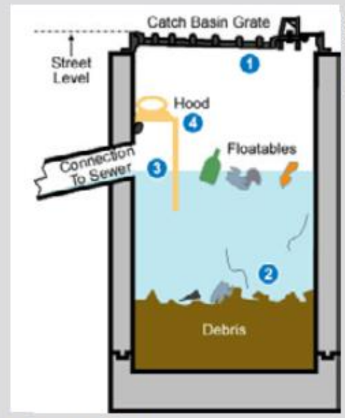


Image: USEPA

Figure 5-2. Hooded catch basin

Figure 5-18. Modified catch basin schematics.
(Author: EPA/Tetra Tech, Inc., Source: Green Streets Handbook)

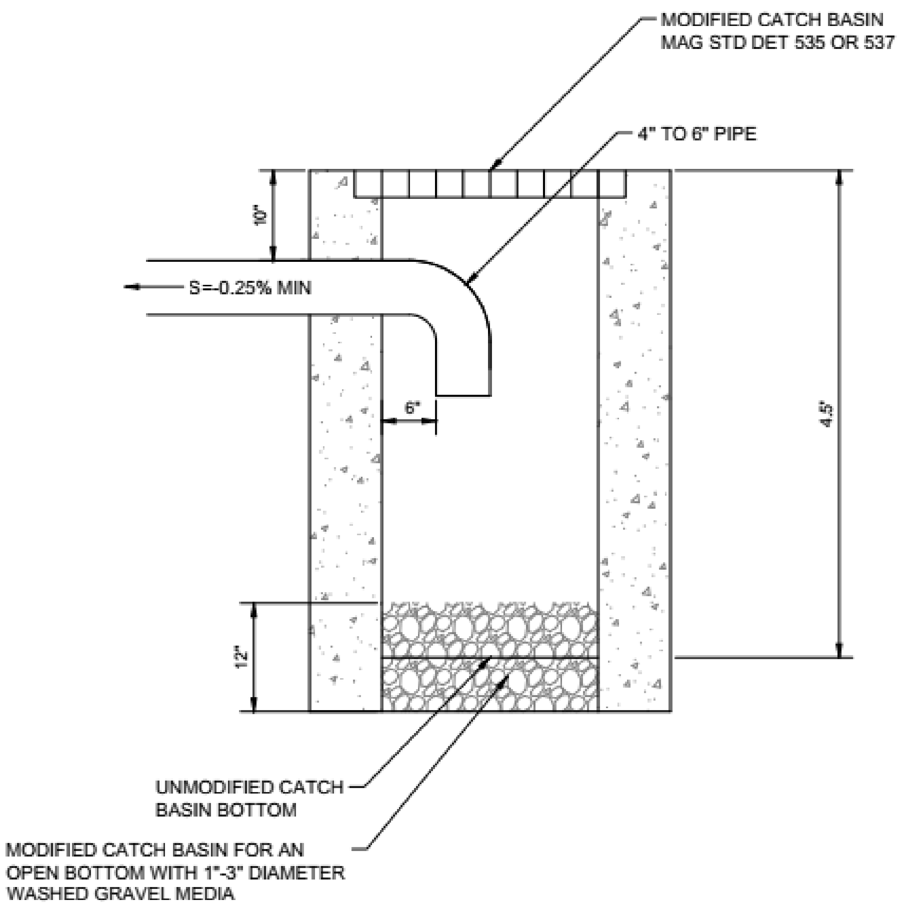


Figure 5-19. Modified catch basin example with inverted pipe elbow.

5.14.4 Flow-Through Structures

5.14.4.1 Description

Flow-through structures are typically self-contained, proprietary systems that improve water quality through the removal of coarse sediments, floatables, oil, and grit from runoff. They differ from modified catch basins through increased pollutant removal efficiency, their scalability and relative ease of maintenance. They are used where space is limited, modified catch basins may be insufficient, and the threat of clogging or loss of function are especially high for downstream underground BMP components. Flow-through structures vary in their approach to pollutant removal, where some function like modified catch basins while others use vortex actions to separate sediment and debris. Site conditions may define the type of flow-through structure, often driven by hydraulic head and the ability to move stormwater through the system. They are usually subsurface structures that can be placed in parking lots, streets or other areas where vehicular traffic exists. Variations of flow-through structure systems may or may not include options with integrated inlets.

Flow-through structure examples are shown in Figure 5-20 and Figure 5-21. Standard details for example flow-through structures can be found on Contech Engineered Solutions website (https://www.conteches.com/).

5.14.4.2 Benefits

Flow-through structure installation includes the following benefits:

- Improves function and longevity of other BMP components.
- Can be placed in locations with vehicular traffic.
- Efficient and effective sediment removal.
- Scalable and flexible for many hydraulic scenarios.
- Relatively simple to install and retrofit.
- Low likelihood of failure.
- Low maintenance costs.

5.14.4.3 Application

Flow-through structures should be used at a BMP inflow location. These structures are typically proprietary, prefabricated offsite, and installed onsite as a single unit. Assembly of multiple components may be required for larger systems. Since the types of structures vary and installation may be different between systems, correct application should refer to the manufacture's recommendations.

5.14.4.4 Maintenance

Flow-through structures are designed to collect sediment and other debris; and therefore, flow-through structures should be maintained routinely and after runoff-producing storm events. Typically, this involves removal of accumulated sediment and debris from the sump through vacuuming. Proper maintenance should adhere to manufacture's recommendations for each of the respective systems.

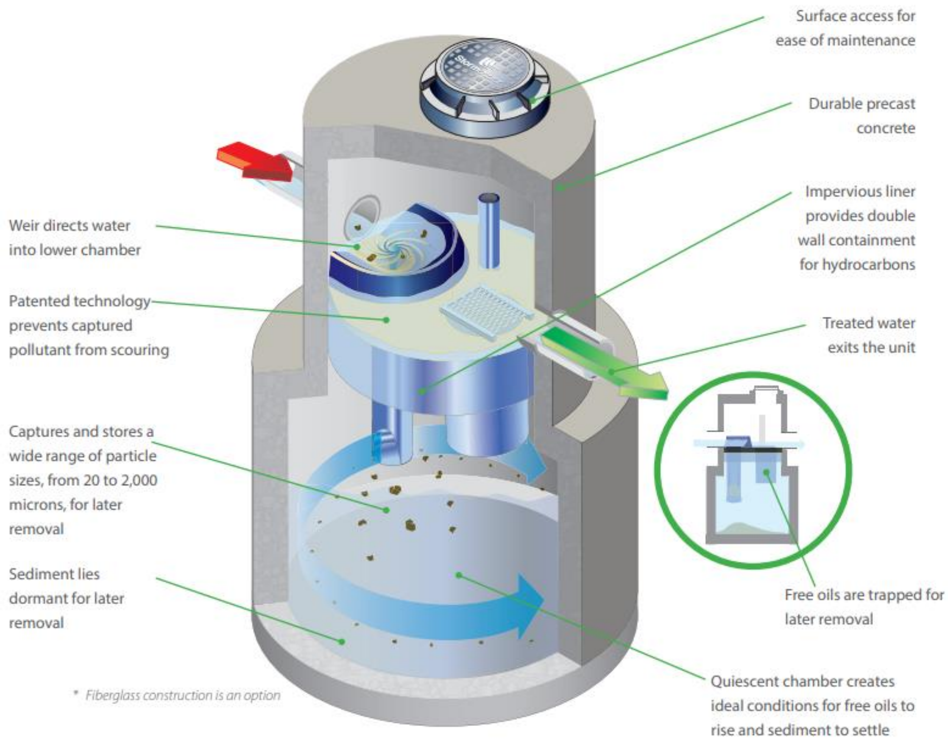


Figure 5-20. Flow-through structure example – Stormceptor® STC.
(Source: Contech Engineered Solutions)

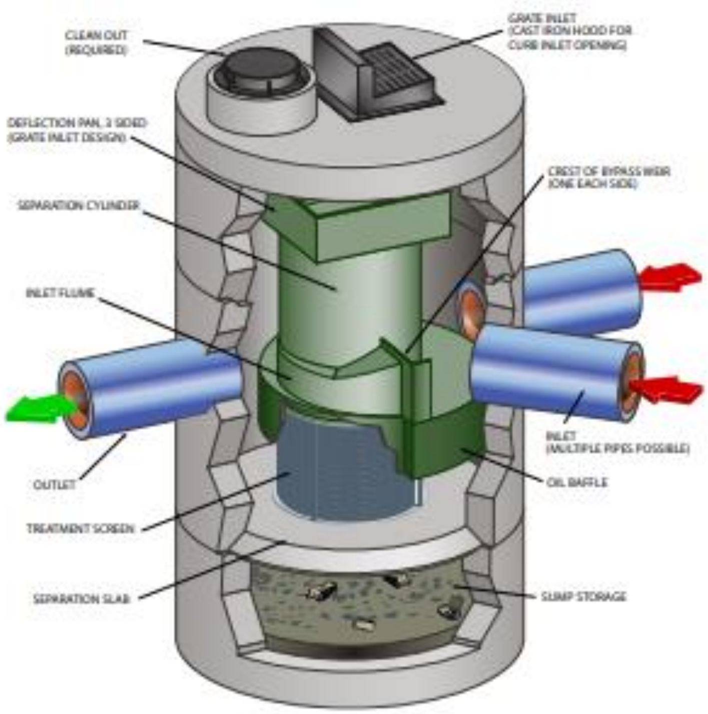


Figure 5-21. Flow-through structure example – CDS® Unit.
(Source: Contech Engineered Solutions)

6 RETHINKING COST-BENEFIT ANALYSIS

6.1 Cost-Benefit Analysis

A cost-benefit analysis is a process to quantify the benefits of a decision or action and compare against the costs associated with that decision or action. Because LID is multi-beneficial, it provides multiple layers of "value" over a typical traditional, single-purpose project (i.e., solely flood risk reduction). Therefore, traditional cost-benefit analyses, like only considering structural losses, will not fully capture all of the benefits a LID project will offer.

Simply comparing construction costs alone between LID infrastructure and traditional single purpose, grey infrastructure will not yield an accurate comparison. The *social*, *economic*, and *environmental* benefits must be estimated for a robust and all-encompassing cost-benefit analysis. Often, LID projects create significantly more value over traditional grey infrastructure projects when these additional benefits are valued. For example, in the City of Tucson's *Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area*, the benefits of implementing Green Stormwater Infrastructure (GSI) were evaluated. The study concluded that for *"every dollar the community invests in a GSI fund will create 2 to 4 dollars of community benefits in return".*

The valuation of social, economic, and environmental benefits in decisions making, also known as the Triple Bottom Line (TBL) approach, is widely used, and is strongly considered for current LID decision making. Section 6.1.1 provides more detail on how TBL is used in the LID context, and lists example parameters.

The Community Image concept (Section 6.1.2) is a valuation process that is broader in scope than TBL and is useful for community-level planning. Green infrastructure is just a single component in the overall "community image" (how a community sees itself and how it is seen by others). Successful urban design creates a positive community image (balance of green infrastructure, water systems, transportation systems, and architecture), and increases a community's market value.

The Project Design Dividends matrix (Section 6.1.3) is an urban design-focused value measuring tool, useful for the project-level scale of design. The matrix includes the traditional TBL value categories (social, economic, and environmental), and adds an additional value - *visual*. Each value has prescribed indicators, and each receives points. The matrix is a great resource for measuring value benefits, and for prescribing a value benefits checklist requested of developments.

For more information on TBL, Project Design Dividends, and Community Image, see *Urban Design and the Bottom Line: Optimizing the Return on Perception* (2008) by Dennis Jerke, ASLA.

6.1.1 The Triple Bottom Line

The Triple Bottom Line (TBL) is a cost-benefit accounting framework that incorporates three dimensions of performance: social, economic, and environmental. This differs from a basic cost-benefit reporting framework because it captures environmental and social components of value, which typically requires an additional effort to measure beyond simple economic costing. Measuring the value of LID components requires a TBL valuation, at the very least, to be comparable to grey infrastructure. Many social and environmental values of LID outpace the upfront economic costs. The same value system is often interchanged with "People, Planet, Profit", or the "3Ps". As illustrated in Figure 6-1, a project can only be defined as sustainable/successful if there is a balance between all three components.

When performing a TBL cost-benefit analysis, a dollar value is placed on benefits not typically considered. For example, a future downtown Lake Havasu City multi-transit, pedestrian-centric downtown streetscape redesign can list values such as reduced cooling bills due to additional tree canopy shading, increased downtown tourism dollars, decreased street maintenance due to LID sediment control, increased retail revenue due to increased residency time of downtown patrons, etc. If this same design used a basic analysis, other than TBL, only a high initial capital cost would be captured against direct immediate benefits, making it a less competitive option when compared to a lower grey infrastructure cost.

Parameters considered in a TBL cost-benefit analysis include, but may not be limited to, the following:

- Construction costs
- Annual maintenance costs
- Flood risk reduction
- Water quality improvement
- Impacts to irrigation
- Heat island impact
- Property value uplift

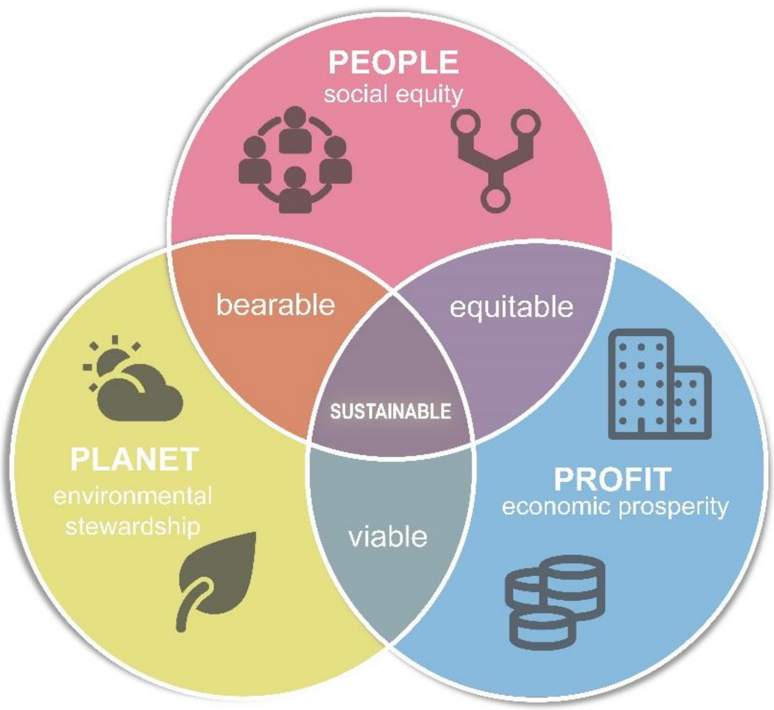


Figure 6-1. Triple Bottom Line Overview

6.1.2 Community Image

The concept of a "Community Image" is useful for zooming out from a TBL approach to a larger urban design level. The image of the community is how the community sees itself, and how it is seen by others outside the community. LID (Green Infrastructure in this case) is just one of four "image systems" – which includes Green Infrastructure, Water Systems, Transportation Systems, and Architecture. High community image projects increase both community value and connectivity, which in turn makes the community more competitive in the marketplace.

For example, a future downtown Lake Havasu City multi-transit, pedestrian-centric downtown streetscape redesign can simply include LID BMP features. However, maximizing the community image might require that BMPs pair with new architectural developments to interact with the landscape, landscape architecture and architecture that reinforces the importance of water in the desert city, and alternative transportation systems that connect people from downtown across the city.

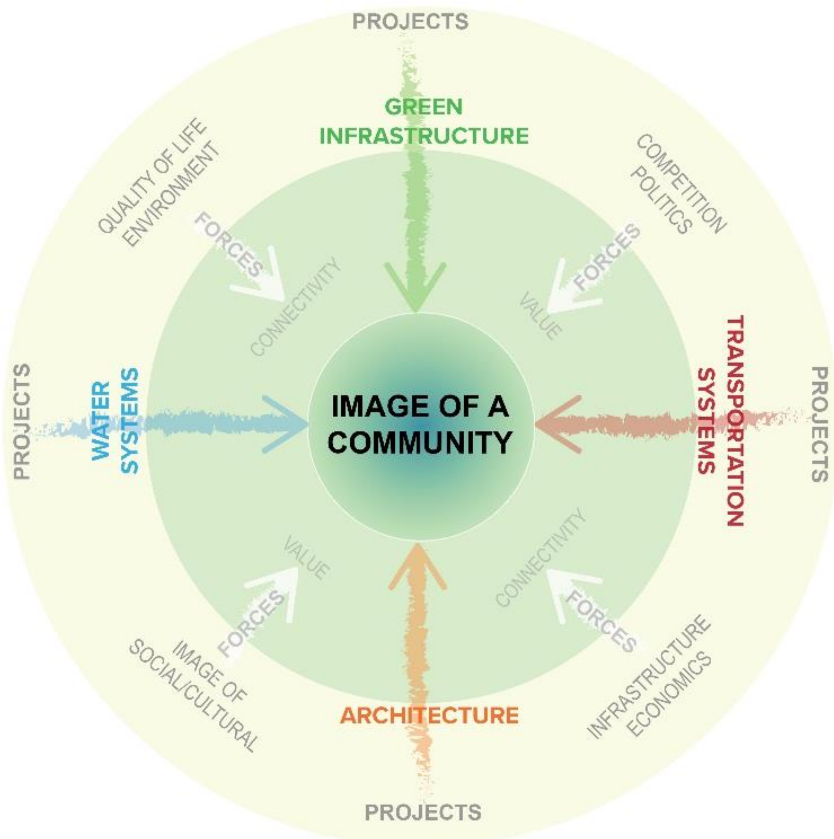


Figure 6-2. The Four Keys of Community Systems.

6.1.3 Project Design Dividends

Project design dividends can be measured using a Design Dividends Matrix. The values are similar to those of a TBL valuation but include a visual category similar to those of the Community Image. The four design value categories include *economic value*, *social & cultural value*, *environmental value*, and *visual value*. For the matrix, each value category is assigned a list of potential benefits, which are then measured through a point system (indicators). The overall score gives the value generated for any specific project. The matrix can be used as a general framework for measuring LID project image rating success. The list of potential benefits and point indicators will change for each specific project, based on community needs and stakeholder feedback. Figure 6-3 is an example of a compiled matrix with a design score for each value.

Figure 6-3. Design Dividends Matrix

6.1.4 Summary

The benefits of LID are diverse, multi-faceted, and long-term and require a wider perspective to fully evaluate the costs of initial implementation. An LID approach may not favorably compare to a grey infrastructure approach on a pure immediate benefit basis, but due to its single purpose nature, grey infrastructure elements are unlikely to capture additional benefits beyond installation. LID approaches provide multiple benefits and are cost competitive when one accounts for those additional benefits. In this chapter we have provided several methods to assess the value of an LID element - the Triple Bottom Line method, the Community Image method, and the Project Dividends method. Each is different and span a range of scales, but all are valid approaches to fully assess the full range of LID benefits.

7 Implementation Strategies

As discussed in Section 1.2, the purpose of the *LID Master Plan* is to provide Lake Havasu City staff, residents, business owners, the development community, engineers, designers, landscape architects, and contractors proper guidance, specifications, standards, details, and direction for strategic implementation of LID BMPs, which can be implemented throughout the City to promote flood reduction, water conservation, and water quality. The *LID Master Plan* is a planning-level document that can be used to advance the City's future master planning efforts by promoting resilient community development. LID falls under the purview of multiple City Departments, such as: Public Works, Parks & Recreation, and Development Services; therefore, to effectively maximize LID benefits, LID implementation should be planned and managed in a proactive, integrative way across numerous City departments.

This section provides a roadmap for action and outlines what can be done to move the *LID Master Plan* forward. Implementation strategies include adherence and adoption of LID policies, development of LID programs, and identification of future LID projects. Furthermore, this section is useful in guiding the City when setting priorities, allocating finances, and assessing achievements. Ultimately, the *LID Master Plan* should translate to specific actions.

When implementing LID strategies within a watershed, it is important to plan in an upstream-to-downstream manner before runoff turns into flooding and pollutants reach hazardous concentrations. Basically, LID should be placed in effort to prevent the identified issue or degradation before it even occurs. Therefore, implementation of LID BMPs should start in upper watershed areas and work downstream as needed, until the desired outcome is met.

7.1 Adherence to Existing Policies and Recommended New Policies

Lake Havasu City is a proactive stormwater management community, with sustainability of natural resources a primary focus. Successful implementation of the *LID Master Plan* may be achieved through adherence to existing City policies, as well as consideration and adoption of new City policies.

7.1.1 Existing City Policies

7.1.1.1 Lake Havasu City 2016 General Plan

The *Lake Havasu City 2016 General Plan* is a "*long-range plan to guide the future growth of the community.*" Arizona Revised Statues requires the City to adopt the *Lake Havasu City 2016 General Plan (General Plan),* which is the principal guide to physical development. According to the *General Plan*, the purpose of the document is to:

- Express Community's vision.
- Identify the Community's goals and development priorities.
- Serve as a policy guide for local decision-making.
- Fulfill legal requirements created by state law.

The 2016 *General Plan* can be viewed and obtained from the City's website (http://www.lhcaz.gov/docs/default-source/department-documents/generalPlan2016.pdf?sfvrsn=e5b307c_35).

The *General Plan* puts forward guiding principles, goals, and policies as it relates to growth and future development. *General Plan* guiding principles, goals and policies associated with Growth Management (GM), as they relate to implementation of the *LID Mater Plan*, include the following:

Guiding Principle GM.2: Conservation of the City's Diverse Natural Resources.

- ✓ ***Goal GM.2.1: Protect and preserve natural features and environmentally sensitive areas with the planning area.***
  - ***GM.2.1.a – Washes and Floodplains:*** *Protect major natural washes and floodplains to minimize flood hazards, maintain natura/riparian areas for wildlife migration, and provide natural groundwater recharge of the aquifer.*
  - ***GM.2.1.c – Protecting Native Habitats:*** *Encourage the preservation of indigenous vegetation and riparian habitats as part of larger planned development, where possible. Evaluate the impact of new development on special-status or endangered flora and fauna species.*
  - ***GM.2.1.d – Environmental Protection Areas:*** *Protect wildlife habitat and corridors by avoiding sensitive natural features, such as wetlands, riparian areas, sensitive plant and animal sites, and migration corridors. When it is not possible to avoid these natural areas, sensitive areas shall be protected by using innovative planning, design, buffering, and management practices.*
- ✓ ***Goal GM.2.2: Implementation activities and actions that maintain lake and groundwater quality to meet state standards.***
  - ***GM.2.2.c – Best Management Practices:*** *Encourage the use of Stormwater Best Management Practices for addressing nonpoint pollution, such as stormwater retention or on-site water treatment technologies, and other techniques to minimize sediment and other pollutant runoff into the area's waters.*
  - ***GM.2.2.d – Responsible Grading:*** *Encourage the use of grading practices that minimize soil disturbance to ensure that they do not contribute to flooding and erosion.*
  - ***GM.2.2.e – Landscape Materials:*** *Promote use of native landscape plants that require minimal use of pesticides and fertilizers. Encourage use of organic pesticides and fertilizers in existing turf areas to reduce impact on area groundwater and the Lake.*

Guiding Principle GM.3: Reduced Water and Energy Consumption

- ✓ ***Goal GM.3.1: Ensure that the implementation of the General Plan does not negatively impact the supply of Lake Havasu City's water resources.***
  - ***GM.3.1.a – Water Conservation:*** *Implement the water conservation strategies outlined in Lake Havasu City's Water Conservation Plan. As part of the plan's implementation, maintain an aggressive water conservation program that will maximize current resources.*

- ***GM.3.1.b – Drought Tolerant Landscaping:*** *Encourage the use of drought tolerant trees and native vegetation for landscaping, and irrigation systems that can be tailored to meet the needs of varied landscape materials, to reduce water consumption.*
- ***GM.3.1.c – Public Education and Outreach:*** *Increase awareness of the City's historical water-per-capita consumption rate, its target for the future, and the range of ways households and business can increase their conservation efforts.*

✓ ***Goal GM.3.2: Promote the use of environmentally-friendly development practices.***

- ***GM.3.2.a – New Construction and Rehabilitation:*** *Support reduced water and energy consumption in new construction and the rehabilitation of existing development through the use of low-flow plumbing fixtures, orienting new streets and building to optimize solar access, encouraging the use of solar energy systems, and other innovative techniques.*
- ***GM.3.2.b – Municipal Buildings and Facilities:*** *Continue to demonstrate leadership in energy [natural resources] conservation through City projects and purchases.*

7.1.1.2 Lake Havasu City Water Conservation Plan

The *Lake Havasu City Water Conservation Plan* provides information and policy goals associated with conservation of the City's most critical resource – water. As discussed in Section 1.6.2, the City understands that "W*ith drought conditions remaining relatively unscathed in the last two decades, future water supply availability is more uncertain than ever*." Furthermore, the City recognizes that "*Even small reductions in consumption spread out over such a large user base can potentially realize significant savings."* Various five-year policy goals identified in the *Water Conservation Plan*, as they pertain to implementation of the *LID Master Plan*, include the following:

- Continued decrease of Lake Havasu City's per capita water consumption.
- Increased water conservation education and outreach.
- Increased conversion of potable water irrigation to effluent water [stormwater] irrigation.
- Continue a program to install or give incentives to install rainwater harvesting systems on City, school, and commercial roofs and parking lots adjacent to irrigable landscaping.

7.1.2 Recommended New City Policies

7.1.2.1 *Plan Tucson* Recommended Policies

Within Arizona, the City of Tucson (Tucson) is considered a leader in LID planning and implementation. A guiding policy document related to Tucson's Green Stormwater Infrastructure (GSI) is the *Plan Tucson: City of Tucson General and Sustainability Plan 2013* (*Plan Tucson*). *Plan Tucson* is a long-range (10-year) planning document intended to guide decisions affecting elements that shape Tucson, such as housing, jobs, land use, transportation, and water and energy resources. *Plan Tucson* offers goals and policies that provide a framework to guide future actions with the understanding that how Tucson has grown in the past will not necessarily work in the future. *Plan Tucson* policies addressing GSI, which are recommended for consideration and adoption by Lake Havasu City, are listed below in Table 7-1. It should be noted that in general, Green Stormwater Infrastructure (GSI) is synonymous with Low Impact Development (LID).

Table 7-1. *Plan Tucson* policies recommended for consideration and adoption by Lake Havasu City.

Water Resources
Expand the use of alternative sources of water for potable and non-potable uses, including rainwater, greywater, reclaimed water, effluent, and stormwater.
Ensure an adequate amount of water to meet the needs of riparian ecosystems.
Protect groundwater, surface water, and stormwater from contamination.
Integrate the use of Green Stormwater Infrastructure and Low Impact Development for stormwater management in public and private development and redevelopment projects.
Conduct ongoing drought and climate variability planning.
Energy and Climate Readiness
Reduce the urban heat island effect by minimizing heat generation and retention from the built environment using a range of strategies.
Assess and address the vulnerability of the community's health and safety, economy, and natural resources to climate change, and develop assurances that vulnerable and disadvantaged populations are not disproportionately impacted by climate change.
Green Stormwater Infrastructure/Low Impact Development
Encourage GSI and LID techniques for stormwater management in public and private new development and redevelopment, and in roadway projects.
Rehabilitate and enhance natural drainage systems, water detention and retention basins, and other infiltration areas for multiple benefits, such as recreation, wildlife habitat, and stormwater management.
Expand and maintain a healthy, drought-tolerant, low-water-use tree canopy and urban forest to provide ecosystem services, mitigate the urban heat island, and improve the attractiveness of neighborhoods and the city as a whole.
Create, preserve, and manage biologically rich, connected open space; wildlife and plant habitat; and wildlife corridors, including natural washes and pockets of native vegetation, while working to eradicate invasive species.
Protect, restore, enhance, and manage trees for their long-term health, including providing guidance on proper planting, care, and maintenance.
Land Use, Transportation, and Urban Design
Support urban agriculture and GSI opportunities in new development or redevelopment when appropriate.
Design and retrofit streets and other rights-of-way to include GSI and water harvesting, complement the surrounding context, and offer multi-modal transportation choices that are convenient, attractive, safe, and health.

Public Safety Policy
Reduce potential harm to life and property in natural hazard areas and from hazards resulting from human activities and development through preventive measures.
Public Health
Support streetscape and roadway design that incorporates features that provide healthy, attractive environments to encourage more physical activity.

Plan Tucson can be viewed and obtained from the City of Tucson's website (https://www.tucsonaz.gov/pdsd/plan-tucson).

7.1.2.2 Revision to City's Current Stormwater Management Permitting, Policies, and Procedures

According to the *Lake Havasu City Stormwater Management Program: Development & Permitting, Policies & Procedures (Stormwater Permitting, Policies, and Procedures)*, the purpose of the document is "*to provide direction for the development community, architects, engineers, contractors and City staff to assure proper BMP's for stormwater controls are included on plan documents and proper inspections are performed with the ultimate goal of minimizing pollution from new development and redevelopment.*" At the time of this *LID Master Plan*, the City's *Stormwater Permitting, Policies, and Procedures* document has no reference to LID implementation. It is recommended that the City's current Erosion & Sediment Control Plan and Inspection Requirements include the considerations for LID implementation outlined in Table 2-1.

7.2 LID Implementation Horizons

It is recognized that implementation of the *LID Master Plan* requires planning on multiple horizons – from annual Capital Improvement Program (CIP) planning to long-range planning. *LID Master Plan* implementation horizons are depicted graphically in Figure 7-1.

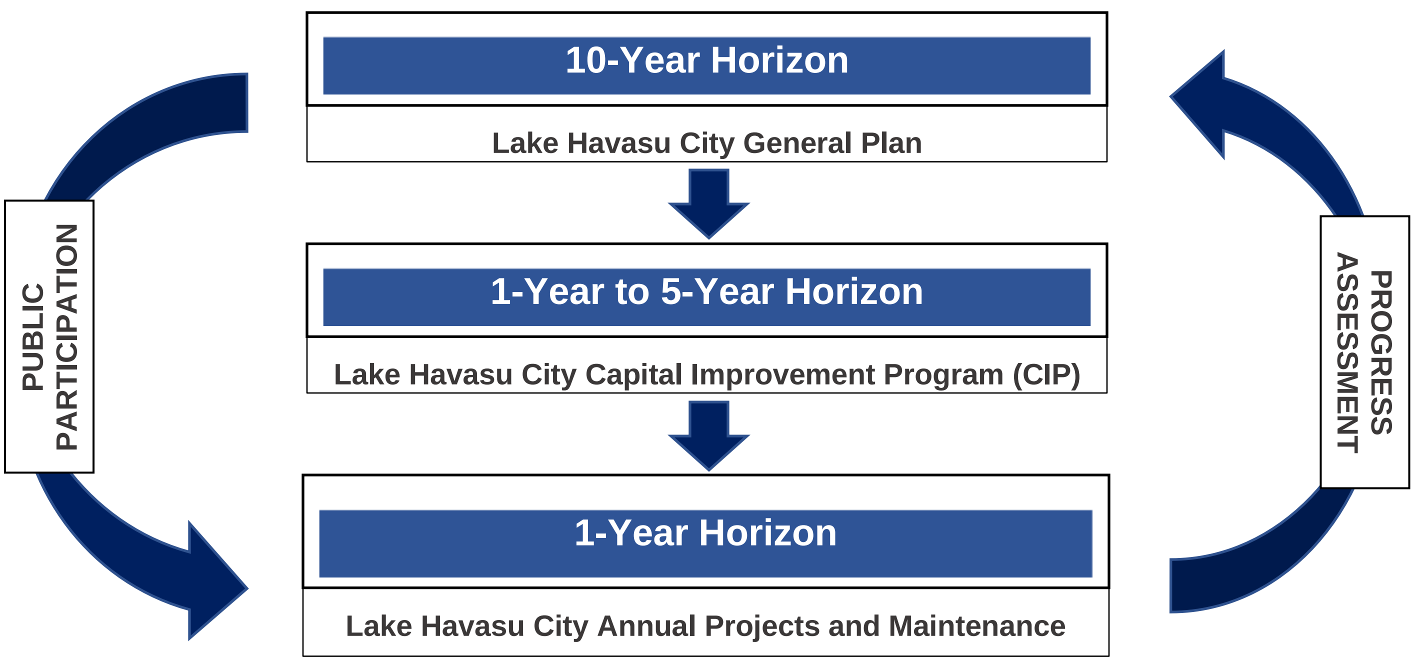


Figure 7-1. *LID Master Plan* implementation planning horizons.

7.3 Example Programs

Developing a LID Program is a key implementation strategy. An LID Program can provide creative funding solutions and aid with the City's overall sustainability master planning efforts. LID Program examples from the City of Tucson, AZ and Raleigh, NC are discussed below.

7.3.1 City of Tucson Green Stormwater Infrastructure Program

According to the City of Tucson (https://www.tucsonaz.gov/gsi), on May 1, 2020, the City of Tucson included a new Green Stormwater Infrastructure (GSI) fee on the utility services statements for residents and businesses. At an estimated cost of $1 per month for the average residential customer, it is anticipated that this GSI fee will raise about $3 million each year. The funding will be used to plan, build, and maintain GSI projects that capture urban runoff from public streets and parking lots, diverting it to water harvesting areas.

The GSI fee was developed to address two identified critical areas of need within the City of Tucson: effectively managing stormwater; and increasing tree canopy while conserving precious water resources. General goals of the GSI Program include the following:

- Provide a reliable and dedicated funding source for planning, implementing, and maintaining GSI projects.
- Address and reduce flooding issues on neighborhood streets.
- Support tree/plant growth along streets and within public areas using stormwater as the primary source of irrigation.
- Provide an affordable alternative to building and maintaining expensive underground stormwater infrastructure

An outreach example for Tucson's Green Stormwater Infrastructure Program is shown in Figure 7-2.

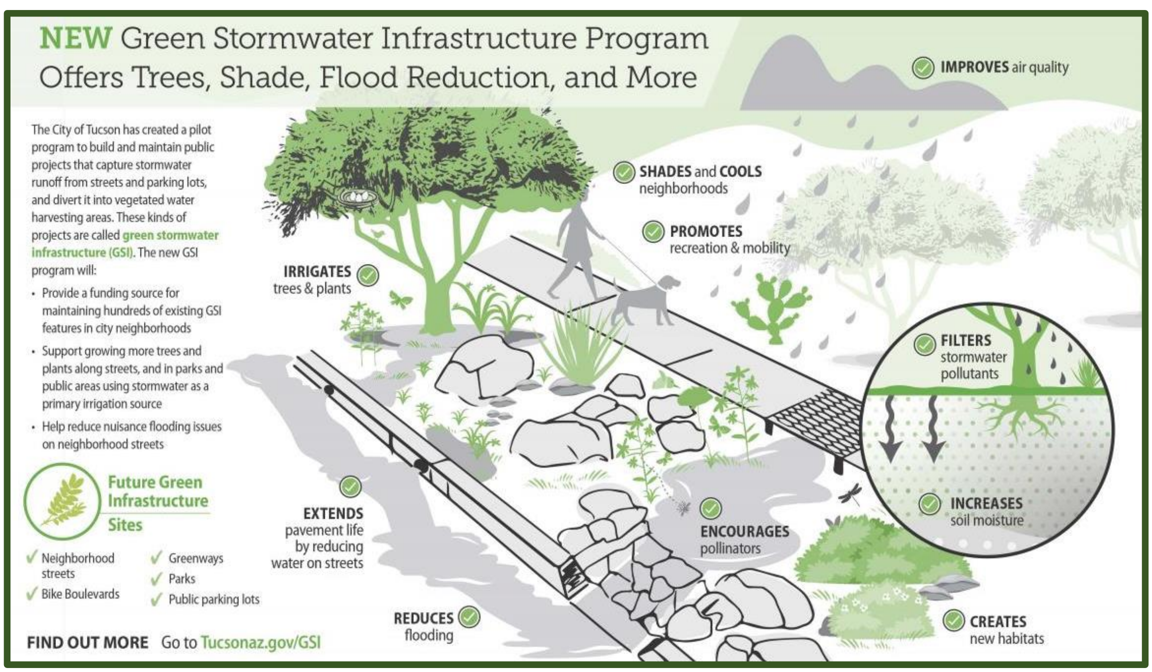


Figure 7-2. City of Tucson's Green Stormwater Infrastructure Program outreach figure.

According to the *City of Tucson Green Stormwater Infrastructure Fund Proposal* (https://www.tucsonaz.gov/files/water/GSI_Proposal_Final.PDF), the City's GSI Program will provide multiple secondary environmental, economic, and community benefits, which include the following:

- Stormwater flows would be directed away from natural water courses, which would reduce localized flooding, improve emergency vehicle access, and reduce property damage.
- The quality of water that is collected and conveyed in the stormwater system would be improved (water quality BMPs can be incorporated into GSI design).
- Increased vegetation and tree canopy would improve air quality removing pollutants from the air.
- Increased vegetation and tree canopy would also provide more shade and reduce building energy demands, particularly during the summer.
- Urban communities would be revitalized by providing neighborhood beautification and much-needed green space for recreation, increasing the value of adjacent properties, and providing wildlife habitat.
- GSI could be designed to improve pedestrian safety through traffic calming. GSI could also be designed to contribute to the revitalization of historic streets and strengthen the community by providing jobs and training to residents (for example, construction, nurseries, maintenance).
- The increased vegetation and neighborhood beautification would help promote and support biking, walking, and transit initiatives.
- Public education opportunities would be increased.
- Implementation of GSI has the potential to create new job opportunities or sustain existing jobs, especially in the operation and maintenance fields for workers who may otherwise be unemployed or underemployed. This could be particularly important for socially and economically disadvantaged neighborhoods within the City.
- The natural hydrologic function of urban areas would be restored, urban watershed management will be improved, and precipitation can be treated as a resource rather than waste, especially in shallow groundwater areas.

The GSI Program's annual budget is intended to cover costs for a GSI Manager, GSI supporting staff, an Outreach Coordinator, GSI maintenance of existing facilities, and GSI projects identified in the City's Capital Improvement Program.

The GSI Program includes annual measurements and reporting to track number of projects, costs, number of trees planted, stormwater capture volumes, and changes in impervious area. A key GSI Program metric is "Greened Acres", which accounts for conversion of highly impervious landscape through the implementation of GSI projects.

7.3.2 City of Raleigh Green Stormwater Infrastructure Advancement Plan

At the directive of the City of Raleigh (North Carolina) City Council, the Raleigh Stormwater Management Advisory Commission prepared the *Plan for Continuing to Advance the Use of Green Stormwater Infrastructure (GSI) Practices in Raleigh*, here within referred to as the *Raleigh GSI Plan* (https://go.boarddocs.com/nc/raleigh/Board.nsf/files/C49JWM4F2F63/$file/20210706CCOReportRecommendofSMACAdvancingGSI.pdf). In part, the *Raleigh GSI Plan* (June 2021) was prepared in response to the private development community's lack of interest, skepticism, and unfamiliarity with GSI. To counter the sentiments expressed by developers, the City of Raleigh made the decision to "lead by example" and adopt the following City Action Items:

City Action #1: Lead by example by adopting and implementing a formal City policy that requires evaluation of GSI on the City's development and improvement projects.

City Action #2: Provide information, support, recognition, and incentives to private developers and their designers for incorporating GSI into their development projects.

City Action #3: Increase awareness of potential benefits of using GSI in redevelopment and new development as conditions in the City's cases for property rezoning.

City Action #4: Address potential benefits of GSI in the City's templates of plans for roadway corridors, neighborhoods, and parks and routinely address GSI in these types of plans and reports.

City Action #5: Assess the Unified Development Ordinance GSI text changes adopted in 2017 for benefits realized and opportunities for improvements.

City Action #6: Continue to implement and build the program for inspecting and maintaining City-owned stormwater control measures, which includes GSI practices.

City of Raleigh's GSI action items, policies and evaluation guidelines are included with the *Raleigh GSI Plan*. Core water conservation and water quality goals outlined as part of the *Raleigh GSI Plan* include "*keeping and treating rainfall on-site or as close to site as much as possible, thereby mimicking the flow of water in a natural setting and reducing non-point source pollution form stormwater run-off; increasing water conservation measures and reducing overall demand for water; minimizing soil erosion and sedimentation; reducing hazardous and damaging flooding; and reducing nutrient loads.*"

Various City of Raleigh GSI policies and actions (see provided *Raleigh GSI* Plan) recommended for consideration by Lake Havasu City include the following:

Policy EP 3.4 Low Impact Systems for Parking: Well-maintained permeable pavement and other low impact systems for parking areas should be encouraged throughout the city, especially in environmentally sensitive areas and floodplains.

Policy EP 3.8 Low Impact Development: Promote the use of LID techniques to help mitigate the impact of stormwater runoff.

Policy EP 3.18 Green Infrastructure: Continue to improve surface water quality and protect water resources through the design, construction, and installation of Green Infrastructure (GI) for City projects and facilities. Green Infrastructure uses vegetation, soils, and on-natural materials to absorb and filter polluted water that would normally runoff impervious surfaces directly into a waterway. Low Impact Development (LID) incorporates many of the principles related to Green Infrastructure. Widespread use of Green Infrastructure will also better prepare the City for the effect of climate change along with managing the quality and quantity of stormwater runoff.

Action EP 3.1 Demonstration Projects: Work with other City departments, regional partners, and the local development community to promote demonstration projects with the City that use multiple water conservation measures on single sites. Incorporate Best Management Practices (BMPs), such as bioretention cells, permeable pavers, large- and small-scale rainwater harvesting, and similar innovative projects. Offer incentives, such as grants, fee waivers, expediated review, tax breaks, and/or density bonuses or transfer provisions for participating in demonstration programs.

Action EP 3.2 Incorporation of Green Infrastructure/Low Impact Development into City Code: Develop and adopt Low Impact Development (LID) and Green Infrastructure (GI) code and provisions so that rainwater is retained and absorbed on-site as an alternative to traditional approaches that include piping, channelization, and regional detention. Create templates, fact sheets, and costing estimating tools to help administer the GI/LID ordinance at development sites and within the public right-of-way. Develop incentives for GI/LID, such as stormwater utility fee credits, stormwater quality cost share, public-private partnerships, permitting incentives, and others.

7.4 Implementation of Street/Roadway LID Projects

In addition to the numerous natural washes throughout Lake Havasu City, streets/roadways serve as a primary means to collect and covey stormwater in the built environment. Some roadway flow corridors can extend for miles before discharging to a wash or to Lake Havasu, resulting in significant flow accumulation (i.e., urban-induced flood waves) that can cause erosion and property damage. In many cases, the roadway sections (inverted and W-sections) have been designed to convey larger amounts of flow to mitigate flooding and erosion with mixed results.

Despite being a substantial cause of erosion and nuisance flooding within the City, streets/roadways offer an opportunity to effectively implement LID projects. LID projects can reduce runoff volume and strategic placement of LID BMPs can help address flood waves, caused by runoff accumulation, that generate the energy that leads to erosion. In addition, many streets/roadways can provide a supply of runoff to supplement vegetation irrigation. The following sections discuss the approach to optimize LID strategic locations to minimize the number of BMPs required, as well as prioritize those locations that would have an immediate benefit for the City's maintenance staff.

7.4.1 Identification of Potential LID Locations to Reduce Roadway Flows

To identify optimal locations for the implementation of LID BMPs, a flow-based analysis of roadway conveyance was conducted for streets/roadways throughout the City. The intent of this analysis was twofold:

1. Assist with long-term LID programming and planning.
2. Provide the City with potential LID location information for use with transportation and utility planning efforts. This allows the City to synchronize LID implementation with roadway and utility improvements.

The flow-based analysis of roadway conveyance employed two-dimensional (2-D) hydrologic and hydraulic (H&H) modeling results for a 10-year, 24-hour event. The 2-D H&H modeling was conducted as part of the FEMA Risk MAP Project (see Section 1.4). The 2-D H&H modeling input/output and a Technical Support Data Notebook has been provided to the City under separate cover.

Using the 2-D H&H modeling results, roadways conveying more than 10 cfs were identified as “high conveyance roadways.” These high conveyance roadways were considered inappropriate for initial LID implementation due to the potential damage to an LID BMP caused by the relatively high flow conditions. Therefore, the focus turned to the “upstream tributary roadways” where LID implementation was more viable and could reduce flows in the downstream high conveyance roadways. Initial implementation of LID BMPs was determined to be most appropriate within upstream tributary roadways before any consideration of LID in the lower “high conveyance roadways.”

High conveyance roadways and suggested LID BMP locations within upstream tributary roadways are shown in exhibit format in Appendix D. In addition, industrial and commercial areas that area well suited for LID BMPs are identified as LID focus areas on exhibits provided in Appendix D.

7.4.2 Priority Maintenance Streets

As part of the development of the *LID Master Plan*, City staff and maintenance personnel provided input on locations that require routine, post-storm maintenance needs. Overwhelmingly, these locations were transportation-related, where sediment-laden flows within the roadway right-of-way eroded landscapes and deposited material at intersections, sumps, and sections of relatively flat roadway profile. These high priority street/roadway locations requiring routine maintenance needs are shown in exhibit format in Appendix D.

General watershed, site, and drainage similarities between the routine maintenance need locations included relatively steep terrain, highly erodible materials (often landscape materials), potential for substantial flow conveyance within street/roadway right-of-way, and no stormwater management practice or facility present to mitigate flooding or sedimentation issues. Often the street/roadway right-of-way was located within the historically natural drainageway and now served as a “channel” section conveying significant flow and sediment.

Potential LID BMPs to implement to reduce flooding, erosion and sedimentation in high priority streets/roads include the following:

- Roadway swale(s) with rock check dams to slow the flow of water and strategically “drop” sediment.
- Offline enhanced basins with sediment traps within roadway right-of-way to capture runoff volume.
- On-lot enhanced basins to capture parcel runoff volume and sediment, thereby decreasing runoff volume within roadway right-of-way.
- Minimizing hardscape with new and substantially redeveloped sites.
- Terracing and brow ditches (Section 2.5.3) when developing residential parcels.
- Use of permeable hardscapes (Section 5.8) within roadway right-of-way and adjacent parcels.
- Use of medians, traffic circles, and/or drain inlet capture and distribution systems (Section 5.7) within inverted crown section roadways.
- Installation of residential cisterns (Section 5.12) to capture rooftop runoff, thereby reducing overall runoff volume within roadway right-of-way.

The above bulleted list of LID BMPs are for consideration. Site-specific analyses should be conducted for selection of recommended LID BMPs.

The potential LID locations identified in Section 7.4.1 serve as a starting point for the implementation of LID BMPs to resolve these maintenance concerns. Due to the ongoing maintenance needs for these streets, LID implementation at these locations is considered priority over other locations identified for LID projects in the City.

8 SITE-SPECIFIC EXAMPLES OF FUTURE APPLICATIONS OF LID BMPS

Discussed below are five site-specific example applications of LID BMPs. The range of sites include urban streetscape (McCulloch Boulevard), suburban streetscape, mixed-use development (Downtown Catalyst Project), open space development (Island Ball Fields), and residential retrofit development. These site examples demonstrate how various LID BMPs presented in Section 5 are utilized, and how BMPs can be combined for increased effect. Opportunities, challenges, and proposed treatments are provided below for each example site.

8.1 Urban Streetscape Development

McCulloch Boulevard between Smoketree Avenue and past Querio Drive represents the urban streetscape development (see Figure 8-1). This area is a section of the heart of downtown Lake Havasu City and presents many physical constraints, such as existing aboveground and belowground utilities, the need to accommodate vehicular and pedestrian circulation, and the need to provide vehicle parking. LID BMPs can function within these constraints, while enhancing public space and mitigating flood risk, thereby maximizing the triple bottom line benefits of the revitalizing downtown.

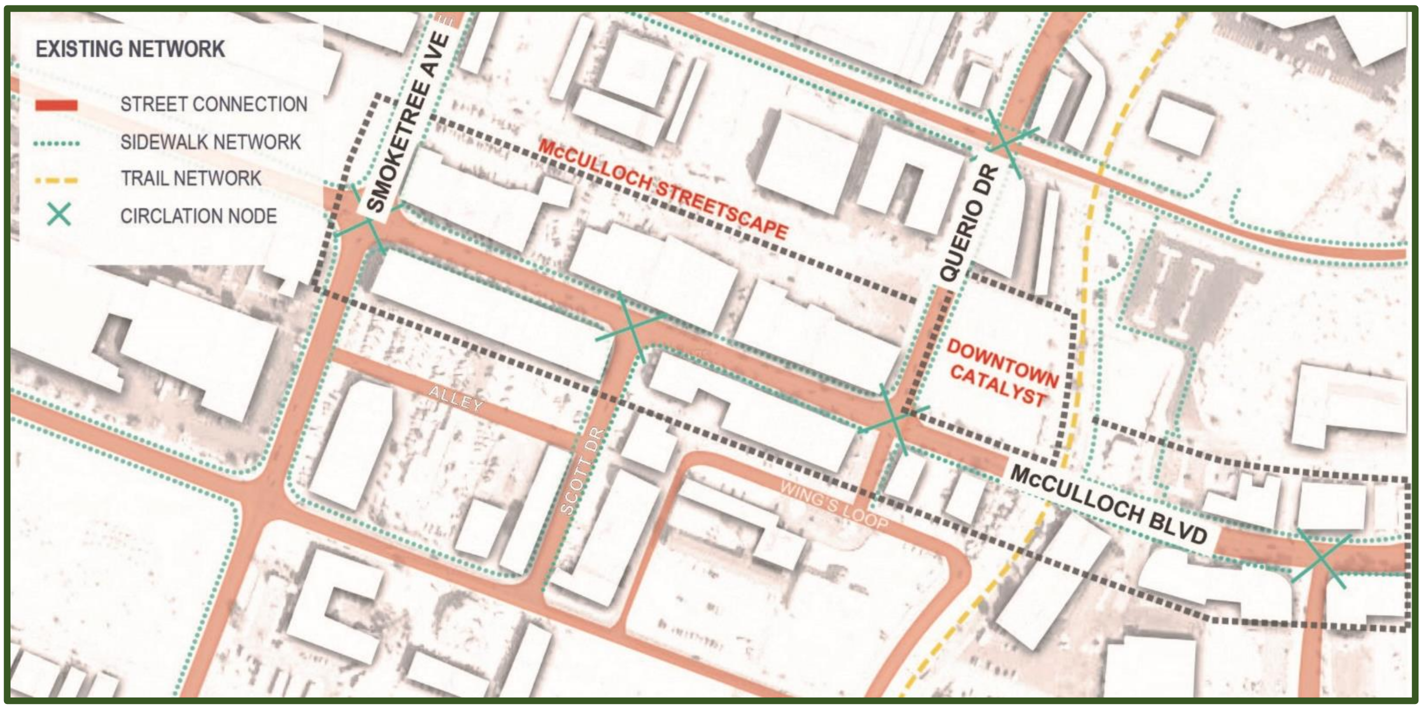


Figure 8-1 McCulloch Boulevard and Downtown Catalyst Project locations.

8.1.1 Opportunities

- Highly trafficked location can maximize interaction with the public, who will view the BMPs.
- Potential for high return on investment.
- Treating stormwater as a resource not a nuisance will enhance planted landscapes.
- Unique opportunity to present a strong sense of place to visitors.

8.1.2 Challenges

- Excessive runoff which can create flooding.
- Excessive sediment buildup and maintenance.
- Excessive impermeable surfacing.
- Excessive urban heat island.
- Lack of shade.
- Lack of usable outdoor public space.
- Lack of landscape area and native plant health.
- Lack of pedestrian safety.

Figure 8-2 McCulloch Blvd Challenges – street.

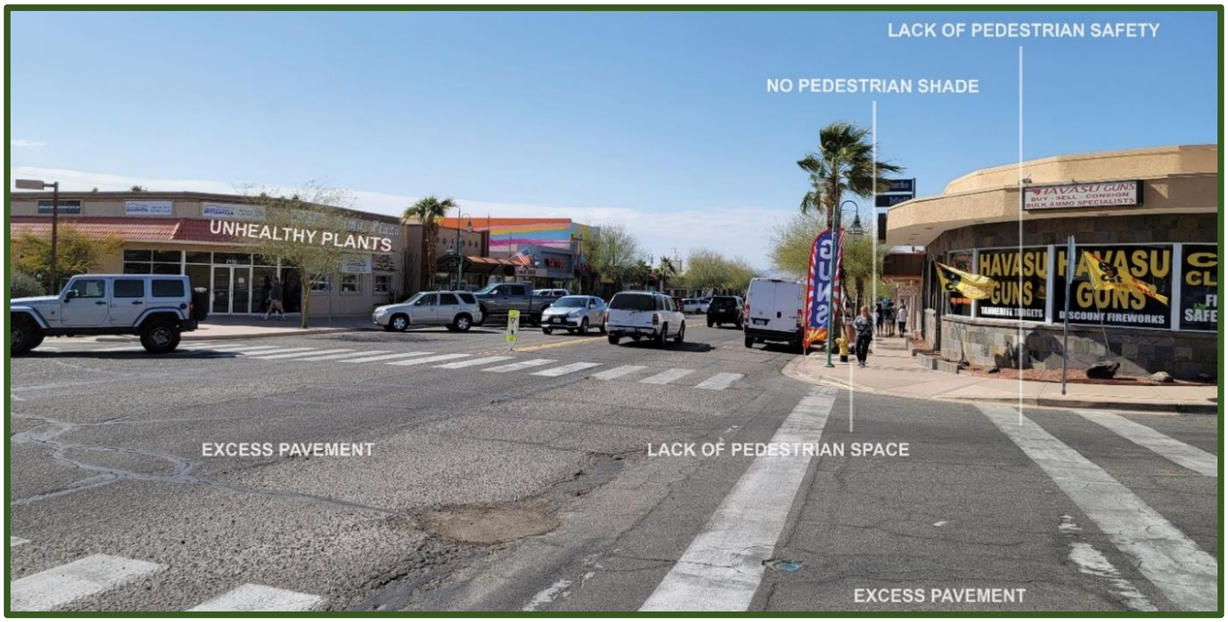


Figure 8-3 McCulloch Blvd Challenges – intersection.

8.1.3 Treatment

- Curb modifications, curb openings, bioswales, and sediment traps:
    - ✓ Narrower car travel lane widths to slow vehicular traffic for improved safety and increase space for LID BMP improvements.
    - ✓ Preserve majority of on-street parking, while adding space for trees and pedestrians.
    - ✓ Add curb extensions and bulb outs for new bioswales.
    - ✓ Add curb cuts with sediment traps to create bioswales.
    - ✓ Add street trees in bioswales.
    - ✓ Add pedestrian bridges across bioswales at crosswalk areas.
    - ✓ Construct decks above curb extensions for commercial patio space and bike parking.
- Permeable Hardscape and Suspended Pavement:
    - ✓ Repave with permeable asphalt or concrete at roadway and adjacent parking lots.
    - ✓ Repave with permeable pavers or block at on-street parking, sidewalk, and adjacent parking lots.
    - ✓ Add pervious storage media and/or structural soil under and adjacent to permeable pavement.
    - ✓ Connect street tree wells to pervious storage media and/or structural soil system.

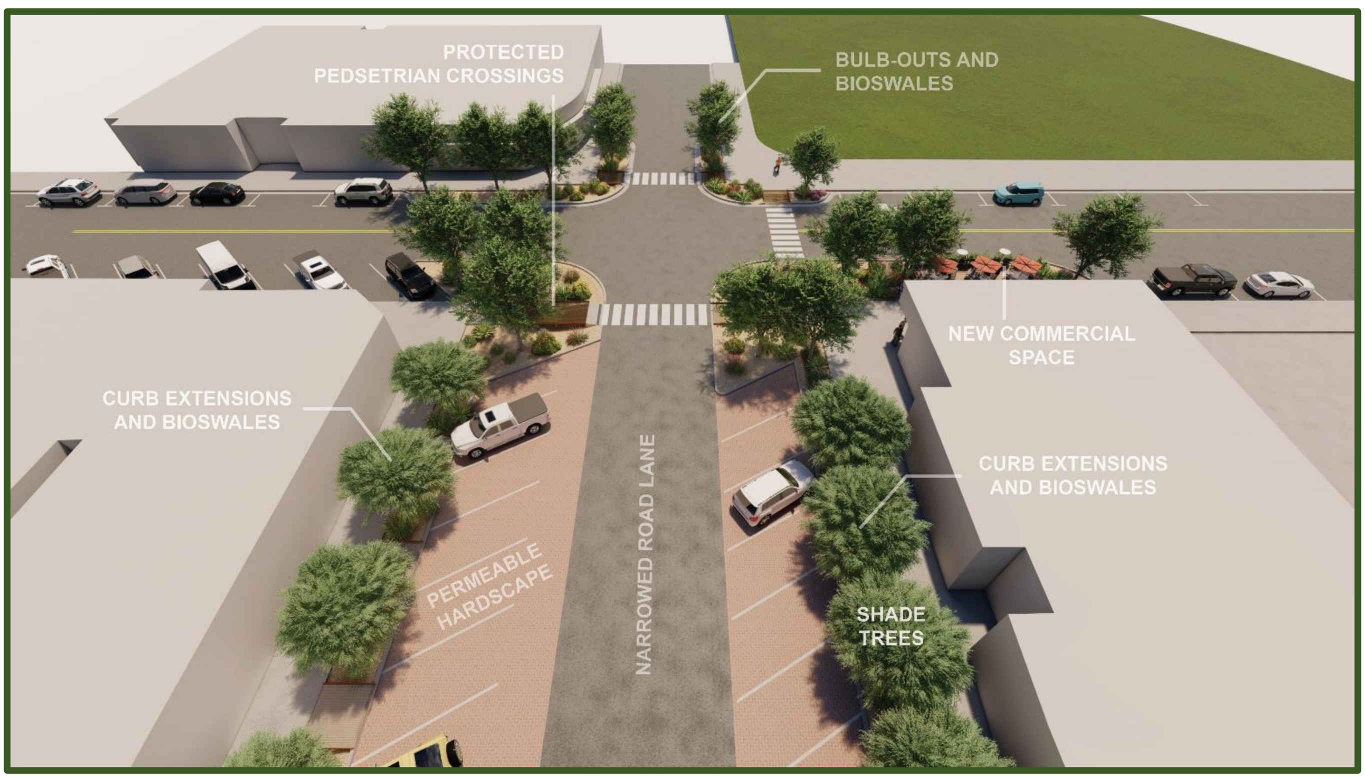


Figure 8-4. McCulloch Blvd and Querio Dr intersection and parking.

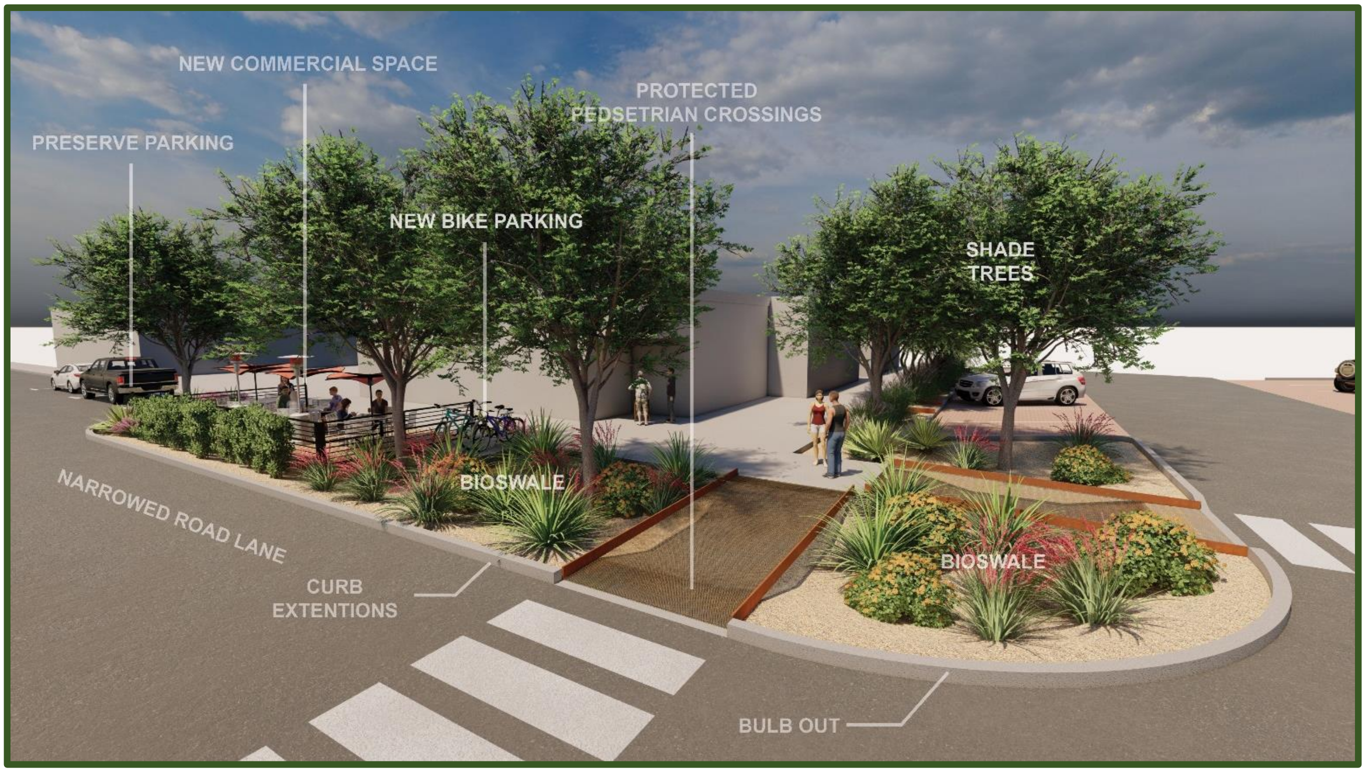


Figure 8-5. McCulloch Blvd - BMP programming examples.

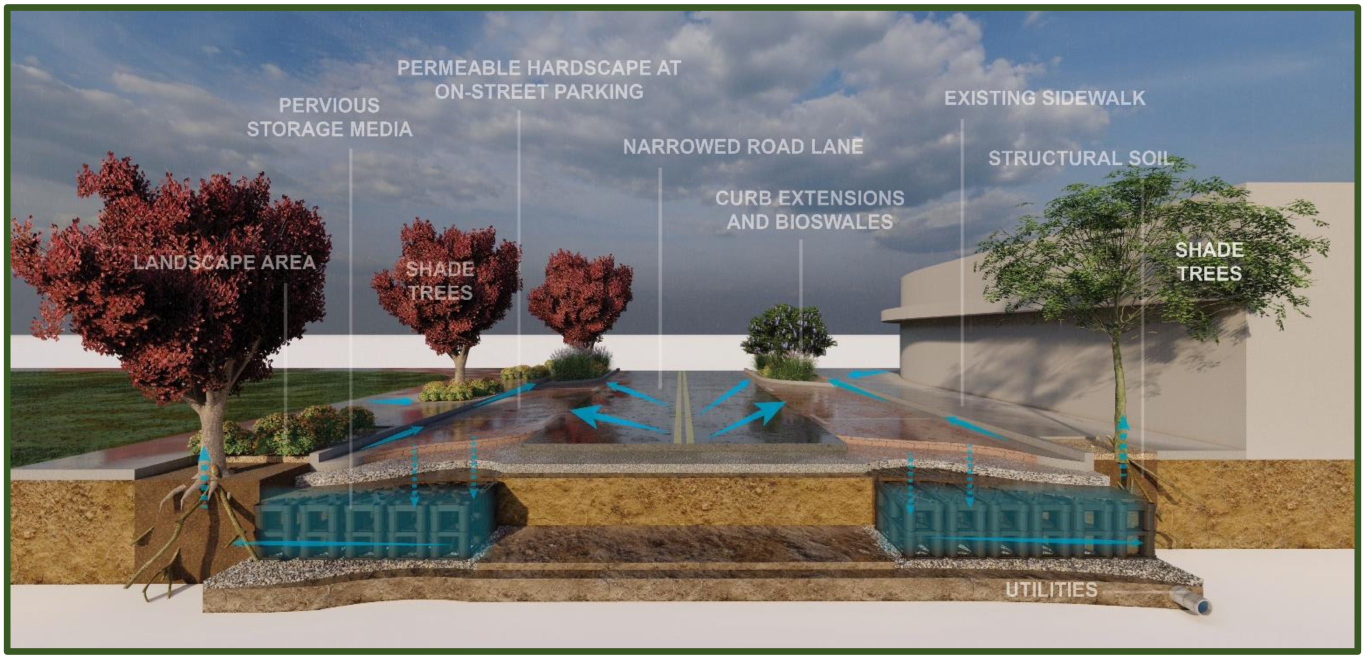


Figure 8-6. Healthy street trees and BMP examples.

8.2 Suburban Streetscape Development

Suburban and neighborhood streets are also good candidates for LID intervention, as they tend to be wide, relatively new, and have fewer spatial pressures than urban streetscapes. For example, on-street parking, while important, is not as critical as in an urban condition where retail and businesses are reliant upon parking. Also, the design aesthetic of neighborhoods lends itself to a more pastoral, green setting. The example area below is a generalized suburban neighborhood in Lake Havasu City.

8.2.1 Opportunities

- Wide streets offer room to work.
- Residents can make daily observations and reports.
- Fewer overhead utilities than an urban streetscape; therefore, tree canopies can be larger.
- Captured stormwater will be relatively clean.

8.2.2 Challenges

- Excessive residential street widths.
- Excessive impermeable surfacing.
- Lack of shade.
- Lack of landscape area and plant health.
- Potential lack of neighborhood support.
- Single BMP interventions may be too few or too small, multiple interventions may be necessary to adequately function.

Figure 8-7 Typical residential site – challenges.

8.2.3 Treatments

- Curb modifications, curb openings, bioswales, and sediment traps:
  - ✓ Narrow car travel lane widths.
  - ✓ Preserve selective on-street parking.
  - ✓ Add curb extensions, bulb outs, and chicanes for new bioswales.
  - ✓ Add curb cuts with sediment traps to create bioswales.
  - ✓ Add check dams to streetscape bioswales.
  - ✓ Add street trees in bioswales.
  - ✓ Add bioswales to residential lots.
- Permeable hardscape and suspended pavement:
  - ✓ Repave driveways with permeable hardscape.
  - ✓ Repave on-street parking with permeable hardscape.
  - ✓ Repave pedestrian crosswalks with permeable hardscape.
  - ✓ Add pervious storage media and/or structural soil under and adjacent to permeable pavement.
  - ✓ Connect street tree wells to pervious storage media and/or structural soil system.

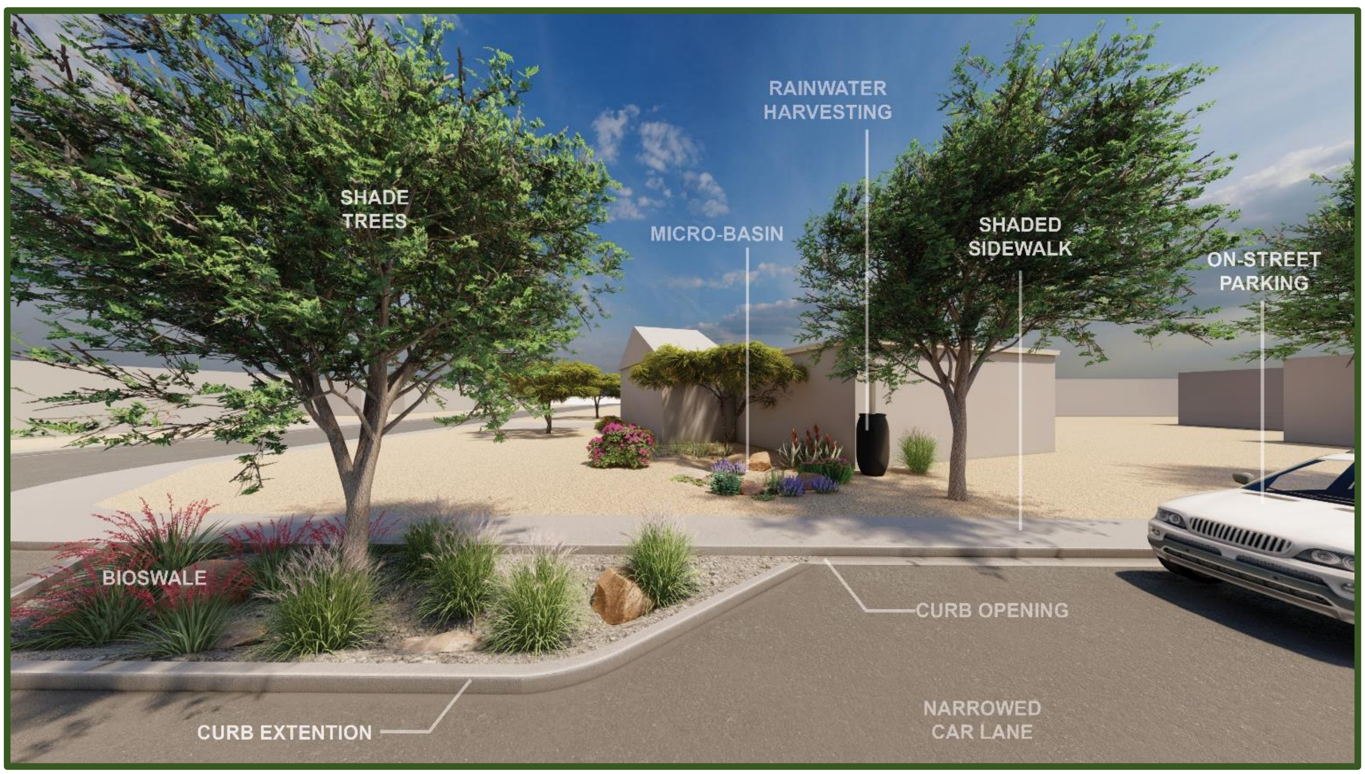


Figure 8-8 Residential BMPs - as seen from street.

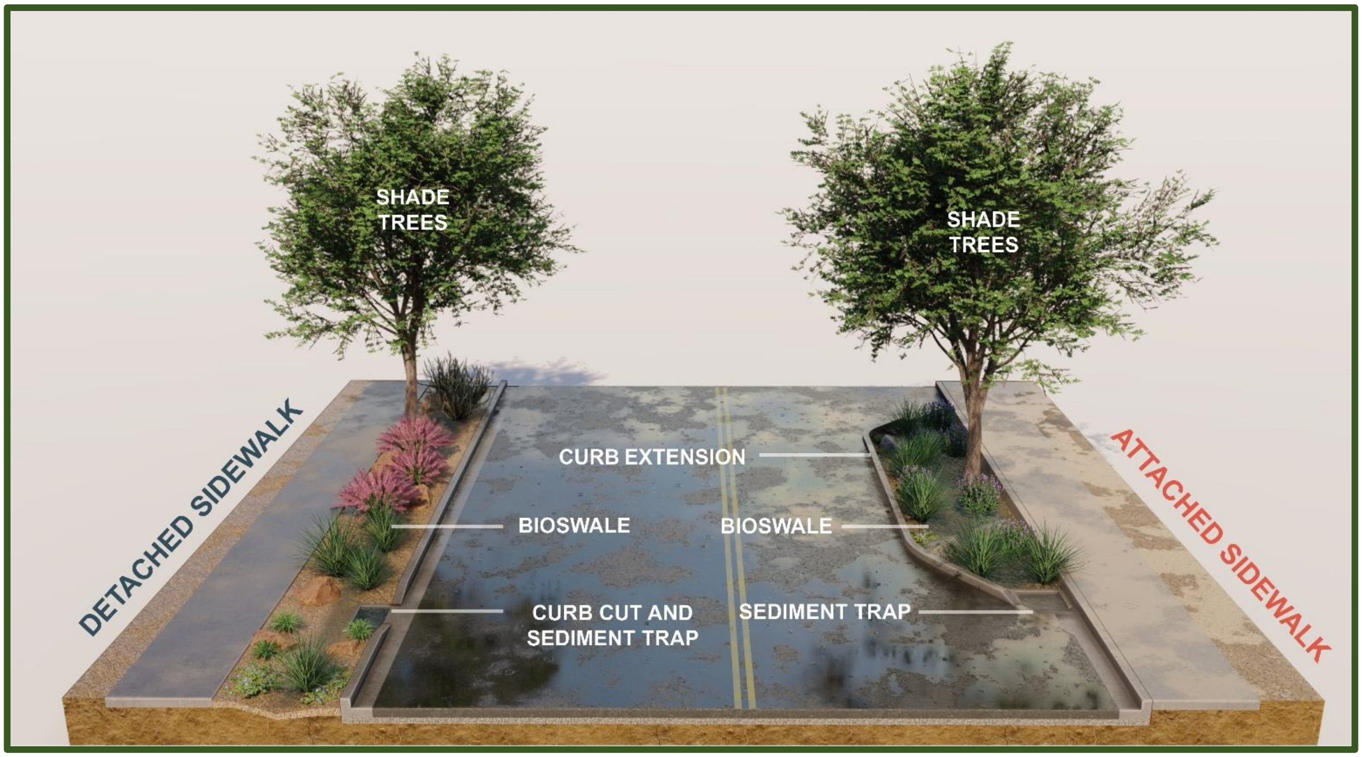


Figure 8-9 Residential BMPs – with vertical curb.

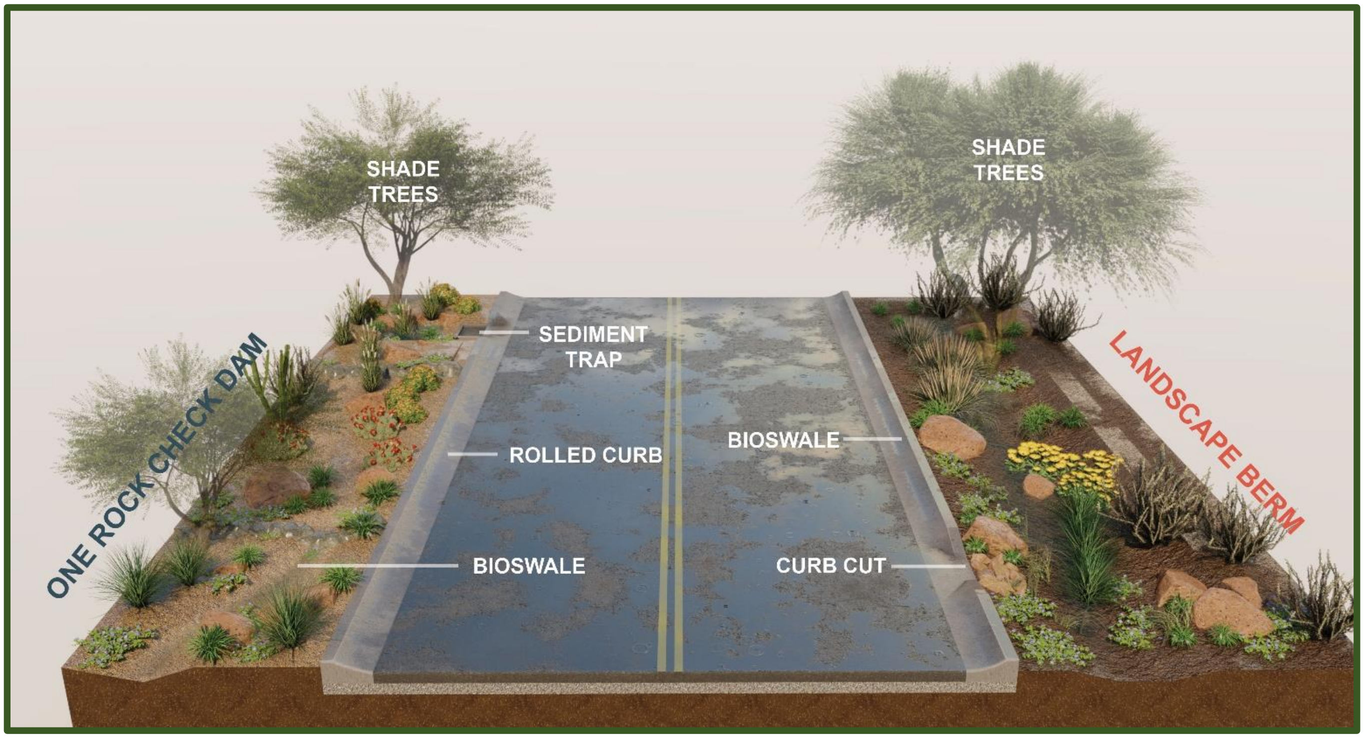


Figure 8-10 Residential BMPs – without sidewalk.

8.3 Inverted Crown Section Roadways – Urban and Suburban

A large proportion of existing roadways within Lake Havasu City, both Urban and Suburban, were designed and constructed as inverted crown section type roadways. This means that the center of the roadway is the lowest part of the roadway; and therefore, stormwater is conveyed down the center of these streets, as opposed to being conveyed along the curb line, as in the case of crowned roadways. Inverting - or lowering - the crown creates a different situation related to LID BMPs. Simply put, the BMPs need to go where the water is, so there are some unique BMPs that function well in these situations. The below graphics depict a generalized inverted crown section roadway with LID BMPs.

8.3.1 Opportunities

- Predictable flow path of water.
- Water is allowed to pass through or over the BMP.
- Fewer overhead utilities than along a roadway curb line.
- This type of roadway lends itself to hosting multiple BMPs in a series.
- Can create the ancillary benefit of calming traffic.

8.3.2 Challenges

- Median and traffic circle BMPs may be narrow, owing to required width of travel lanes.
- Tree canopies may overhang travel lanes if wide canopy trees are planted.
- Does not shade pedestrian pathways.
- Maintenance requires personnel to enter and work within the roadway.
- Stormwater capture may be limited, as overflow piping will convey water away to prevent flooding of travel lanes.
- Occasionally these BMPs are struck be vehicles.
- Drain inlet BMPs, when installed as a retrofit, will require roadway patching and construction of a roadside BMP.

8.3.3 Treatments

- Median bioswales:
  - ✓ Narrow car travel lane widths.
  - ✓ Preserve selective on-street parking.
  - ✓ Remove existing pavement to allow for the median.
  - ✓ Add curb cuts with sediment traps to create bioswales.
  - ✓ Add check dams to streetscape medians.
  - ✓ Add street trees in medians.
  - ✓ Width should accommodate large vehicles and towed vehicles.

- Drain capture and distribution to landscape:
    - ✓ Does not impact travel lane widths.
    - ✓ Preserve selective on-street parking.
    - ✓ Remove existing pavement to place the inlet and piping.
    - ✓ Utilize traffic rated Drain Inlet structure.
    - ✓ Can be utilized on narrow roads where medians are not practical.
- Traffic circles:
    - ✓ Remove existing pavement to accommodate BMP.
    - ✓ Preserve manholes that may exist at the center of the intersection.
    - ✓ Provide curbs with breaks or curb cuts to delineate the traffic circle
    - ✓ Provide additional bollards or warning markers as warranted by intersection width and traffic speed.

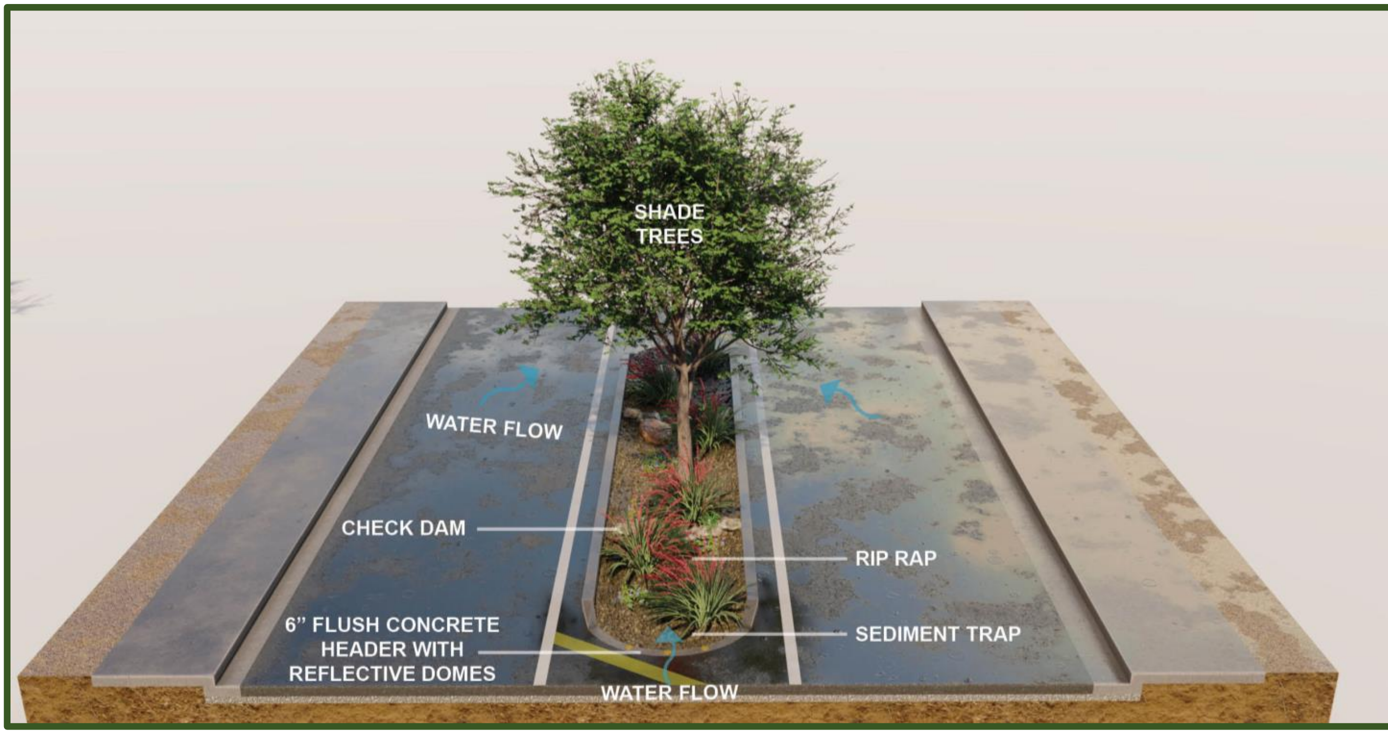


Figure 8-11. Inverted Crown Roadway BMPs – median.

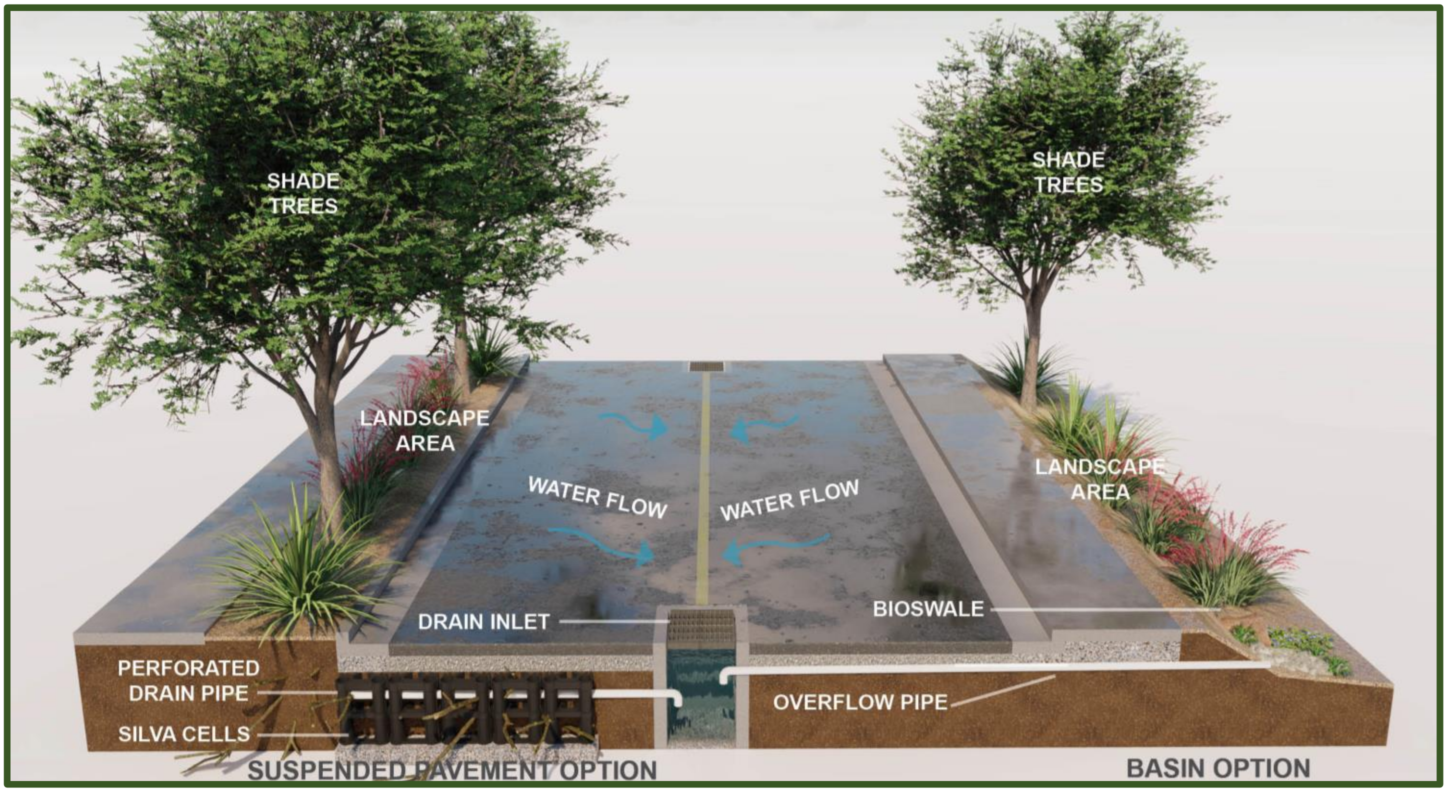


Figure 8-12. Inverted Crown Roadway BMPs – drain inlet capture and distribution to landscape.

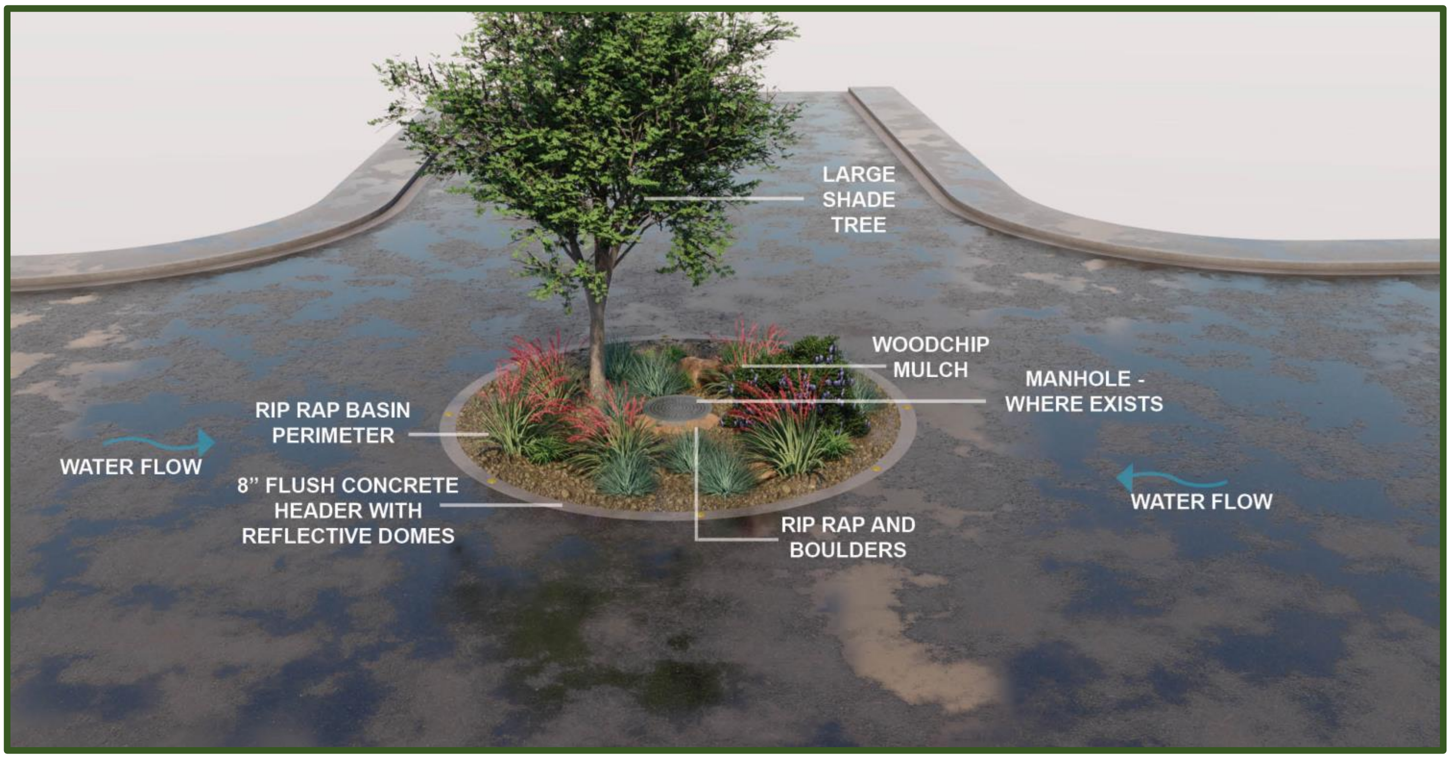


Figure 8-13. Inverted Crown Roadways BMPs – traffic circle with landscape.

8.4 Downtown Catalyst Project

The Downtown Catalyst Project, a mixed-use development type project on the corner of Querio Drive and McCulloch Boulevard (see Figure 8-14) is a prime opportunity for using LID BMPs. The existing site has a variety of well identified challenges, which the future Downtown Catalyst Project can help mitigate if LID BMPs are used.

8.4.1 Opportunities

- Highly trafficked location can maximize interaction with the public, who will view the BMPs.
- Potential for high return on investment.
- Treating stormwater as a resource not a nuisance will enhance planted landscapes.
- Unique opportunity to present a strong sense of place to visitors.
- The City is currently engaged in a design effort to redevelop this site.
- The size of the site offers the opportunity to integrate multiple BMPs while not sacrificing uses.

8.4.2 Challenges

- Excessive adjacent street pavement.
- Excessive runoff.
- Excessive sediment buildup and maintenance.
- Excessive urban heat island.
- Lack of shade.
- Lack of landscape area and plant health.
- Lack of pedestrian safety.

Figure 8-14 Downtown Catalyst Project challenges.

8.4.3 Treatment

- Curb modifications, curb openings, bioswales, enhanced basins, and sediment traps:
  - ✓ Preserve majority of on-street parking, while adding space for trees and pedestrians.
  - ✓ Add curb extensions and bulb outs for new bioswales.
  - ✓ Add curb cuts with sediment traps to create bioswales and bioretention planters.
  - ✓ Add bioretention planters at streetscape to collect overflow from bioswales at curb extensions.
  - ✓ Add street trees at bioswales and bioretention planters.
- Soil modification:
  - ✓ Add Biochar and mulch to bioretention planters.
- Permeable hardscape and suspended pavement:
  - ✓ Repave with permeable asphalt or concrete at roadway and adjacent parking lots.
  - ✓ Repave with permeable pavers or block at on-street parking, sidewalk, and adjacent parking lots.
  - ✓ Add pervious storage media and/or structural soil under and adjacent to permeable pavement.
  - ✓ Connect street tree wells to pervious storage media and/or structural soil system.
- Cistern rainfall collection:
  - ✓ Add aboveground or underground cisterns to collect and store rainwater to supplement irrigation for new development.
- Greywater collection:
  - ✓ Utilize AC condensate collected from nearby buildings for entry water feature.
  - ✓ Reduce building setbacks to create microclimate.
  - ✓ Provide amenities and indications of LID activities such as rain-chains at corner plazas.

Figure 8-15 Downtown Catalyst Project street and entry BMP examples.

Figure 8-16 Downtown Catalyst Project - BMPs link street and architecture.

Figure 8-17 Downtown Catalyst Project - BMPs and architecture together create a microclimate.

8.5 Island Ball Fields Park

Lake Havasu City's Island Ball Fields Park is an active-use recreation facility located on Pittsburgh Point (Island), accessed via the London Bridge. The park has football/soccer and softball fields that require turf/grass to be used recreationally. The park is adjacent to the City's Island Wastewater Treatment Plant. The facility provides treated effluent irrigation to the fields as a means of disposal. As reported by the City, the maximum amount of effluent provided for irrigation is approximately 31,000 cubic feet (0.7 acre-feet) per month. Based on the City's assumed future demand, the City's target maximum infiltration rate for the Island Ball Fields Park to effectively dispose effluent is approximately 18 acre-feet per year (1.5 acre-feet per month or 2,178 cubic feet per day).

The current drainage issue within the Island Ball Fields Park is poorly draining soils, resulting in excessive ponding of wastewater effluent. The extent and duration of wastewater effluent ponding can adversely impact the City's use of the park and may cause vector issues. Therefore, the City seeks to employ LID treatments to improve infiltration. It should be noted that given the park's proximity to Lake Havasu, the depth to groundwater is relatively shallow.

The Island Ball Fields Park is shown below in Photograph 8-1, Photograph 8-2, Photograph 8-3, and Photograph 8-4.

8.5.1 Opportunities

- High public visibility.
- Active recreation areas are in demand in Lake Havasu City.
- Low-cost solutions are possible.

- Less irrigation demand.

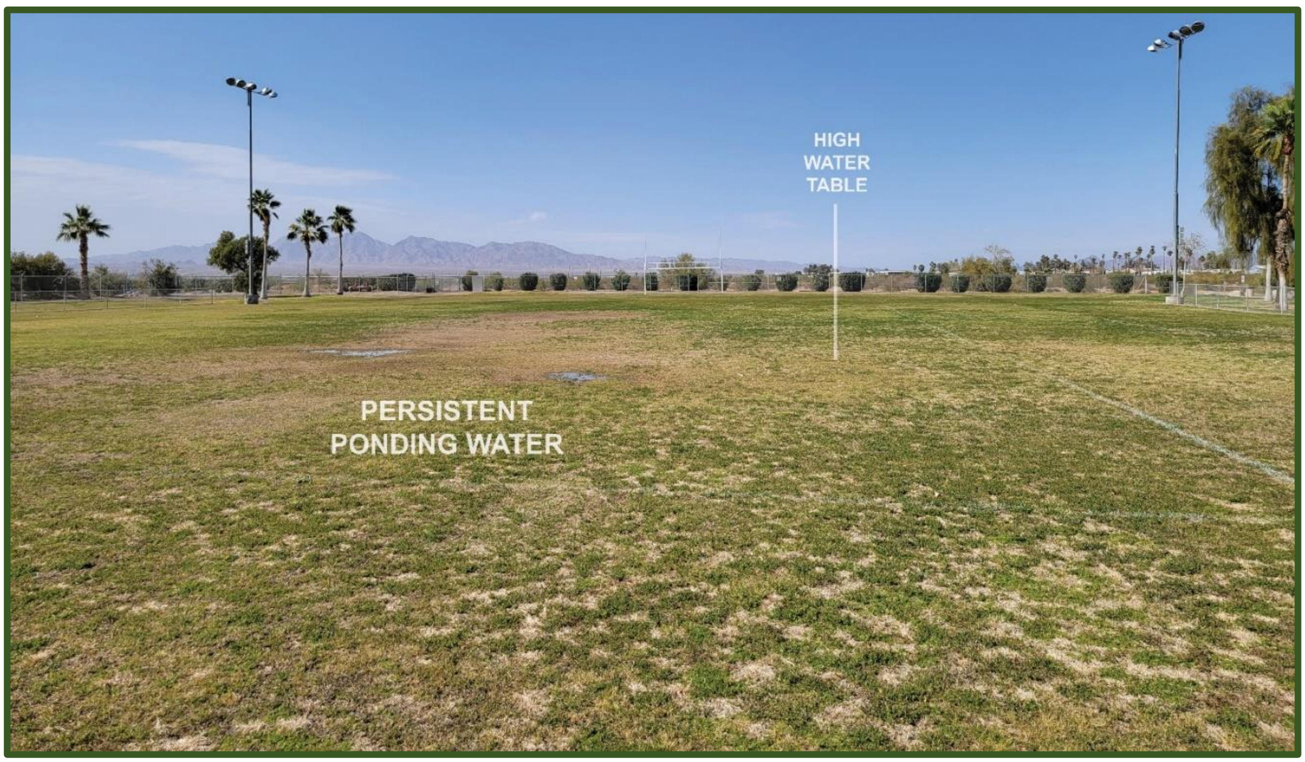
8.5.2 Challenges

- High water table and slow percolation rate.
- Surface ponding from irrigation and precipitation events.
- Seasonal use patterns can lead to overuse and soil compaction in certain seasons.

8.5.3 Treatment

As part of the development of the *LID Master Plan*, the Project Team coordinated with Parjana for assessment of the Energy-Passive Groundwater Recharge Product (Section 5.10.1) to increase infiltration rates within the Island Ball Fields Park. The EGRP® technology has been used in similar scenarios (poorly draining recreational fields) and has been shown to promote infiltration in poorly draining soils, which translates to groundwater recharge, runoff mitigation, pollution mitigation, improved soil productivity, and vector control.

Based on a project quote from Parjana (below Figure 8-18), an EGRP® technology system could be installed to infiltrate up to 0.3 acre-feet of irrigation effluent within a 24-hour period. At the time of the project quote, the cost for design and installation ranges between $252,000 and $275,000.



Photograph 8-1. Island Ball Fields Park – challenges.

Photograph 8-2. Island Ball Fields Park – areas of routine ponding.

Photograph 8-3. Island Ball Fields Park - softball outfield area.

Photograph 8-4. Island Ball Fields Park - area of nuisance ponding in softball field area.

PARJANA

21455 Melrose Ave, Bldg. R #22, Southfield, MI 48075
Phone: 855-Parjana (855-727-5262) Fax: 313-918-1198
Website: parjana.com Email: info@parjanadistribution.com

REQUEST FOR RANGE

Contract OPPT001639: 1150 MCulloch Blvd N, Lake Havasu City, 86403, USA
Project Type: Commercial I

Date:	**Prepared By:**	**Approved By:**	**Service Performed For:**
5/4/2021	A.C.	J.K.	The Water Group

Quotation:

Anticipated cost range based upon current site information provided to Parjana®:

Option	Design Criteria/Proposed Solution	Cost	Design Fee
1	To infiltrate a 0.3 AF in a 24-hour period.	$233,198.00 - $256,518.00	$18,655.00

NOTE: This is an initial range estimate for the above project. The exact cost will be provided upon a Layout Design request. The Design Fee is an addition to the project cost and it will be required in order to move forward with the project. For two years of monitoring temperature, humidity, rainfall, and infiltration data an additional $45,000.00 is added to the final cost. This monitoring includes two reports per year for two years and monitoring equipment. Biochar system can be added if desired.

Site Analysis Notes: None other to report. The plan is to resolve the water issues at the selected installation areas.

Figure 8-18. Quote from Parjana (May 4, 2021) provided to City for installation of EGRP® technology.

8.6 Residential Retrofit

Significant water savings can be realized through residential design and retrofit. As seen in Figure 5-16, the average single-family residence (assuming 4.38 inches of annual rainfall,1,000 SF roof capture, and two adults per household) can capture close 15,500 gallons of water per year through a combination of rainwater and greywater collection. That is approximately two to three months of water for a typical single-family residence (LHC Water Conservation Plan, 2-11). Figure 8-19 and Figure 8-20 show a typical single family residential example of these applications.

8.6.1 Opportunities

- Residents take personal responsibility in water conservation.
- Can improve at-home health and well-being.
- Small changes can add up to large savings.
- Top of watershed re-purposing of water maximizes impact.
- Multiple alternative sources available.

8.6.2 Challenges

- Costs of residential retrofit are currently placed on homeowner.
- Space for cisterns or equipment may be limited.

8.6.3 Treatment

- Permeable hardscape and suspended pavement:
  - ✓ Repave driveways with permeable hardscape.
  - ✓ Repave on-street parking with permeable hardscape.
  - ✓ Add pervious storage media and/or structural soil under and adjacent to permeable pavement.
- Soil modification:
  - ✓ Add biochar and/or mulch to residential lot landscape areas.
- Cistern rainwater collection:
  - ✓ Add aboveground cistern to residence to collect and keep rainwater to supplement irrigation.
  - ✓ Add cistern overflow outlet to bioswale.
- Greywater collection:
  - ✓ Utilize HVAC condensate collected from residential unit.
  - ✓ Add laundry water recycling system (direct to landscape).
  - ✓ Add shower water recycling system (to cistern).

Figure 8-19 Residential BMPs - as seen from yard

Figure 8-20 Residential BMPs - as seen from backyard

9 REFERENCES

ACF Environmental . (2021). *EGRP Stormwater Infiltration System*. Retrieved from ACF Environmental : https://acfenvironmental.com/products/stormwater-management/drainage/egrp/

ACF Environmental. (2021). *R-Tank® Stormwater Modules*. Retrieved from ACF Environmental: https://acfenvironmental.com/products/engineered-applications/stormwater-management-lid/space-efficient-storage/r-tank/

Arizona Department of Environmental Quality. (September 2021). *Arizona Pollutant Discharge Elimination System General Permit for Stormwater Discharges From Small Municipal Separate Sewer Systems to Protected Surface Waters.*

Arizona Department of Environmental Quality. (n.d.). *Using Gray Water at Home*. Retrieved from https://www.azdeq.gov/GrayWater

Arizona Municipal Water Users Association. (2022). *Plants for the Arizona Desert*. Retrieved from amwua: One for Water: https://www.amwua.org/plants

Bureau of Reclamation, United States Depertment of Interior. (September 2020). *Impacts of Grade Control Structure Installations on Hydrology and Sediment Transport as an Adaptive Management Strategy.*

City of Los Angeles. (May 2016). *Planning and Land Development Handbook for Low Impact Development (LID), Part B Planning Activities* (5th ed.).

City of Mesa. (April 2015). *Low Impact Development Toolkit.*

City of Phoenix. (June 2018). *Triple Bottom Line Cost Benefit Analysis of Green Infrastructure/Low Impact Development (GI/LID) in Phoenix, AZ.*

City of Scottsdale. (January 2019). *Greater Phoenix Metro Green Infrastructure Handbook: Low-Impact Development Details for Alternative Stormwater Management.* City of Scottsdale.

City of Tucson. (2013). *Plan Tucson: City of Tucson Gernal & Sustainability Plan 2013.*

City of Tucson. (2022). *Green Stormwater Infrastructure*. Retrieved from https://www.tucsonaz.gov/gsi

City of Tucson. (August 2019). *Green Stormwater Infrastructure Fund Proposal.*

City of Tucson. (May 2015). *Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area.*

City of Tucson. (October 2005). *Water Harvesting Guidance Manual.*

Colorado State University Extension. (January 2016). *Biochar in Colorado.*

Colwell Shelor. (2018). *Arizona State University Orange Mall Green Infrastructure*. Retrieved from Colwell Shelor Landscape Architecture : https://colwellshelor.com/works/arizona-state-university-orange-mall-green-infrastructure/

Contech Engineered Solutions LLC. (2022). *CDS® Stormwater Treatment*. Retrieved from Contech Engineered Solutions: A Quikcrete Company: https://www.conteches.com/stormwater-management/treatment/cds

Contech Engineered Solutions LLC. (2022). *Stormceptor Systems*. Retrieved from Contech Engineered Solutions: A Quikcrete Company: https://www.conteches.com/stormwater-management/treatment/stormceptor-systems

County of Los Angeles, Department of Public Works. (February). *Low Impact Development Standards Manual.*

Deeproot. (2021). *Silva Cells*. Retrieved from Deeproot: https://www.deeproot.com/

Federal Emergency Management Agency, Department of Homeland Security. (January 2017). *Innovative Drought and Flood Mitigation Projects.*

Federal Emergency Management Agency, Department of Homeland Security. (June 2021). *Building Community Resilience with Nature-Based Solutions: A Guide for Local Communities.*

Flood Control District of Maricopa County. (December 2019). *Reduce Your Flood Risk: A Resource Guide.*

Hasan, M., Vasquez , R., & Geza , M. (2021). Application of Biochar in Stormwater Treatment: Experimental and Modeling Investigation. *Processes*, 9(5), 860.

Heritage Hydraulics. (2021). *EGRP®*. Retrieved from Heritage Hydraulics: https://heritagehydrologics.com/egrp/

International Biochar Initiative. (2018). *Biochar Is a Valuable Soil Amendment*. Retrieved from Biochar International : https://biochar-international.org/biochar/

Jerke, D. (2008). *Urban Design and the Bottom Line: Optimizing the return on perception.* Washington, DC: Urban Land Institute .

Kraaijenbrink, J. (2019, December 10). *What The 3Ps Of The Triple Bottom Line Really Mean*. Retrieved from Forbes: https://www.forbes.com/sites/jeroenkraaijenbrink/2019/12/10/what-the-3ps-of-the-triple-bottom-line-really-mean/?sh=2afd05ed5143

Lake Havasu City. (2016). *2016 General Plan.* Lake Havasu City.

Lake Havasu City. (December 2013). *Amendments to Title 8 of the Lake Havasu City Code to Add Chapter 8.28 Stormwater.*

Lake Havasu City. (December 2019). *Water Conservation Plan, 2020 Update.*

Lake Havasu City. (January 2014). *Ordinance No. 14-1105.*

Lake Havasu City. (March 2014). *(Revised) Stormwater Management Program.*

Lake Havasu City. (n.d.). *Stormwater Management Program: Development & Permitting, Policies & Procedures.*

Maricopa Association of Governments. (2022). *Uniform Standard Details for Public Works Construction.*

Mohave County Flood Control District. (August 2018). *Stormwater Management Ordinance.*

Mohave County Flood Control District. (December 2019). *Mohave County Low Impact Development Guide for Flood Protection and Water Sustainability.*

Mohave County. (May 2018). *Drainage Design Manual for Mohave County.*

NACTO. (2021). *Biofiltration Planter*. Retrieved from National Association of City Transportation Officials (NACTO): https://nacto.org/publication/urban-street-stormwater-guide/stormwater-elements/green-stormwater-elements/biofiltration-planter/

Natural Resources Conservation Service, Unitied States Depertment of Agriculture. (2019). *Web Soil Survey*. Retrieved from https://websoilsurvey.nrcs.usda.gov/app/

NPCA. (2019). *Diversifying Your Products For a Rainy Day*. Retrieved from NPCA: https://precast.org/2019/01/diversifying-your-products-for-a-rainy-day/

Office of the Secretary of State, Administrative Rules Division. (September 2019). *Arizona Administrative Code Title 18 (Environmental Quality), Chapter 9 (Depertment of Environmental Quality - Water Pollution Control), Article 7 (Use of Recycled Water) - Part D (Gray Water).*

PaveDrain. (2020). *Why PaveDrain?* . Retrieved from PaveDrain: https://www.pavedrain.com/

Peterson, J. (2021, September 10). *How to Recycle Air Conditioning Water Condensation.* . Retrieved from Sciencing: https://sciencing.com/recycle-air-conditioning-water-condensation-23439.html

Pima County and City of Tucson, AZ. (March 2015). *Low Impact Development and Green Infrastructure Guidance Manual.*

Riverside County Flood Control and Water Conservation District. (September 2011). *Design Handbook for Low Impact Development Best Management Practices.*

State of Arizona Department of Environmental Quality, Water Quality Division. (September 2021). *Arizona Pollutant Discharge Elimination System General Permit for Stormwater Discharges Associated with Construction Activity to Protected Surface Waters.*

State of Arizona Department of Environmental Quality, Water Quality Division. (September 2021). *Arizona Pollutant Discharge Elimination System General Permit for Stormwater Discharges Associated with Industrial Activity - Mineral Industry to Protected Surface Waters.*

Stormwater Management Advisory Commission, Raleigh City Council. (June 2021). *Plan for Continuing to Advance the Use of Green Stormwater Infrastructure (GSI) in Raleigh.*

United States Environmental Protection Agency. (2021, July). *Using Low Impact Development and Green Infrastructure to Get Benefits From FEMA Programs*. Retrieved from https://www.epa.gov/nps/using-low-impact-development-and-green-infrastructure-get-benefits-fema-programs

United States Environmental Protection Agency. (March 2020). *Recommendations for Integrating Green Infrastructure into the Maricopa County Multi-jurisdictional Hazard Mitigation Plan.*

United States Environmental Protection Agency. (March 2021). *Green Streets Handbook.*

United States Environmental Protection Agency, Office of Research and Development. (May 2018). *Improving the Resilience of Best Management Practices in a Changing Environment: Urban Stormwater Modeling Studies.*

United States Environmental Protection Agency, Office of Water. (July 2007). *National Management Measures to Control Nonpoint Source Pollution from Hydromodification.*

United States Environmental Protection Agency, Office of Water. (June 2017). *Green Infrastructure in Parks: A Guide to Collaboration, Funding, and Community Engagement.*

United States Environmental Protection Agency, Office of Wetlands, Oceans, and Wetlands. (March 2012). *Benefits of Low Impact Development: How LID Can Protect Your Community's Resources (LID Barrier Busters Fact Sheet Series).*

Urban Drainage and Flood Control District. (November 2010). *Urban Storm Drainage Criteria Manual: Volume 3, Best Management Practices.*

Urban Horticulture Institute. (2015). *CU-Structural Soil® A Comprehensive Guide.* New York: Cornell University. Retrieved from http://www.hort.cornell.edu/uhi/outreach/pdfs/CU-Structural%20Soil%20-%20A%20Comprehensive%20Guide.pdf

Water - Use it Wisely. (2022). *Water - Use it Wisely*. Retrieved from https://wateruseitwisely.com/

Wheat Design. (2019). *St. Mary's Road*. Retrieved from Wheat Design Group - Landscape Architects: https://www.wheatdesigngroup.com/st-marys-road

APPENDIX A

City LID Resources

Lake Havasu City Recommended Landscaping Plant List

Lake Havasu City Recommended Landscaping Plant List Disclaimer

Lake Havasu City has revised the recommended landscaping plant list. This new list consists of plants that can be adapted to desert environments in the Southwestern United States. This list only contains water conscious species classified as having very low, low, and low-medium water use requirements. Species that are classified as having medium or higher water use requirements were not permitted on this list. Such water use classification is determined by the type of plant, its average size, and its water requirements compared to other plants. For example, a large tree may be classified as having low water use requirements if it requires a low amount of water compared to most other large trees.

This list is not intended to restrict what plants residents choose to plant in their yards, and this list may include plant species that may not survive or prosper in certain desert microclimates such as those with lower elevations or higher temperatures. In addition, this list is not intended to be a list of the only plants allowed in the region, nor is it intended to be an exhaustive list of all desert-appropriate plants capable of surviving in the region. This list was created with the intention to help residents, businesses, and landscapers make informed decisions on which plants to landscape that are water conscious and appropriate for specific environmental conditions. Lake Havasu City does not require the use of any or all plants found on this list.

List Characteristics

This list is divided between trees, shrubs, groundcovers, vines, succulents and perennials. It is then sorted alphabetically by the common names of the plants. There are several columns of attributes that can be used to determine which plants are appropriate to use in specific situations.

Lake Havasu City Specific Species

If you wish to narrow your search down to plants that are specific to Lake Havasu City's environmental conditions, please refer to the highlighted species in this plant list.

KEY

"Invincible": Tolerant of heat, cold, and wind, water efficient, low-maitenance, non-invasive, pest and disease resistant.

Water Use: **V**ery **L**ow, **L**ow, **M**edium

Tree Size: **S**mall (< 25 ft), **M**edium (25-40 ft), **L**arge (> 40 ft)

Tree Type: **D**eciduous, **E**vergreen, **S**emievergreen

Growth Rate: **S**low, **M**oderate, **F**ast

Biogenic Volatile Organic Compounds (BVOCs): **L**ow, **M**edium, **H**igh

Comments:

1. Organic mulch recommended
2. Many cultivars
3. Species may form dense thickets
4. Not cold hardy below 28°F
5. Invasive Species
6. Mojave native
7. Toxic (parts specified)
8. May be trained as a small tree
9. Needs a protected/ shaded site

Common Name	Botanical Name	"Invincible"	Water Use	Tree Size	Average Height	Average Width	Coverage	Tree Type	Growth Rate	Thorns	BVOCs	Street/ Shade Tree	Buffer Tree	Patio Tree	Tolerates Turf	Can be placed under overhead utility lines	Comments
			VL, L, M	S, M, L	(feet)	(feet)	(sq. feet)	D, E, S	S, M, F	Yes/ No	L, M, H	Yes/ No	Yes/ No	Yes/ No	Yes/ No	Yes/ No	
Trees																	
Argentine Mesquite	*Prosopis alba*		L, M	M	30	30	530	S	F	Y	---	Y	Y	N	N	N	
Arizona Cypress	*Cupressus glabra*		L, M	L	50	15	133	E	M, F	N	L	Y	N	N	Y	N	
Blue Palo Verde	*Parkinsonia florida*	•	L, M	M	30	30	530	D	M	N	M	Y	Y	Y	N	N	
California Fan Palm	*Washingtonia filifera*		L	L	50	15	133	E	S, M	Y	M	Y	N	Y	N	N	
California Pepper Tree	*Schinus molle*		L	M	30	30	530	E	M, F	N	M	Y	Y	N	Y	N	9
Carob Tree	*Ceratonia siliqua*		L, M	M	35	20	236	E	M	N	M	Y	N	N	Y	N	4
Cascalote	*Caesalpinia cacalaco*		L, M	S	20	20	236	E	M	Y	---	N	Y	Y	N	N	
Catclaw Acacia	*Acacia greggii*	•	L	S	15	20	236	D	S, M	Y	L	N	N	N	N	Y	6
Chilean Mesquite	*Prosopis chilensis*	•	L, M	M	30	30	530	S	F	Y	---	Y	Y	N	N	N	
Chitalpa	*x Chitalpa tashkentensis*		L, M	S	20	20	236	D	M	N	M	Y	Y	N	Y	Y	
Colorado Mesquite	*P. a.* 'Colorado'		L, M	M	30	30	530	S	F	Y	---	Y	Y	N	N	N	
Coolibah Tree	*Eucalyptus microtheca*	•	L, M	M	40	25	368	E	M	N	H	Y	Y	N	N	N	4
Desert Ironwood	*Olneya tesota*	•	L	M	25	20	368	E	S	Y	---	N	N	N	Y	N	6
Desert Museum Palo Verde	*Parkinsonia x* 'Desert Museum'	•	L, M	M	25	25	368	S	F	N	M	Y	N	N	N	N	
Desert Willow	*Chilopsis linearis*	•	L, M	M	25	20	236	D	M	N	M	Y	Y	N	N	N	6
Escarpment Oak	*Quercus fusiformis*	•	L, M	L	30	30	530	E	M, F	N	H	Y	Y	N	Y	N	
Feather Bush	*Lysiloma microphylla v. thornberi*		L	S	15	15	133	S	M	Y	---	Y	N	Y	N	N	
Foothills Palo Verde	*Parkinsonia microphylla*	•	L	S	20	20	236	D	S, M	Y	M	Y	Y	Y	N	Y	
Golden Ball Lead Tree	*Leucaena retusa*		L, M	S	20	20	236	D	M	N	M	N	N	N	N	Y	
Jacaranda	*Jacaranda acutifolia*		L, M	M	30	30	530	S	M	N	---	Y	Y	Y	N	N	
Kidneywood	*Eysenhardtia orthocarpa*	•	L	S	18	25	368	S	M	N	---	N	N	N	N	Y	
Mastic Tree	*Pistacia lentiscus*		L	S	17	20	236	E	S	N	---	Y	Y	Y	Y	Y	4
Mexican Blue Palm	*Brahea armata*		L, M	M	30	15	133	E	S	Y	M	Y	N	N	N	N	
Mexican Buckeye	*Ungnadia speciosa*		L, M	S	10	12	85	D	S	N	---	N	N	Y	N	Y	7 (seeds)
Mexican Ebony	*Pithecellobium mexicanum*		L, M	M	30	20	236	D	M	Y	---	Y	N	Y	N	N	
Mexican Palo Verde	*Parkinsonia aculeata*		L, M	S	20	20	236	D	F	Y	M	Y	Y	Y	N	Y	
Mulga Acacia	*Acacia aneura*	•	L	S	20	15	133	E	S, M	N	M	Y	N	Y	N	Y	
Native/Velvet Mesquite	*Prosopis velutina(=juliflora)*	•	L	M	30	30	530	D	M	Y	L	Y	Y	N	N	N	6
Netleaf Hackberry	*Celtis reticulata*	•	L, M	S	15	15	133	D	S	N	L	N	N	Y	N	Y	6
Prarie/flameleaf Sumac	*Rhus lanceolata*		L, M	S	15	20	236	D	M	N	L	N	N	Y	N	Y	4
Screwbean Mesquite	*Prosopis pubescens*	•	L	S	20	25	368	D	S	Y	M	Y	Y	Y	N	Y	6
Shoestring Acacia	*Acacia stenophylla*	•	L	M	40	20	236	E	M, F	N	L	Y	Y	Y	N	N	
Silver Dollar Gum	*Eucalyptus polyanthemos*		L, M	L	40	30	530	E	F	N	H	Y	Y	N	N	N	4
Silver Mountain Laurel	*S.s. v.* 'Silver Peso,' 'Sierra Silver'		L, M	S	15	12	85	E	S, M	N	---	N	N	Y	N	Y	7 (seeds)
Smoke Bush	*Cotinus coggygria*		L, M	S	15	15	133	D	S	N	M	N	N	Y	Y	Y	
Smoke Tree	*Psorothamnus spinosus*	•	L, M	M	25	25	368	S	M	Y	---	N	Y	N	Y	N	6
Sonoran Emarald Palo Verde	*Parkinsonia x* 'Sonoran Emerald'	•	L, M	M	25	25	368	S	F	N	M	Y	N	N	N	N	
Sweet Acacia	*Acacia Farnesiana (=A. smallii)*	•	L	S	20	20	236	E	S, M	Y	M	Y	Y	Y	N	Y	
Texas Ebony	*Ebenopsis ebano(=Pithecellobium)*	•	L	M	25	20	236	S	S, M	Y	---	N	N	Y	N	N	
Texas Honey Mesquite	*Prosopis glandulosa glandulosa*		L	M	30	35	722	D	F	Y	M	Y	Y	N	N	N	
Texas Mountain Laurel	*Sophora secundiflora*	•	L, M	S	15	12	85	E	S, M	N	---	N	N	Y	N	Y	7 (seeds)
Texas Red Oak	*Quercus buckleyi*		L, M	M	30	30	530	D	S, M	N	H	Y	Y	N	Y	N	

KEY **"Invincible":** Tolerant of heat, cold, and wind, water efficient, low-maitenance, non-invasive, pest and disease resistant. **Water Use:** Very Low, Low, Medium **Tree Size:** Small (< 25 ft), Medium (25-40 ft), Large (> 40 ft) **Tree Type:** Deciduous, Evergreen, Semievergreen **Growth Rate:** Slow, Moderate, Fast **Biogenic Volatile Organic Compounds (BVOCs):** Low, Medium, High	Comments: 1. Organic mulch recommended 2. Many cultivars 3. Species may form dense thickets 4. Not cold hardy below 28°F 5. Invasive Species 6. Mojave native 7. Toxic (parts specified) 8. May be trained as a small tree 9. Needs a protected/ shaded site	**"Invincible"**	**Water Use**	**Tree Size**	**Average Height**	**Average Width**	**Coverage**	**Tree Type**	**Growth Rate**	**Thorns**	**BVOCs**	**Street/ Shade Tree**	**Buffer Tree**	**Patio Tree**	**Tolerates Turf**	**Can be placed under overhead utility lines**	**Comments**
Common Name	**Botanical Name**		VL, L, M	S, M, L	(feet)	(feet)	(sq. feet)	D, E, S	S, M, F	Yes/ No	L, M, H	Yes/ No	Yes/ No	Yes/ No	Yes/ No	Yes/ No	
Trees Continued																	
Thornless Argentine Mesquite	*P. a.* 'Cooperi'		L, M	M	30	30	530	S	F	N	---	Y	Y	N	N	N	
Thornless Chilean Mesquite	*P. c.* 'Thornless' or Arizona'	•	L, M	M	30	30	530	S	F	N	---	Y	Y	N	N	N	
Thornless Honey Mesquite	*P. g.* 'Maverick'		L	M	30	30	530	D	F	N	M	Y	Y	N	N	N	
Thornless Hybrid Mesquite	*Prosopis x* 'Phoenix'		L	M	30	30	530	D	F	N	---	Y	Y	N	N	N	
Thornless Hybrid Mesquite	*Prosopis x* 'Rio Salado'		L	M	30	30	530	D	F	N	---	Y	Y	N	N	N	
Western Honey Mesquite	*Prosopis glandulosa torreyana*	•	L	S	20	20	236	D	F	Y	M	Y	N	Y	N	Y	6
Western Redbud	*Cercis occidentalis*		L, M	S	13	15	133	D	S, M	N	L	N	N	Y	Y	Y	6
White Thorn Acacia	*Acacia constricta*	•	L	S	10	15	133	D	S	Y	M	Y	N	Y	N	Y	
Willow Acacia	*Acacia salicina*		L	M	30	15	133	E	F	N	---	N	Y	N	N	N	
Limited Use and Fruit Trees (Not Appropriate in All Locations)																	
Fern of the Desert	*Lysiloma watsonii*		L	S	20	15	133	S, D	S, M	N	---	N	N	N	N	Y	4

KEY

"Invincible": Tolerant of heat, cold, and wind, water efficient, low-maitenance, non-invasive, pest and disease resistant.
Water Use: Very Low, Low, Medium
Height, Width, Coverage at mature growth
Tree Type: Deciduous, Evergreen, Semievergreen
Growth Rate: Slow, Moderate, Fast
Drought Tolerance: Low, Medium, High
Exposure: Full sun, Partial shade Shade

Comments:
1. Organic mulch recommended
2. Many cultivars
3. Species may form dense thickets
4. Not cold hardy below 28°F
5. Invasive Species
6. Mojave native
7. Toxic (parts specified)
8. May be trained as a small tree
9. Needs a protected/ shaded site

Common Name	Botanical Name	"Invincible"	Water Use	Average Height	Average Width	Coverage	Tree Type	Growth Rate	Drought Tolerance	Thorns	Physical Barrier	Hedge or Screen	Exposure	Comments
			VL, L, M	(feet)	(feet)	(sq. feet)	D, E, S	S, M, F	L, M, H	Yes/No	Yes/ No	Yes/ No	F, P, S	
Shrubs														
Apache Plume	*Fallugia paradoxa*	•	L	6	4	13	S	F	H	N	Y	Y	F, P	6
Arizona Mescal Bean	*Sophora arizonica*	•	L, M	10	8	50	E	S	M	N	N	N	F, P	7 (seeds), 8
Arizona Rosewood	*Vauquelinia californica*	•	L	15	10	79	E	M	H	N	Y	Y	F, P	8
Autumn Sage	*Salvia greggii*		L, M	2	2	3	S	F	M	N	N	N	F, P	2
Baja Fairy Duster	*Calliandra californica*	•	L	5	6	28	E	S, M	H	N	N	N	F, P	
Bee Brush	*Aloysia gratissima*		VL	6	6	28	S	M	H	Y	N	N	F	
Berlandier Acacia, Guajillo	*Acacia berlandieri*		L, M	12	12	113	D	M	H	N	N	N	F, P	
Big Sage Bush	*Artemisia tridentata*	•	L	4	3	7	E	M	H	N	N	Y	F	6
Black Dalea	*Dalea frutescens*	•	L	4	5	20	S	M	H	N	Y	Y	F	
Blackbrush	*Coleogyne ramosissima*	•	L	5	5	20	S	S	H	N	Y	Y	F	
Blackbrush Acacia	*Acacia rigidula*		L	10	10	79	S	S	H	Y	Y	N	P	
Bladdersage	*Salazaria mexicana*	•	VL	3	3	7	D	M	H	N	N	N	F	6
Blue Texas, Cimarron Ranger	*Leucophyllum zygophyllum* 'Cimarron'	•	L	3	3	7	E	S	H	N	Y	Y	F	
Brewer's Saltbush	*A. l. breweri*	•	L	7	7	38	E	M	H	Y	Y	Y	F	6
Brittlebush	*Encelia farinosa*	•	VL	3	4	13	D	M	H	N	N	N	F	6
Buckwheat	*Eriogonum sp.*	•	L	3	3	7	D	M	H	N	N	N	F	
California Justicia	*Justicia californica*	•	L	3	4	13	D	M	H	N	N	N	F	
Centennial Broom	*Baccharis x* 'Centennial'		L	3	5	20	E	F	H	N	N	N	F	
Chaparral Sage	*Salvia clevelandii*	•	L	5	6	28	E	M	H	N	Y	N	F, P	
Chihuahuan Sage	*Leucophyllum laevigatum*	•	L	6	6	28	E	S	H	N	Y	Y	F	
Cliff Goldenbush	*Ericameria cuneata*	•	L	2	3	7	D	S	H	N	N	N	F	6
Cliff Rose	*Purshia stansburiana (=Cowania)*	•	L	6	6	28	E	S	H	N	N	Y	F, P	6
Compact Jojoba	*S. c. 'Vista'*	•	VL, L	4	4	13	E	S, M	H	N	Y	N	F, P	
Compact Texas Ranger	*L. f. 'Compacta'*	•	L	5	5	20	E	S	H	N	Y	Y	F	
Cooper's Wolfberry, Peach Thorn	*Lycium cooperi*	•	L	5	6	28	E	F	H	Y	Y	Y	F, P	6
Creeping Acacia	*Acacia redolens*	•	VL	3	10	79	E	F	H	N	N	N	F	
Creosote Bush	*Larrea tridentata*	•	VL	8	6	28	E	M	H	N	N	Y	F	6
Damianta	*Chrysactinia mexicana*	•	L	2	2	3	E	S, M	M	N	N	N	F	
Desert Almond	*Prunus fasciculata*	•	L	4	4	13	D	M	H	N	N	N	F	6
Desert Broom, Coyote Bush	*Baccharis sarothroides*		L	6	7	38	E	M	H	N	Y	N	F	3, 5, 6
Desert Hackberry	*Celtis pallida*		VL	8	10	79	E	M	H	Y	Y	N	F	
Desert Milkweed	*Asclepias subulata*	•	L	5	5	20	E	S	H	N	Y	Y	F	6
Desert Olive, New Mexico Privet	*Forestiera pubescens (=neomexicana)*	•	L	6	6	28	D	M	H	N	Y	Y	F, P	6
Desert Ruellia	*Ruellia peninsularis*	•	L	4	5	20	S	M	H	N	N	Y	F	
Desert Senna, Desert Cassia	*Senna nemophila (=Cassia)*		L	6	6	28	E	M	H	N	N	N	F, P	4
Devil's River, Orange Daisy	*Wedelia texana* 'Devil's River' *(= Zexmenia)*		L, M	3	3	7	S, D	M	H	N	N	N	F, P	
Easter Egg Eremophila	*Eremophila racemosa*		L	5	5	20	E	M	H	N	Y	Y	F	
Eremophila, Emu Bush	*Eremophila sp.*	•	L	4	4	13	E	M	H	N	Y	Y	F, P	
Feathery Senna, Feathery Cassia	*Senna artemisioides (=Cassia)*	•	VL, L	6	6	28	E	M	H	N	N	Y	F, P	
Fern Bush, Desert Sweet	*Chamaebatiaria millefolium*		L	5	5	20	S	M	M	N	Y	N	F, P	
Fire and Ice Emu Bush	*Eremophila glabra* 'Murchinson River'		L	3	6	28	E	M	H	N	Y	Y	F	

KEY

"Invincible": Tolerant of heat, cold, and wind, water efficient, low-maitenance, non-invasive, pest and disease resistant.
Water Use: **V**ery **L**ow, **L**ow, **M**edium
Height, Width, Coverage at mature growth
Tree Type: **D**eciduous, **E**vergreen, **S**emievergreen
Growth Rate: **S**low, **M**oderate, **F**ast
Drought Tolerance: **L**ow, **M**edium, **H**igh
Exposure: **F**ull sun, **P**artial shade **S**hade

Comments:
1. Organic mulch recommended
2. Many cultivars
3. Species may form dense thickets
4. Not cold hardy below 28°F
5. Invasive Species
6. Mojave native
7. Toxic (parts specified)
8. May be trained as a small tree
9. Needs a protected/ shaded site

Common Name	Botanical Name	"Invincible"	Water Use (VL, L, M)	Average Height (feet)	Average Width (feet)	Coverage (sq. feet)	Tree Type (D, E, S)	Growth Rate (S, M, F)	Drought Tolerance (L, M, H)	Thorns (Yes/No)	Physical Barrier (Yes/ No)	Hedge or Screen (Yes/ No)	Exposure (F, P, S)	Comments
Shrubs Continued														
Fremont's Barberry	*Berberis fremontii*	•	L	6	4	13	E	S	H	Y	Y	Y	F, P	6
Green Cloud Texas Ranger	*L. f.* 'Green Cloud'	•	L	6	6	28	E	S	H	N	Y	Y	F	
Green Lavender Cotton	*Santolina rosmarinifolia (=S. virens)*		L, M	2	3	7	E	M	M	N	N	N	F, P	
Golden Senna	*Cassia candolleana*		VL	6	6	28	E	F	H	N	N	N	F	
Greythorn	*Ziziphus obtusifolia*	•	L	6	8	50	D	S, M	H	Y	Y	Y	F, P	6
Guayacan	*Guaiacum coulteri*		L	5	5	20	S	S, M	M	N	N	Y	F, P	
Houdini Texas Ranger	*Leucophyllum revolutum* 'Houdini'		L	4	4	13	E	S	H	N	Y	Y	F	
Indigo Bush	*Psorothamnus fremontii*	•	VL	3	4	13	D	S	H	N	N	N	F	6
Jojoba	*Simmondsia chinensis*	•	VL, L	6	6	28	E	S, M	H	N	Y	Y	F, P	
Juniper	*Juniperus sp.*		L, M	20	10	79	E	M	M	N	var.	var.	F, P	2
Knifeleaf Acacia	*Acacia cultriformis*		L	10	10	79	E	M	M	N	N	Y	F, P	4
Las Vegas Valley Buckwheat	*Eriogonum corymbosum var. nilesii*	•	VL	3	3	7	D	M	H	N	N	N	F	6
Lavender Cotton	*Santolina chamaecyparissus*		L, M	2	3	7	E	M	M	N	N	N	F, P	
Lavender Spice	*Poliomintha maderensis*		L, M	3	3	7	E, S	M	M	N	N	N	F, P	
Leatherleaf Acacia	*Acacia craspedocarpa*		L	10	15	177	E	S	M	N	N	Y	F	
Littleleaf Sumac	*Rhus microphylla*	•	L	8	12	113	D	M	H	Y	Y	Y	F, P	
Lynn's Legacy Texas Ranger	*Leucophyllum langmaniae* 'Lynn's Legacy'	•	L	5	5	20	E	S	H	N	Y	Y	F	
Mexican Bird of Paradise	*Caesalpinia mexicana*	•	L	12	6	28	D, E	F	H	N	N	N	F, P	2, 7 (seed pods)
Mexican Cliffrose	*Purshia mexicana*	•	L	7	4	13	E	S	M	N	N	N	F	6
Mexican Elderberry	*Sambucus mexicana*	•	L, M	15	15	177	D, S	M, F	H	N	Y	Y	F, P	6, 8
Mexican Flame	*Anisacanthus quadrifidus-wrightii*		L	4	4	13	D	M	H	N	N	Y	F, P	
Mojave Sage	*Salvia mohavensis*	•	VL	3	3	7	E	M	H	N	N	N	F, P	6
Mormon Tea	*Ephedra viridis*	•	L	3	3	7	E	S	H	N	N	N	F	6
Narrowleaf Rosewood	*Vauquelinia corymbosa var. heterodon*	•	L, M	15	15	177	E	M	H	N	Y	Y	F, P	8
Nevada Jointfir	*Ephedra nevadensis*	•	VL	3	3	7	E	M	H	N	N	N	F	6
Nevada Smokebush	*Psorothamnus polydenius*	•	VL	5	4	13	D	S	H	N	N	N	F	6
Orange Jubilee' Tecoma	*Tecoma x* 'Orange Jubilee'		L, M	8	8	50	D,S	F	M	N	N	N	F, P	
Pale Wolfberry	*Lycium pallidum var. heterodon*		L	5	6	28	E	F	H	Y	Y	Y	F, P	
Pineleaf Milkweed	*Asclepias linaria*	•	VL	3	3	7	E	M	H	N	N	N	F	6
Pink Fairy Duster	*Calliandra eriophylla*	•	L	3	3	7	E	S, M	H	N	N	N	F, P	
Pink Indigo Bush	*Dalea pulchra*	•	L	4	5	20	E	M, F	H	N	Y	Y	F	
Purple Orchid Tree	*Bauhinia variegata*		L, M	8	6	28	S	S, M	M	N	Y	Y	F, P	
Purple Rock Rose	*Cistus purpureus*		L	4	4	13	E	F	H	N	N	N	F	
Purple Sage, Desert Sage	*Salvia dorrii*	•	L	2	3	7	E, S	M	H	N	N	N	F, P	6
Quailbush	*Atriplex lentiformis*	•	L	6	8	50	D	M	H	Y	Y	Y	F	6
Rain Cloud Texas Ranger	*Leucophyllum x* 'Rain Cloud'	•	L	5	4	13	E	S	H	N	Y	Y	F	
Red Bird of Paradise	*Caesalpinia pulcherrima*		L	6	6	28	D, E	F	H	Y	N	N	F	2, 7 (seed pods)
Rio Bravo Texas Ranger	*L. l.* 'Rio Bravo'	•	L	6	6	28	E	S	H	N	Y	Y	F	
Saltbush, Desert Holly	*Atriplex hymenelytra*	•	VL	2	2	3	E	S	H	N	N	N	F	6
Sand Sage	*Artemisia filifolia*	•	L	4	3	7	E	M	H	N	N	Y	F	6
Scarlet Sage	*Salvia coccinea*		L, M	3	4	13	S	M	M	N	N	N	F, P	

KEY

"Invincible": Tolerant of heat, cold, and wind, water efficient, low-maitenance, non-invasive, pest and disease resistant.
Water Use: **V**ery **L**ow, **L**ow, **M**edium
Height, Width, Coverage at mature growth
Tree Type: **D**eciduous, **E**vergreen, **S**emievergreen
Growth Rate: **S**low, **M**oderate, **F**ast
Drought Tolerance: **L**ow, **M**edium, **H**igh
Exposure: **F**ull sun, **P**artial shade **S**hade

Comments:
1. Organic mulch recommended
2. Many cultivars
3. Species may form dense thickets
4. Not cold hardy below 28°F
5. Invasive Species
6. Mojave native
7. Toxic (parts specified)
8. May be trained as a small tree
9. Needs a protected/ shaded site

Common Name	Botanical Name	"Invincible"	Water Use	Average Height	Average Width	Coverage	Tree Type	Growth Rate	Drought Tolerance	Thorns	Physical Barrier	Hedge or Screen	Exposure	Comments
			VL, L, M	(feet)	(feet)	(sq. feet)	D, E, S	S, M, F	L, M, H	Yes/No	Yes/ No	Yes/ No	F, P, S	
Shrubs Continued														
Scrub Live Oak	*Quercus turbinella*	•	L	6	6	28	E	S	H	Y	Y	Y	F, P, S	6
Shadscale	*Atriplex confertifolia*	•	VL	2	3	7	D	F	H	Y	N	N	F	6
Shrubby Cassia	*Senna wislizenii (=Cassia)*		L	8	6	28	D	M	H	N	N	N	F, P	
Shrubby Jerusalem Sage	*Phlomis fruiticosa*		L, M	3	3	7	E	M	M	N	N	N	F, P	1
Sierra Bouquet Texas Ranger	*Leucophyllum pruinosum* 'Sierra Bouquet'	•	L	6	6	28	E	S	H	N	Y	Y	F	
Silver Cloud Texas Ranger	*Leucophyllum candidum* 'Silver Cloud'	•	L	5	5	20	E	S	H	N	Y	Y	F	
Silver Dalea	*Dalea bicolor* 'argyraea'	•	L	3	3	7	E	F	H	N	N	N	F	
Silvery Senna, Silver Leaf Cassia	*Senna phyllodinea (=Cassia)*		L	6	6	28	E	M	H	N	N	N	F, P	4
Slender Fuchsia	*Eremophila decipiens*		L	3	3	7	E	M	H	N	Y	Y	F, P	
Snakeweed	*Gutierrezia sarothrae*	•	VL	2	2	3	S	M	H	N	N	N	F, P	6
Spiny Senna	*Senna armata (=Cassia)*	•	VL	3	4	13	D	M	H	Y	N	N	F	6
Spotted Emu Bush	*Eremophila maculata*		L	6	6	28	E	S	H	N	Y	Y	F, P	
Summertime Blue Emu Bush	*Eremophila x* 'Summertime Blue' *(polyclada)*		L	6	10	79	E	F	H	N	Y	Y	F	
Sunrise' Tecoma	*Tecoma x* 'Sunrise'™		L, M	8	8	50	D, S	F	M	N	N	N	F, P	
Sweet Bush	*Bebbia juncea*	•	L	3	3	7	S	M	H	N	N	N	F	6
Texas Ranger, Texas Sage, Cenizo	*Leucophyllum frutescens*	•	L	6	6	28	E	S	H	N	Y	Y	F	
Thompson Broom	*Baccharis x* 'Starn' *(male hybrid)*		L	3	5	20	E	M	H	N	N	N	F	
Thunder Cloud Texas Ranger	*L. c.* 'Thunder Cloud'	•	L	3	4	13	E	S	H	N	Y	Y	F	
Thurber's Desert Honeysuckle	*Anisacanthus thurberi*		L	6	6	28	D	M	M	N	N	N	F, P	
Turpentine Broom	*Thamnosma montana*	•	VL	2	2	3	D	S	H	N	N	N	F	6
Turpentine Bush	*Ericameria laricifolia*	•	VL	2	3	7	D	S	H	N	N	N	F	
Utah Butterfly Bush	*Buddleja utahensis*	•	L	2	2	3	E	M	H	N	N	N	F, P	6
Valentine Emu Bush	*E. m.* 'Valentine'		L	4	5	20	E	M	H	N	Y	Y	F	
Velvet-leaf Mallow	*Abutilon palmeri*		L, M	4	4	13	E, S	M	M	N	N	N	F, P	
Velvet-leaf Senna	*Senna lindheimeriana (=Cassia)*	•	L	3	3	7	E	M	H	N	N	N	F, P	
Virgin River Brittlebush	*Encelia virginensis*	•	VL	2	2	3	S	M	H	N	N	N	F	6
Weeping Dalea	*Dalea versicolor v. sessilis*		L	3	4	13	E	M	M	N	N	Y	F, P	
White Bursage	*Ambrosia dumosa*	•	L	2	4	13	E	F	H	N	N	N	F	6
White Cloud Texas Ranger	*L. f.* 'White Cloud'	•	L	6	6	28	E	S	H	N	Y	Y	F	
White Plumbago	*Plumbago scandens*		L	3	3	7	E	F	M	N	N	Y	P, S	
Wild Buckwheat	*Eriogonum fasciculatum*	•	L	2	3	7	E	F	H	N	N	N	F	6
Winter Gold Emu Bush	*E. m.* 'Winter Gold'		L	4	6	28	E	M	H	N	Y	Y	F, P	
Winterfat	*Krascheninnikovia lanata*	•	VL	2	3	7	E	F	H	N	N	N	F	6
Wolf Berry	*Lycium andersonii*	•	VL	6	4	13	D	M	H	Y	N	Y	F	6
Wooly Bursage	*Ambrosia eriocentra*	•	L	3	3	7	E	M	H	N	N	N	F, P	6
Wooly Butterfly Bush	*Buddleja marrubifolia*	•	L	5	5	20	E	F	H	N	Y	Y	F, P	
Yellow Bird of Paradise	*Caesalpinia gilliesii*		L	8	6	28	D, E	F	H	N	N	N	F	2, 7 (seed pods)
Yellow Rabbit Brush	*Chrysothamnus viscidiflorus*	•	L	3	3	7	D	M	H	N	N	N	F	
Yellow Bush Snapdragon	*Keckellia antirrhinoides*	•	L	4	4	13	S	M	H	N	N	Y	F, P	6
Yellow Trumpet Flower	*Tecoma stans*		L, M	8	8	50	S	F	M	N	N	N	F, P	2, 8
Yerba Santa	*Eriodictyon angustifolium*	•	L	3	3	7	E	M	H	N	N	N	F, P	6

KEY

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Water Use: Very Low, Low, Medium
Height, Width, Coverage at mature growth
Tree Type: Deciduous, Evergreen, Semievergreen
Growth Rate: Slow, Moderate, Fast
Drought Tolerance: Low, Medium, High
Exposure: Full sun, Partial shade Shade

Comments:
1. Organic mulch recommended
2. Many cultivars
3. Species may form dense thickets
4. Not cold hardy below 28°F
5. Invasive Species
6. Mojave native
7. Toxic (parts specified)
8. May be trained as a small tree
9. Needs a protected/ shaded site

Common Name	Botanical Name	"Invincible"	Water Use	Average Height	Average Width	Coverage	Tree Type	Growth Rate	Drought Tolerance	Thorns	Physical Barrier	Hedge or Screen	Exposure	Comments
			VL, L, M	(feet)	(feet)	(sq. feet)	D, E, S	S, M, F	L, M, H	Yes/No	Yes/ No	Yes/ No	F, P, S	
Groundcovers														
Bush Morning Glory	*Convolvulus cneorum*		L	2	4	13	E	F	M	N	N	N	F	
Desert Carpet Creeping Acacia	*Acacia redolens* ' Desert Carpet'	•	VL	2	12	113	E	S, M	H	N	N	N	F	
Desert Sand Verbena	*Abronia villosa*	•	L	1	2	3	D	M	H	N	N	N	F	6
Dwarf Coyote Brush	*Baccharis pilularis* ' Pigeon Point'	•	L	1	8	50	E	F	L	N	N	N	F	
Four O'Clock	*Mirabilis multiflora*	•	L	2	2	3	D	F	H	N	N	N	F, P	6
Goodding Verbena	*Glandularia gooddinggii (=Verbena)*	•	L	1	3	7	D	M	H	N	N	N	F	6
Goosefoot Mallow	*Sphaeralcea grossulariifolia*	•	VL	2	4	13	E	F	H	N	N	N	P	6
Ground Morning Glory	*Convolvulus mauritanicus*		L	1	3	7	P	F	M	N	N	N	F	
Moss Verbena	*Glandularia pulchella (= Verbena)*		L, M	1	3	7	E	M	L	N	N	N	F, P	
Peruvian Verbena	*Glandularia peruviana (=Verbena)*		L	1	2	3	D	F	L	N	N	N	P	
Prostate Indigo Bush	*Dalea greggii*	•	L	1	8	50	E	F	H	N	N	N	F	
Rock Verbena	*Glandularia tenera (=Verbena)*		L	1	2	3	P	F	L	N	N	N	P	
Sandpaper Verbena	*Verbena rigida*		L	1	3	7	P	F	L	N	N	N	F	
Sierra Gold Dalea	*Dalea capitata* ' Sierra Gold'	•	L	1	3	7	D	F	H	N	N	N	F	
Sierra Sundrop	*Calylophus hartwegii*		L	1	2	3	D	F	H	N	N	N	F	
Silver Dichondra, Kidneyweed	*Dichondra argentea* ' Silver Falls'		L	1	3	7	S	F	M	N	N	N	F, P	
Spurge, Gopher Plant	*Euphorbia rigida*	•	L	2	3	7	E	F	H	N	N	N	F	
Vines														
Arizona Grape Ivy	*Cissus trifoliata var. incisa*		L, M	10	5	20	S	M	M	N	N	N	P, S	
Canyon Grape	*Vitis arizonica*	•	L	10	10	79	D	M	M	N	N	N	F	6
Cape Honeysuckle	*Tecomaria capensis*		L	8	5	20	E	M	L	N	N	Y	F, P	4
Cat's Claw Vine	*Macfadyena unguis-cati*		L	15	10	79	S	M	L	N	N	Y	F, P	3
Hacienda Creeper	*Parthenocissus sp.* ' Hacienda Creeper'		L, M	15	10	79	D	F	M	N	N	N	F, P	
Pink Trumpet Vine	*Podranea ricasoliana*		L	20	10	79	S	M	M	N	N	Y	F, P	
Snapdragon Vine	*Maurandya antirrhiniflora*		L	8	5	20	D	M	M	N	N	N	F, P	6
Yucca Vine	*Merremia aurea*		L	10	10	79	D	M	M	N	N	N	F, P	
Agaves, Cacti, Succulents, and Yuccas														
Adam's Needle	*Yucca filamentosa*		L	3	3	7	E	M	H	Y	Y	N	F, P	
African Aloe	*Aloe saponaria*		L	2	1	1	E	M	M	Y	N	N	P	
Agave Ocahui	*Agave ocahui*		VL	2	3	7	E	S	H	Y	Y	N	F	
Aloe Vera	*Aloe barbadensis*		L	2	2	3	E	S, M	M	Y	N	N	F, P	
Artichoke Agave	*A. p. var. truncata*		VL	3	3	7	E	S, M	H	Y	N	N	F, P	
Australis Yucca	*Yucca australis*		L	30	10	79	E	S	H	Y	N	N	F	
Banana Yucca	*Yucca baccata*	•	L	4	6	28	E	S	H	Y	Y	N	F, P	6
Beaked Yucca	*Yucca rostrata*	•	L	10	3	7	E	S, M	H	Y	N	N	F	
Bear Grass	*Nolina microcarpa*	•	L	4	5	20	E	M	H	N	N	Y	F	
Beavertail Cactus	*Opuntia basilaris*	•	L	1	4	13	E	M	H	Y	Y	N	F	6
Beehive Cactus	*E. v. var. bisbeena*	•	L	1	1	1	E	S, M	H	Y	N	N	F, P	
Bell-flowered Hesperaloe	*Hesperaloe campanulata*		L	3	3	7	E	M	H	N	N	Y	F, P	
Bigelow's Nolina	*Nolina bigelovii*	•	L	6	4	13	E	M	H	N	N	Y	F	6
Black Spine Prickly Pear	*Opuntia macrocentra*	•	L	4	3	8	E	M	H	N	Y	N	F	

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Drought Tolerance: Low, Medium, High
Exposure: Full sun, Partial shade Shade

Comments:
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Common Name	Botanical Name	"Invincible"	Water Use VL, L, M	Average Height (feet)	Average Width (feet)	Coverage (sq. feet)	Tree Type D, E, S	Growth Rate S, M, F	Drought Tolerance L, M, H	Thorns Yes/No	Physical Barrier Yes/ No	Hedge or Screen Yes/ No	Exposure F, P, S	Comments
Agaves, Cacti, Succulents, and Yuccas Continued														
Blue Myrtle Cactus	*Myrtillocactus geometrizans*		L	15	10	79	E	M	H	Y	Y	N	F	
Blue Nolina	*Nolina nelsonii*	•	L	5	5	20	E	M	H	N	N	Y	F	
Blue Yucca	*Yucca rigida*	•	L	12	3	7	E	M	H	Y	N	N	F	
Bristly Prickly Pear	*O. e. acicularis*	•	L	8	10	79	E	M	H	Y	Y	N	F, P	
Buckhorn Cholla	*Cylindropuntia acanthocarpa (=Opuntia)*	•	L	6	6	28	E	M	H	Y	Y	N	F	6
Bunny Ears	*Opuntia microdasys*	•	L	3	5	20	E	M	H	Y	Y	N	F	
Cabbage Head Agave	*Agave parrasana*		L	2	2	3	E	S	H	Y	Y	N	F, P	
Cacti	*Trichocereus sp (= Echinopsis)*		L	15	3	7	E	M	H	Y	N	N	F	
Candelilla	*Euphorbia antisyphilitica*	•	VL	1	2	3	E	M	H	N	N	N	F, P	
Cardon Grande	*Trichocereus terscheckii*		L	15	8	79	E	M	H	Y	Y	N	F	
Century Plant	*Agave americana*		L	5	8	50	E	M	H	Y	Y	N	F	
Chahuiqui	*Agave multifilifera*		L, M	3	4	13	E	S	M	Y	Y	N	F, P	
Chain-fruit Cholla, Jumping Cactus	*Cylindropuntia fulgida (=Opuntia)*		L	8	5	20	E	M	H	Y	Y	N	F	
Claret Cup	*Echinocereus triglochidiatus*	•	L	1	2	3	E	S, M	H	Y	N	N	F	6
Common Pincushion	*Escobaria vivipara (=Coryphantha)*	•	L	1	1	1	E	S, M	H	Y	N	N	F, P	6
Compass Barrel Cactus	*Ferocactus acanthodes (=Cylindraceus)*	•	L	6	2	3	E	S	H	Y	N	N	F	6
Constricta Yucca	*Yucca constricta*		L	4	3	7	E	S	H	Y	N	N	F	
Cottontop Cactus	*Echinocactus polycephalus*	•	VL	2	3	7	E	S	H	Y	N	N	F	6
Cowhorn Agave	*Agave bovicornuta*		L	4	4	13	E	F	H	Y	N	N	P	
Cow's Tongue, Angel's Wing Cactus	*O. e. linguiformis*	•	L	6	8	50	E	M	H	Y	Y	N	F	
Dawe's Aloe	*Aloe dawei*	•	VL	2	3	7	E	M	H	Y	N	N	F, P	
Desert Spoon	*Dasylirion wheeleri*	•	L	5	6	28	E	M	H	Y	Y	N	F	
Diamond Cholla	*Cylindropuntia ramosissima (=Opuntia)*	•	L	3	5	20	E	S, M	H	Y	Y	N	F	6
Durango Delight Agave	*Agave schidigera* ' Durango Delight'™		L	2	3	7	E	F	H	Y	Y	N	F, P	
Elephant's Food	*Portulacaria afra*		L	3	4	13	E	M	M	N	N	Y	P, S	
Englemann's Prickly Pear	*Opuntia engelmannii*	•	L	6	6	28	E	S, M	H	Y	Y	N	F, P	6
Ferox Agave	*Agave salmiana ssp. ferox*		L, M	6	8	50	E	S, M	M	Y	Y	N	F, P	
Fishhook Barrel Cactus	*Ferocactus wislizeni*	•	L	6	2	3	E	S, M	H	Y	N	N	F	
Giant Sword Flower	*Hersperaloe funifera*	•	L	6	6	28	E	M	H	N	N	Y	F	
Gold Tooth Aloe	*Aloe nobilius*		L	1	1	1	E	S, M	M	Y	N	N	F, P	
Golden Barrel	*Echinocactus grusonii*		L	2	3	7	E	M	H	Y	Y	N	F	
Golden Torch Cactus	*Trichocereus spachianus (= Echinopsis)*		L	6	3	7	E	S, M	H	Y	N	N	F, P	2
Green Desert Spoon	*Dasylirion acrotriche*	•	L	5	6	28	E	M	H	Y	Y	N	F	
Green Spider Agave	*Agave bracteosa*		L	1	1	1	E	S	H	N	N	N	F, P	
Harriman's Yucca	*Yucca harrimaniae*	•	L	1	1	1	E	S	H	Y	N	N	F	
Havard Agave	*Agave havardiana*		L	3	4	13	E	M	H	Y	Y	N	F, P	
Huachuca Agave	*A. p. var. huachucensis*		L	2	3	7	E	S	H	Y	N	N	F, P	
Indian Fig Cactus	*Opuntia ficus-indica*	•	L	15	10	79	E	M, F	M	Y/N	Y	Y	F	
Joshua Tree	*Yucca brevifolia*	•	L	15	10	79	E	S	H	Y	N	N	F	6
Mescal Ceniza	*Agave colorata*		L	3	3	7	E	M	H	Y	Y	N	F	
Medio Picta Century Plant	*A. a. var. medio-picta*		L	4	6	28	E	S	H	Y	Y	N	F	

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Common Name	Botanical Name	"Invincible"	Water Use	Average Height	Average Width	Coverage	Tree Type	Growth Rate	Drought Tolerance	Thorns	Physical Barrier	Hedge or Screen	Exposure	Comments
			VL, L, M	(feet)	(feet)	(sq. feet)	D, E, S	S, M, F	L, M, H	Yes/No	Yes/ No	Yes/ No	F, P, S	
Agaves, Cacti, Succulents, and Yuccas Continued														
Mexican Fencepost	*Pachycereus marginatus*	•	VL	10	6	28	E	F	H	Y	Y	N	F	
Mojave Prickly Pear	*Opuntia phaeacantha*	•	L	3	6	28	E	S	H	Y	Y	N	F	6
Mojave Yucca	*Yucca schidigera*	•	L	8	8	50	E	S	H	Y	N	N	F	6
Mountain Agave	*Agave montana*		L	4	5	20	E	S	H	Y	Y	N	F, P	
Mountain Yucca	*Yucca schottii*		L	12	5	20	E	S, M	H	Y	N	N	F, P	
Muphey's Agave	*Agave murpheyi*		L	3	3	7	E	M	H	Y	N	N	F	
Nevada Agave	*Agave utahensis ssp. nevadensis*	•	VL	1	1	1	E	S	M	Y	N	N	F, P	6
New Mexico Agave	*A. p. var. neomexicana*		L, M	1	2	3	E	S	H	Y	Y	N	F	
Night Blooming Yucca	*Hesperaloe nocturna*	•	L	5	6	28	E	M	H	N	N	Y	F, P	
Ocotillo	*Fouquieria splendens*	•	L	12	6	28	D	S	H	Y	Y	N	F, P	6
Old Man Of The Andes	*Oreocereus celsianus*		L	6	2	3	E	M	H	Y	N	N	F, P	
Old Man Prickly Pear	*Opuntia erinacea 'erinacea'*	•	L	2	3	7	E	S, M	H	Y	Y	N	F	6
Orange Tuna Cactus	*Opuntia riviereana*	•	L	5	8	50	E	M	H	Y	Y	N	F	
Our Lord's Candle, Chaparral Yucca	*Yucca whipplei*	•	L	3	6	28	E	S	H	Y	Y	N	F	6
Pale Leaf Yucca	*Yucca pallida*		L	1	2	3	E	S	H	Y	N	N	F	
Palm Yucca	*Yucca faxoniana*	•	L	12	6	28	E	S	H	Y	N	N	F	
Palmer's Agave	*Agave palmeri*		L	3	3	7	E	S	H	Y	Y	N	F	
Pancake Prickly Pear	*Opuntia chlorotica*	•	L	4	5	20	E	M	H	Y	Y	N	F	6
Paper Spine Cactus	*Tephrocactus articulatus*		L	1	3	7	E	S	M	Y	Y	N	F, P	
Paraguay Cactus	*Opuntia paraguayensis*		L	6	4	13	E	M	M	Y	Y	N	F, P	
Parry's Agave	*Agave parryi*		L	3	3	7	E	S	H	Y	Y	N	F	
Pencil Cholla	*Cylindropuntia arbuscula (=Opuntia)*	•	L	8	3	7	E	M	H	Y	Y	N	F	
Peruvian Apple	*Cereus hildmannianus (= peruvianus)*		L	8	3	7	E	M	H	Y	Y	N	F	4
Pincushion, Fishhook Cactus	*Mammillaria tetrancistra*	•	L	1	1	1	E	S, M	H	Y	N	N	F, P	6
Pine Cone Prickly Pear, Paper Spine	*Opuntia turpinii (= Tephrocactus)*	•	L	1	2	3	E	M	H	N	N	N	P	
Purple Prickly Pear, Purple Pancake	*Opuntia santa rita 'Tubac' (= O. violacea)*	•	L	4	6	28	E	M	H	Y	Y	N	F	
Queen of the Night	*Cereus hildmannianus*	•	VL	15	10	79	E	F	H	Y	Y	N	F	
Queen Victoria Agave	*Agave victoriae-reginae*	•	L	2	2	3	E	S	H	Y	N	N	F	
Red Yucca	*Hesperaloe parviflora*	•	L	3	3	7	E	M	H	N	N	Y	F	
Rough-Leaved Agave	*Agave scabra*		L	4	4	13	E	S	H	Y	Y	N	F	
Saguaro (spear)	*Carnegiea gigantea*		L	12	2	3	E	S	H	Y	Y	N	F	
Saguaro (with arms)	*Carnegiea gigantea*		L	20	6	28	E	S	H	Y	Y	N	F	
San Pedro Cactus	*Trichocereus pachanoi (= Echinopsis)*		L	8	6	28	E	M	H	Y	N	N	F	
Senita	*Lophocereus schottii*	•	VL	10	10	79	E	S	H	Y	Y	N	F	
Silver Cholla	*Cylindropuntia echinocarpa (=Opuntia)*	•	L	3	4	13	E	M	H	Y	Y	N	F	6
Silver Dollar Cactus	*Opuntia robusta*	•	L	18	10	79	E	M	H	Y	Y	N	F	
Slipper Flower	*Pedilanthus macrocarpus*	•	VL	3	3	7	E	M	H	N	N	N	F, P	
Smooth Agave	*Agave desmettiana*		L	3	3	7	E	F	H	Y	Y	N	F, P	
Soaptree Yucca	*Yucca elata*	•	L	10	8	50	E	S	H	Y	N	N	F, P	
Soapweed, Narrowleaf Yucca	*Yucca glauca*		L	3	4	13	E	S	H	Y	Y	N	F	
Spanish Bayonet	*Yucca aloifolia*		L	8	8	50	E	S	H	Y	Y	N	F	

KEY

"Invincible": Tolerant of heat, cold, and wind, water efficient, low-maitenance, non-invasive, pest and disease resistant.
Water Use: Very Low, Low, Medium
Height, Width, Coverage at mature growth
Tree Type: Deciduous, Evergreen, Semievergreen
Growth Rate: Slow, Moderate, Fast
Drought Tolerance: Low, Medium, High
Exposure: Full sun, Partial shade Shade

Comments:
1. Organic mulch recommended
2. Many cultivars
3. Species may form dense thickets
4. Not cold hardy below 28°F
5. Invasive Species
6. Mojave native
7. Toxic (parts specified)
8. May be trained as a small tree
9. Needs a protected/ shaded site

Common Name	Botanical Name	"Invincible"	Water Use	Average Height	Average Width	Coverage	Tree Type	Growth Rate	Drought Tolerance	Thorns	Physical Barrier	Hedge or Screen	Exposure	Comments
			VL, L, M	(feet)	(feet)	(sq. feet)	D, E, S	S, M, F	L, M, H	Yes/No	Yes/ No	Yes/ No	F, P, S	
Agaves, Cacti, Succulents, and Yuccas Continued														
Spanish Dagger	*Yucca gloriosa*		L	10	8	50	E	S, M	H	N	N	N	F, P	
Spider Aloe	*Aloe x spinosissima*		L	3	3	7	E	S	H	Y	N	N	P	
Staghorn Cholla	*Cylindropuntia versicolor (=Opuntia)*	•	L	6	5	20	E	M	H	Y	Y	N	F	
Stick Palm	*Dasylirion longissimum*	•	L	8	6	28	E	M	H	Y	Y	N	F	
Strawberry Hedgehog	*Echinocereus engelmannii*	•	L	1	3	7	E	S	H	Y	N	N	F	6
Tap Aloe, Cape Aloe	*Aloe ferox*		L	6	5	20	E	S	M	Y	N	N	F, P	4
Teddy Bear Cholla	*Cylindropuntia bigelovii (=Opuntia)*	•	L	6	4	13	E	M	H	Y	Y	N	F	6
Texas Bear Grass	*Nolina texana*	•	L	3	3	7	E	M	H	N	N	Y	F	
Thompson's Yucca	*Yucca thompsoniana*		L	10	8	50	E	S	H	Y	Y	N	F	
Thread-leaf Agave	*Agave filifera*		L	2	2	3	E	M	H	Y	Y	N	F, P	
Torrey Yucca	*Yucca torreyi*		L	15	6	28	E	S	H	Y	Y	N	F	
Totem Pole	*Lophocereus schottii f. monstrosus*	•	VL	10	10	79	E	S	H	N	N	N	F	
Tree Aloe	*Aloe arborescens*		L	6	6	28	E	S	M	Y	N	N	F, P	4
Treebear Grass	*Nolina matapensis*	•	L	12	6	28	E	M	H	N	N	Y	F	
Twin-Flowered Agave	*Agave geminiflora*		L	3	4	13	E	M	H	Y	Y	N	F	
Twisted Yucca	*Yucca rupicola*	•	L	2	3	7	E	S	H	N	N	N	F, P	
Variegated Agave	*Agave angustifolia var. marginata*		L	3	3	7	E	S	H	Y	Y	N	F, P	
Weber Agave	*Agave weberi*		L	5	8	50	E	M, F	H	Y	Y	N	F, P	
Weeping Yucca	*Yucca recurvifolia*		L	6	6	28	E	S	H	Y	N	N	F, P	
Whale's Tongue Agave	*Agave ovatifolia*		L	3	4	13	E	S, M	H	Y	Y	N	F, P	
Yellow Margin Century Plant	*A. a. var. aurea-marginata*		L	4	5	20	E	S	H	Y	Y	N	F, P	
Yellow Yucca	*H. p.* 'Yellow'	•	L	3	3	7	E	M	H	N	N	Y	F	
Ornamental Grasses														
Alkali Sacaton Grass	*Sporobolus airoides*	•	L	4	2	3	D	M	M	N	N	N	F	6
Bamboo Muhly	*Muhlenbergia dumosa*		L, M	4	4	13	E, S	M,F	M	N	N	N	F, P	
Big Galleta Grass	*Pleuraphis rigida (= Hilaria rigida)*	•	VL	3	2	3	S	F	H	N	N	N	F	6
Blue Grama Grass	*Bouteloua gracilis*	•	VL	2	2	3	E	F	H	N	N	N	F	6
Desert Needlegrass	*Achnatherum speciosum*	•	VL	1	1	1	D	F	H	N	N	N	F	6
Indian Ricegrass	*Achnatherum hymenoides (=Oryzopsis)*	•	VL	1	1	1	D	F	H	N	N	N	F	6
Pink Muhly	*Muhlenbergia capillaris*		L	3	3	7	D	F	M	N	N	N	F, P	
Side-Oats Grama	*Bouteloua curtipendula*	•	L	2	2	3	D	F	H	N	N	N	F, P	6
Perennials (Small Accent Areas Only)														
Angelita Daisy	*Tetraneuris acaulis (=Hymenoxys)*	•	L, M	1	1	1	E	M	M	N	N	N	F, P	
Arizona Poppy, Orange Caltrop	*Kallstroemia grandiflora*		L	1	1	1	S	F	M	N	N	N	F	
Blackfoot Daisy	*Melampodium leucanthum*		L	1	2	3	S	M	M	N	N	N	F, P	
Blue Flax	*Linum lewisii*		L	2	1	1	D	M	M	N	N	N	F	6
Bridge Penstemon	*Penstemon rostriflorus*		L	2	1	1	E	M	HM	N	N	N	F, P	6
California Poppy	*Eschscholzia californica*		L	1	1	1	D	F	H	N	N	N	F	6
Canyon Penstemon	*Penstemon pseudospectabilis*	•	L	2	4	13	E	F	H	N	N	N	F	
Chocolate Flower	*Berlandiera lyrata*	•	L	1	2	3	E	F	H	N	N	N	F, P	
Desert Alyssum	*Lepidium fremontii*	•	VL	2	2	3	D	F	H	N	N	N	F	6

KEY

"Invincible": Tolerant of heat, cold, and wind, water efficient, low-maitenance, non-invasive, pest and disease resistant.
Water Use: <u>V</u>ery <u>L</u>ow, <u>L</u>ow, <u>M</u>edium
Height, Width, Coverage at mature growth
Tree Type: <u>D</u>eciduous, <u>E</u>vergreen, <u>S</u>emievergreen
Growth Rate: <u>S</u>low, <u>M</u>oderate, <u>F</u>ast
Drought Tolerance: <u>L</u>ow, <u>M</u>edium, <u>H</u>igh
Exposure: <u>F</u>ull sun, <u>P</u>artial shade <u>S</u>hade

Comments:
1. Organic mulch recommended
2. Many cultivars
3. Species may form dense thickets
4. Not cold hardy below 28°F
5. Invasive Species
6. Mojave native
7. Toxic (parts specified)
8. May be trained as a small tree
9. Needs a protected/ shaded site

Common Name	Botanical Name	"Invincible"	Water Use	Average Height	Average Width	Coverage	Tree Type	Growth Rate	Drought Tolerance	Thorns	Physical Barrier	Hedge or Screen	Exposure	Comments
			VL, L, M	(feet)	(feet)	(sq. feet)	D, E, S	S, M, F	L, M, H	Yes/No	Yes/ No	Yes/ No	F, P, S	
Perennials (Small Accent Areas Only) Continued														
Desert Bluestar	*Amsonia tomentosa*	•	VL	1	1	1	D	M	H	N	N	N	F	6
Desert Marigold	*Baileya multiradiata*	•	L	1	2	3	D	M	H	N	N	N	F	6
Desert Prince's Plume	*Stanleya pinata*	•	VL	4	3	7	D	F	H	N	N	N	F	6
Desert Zinnia	*Zinnia acerosa*	•	L	1	1	1	D	F	H	N	N	N	F, P	
Dwarf Morning Glory	*Convolvulus tricolor*		L	1	2	3	D	F	L	N	N	N	F, P	
Fern Leaf Yarrow	*Achillea filipendulina*		L	3	3	7	E	F	M	N	N	N	F	2
Firecracker Penstemon	*Penstemon eatonii*	•	L	3	2	3	E	M	H	N	N	N	F, P	6
Globe Mallow	*Sphaeralcea ambigua*	•	L	3	3	7	S	F	H	N	N	N	F, P	2, 6
Golden Dogbane	*Thymophylla pentachaeta (=Dyssodia)*	•	VL	1	2	3	E	F	H	N	N	N	F	6
Goldeneye	*Viguiera parishii (=deltoidea)*	•	VL	3	3	7	S	M	H	N	N	N	F	6
Hummingbird Flower	*Epilobium canum (=Zauschneria californica)*		L	3	4	13	D	M	M	N	N	N	F, P	3
Lippia	*Lippia repens*		L	1	2	3	S	M	M	N	N	N	F, P	
Mexican Blue Penstemon	*Penstemon amphorellae*		L, M	1	2	3	S	M	M	N	N	N	F, P	
Mojave Aster	*Xylorhiza tortifolia*	•	VL	1	1	1	D	M	H	N	N	N	F	6
Native Fleabane	*Erigeron divergens*	•	VL	1	3	7	E	F	H	N	N	N	F, P	6
Paper Flower	*Psilostrophe cooperi*	•	L	2	3	7	D	F	H	N	N	N	F, P	6
Parry's Penstemon	*Penstemon parryi*	•	L	2	3	7	E	F	H	N	N	N	F, P	
Pinto Beardtongue	*Penstemon bicolor*	•	VL	2	2	3	E	F	H	N	N	N	F	6
Powis Castle Wormwood	*Artemisia x 'Powis Castle'*	•	L	2	3	7	E	F	M	N	N	N	F, P	
Prarie Sage	*Artemisia ludoviciana*	•	L	3	3	7	D	F	M	N	N	N	F, P	6
Prarie Zinnia	*Zinnia grandiflora*		L	1	1	1	D	F	H	N	N	N	F, P	
Preuss' Milkvetch	*Astragalus preussii*	•	VL	2	2	3	D	F	H	N	N	N	F	6
Rosy Two-tone Beardtongue	*P. b. ssp.roseus*	•	L	2	2	3	S	F	H	N	N	N	F, P	6
Russian Sage	*Perovskia atriplicifolia*	•	L	3	2	3	D	M	H	N	N	N	F, P	
Scarlet Bugler	*Penstemon barbatus*		L	4	2	3	E	M	M	N	N	N	F, P	
Scarlet Gaura	*Gaura coccinea*	•	L	1	2	3	D	F	H	N	N	N	F, P	6
Scented Penstemon	*Penstemon palmeri*	•	VL	4	2	3	E	F	H	N	N	N	F	6
Silver King Artemisia	*A. l. albula 'Silver King'*	•	L	3	3	7	D	F	M	N	N	N	F, P	
Silverleaf Sunray	*Enceliopsis argophylla*	•	VL	1	1	1	S	F	H	N	N	N	F	6
Skyrocket	*Ipomopsis arizonica (=Gilia aggregata)*	•	L	2	1	1	E	F	H	N	N	N	F, P	6
Superb Penstemon	*Penstemon superbus*		L, M	4	3	7	E	F	M	N	N	N	F, P	
Texas Tuberose	*Manfreda maculosa*		L, M	1	1	1	D	S, M	M	N	N	N	P, S	
Wild Petunia	*Ruellia brittoniana*		L	2	3	7	E	F	H	N	N	N	F, P	5
Wooly Paper Flower	*Psilostrophe tagetina*	•	L	2	3	7	D	F	H	N	N	N	F, P	

KEY

"Invincible": Tolerant of heat, cold, and wind, water efficient, low-maitenance, non-invasive, pest and disease resistant.

Water Use: **V**ery **L**ow, **L**ow, **M**edium

Height, Width, Coverage at mature growth

Tree Type: **D**eciduous, **E**vergreen, **S**emievergreen

Growth Rate: **S**low, **M**oderate, **F**ast

Drought Tolerance: **L**ow, **M**edium, **H**igh

Exposure: **F**ull sun, **P**artial shade **S**hade

Comments:

1. Organic mulch recommended
2. Many cultivars
3. Species may form dense thickets
4. Not cold hardy below 28°F
5. Invasive Species
6. Mojave native
7. Toxic (parts specified)
8. May be trained as a small tree
9. Needs a protected/ shaded site

Common Name	Botanical Name	"Invincible"	Water Use	Average Height	Average Width	Coverage	Tree Type	Growth Rate	Drought Tolerance	Thorns	Physical Barrier	Hedge or Screen	Exposure	Comments
			VL, L, M	(feet)	(feet)	(sq. feet)	D, E, S	S, M, F	L, M, H	Yes/No	Yes/ No	Yes/ No	F, P, S	
Plants With Special Needs (Not Suitable For All Locations)														
Desert Lavender	*Hyptis emoryi*		L	6	6	28	S	S, M	H	N	N	N	F, P	4, 6
Green Bush Daisy	*E. p. 'Viridis'*		L	3	3	7	E	F	H	N	N	Y	F	1
Old Man Cactus	*Cephalocereus senilis*		L	6	4	13	E	S	M	Y	Y	N	P	4
Organ Pipe Cactus	*Stenocereus thurberi*		L	10	3	7	E	S	H	Y	Y	N	F, P	4
Yellow Bush Daisy	*Euryops pectinatus*		L	3	3	7	E	F	H	N	N	Y	F	1

References:

Arizona Municipal Water Users Association Plant Guide: http://www.amwua.org/plants/

Garden Oracle Plant List: http://gardenoracle.com/plantlist.html

Southern Nevada Water Authority Landscapes Plant List: https://www.snwa.com/assets/pdf/wsl_plantlist.pdf

United States Department of Agriculture Plants Database: http://plants.usda.gov/

University of Arizona Arid Plant List: http://ag.arizona.edu/pima/gardening/aridplants/aridplant_botindex.html

Wildflower Center Native Plant Database: https://www.wildflower.org/plants/

When recorded return to:
Lake Havasu City
ATTN: City Clerk
2330 McCulloch Blvd. N
Lake Havasu City, AZ 86403

LAKE HAVASU CITY

Development Services Department

2330 McCulloch Boulevard North, Lake Havasu City, AZ 86403
928.453.4148 ♦ www.lhcaz.gov

STORMWATER MANAGEMENT/BMP FACILITIES MAINTENANCE AGREEMENT

This Stormwater Management/BMP Facilities Maintenance Agreement ("Agreement"), is made and entered into this _________day of _________________, 20_____, by and between ____ ("Landowner,") and Lake Havasu City, Arizona ("City").

Recitals:

Property: Landowner is the owner of certain property described as:

Parcel Number
____,

Physical Address
____ as recorded by deed in the last land records of Mohave County, Arizona ("Property").

Plan: Landowner is proceeding to build on and develop the Property, known as:

Name of Plan/Development ____, ("Plan"), approved by City Permit No. ____________________________. The Plan provides for management of stormwater within the confines of the Property.

Facilities: City and Landowner, its successors and assigns, agree that the health, safety, and welfare of the residents of Lake Havasu City, Arizona, require that on-site stormwater management/BMP facilities be constructed and maintained on the Property. City requires that on-site stormwater management/BMP facilities, as shown on the Plan, be constructed and adequately maintained by Landowner, its successors and assigns.

Agreement: The parties agree as follows:

1. The on-site stormwater management/BMP facilities shall be constructed by the Landowner, its successors, and assigns, in accordance with the plans and specifications identified in the Plan and shall, upon construction completion, be certified as such by the Plan's Engineer of Record.

2. Landowner, its successors and assigns, shall adequately maintain the stormwater management/BMP facilities as outlined in the Plan and contained within the Property. This includes all pipes and channels built to convey stormwater to and from the facilities, as well as all structures, improvements, and vegetation provided to control the quantity and quality of the stormwater. Adequate maintenance means good working condition, so that these facilities are performing their design functions. Those maintenance procedures outlined in the Plan and the City's approved BMP guidelines shall be practiced at a minimum. Common maintenance shall include the removal of debris (leaves, lawn clippings, sticks, etc.) and trash after rainfall events, checking outlet structures for clogging and cleaning, as necessary, repairing erosive areas promptly upon observation, and removing accumulated sediment.

3. Landowner, its successors and assigns, shall inspect the stormwater management/BMP facility and report to the City if any major repairs (i.e., structural) are necessary. The purpose of the inspection and reporting is to ensure safe and proper functioning of the facilities. The inspection shall cover the entire facilities, berms, outlet structure, pond areas, access roads, etc. and shall be performed at such times and such manner as to accomplish these objectives.

4. Landowner, its successors and assigns, will perform the work necessary to keep these facilities in good working order as appropriate. In the event a maintenance schedule for the stormwater management/BMP facilities (including sediment removal) is outlined on the approved Plan or in the City's BMP guidelines, Landowner, its successors, and assigns, shall adhere to the schedule.

5. Landowner, its successors and assigns, hereby grant permission to the City, its authorized agents, and employees, to enter upon the Property and to inspect the stormwater management/BMP facilities whenever the City deems necessary. The purpose of inspection may be to check the facility for proper functioning, to follow-up on reported deficiencies or repairs, to respond to citizen complaints, and/or to check for any other reasons the City deems necessary. If problems are observed, the City shall provide the Landowner, its successors, and assigns, copies of the inspection findings and a directive to commence with the repairs within a specific timeframe.

6. In the event Landowner, its successors, and assigns, fail to maintain the stormwater management/BMP facilities in good working condition acceptable to the City, the City may take action in accordance with the applicable sections of the Lake Havasu City Code.

7. This Agreement imposes no liability of any kind whatsoever on the City, and to the fullest extent permitted by law, Landowner, its successors and assigns, agree to indemnify, defend, save, and hold harmless Lake Havasu City, its departments, agencies, boards, commissions, officers, officials, agents, volunteers, and employees ("Indemnitee") for, from, and against any and all claims, actions, liabilities, damages, costs, losses, or expenses (including, but not limited to, court costs, attorneys' fees, and costs of claim processing, investigation and litigation) to which any Indemnitee may become subject, under any theory of liability ("Claims") to the extent that Claims are caused by the negligent acts, recklessness, or intentional misconduct of the Landowner arising out of or as a result of the construction and maintenance of the on-site stormwater management/BMP facilities. Landowner agrees to be responsible for primary loss investigation, defense, and judgement costs where this indemnification is applicable.

8. This Agreement shall be recorded among the land records of Mohave County, Arizona, and shall constitute a covenant running with the land, and shall be binding on Landowner, its administrators, executors, assigns, heirs and any other successors in interests.

Lake Havasu City, Arizona

By: ____
City Manager

Approved as to Form

By: ____
City Attorney

Landowner

By: ________________________________

Name:_________________________

Title: __________________________

STATE OF ARIZONA)
)ss.
County of____________)

This Agreement was acknowledged before me this _________ day of ____________________, 20__, by ____.

____
Notary Public

APPENDIX B

Design Data and Calculations

Lake Havasu City LID Master Plan
Design Volume Capture

Impervious/pervious volume difference per acre

Subbasin Type	A (ac)	C_{100}[1]	Depth[2] (in)	100-yr, 2-hr[3] Volume (ac-ft)	Difference (ac-ft)	Difference (ft^3)
Pervious	1	0.60	**2.34**	0.11700	0.06825	2973
Impervious	1	0.95	**2.34**	0.18525		

[1]Refer to Table 7.10 of the Mohave County Drainage Design Manual (DDM) for runoff coefficents. "Pervious" is assumed to be the average of the 100-year range for Hillslopes, Sonoran Desert and "Impervious" is assumed to be 0.95 for 100-year Pavement and Rooftops.

[2]100-year, 2-hour storm total for McCulloch Boulevard in downtown Lake Havasu City.

[3]Rational Method runoff volume estimate per Equation 7.7 of the Mohave County DDM.

Infiltration loss during BMP filling period

Infil Rate[1] (in/hr)	Duration[2] (hrs)	BMP Area[3] (ft^2)	BMP/Contrib Area[4] (%)	Vol (ft^3)	Vol (ac-ft)
0.5	2	1,982	5%	165	0.00379

[1]Assumes predominant minimum hydraulic conductivity per NRCS soils data for the area.

[2]Two hours of infiltration allowed based on 100-year, 2-hour storm.

[3]Area of BMP assuming a maximum 18 inches of depth for the volume difference per acre.

[4]Percentage of the contributing area occupied by the BMP.

Design rainfall depth for BMP sizing

Required Volume Capture (ft^3)	Infiltration Loss (ft^3)	Adjusted Volume Capture[1] (ft^3)	Adjusted Depth[2] (ft)	Calculated Rainfall Depth (in)	Design Rainfall Depth[3] (in)
2,973	165	2,808	0.0645	0.77	**0.8**

[1]Reduced BMP volume storage requirement due to infiltration loss.

[2]Average rainfall depth per acre based on infiltration adjustment.

[3]Design rainfall depth to be applied to the impervious portion of a contributing area. Examples of impervious surfaces include, but not limited to, asphalt, concrete, buildings, compacted earth, impermeable landscaping fabrics, etc.

Lake Havasu City LID Master Plan
Rain Gauges

Gage #	Percentile 20% Depth (in)	20% Vol Cap (%)	40% Depth (in)	40% Vol Cap (%)	50% Depth (in)	50% Vol Cap (%)	60% Depth (in)	60% Vol Cap (%)	70% Depth (in)	70% Vol Cap (%)	75% Depth (in)	75% Vol Cap (%)
7480	-	-	-	-	-	-	-	-	-	-	-	-
7490	0.12	13.4%	0.28	26.8%	0.36	31.3%	0.48	36.7%	0.76	47.9%	0.93	52.8%
7515	0.12	31.5%	0.22	44.0%	0.28	54.4%	0.36	69.4%	0.43	67.6%	0.69	85.1%
7550	0.16	15.6%	0.28	23.2%	0.36	27.4%	0.60	38.4%	0.88	48.6%	1.06	52.5%
7555	0.12	30.8%	0.20	43.5%	0.24	46.4%	0.40	65.2%	0.48	70.8%	0.56	79.2%
7619	-	-	-	-	-	-	-	-	-	-	-	-
7630	0.12	14.2%	0.28	28.5%	0.38	33.8%	0.50	40.2%	0.69	48.5%	0.93	56.3%
7668	-	-	-	-	-	-	-	-	-	-	-	-
KHII	0.10	18.5%	0.19	30.7%	0.27	38.7%	0.37	48.1%	0.58	61.8%	0.67	66.7%
Average	**0.12**	**20.7%**	**0.24**	**32.8%**	**0.31**	**38.7%**	**0.45**	**49.7%**	**0.64**	**57.5%**	**0.81**	**65.4%**
Weighted Average*	**0.12**	**18.8%**	**0.24**	**30.9%**	**0.31**	**36.6%**	**0.45**	**46.7%**	**0.66**	**56.6%**	**0.81**	**62.9%**

Gage #	Percentile 80% Depth (in)	80% Vol Cap (%)	85% Depth (in)	85% Vol Cap (%)	90% Depth (in)	90% Vol Cap (%)	95% Depth (in)	95% Vol Cap (%)	100% Depth (in)	100% Vol Cap (%)
7480	-	-	-	-	-	-	-	-	-	-
7490	1.12	57.7%	1.47	65.0%	2.54	80.1%	3.50	88.2%	7.39	99.7%
7515	0.72	90.5%	0.81	91.0%	0.92	93.9%	1.21	99.1%	1.32	100.0%
7550	1.20	55.6%	1.76	65.0%	2.56	74.9%	4.06	85.7%	9.46	98.4%
7555	0.63	79.0%	0.84	89.1%	1.04	95.5%	1.12	97.4%	2.13	99.3%
7619	-	-	-	-	-	-	-	-	-	-
7630	1.09	60.5%	1.57	70.9%	2.13	79.0%	2.94	86.0%	7.36	99.2%
7668	-	-	-	-	-	-	-	-	-	-
KHII	0.78	71.8%	0.94	76.7%	1.23	83.1%	1.71	89.6%	3.93	98.6%
Average	**0.92**	**69.2%**	**1.23**	**76.3%**	**1.74**	**84.4%**	**2.43**	**91.0%**	**5.26**	**99.2%**
Weighted Average*	**0.93**	**66.8%**	**1.25**	**74.2%**	**1.78**	**82.8%**	**2.50**	**89.7%**	**5.62**	**99.0%**

*Average weighted based on the gauge's period of record lengths.

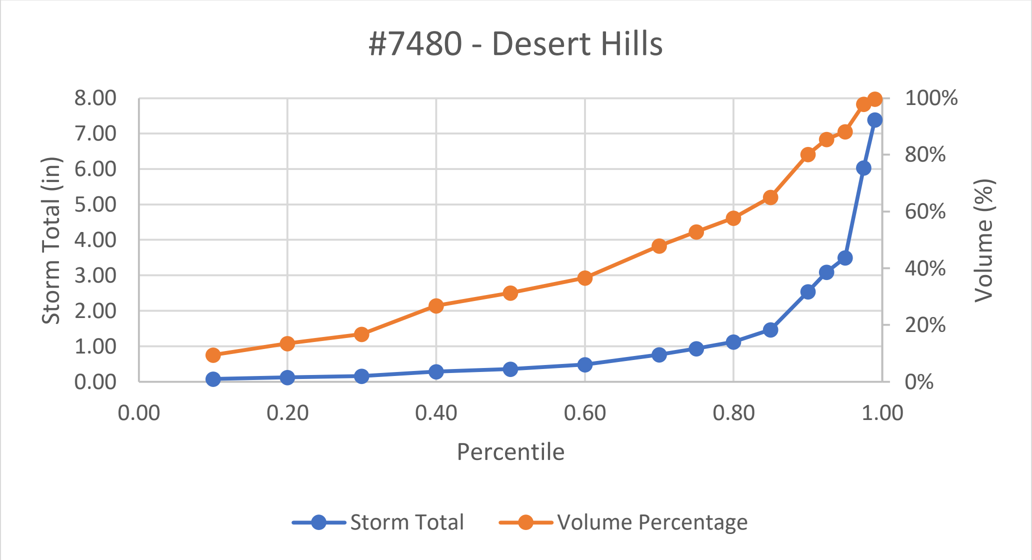
Lake Havasu City LID Master Plan
Rain Gauges

Aggregate statistics based on the last 10-year period of record

Month	Average (in)	Average Low (in)	Average High (in)
January	0.66	0.00	1.72
February	0.40	0.00	1.34
March	0.56	0.01	2.76
April	0.16	0.00	0.75
May	0.02	0.00	0.14
June	0.01	0.00	0.06
July	0.46	0.00	2.42
August	0.47	0.00	1.77
September	0.38	0.00	1.19
October	0.32	0.00	1.16
November	0.38	0.00	2.09
December	0.62	0.00	2.09
Yearly	4.38	2.22	7.74

Lake Havasu City LID Master Plan
Rain Gauges

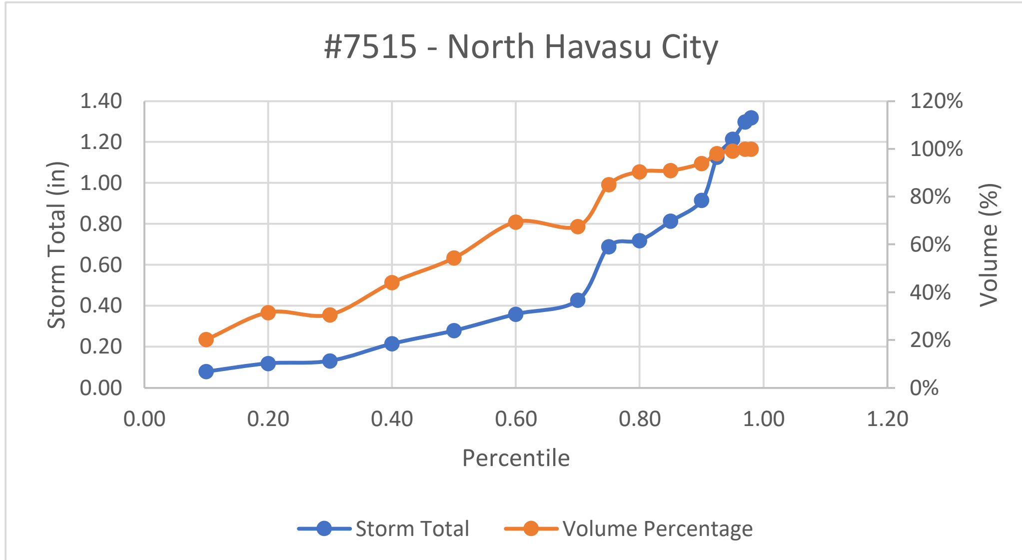
Percentile	Depth	% Vol
0.10	0.08	9%
0.20	0.12	13%
0.30	0.16	17%
0.40	0.28	27%
0.50	0.36	31%
0.60	0.48	37%
0.70	0.76	48%
0.75	0.93	53%
0.80	1.12	58%
0.85	1.47	65%
0.90	2.54	80%
0.93	3.10	85%
0.95	3.50	88%
0.98	6.03	98%
0.99	7.39	100%



Averages		Low	High
4.50	**Yearly**	1.92	8.04
0.38	Monthly	0	2.92
0.63	January	0	1.72
0.40	February	0	1.48
0.55	March	0	2.92
0.20	April	0	0.96
0.01	May	0	0.08
0.01	June	0	0.12
0.36	July	0	1.68
0.42	August	0	1.8
0.56	September	0	2
0.27	October	0	1.08
0.44	November	0	2.4
0.64	December	0	2.08

Lake Havasu City LID Master Plan
Rain Gauges

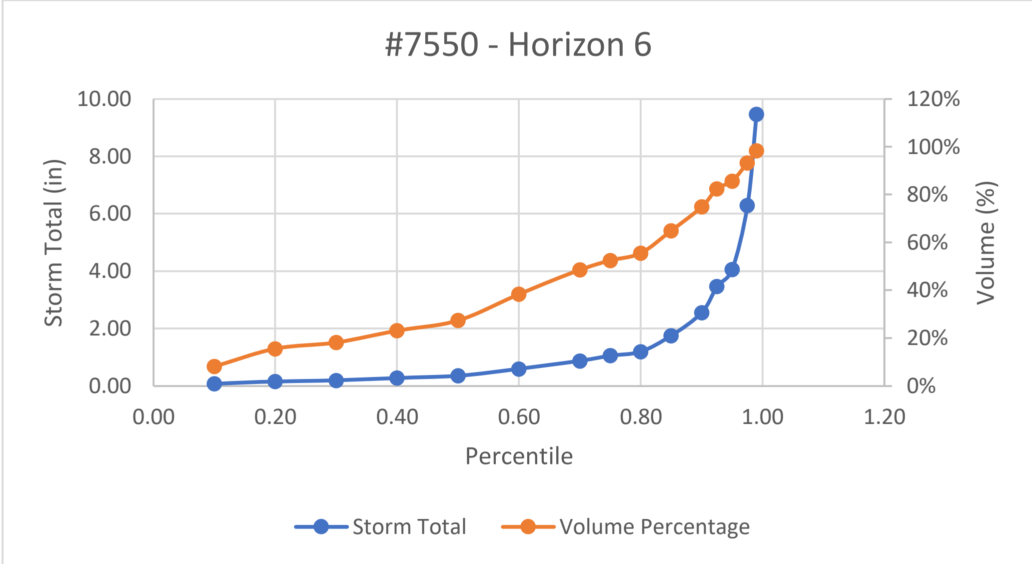
Percentile	Depth	% Vol
0.10	0.08	20%
0.20	0.12	32%
0.30	0.13	31%
0.40	0.22	44%
0.50	0.28	54%
0.60	0.36	69%
0.70	0.43	68%
0.75	0.69	85%
0.80	0.72	90%
0.85	0.81	91%
0.90	0.92	94%
0.93	1.13	98%
0.95	1.21	99%
0.97	1.30	100%
0.98	1.32	100%



Averages		Low	High
3.35	**Yearly**	0.96	6.16
0.32	Monthly	0	2.88
0.81	January	0.04	1.56
0.44	February	0	1.28
0.78	March	0	2.88
0.15	April	0	0.6
0.02	May	0	0.12
0.00	June	0	0
0.01	July	0	0.04
0.14	August	0	0.6
0.29	September	0	0.8
0.37	October	0	1.04
0.33	November	0	1.84
0.46	December	0	1.76

Lake Havasu City LID Master Plan
Rain Gauges

Percentile	Depth	% Vol
0.10	0.08	8%
0.20	0.16	16%
0.30	0.20	18%
0.40	0.28	23%
0.50	0.36	27%
0.60	0.60	38%
0.70	0.88	49%
0.75	1.06	52%
0.80	1.20	56%
0.85	1.76	65%
0.90	2.56	75%
0.93	3.47	83%
0.95	4.06	86%
0.98	6.29	93%
0.99	9.46	98%



Averages		Low	High
4.82	**Yearly**	2.88	7.64
0.40	Monthly	0	4
0.71	January	0	1.88
0.40	February	0	1.36
0.52	March	0	2.52
0.13	April	0	0.32
0.02	May	0	0.16
0.00	June	0	0.04
0.72	July	0	4
0.60	August	0	1.68
0.30	September	0	0.88
0.31	October	0	1.32
0.39	November	0	2.24
0.70	December	0	2.36

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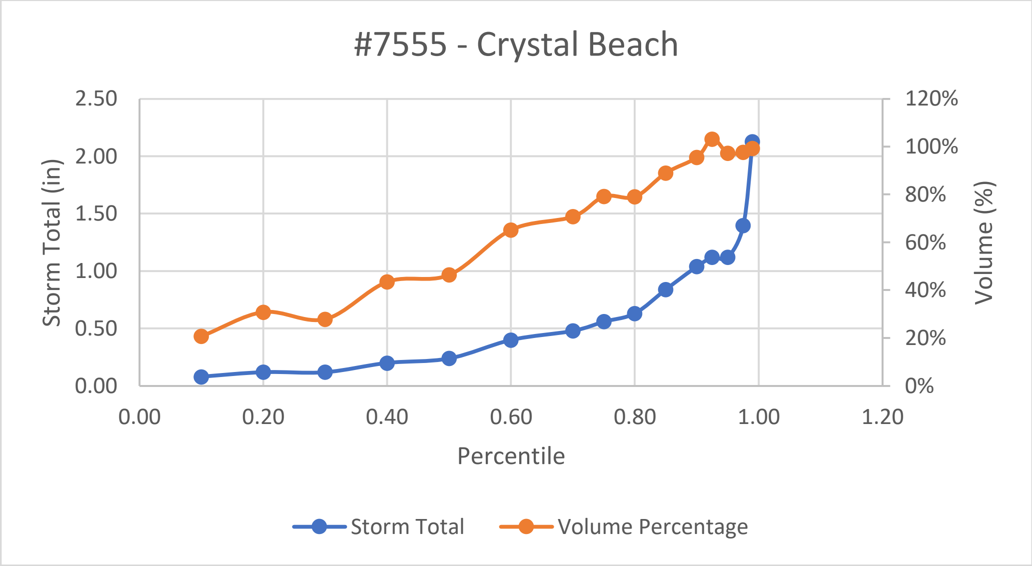
Lake Havasu City LID Master Plan
Rain Gauges

Percentile	Depth	% Vol
0.10	0.08	21%
0.20	0.12	31%
0.30	0.12	28%
0.40	0.20	44%
0.50	0.24	46%
0.60	0.40	65%
0.70	0.48	71%
0.75	0.56	79%
0.80	0.63	79%
0.85	0.84	89%
0.90	1.04	96%
0.93	1.12	103%
0.95	1.12	97%
0.98	1.40	98%
0.99	2.13	99%



Averages		Low	High
4.34	**Yearly**	2.32	8.16
0.36	Monthly	0	2.76
0.64	January	0	1.76
0.42	February	0	1.44
0.50	March	0	2.76
0.19	April	0	1.2
0.03	May	0	0.16
0.00	June	0	0.04
0.38	July	0	1.32
0.44	August	0	2.24
0.44	September	0	1.16
0.31	October	0	1.04
0.38	November	0	2.36
0.60	December	0	2

5/18/2022

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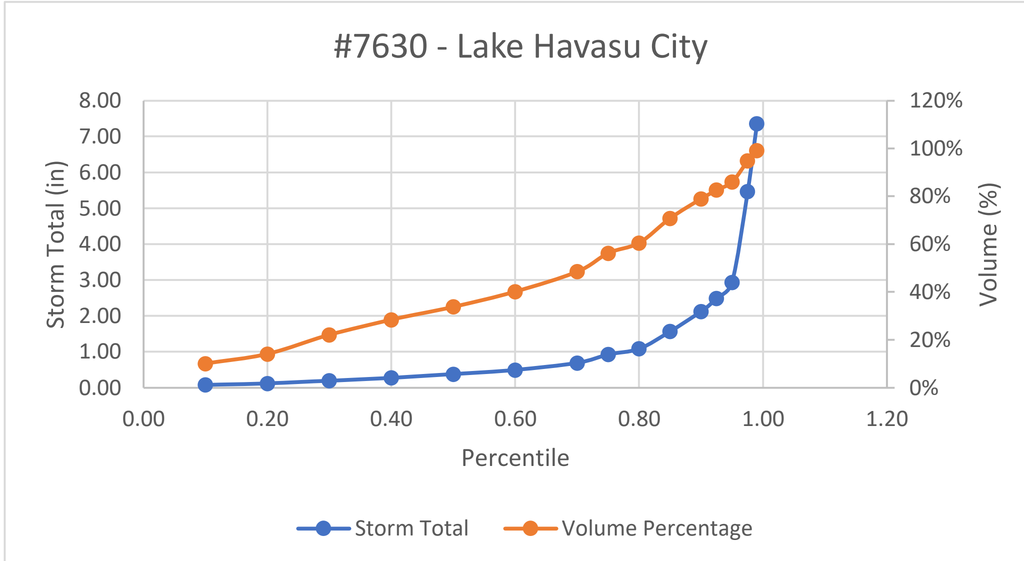
Lake Havasu City LID Master Plan
Rain Gauges

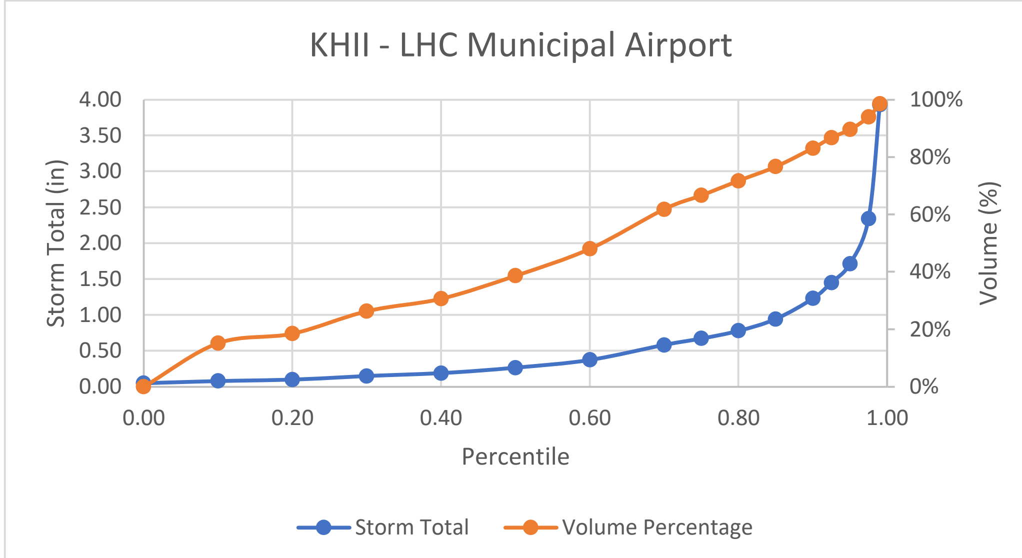


Percentile	Depth	% Vol
0.10	0.08	10%
0.20	0.12	14%
0.30	0.20	22%
0.40	0.28	28%
0.50	0.38	34%
0.60	0.50	40%
0.70	0.69	49%
0.75	0.93	56%
0.80	1.09	61%
0.85	1.57	71%
0.90	2.13	79%
0.93	2.49	83%
0.95	2.94	86%
0.98	5.47	95%
0.99	7.36	99%

Averages		Low	High
4.42	**Yearly**	2.44	7.96
0.37	Monthly	0	3.92
0.59	January	0	1.6
0.35	February	0	1.12
0.53	March	0.04	2.76
0.14	April	0	0.6
0.02	May	0	0.16
0.01	June	0	0.08
0.62	July	0	3.92
0.61	August	0	1.96
0.26	September	0	0.92
0.36	October	0	1.28
0.32	November	0	1.48
0.61	December	0	2.08

Lake Havasu City LID Master Plan
Rain Gauges

Percentile	Depth	% Vol
0.00	0.05	0%
0.10	0.08	15%
0.20	0.10	19%
0.30	0.15	26%
0.40	0.19	31%
0.50	0.27	39%
0.60	0.37	48%
0.70	0.58	62%
0.75	0.67	67%
0.80	0.78	72%
0.85	0.94	77%
0.90	1.23	83%
0.93	1.45	87%
0.95	1.71	90%
0.98	2.34	94%
0.99	3.93	99%



Averages		Low	High
4.93	**Yearly**	0	10.13
0.43	Monthly	0	17.75
0.92	January	0	6.01
0.76	February	0	7.01
0.75	March	0	4.44
0.17	April	0	1.55
0.08	May	0	0.44
0.05	June	0	0.82
0.34	July	0	1.67
0.50	August	0	2.33
0.54	September	0	4.71
0.27	October	0	2.35
0.31	November	0	1.28
0.42	December	0	2.62

Lake Havasu City LID Master Plan
Rain Gauges

Rain gauges within the City

Gauge #	Name	Location	Notes
7480	El Dorado Wash @ S. Palo Verde	Palo Verde Blvd & El Dorado Wash	No rain data
7490	Desert Hills	Hyde Park Ave; 350 feet west of US95	Data starts in Jan 2004
7515	North Lake Havasu	NEC of College Dr & Lake Havasu Ave	Data starts in Oct 2015
7550	Horizon 6	Gold Springs Rd; 3,250 feet east of Lakeside Rd	Data starts in Jan 2004
7555	Crystal Beach	Crystal Beach Rd; 1,450 feet west of Crystal Ave	Data starts in Apr 2007
7619	Turquoise Dr	Turquoise Dr; 280 feet north of Colt Dr	Data starts in Nov 2020
7630	Lake Havasu City	NWC of Acoma Blvd & Spezzano Way	Data starts in Oct 2004
7668	El Dorado Wash @ Jamaica	Jamaica Blvd & El Dorado Wash	No rain data
KHII	LHC Municipal Airport	LHC Municipal Airport	Data range is from 1967 to 2000

NOAA Atlas 14, Volume 1, Version 5
Location name: Lake Havasu City, Arizona, USA*
Latitude: 34.4771°, Longitude: -114.3281°
Elevation: 647.84 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sarah Dietz, Sarah Heim, Lillian Hiner, Kazungu Maitaria, Deborah Martin, Sandra Pavlovic, Ishani Roy, Carl Trypaluk, Dale Unruh, Fenglin Yan, Michael Yekta, Tan Zhao, Geoffrey Bonnin, Daniel Brewer, Li-Chuan Chen, Tye Parzybok, John Yarchoan

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.135 (0.114-0.162)	0.183 (0.155-0.219)	0.272 (0.229-0.325)	0.342 (0.285-0.409)	0.444 (0.363-0.531)	0.530 (0.426-0.636)	0.625 (0.491-0.754)	0.732 (0.562-0.891)	0.895 (0.662-1.11)	1.04 (0.748-1.29)
10-min	0.206 (0.174-0.246)	0.279 (0.235-0.333)	0.414 (0.348-0.494)	0.521 (0.434-0.622)	0.675 (0.552-0.808)	0.806 (0.648-0.968)	0.951 (0.748-1.15)	1.12 (0.854-1.36)	1.36 (1.01-1.68)	1.58 (1.14-1.97)
15-min	0.255 (0.215-0.305)	0.346 (0.292-0.413)	0.513 (0.432-0.612)	0.645 (0.538-0.771)	0.837 (0.684-1.00)	1.00 (0.803-1.20)	1.18 (0.927-1.42)	1.38 (1.06-1.68)	1.69 (1.25-2.08)	1.96 (1.41-2.44)
30-min	0.344 (0.290-0.411)	0.466 (0.393-0.556)	0.691 (0.582-0.824)	0.869 (0.724-1.04)	1.13 (0.922-1.35)	1.35 (1.08-1.62)	1.59 (1.25-1.92)	1.86 (1.43-2.26)	2.27 (1.68-2.81)	2.64 (1.90-3.29)
60-min	0.426 (0.359-0.509)	0.576 (0.486-0.688)	0.855 (0.720-1.02)	1.08 (0.896-1.28)	1.40 (1.14-1.67)	1.67 (1.34-2.00)	1.97 (1.55-2.37)	2.30 (1.77-2.80)	2.82 (2.08-3.47)	3.26 (2.35-4.07)
2-hr	0.502 (0.425-0.600)	0.675 (0.572-0.805)	0.997 (0.837-1.19)	1.26 (1.04-1.50)	1.64 (1.34-1.96)	1.97 (1.58-2.36)	2.34 (1.84-2.82)	2.75 (2.11-3.35)	3.38 (2.50-4.17)	3.93 (2.83-4.92)
3-hr	0.561 (0.478-0.669)	0.749 (0.637-0.894)	1.09 (0.923-1.30)	1.37 (1.15-1.63)	1.79 (1.48-2.13)	2.14 (1.73-2.56)	2.55 (2.02-3.06)	3.01 (2.33-3.64)	3.71 (2.78-4.56)	4.34 (3.15-5.39)
6-hr	0.673 (0.577-0.794)	0.893 (0.767-1.06)	1.28 (1.10-1.51)	1.59 (1.35-1.87)	2.05 (1.71-2.40)	2.43 (1.99-2.87)	2.85 (2.28-3.38)	3.31 (2.60-3.95)	4.04 (3.08-4.90)	4.69 (3.48-5.76)
12-hr	0.809 (0.696-0.949)	1.08 (0.925-1.26)	1.53 (1.31-1.78)	1.89 (1.61-2.20)	2.40 (2.01-2.80)	2.82 (2.33-3.31)	3.27 (2.66-3.86)	3.75 (2.99-4.46)	4.50 (3.48-5.44)	5.17 (3.91-6.32)
24-hr	0.877 (0.784-0.987)	1.15 (1.02-1.29)	1.58 (1.41-1.80)	1.92 (1.70-2.22)	2.41 (2.11-2.83)	2.85 (2.43-3.34)	3.31 (2.76-3.90)	3.79 (3.10-4.51)	4.55 (3.56-5.50)	5.22 (3.94-6.38)
2-day	0.934 (0.834-1.04)	1.21 (1.09-1.36)	1.66 (1.48-1.84)	2.00 (1.79-2.24)	2.47 (2.19-2.86)	2.87 (2.50-3.37)	3.34 (2.82-3.94)	3.83 (3.15-4.55)	4.59 (3.58-5.55)	5.27 (3.98-6.45)
3-day	0.967 (0.866-1.08)	1.26 (1.13-1.40)	1.71 (1.54-1.90)	2.06 (1.85-2.29)	2.53 (2.25-2.87)	2.93 (2.57-3.39)	3.36 (2.90-3.96)	3.84 (3.23-4.58)	4.62 (3.67-5.58)	5.30 (4.03-6.48)
4-day	1.00 (0.899-1.11)	1.30 (1.17-1.45)	1.77 (1.59-1.95)	2.12 (1.91-2.34)	2.60 (2.32-2.88)	2.98 (2.65-3.41)	3.38 (2.97-3.98)	3.86 (3.31-4.60)	4.64 (3.76-5.61)	5.33 (4.09-6.51)
7-day	1.11 (1.00-1.23)	1.44 (1.30-1.60)	1.95 (1.76-2.16)	2.34 (2.11-2.58)	2.86 (2.56-3.16)	3.26 (2.91-3.61)	3.67 (3.25-4.07)	4.09 (3.59-4.64)	4.69 (4.05-5.66)	5.38 (4.38-6.58)
10-day	1.16 (1.04-1.29)	1.52 (1.36-1.69)	2.08 (1.86-2.31)	2.51 (2.24-2.78)	3.09 (2.75-3.43)	3.55 (3.14-3.93)	4.02 (3.53-4.47)	4.50 (3.92-5.04)	5.17 (4.46-5.83)	5.70 (4.86-6.64)
20-day	1.35 (1.20-1.50)	1.77 (1.58-1.97)	2.43 (2.17-2.71)	2.92 (2.60-3.25)	3.59 (3.18-4.00)	4.10 (3.61-4.57)	4.63 (4.05-5.19)	5.16 (4.48-5.80)	5.87 (5.04-6.67)	6.43 (5.46-7.35)
30-day	1.54 (1.36-1.72)	2.02 (1.80-2.26)	2.79 (2.47-3.12)	3.34 (2.96-3.74)	4.07 (3.60-4.55)	4.62 (4.06-5.17)	5.17 (4.51-5.80)	5.72 (4.96-6.43)	6.44 (5.54-7.29)	6.99 (5.97-7.97)
45-day	1.72 (1.50-1.96)	2.29 (2.00-2.60)	3.18 (2.78-3.60)	3.82 (3.33-4.34)	4.67 (4.05-5.29)	5.31 (4.58-6.03)	5.95 (5.10-6.79)	6.58 (5.62-7.54)	7.42 (6.29-8.56)	8.04 (6.75-9.31)
60-day	1.91 (1.66-2.18)	2.53 (2.20-2.90)	3.53 (3.06-4.04)	4.26 (3.67-4.88)	5.21 (4.48-5.97)	5.92 (5.06-6.80)	6.64 (5.66-7.64)	7.36 (6.23-8.52)	8.31 (6.96-9.68)	9.01 (7.50-10.6)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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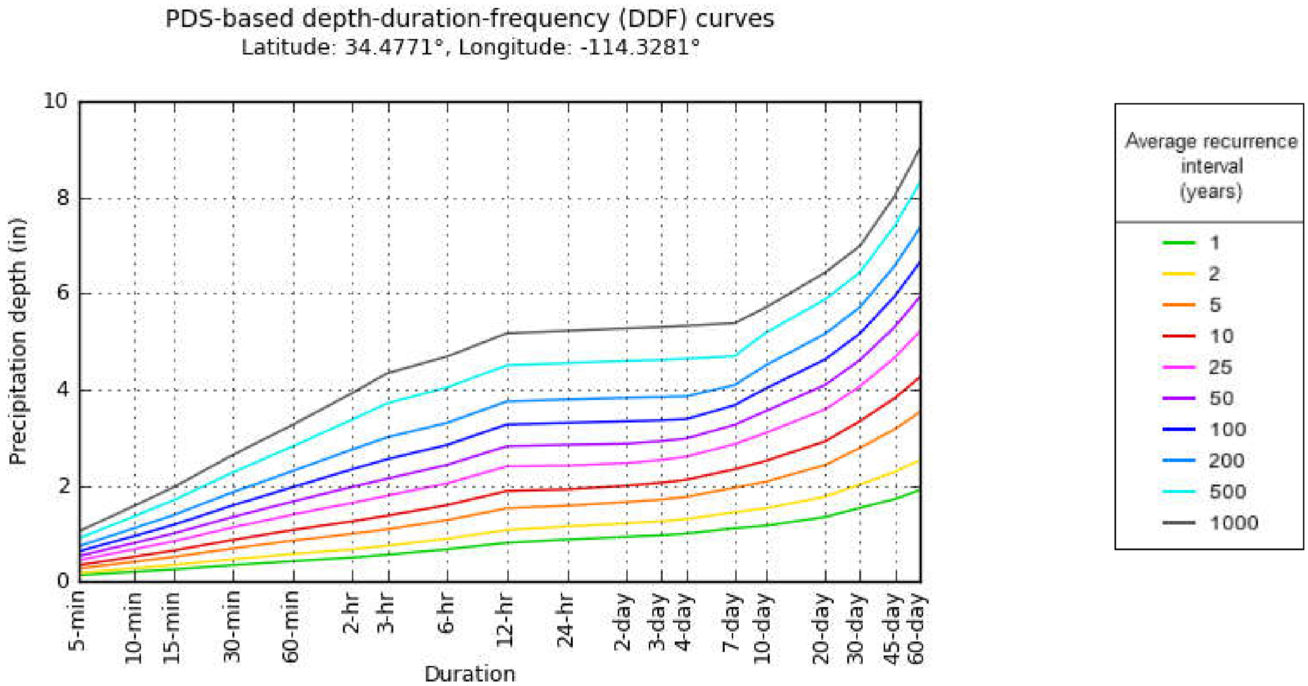
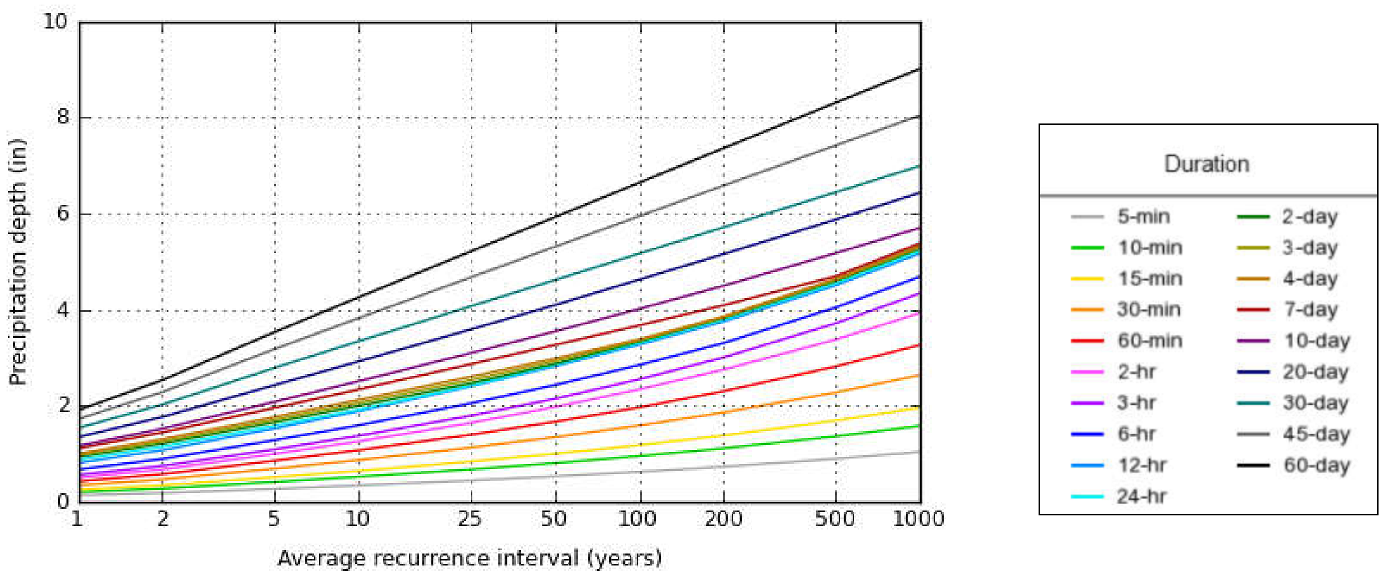
PF graphical





NOAA Atlas 14, Volume 1, Version 5 Created (GMT): Tue Feb 23 18:09:57 2021

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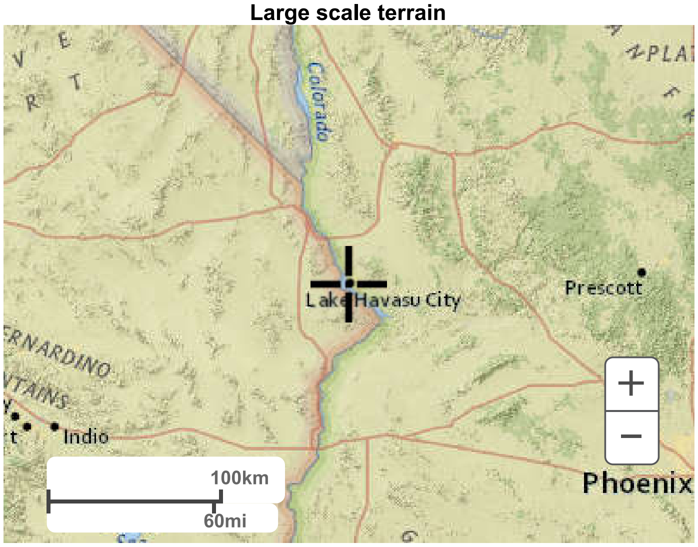
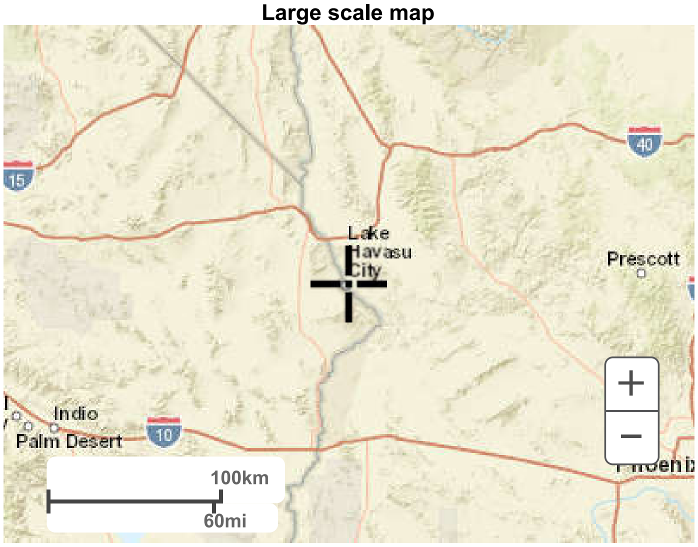
Maps & aerials

Small scale terrain

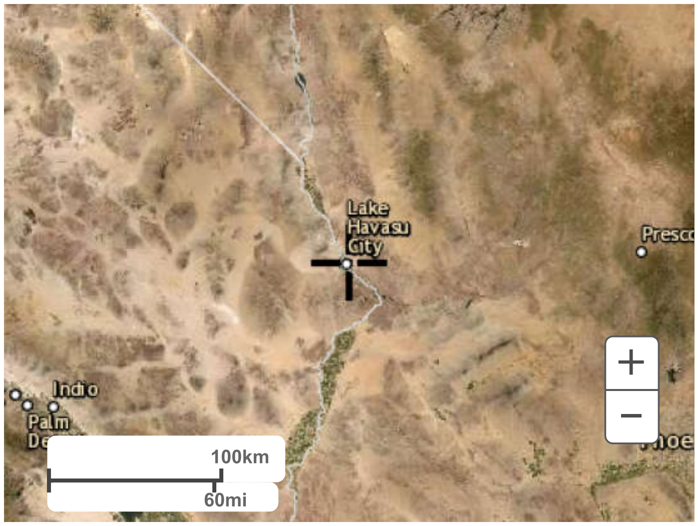
Large scale terrain



Large scale map



Large scale aerial



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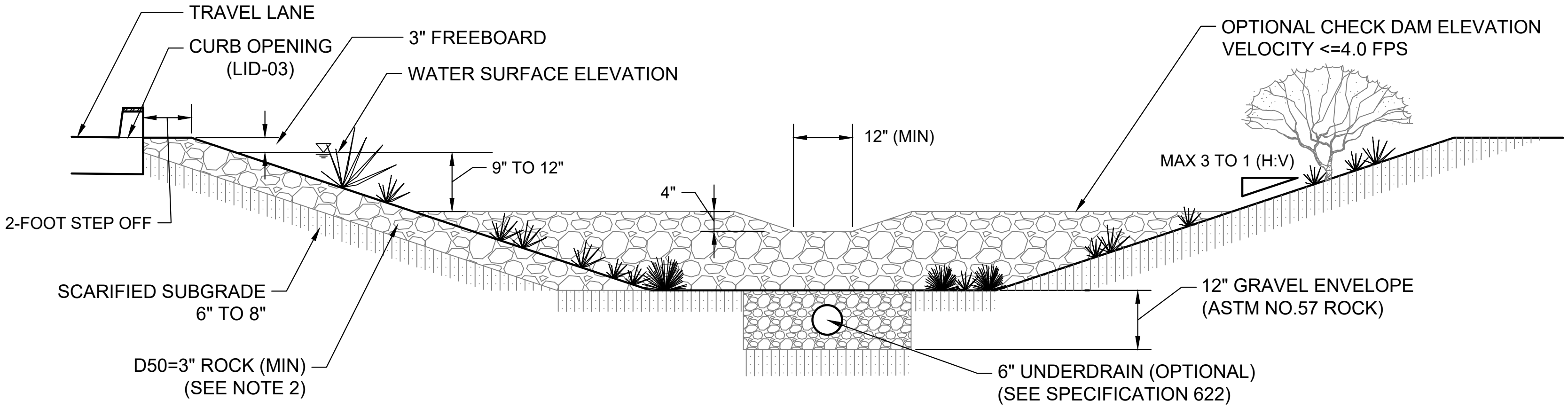
National Weather Service
National Water Center
1325 East West Highway
Silver Spring, MD 20910
Questions?: HDSC.Questions@noaa.gov

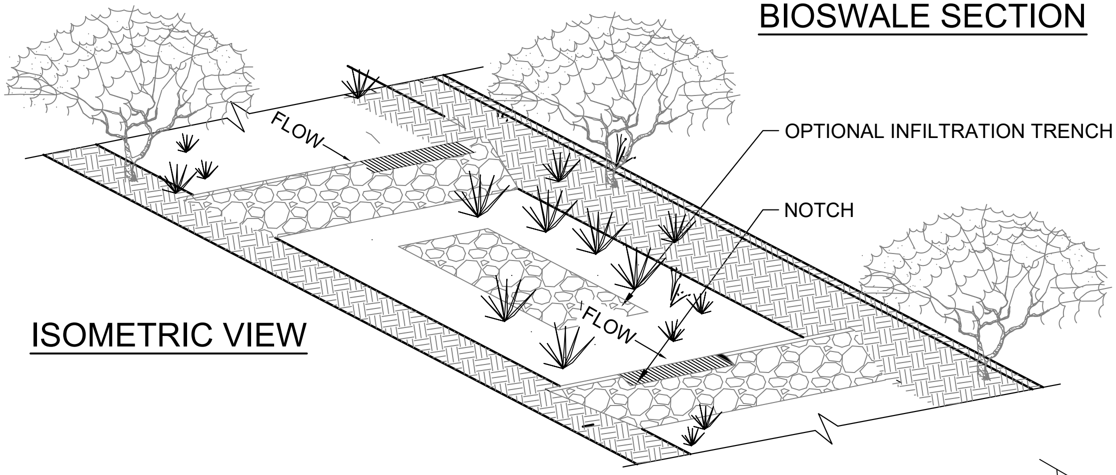
Disclaimer

APPENDIX C

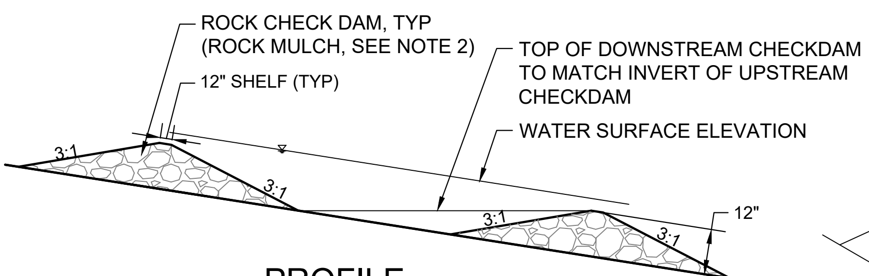
LID Design Details



BIOSWALE SECTION

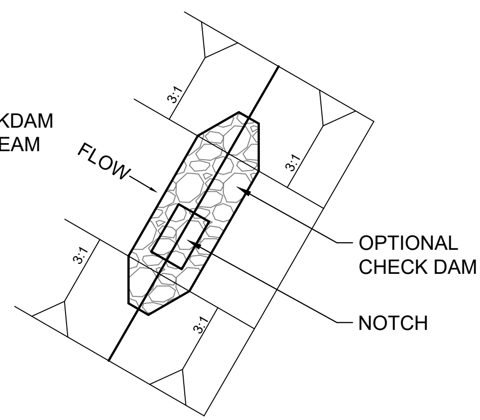


ISOMETRIC VIEW



PROFILE

OPTIONAL ROCK CHECK DAM



PLAN VIEW

GENERAL NOTES:

1. DETAIL IS MODIFIED FROM GREATER PHOENIX METRO GREEN INFRASTRUCTURE HANDBOOK (GPMGIH).
2. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION.
3. CONSULT GPMGIH FOR ADDITIONAL INFORMATION.

BIOSWALE NOTES

1. VEGETATION OFFSET FROM CONCENTRATED FLOW.
2. SPECIFIED LANDSCAPE PLANTS SHOULD BE DROUGHT TOLERANT.
3. DRIP IRRIGATION WILL BE PROVIDED BY A TEMPORARY OR PERMANENT IRRIGATION SYSTEM.

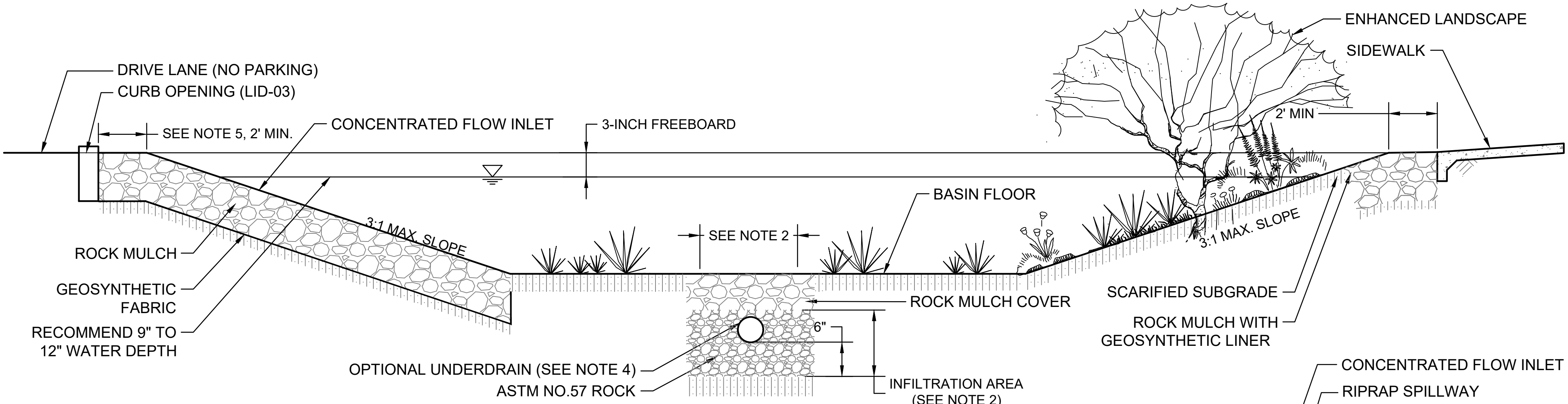
CHECK DAM NOTES

1. OPTIONAL CHECK DAM IS MEANT TO SLOW FLOWS DURING HIGH FLOW EVENTS.
2. D50 SIZE DETERMINED BY THE DESIGN REPORT.
3. NOTCHES SHALL BE OFFSET FROM ONE ANOTHER.
4. OPTIONAL ROCK CHECK DAM TO BE LOCATED TO REDUCE VELOCITIES PER DESIGN REPORT.
5. RIPRAP AND ROCK MULCH REQUIRED WHEN VELOCITIES ARE ANTICIPATED.

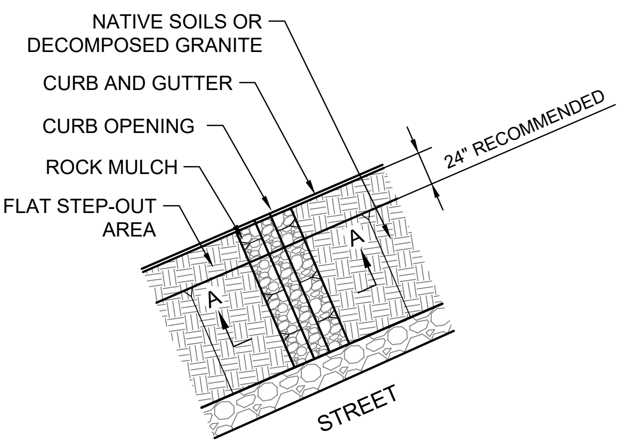
BIOSWALE AND CHECK DAM	DATE: 2022	DETAIL NO. LHC-LID-01

GENERAL NOTES (BASIN):

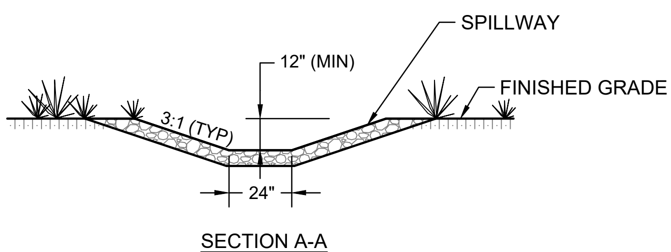
1. SURFACE WATER MUST DRAIN WITHIN LOCAL REQUIREMENTS.
2. INFILTRATION AREA DEPTH AND WIDTH DETERMINED BY PERCOLATING WITHIN LOCAL REQUIREMENTS. WIDTH MUST EXCEED DEPTH.
3. DEDICATED OUTFLOW RECOMMENDED.
4. FOR OPTIONAL PERFORATED UNDERDRAIN
5. REFER TO AASHTO ROADWAY DESIGN BOOK FOR CLEAR ZONE REQUIREMENTS.
6. NO PLANTINGS IN THE CONCENTRATED FLOW INLET.
7. OPTIONAL SEDIMENT TRAP AT CONCENTRATED FLOW INLET.
8. DETAIL IS MODIFIED FROM GREATER PHOENIX METRO GREEN INFRASTRUCTURE HANDBOOK (GPMGIH).
9. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION.



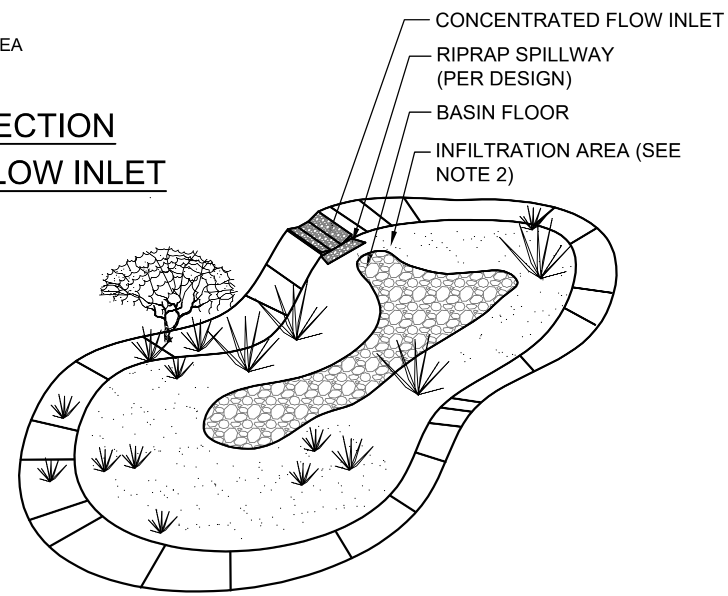
STORMWATER HARVESTING BASIN SECTION WITH CUT THROUGH CONCENTRATED FLOW INLET



PLAN

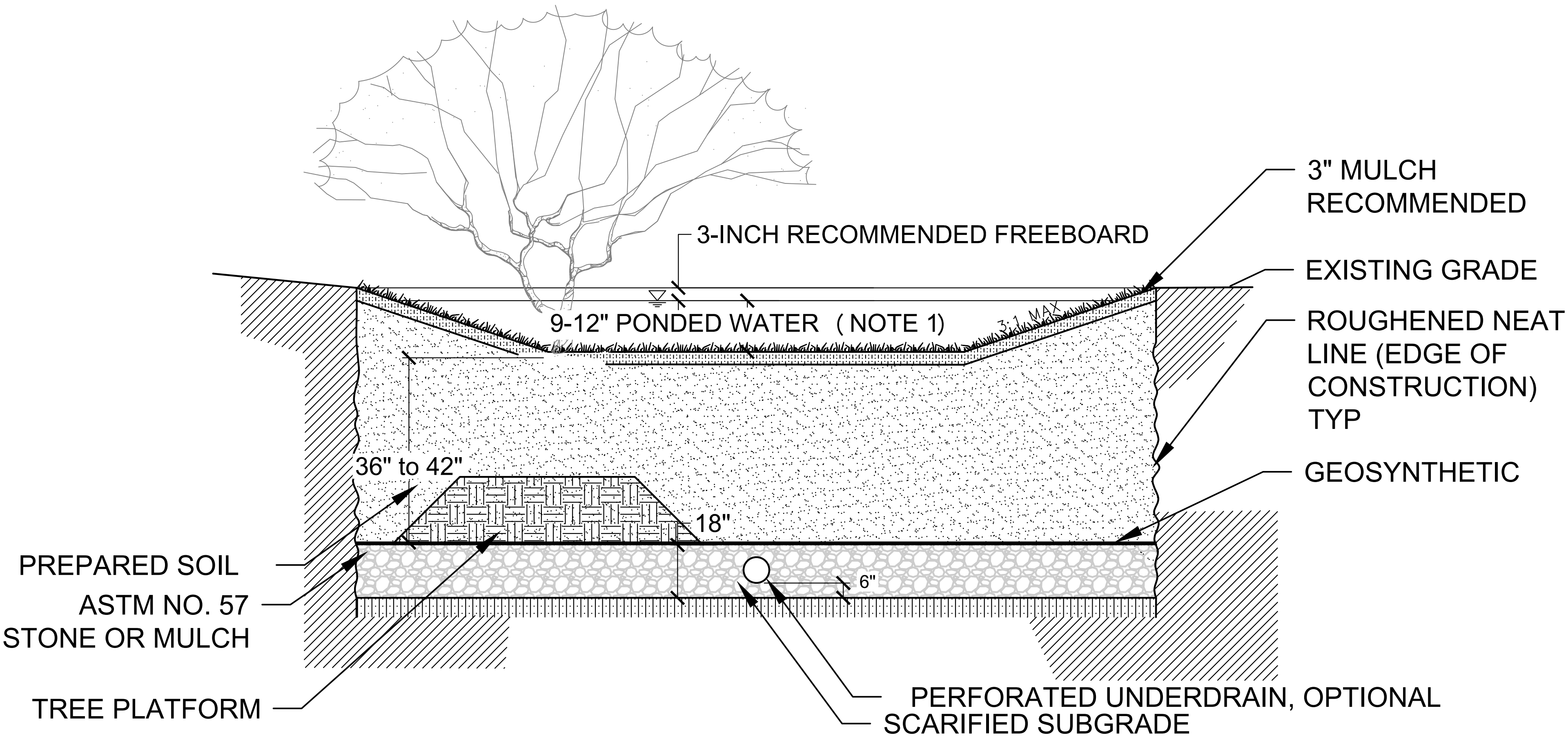


RIPRAP SPILLWAY (PLAN & SECTION)



ISOMETRIC VIEW

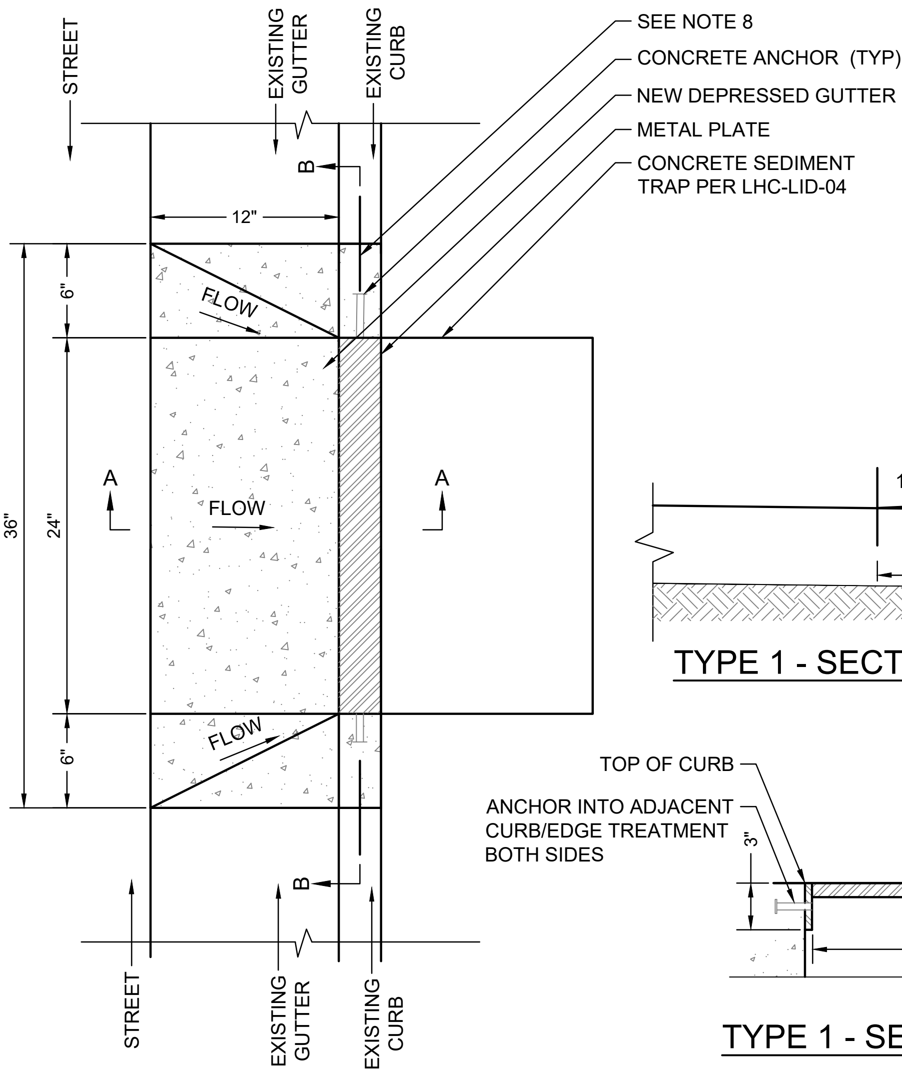
ENHANCED BASIN - STORMWATER HARVESTING BASIN	DATE: 2022	DETAIL NO. LHC-LID-02



NOTES:

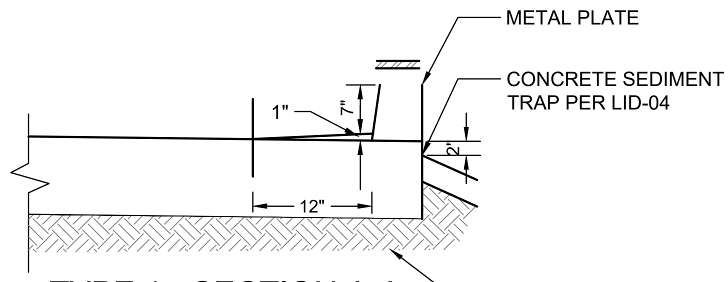
1. SURFACE PONDED WATER MUST PERCOLATE PER LOCAL TIME REQUIREMENT.
2. RECOMMENDED DEPTH OF 36 TO 42 INCHES.
3. OBSERVE BUILDING SETBACK REQUIREMENTS.
4. INTENDED TO CAPTURE SUBWATERSHED, DEDICATED OUTLET STILL REQUIRED.
5. TREE PLATFORM SHALL CONSIST OF COMPACTED ON-SITE SOIL. PLATFORM SHALL BE 1.5X THE WIDTH OF THE ROOTBALL AND INCLUDE 45-DEGREE SIDE SLOPES (MAX.).
6. INSTALL FILTER FABRIC BETWEEN TREE PLATFORM AND NO.57 STONE/ROCK MULCH.
7. DETAIL IS MODIFIED FROM GREATER PHOENIX METRO GREEN INFRASTRUCTURE HANDBOOK (GPMGIH).
8. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION.

ENHANCED BASIN - BIORETENTION PLANTER	DATE: 2022	DETAIL NO. LHC-LID-03

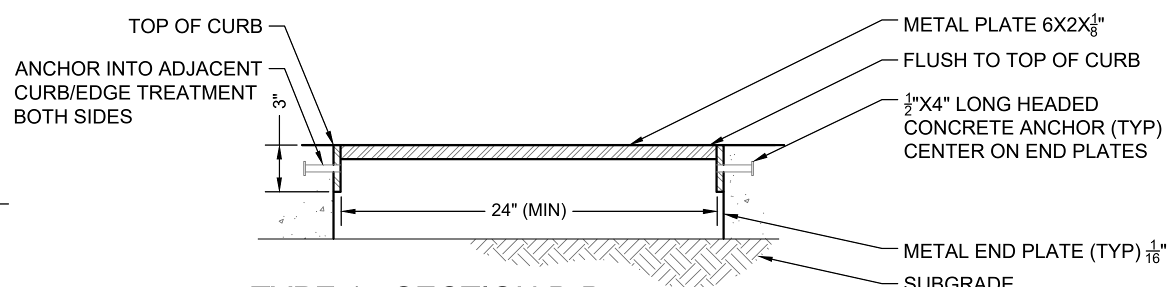


CURB OPENING - TYPE 1

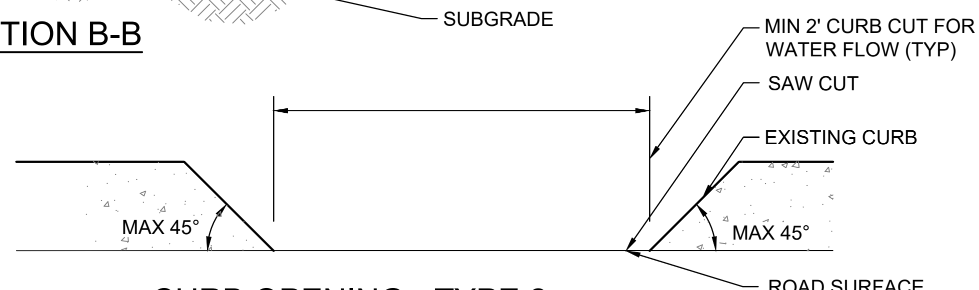
RETROFIT OPENING
WITH VERTICAL CUT



TYPE 1 - SECTION A-A



TYPE 1 - SECTION B-B



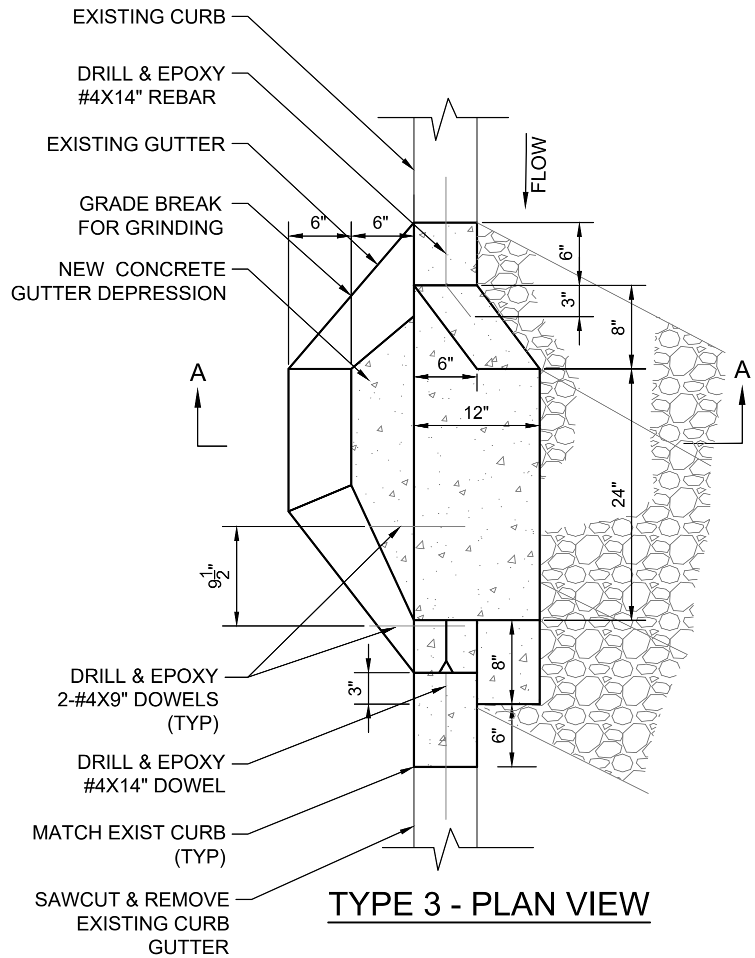
CURB OPENING - TYPE 2

ANGLED CURB CUT

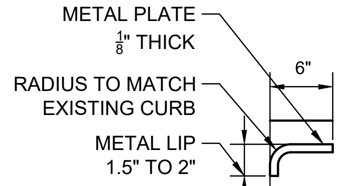
NOTES:

1. HEADED CONCRETE ANCHORS SHALL MEET THE REQUIREMENTS OF ASTM A-108.
2. METAL PLATE 6X2X1/8 CHANNEL SHALL MEET THE REQUIREMENTS OF ASTM A-500 GRADE B.
3. END PLATES SHALL MEET THE REQUIREMENTS OF ASTM A-36.
4. ENTIRE ASSEMBLY SHALL BE HOT DIP GALVANIZED IN ACCORDANCE WITH ASTM A-123.
5. DESIGN VERTICAL WHEEL LOAD IS 8.5 KIPS.
6. SEE SPECIFICATION 341 FOR MATERIAL AND CONSTRUCTION INFORMATION.
7. REFER TO AASHTO ROADWAY DESIGN GUIDE FOR CLEAR ZONE REQUIREMENTS FOR SPEED DESIGNS.
8. DRILL & EPOXY #4x6"REBAR
9. DO NOT CUT DEEPER THAN ROAD SURFACE ELEVATION.
10. ALL CURB OPENINGS SHALL BE MADE BY SAW CUT METHOD.
11. GRIND EXPOSED METAL AND SEAL TO PROTECT FROM CORROSION.
12. DETAIL IS MODIFIED FROM GREATER PHOENIX METRO GREEN INFRASTRUCTURE HANDBOOK (GPMGIH).
13. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION.

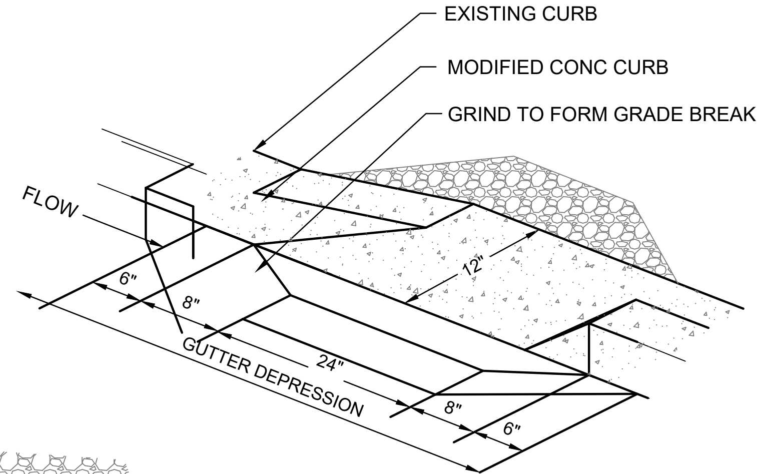
CURB OPENINGS (TYPE 1 & 2)	DATE: 2022	DETAIL NO. LHC-LID-04



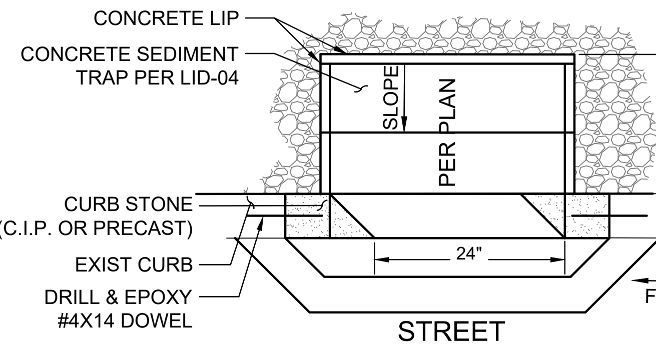
TYPE 3 - PLAN VIEW



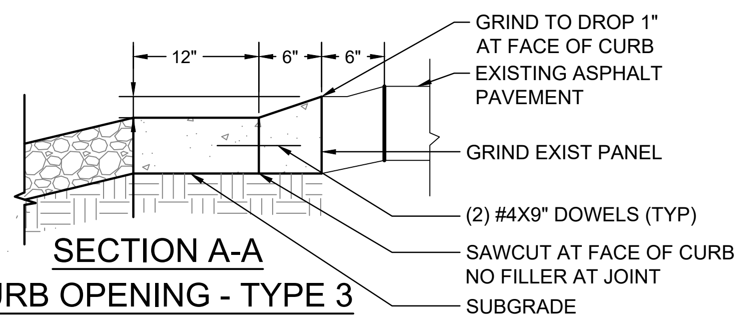
TYPE 4 - SECTION B-B



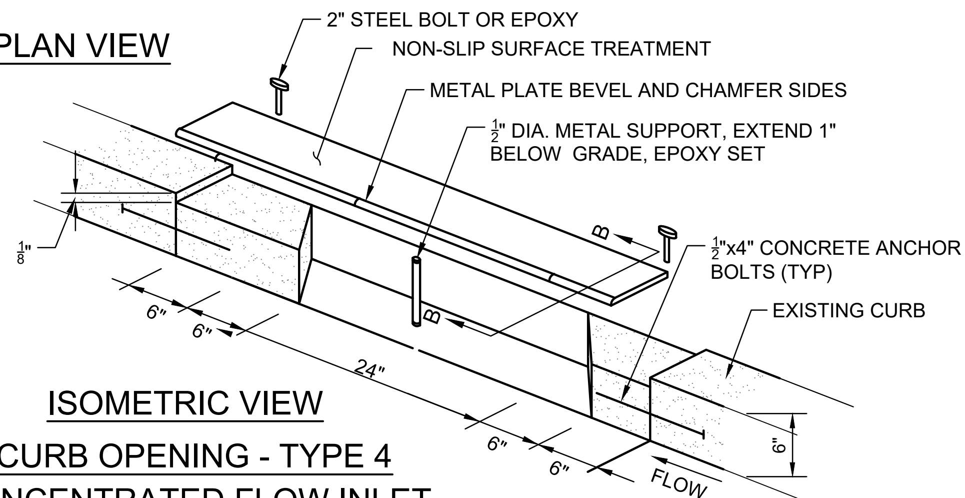
TYPE 3 -ISOMETRIC VIEW



TYPE 4 - PLAN VIEW

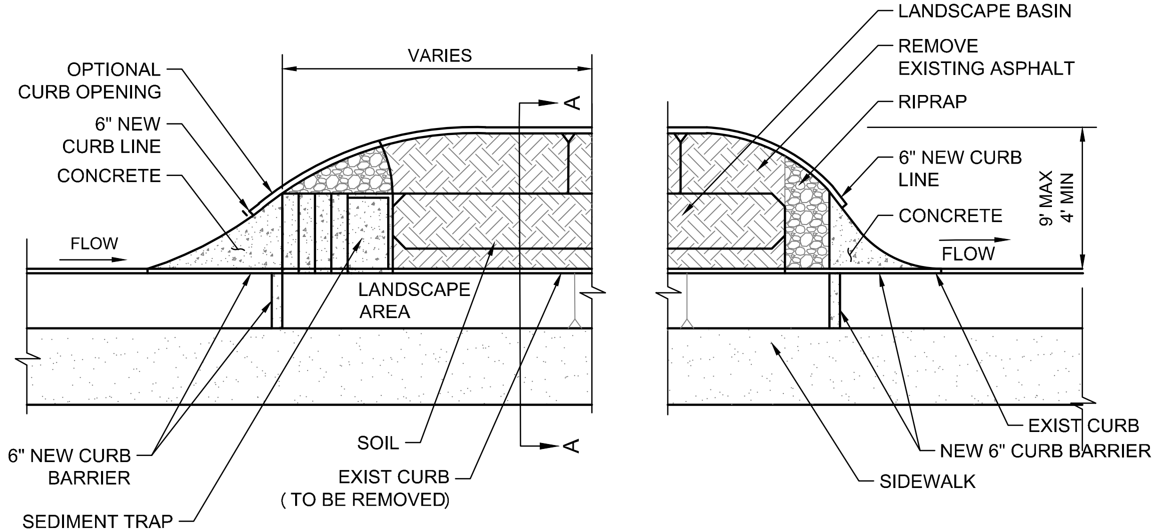


SECTION A-A
CURB OPENING - TYPE 3
CONCENTRATED FLOW INLET

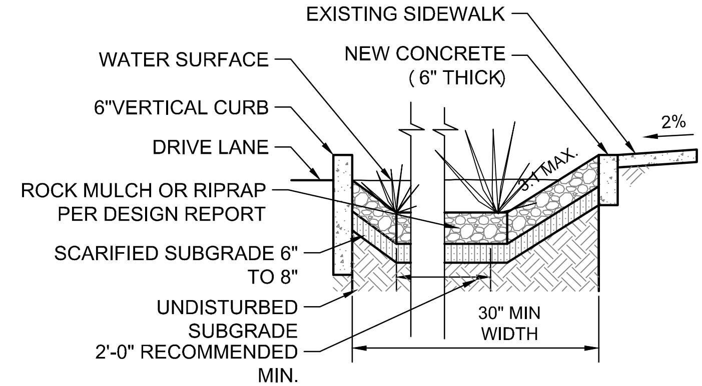


ISOMETRIC VIEW
CURB OPENING - TYPE 4
CONCENTRATED FLOW INLET

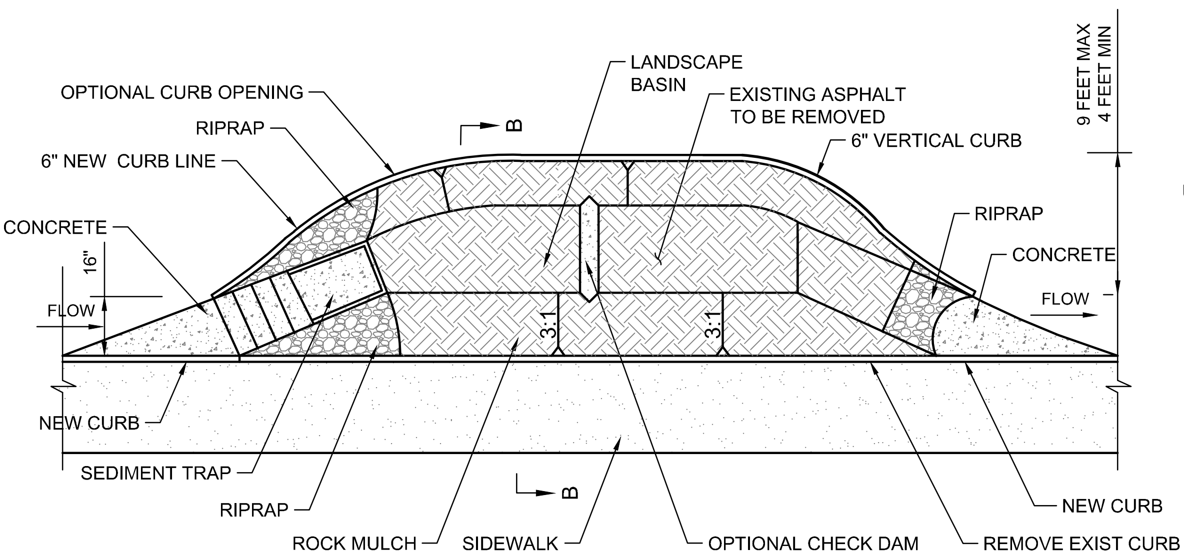
CURB OPENINGS (TYPE 3 & 4)	DATE: 2022	DETAIL NO. LHC-LID-05



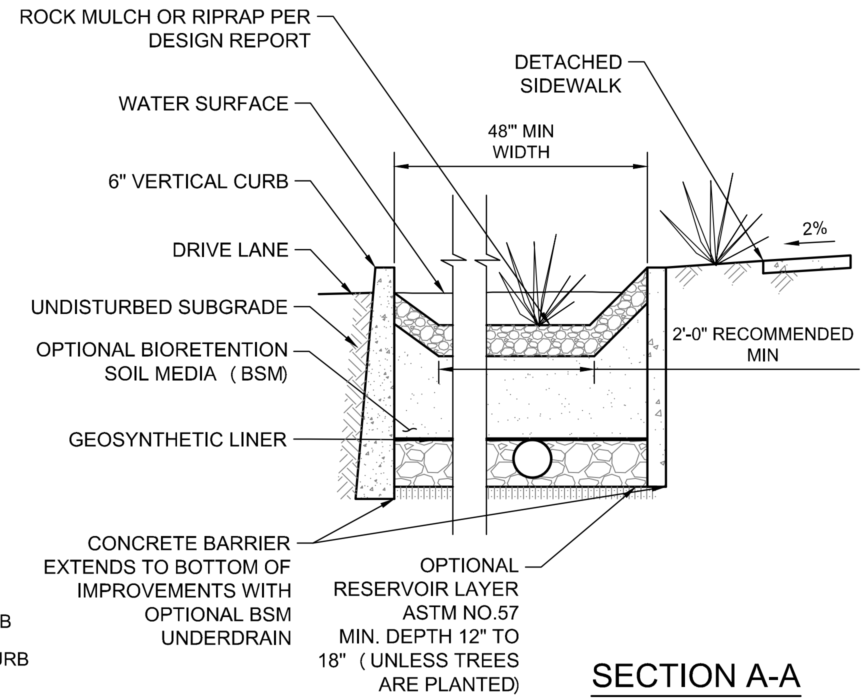
TYPE 1 - DETACHED SIDEWALK



SECTION B-B
W/O BSM

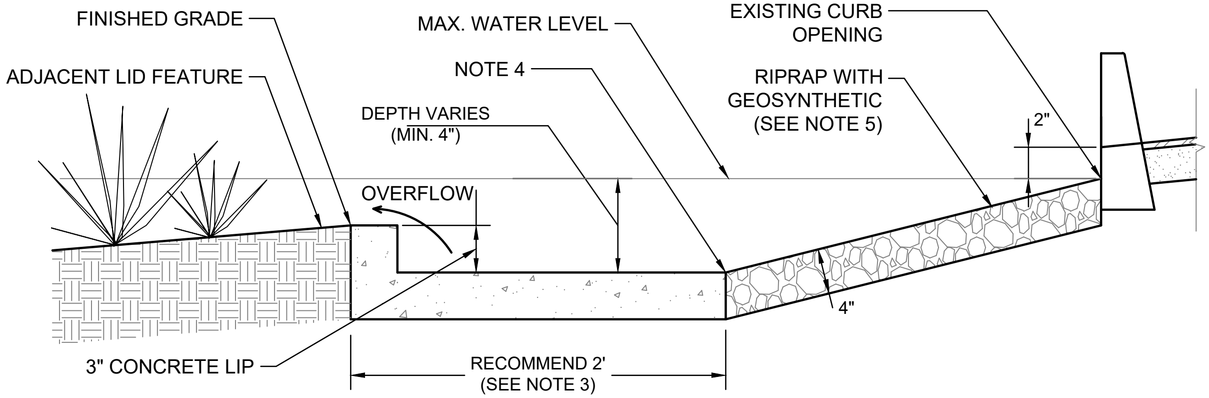


TYPE 2 - SIDEWALK ATTACHED TO CURB

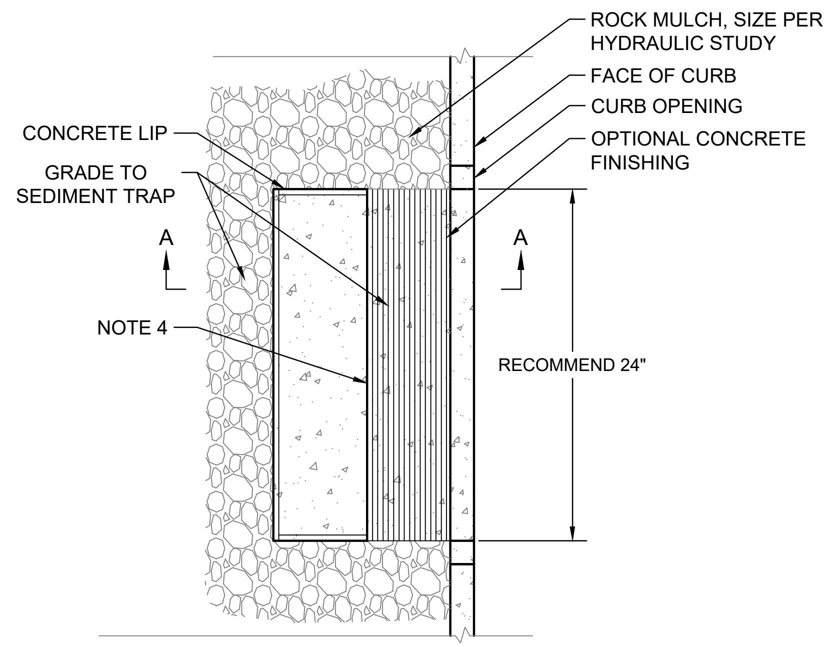


SECTION A-A
WITH BSM OPTION

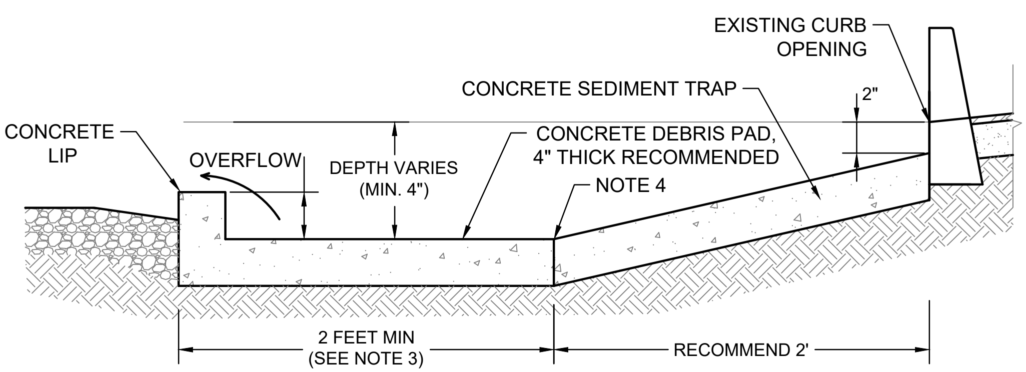
CURB MODIFICATION - CURB EXTENSION	DATE: 2022	DETAIL NO. LHC-LID-06



SEDIMENT TRAP WITH RIPRAP SPILLWAY



SEDIMENT TRAP PLAN VIEW

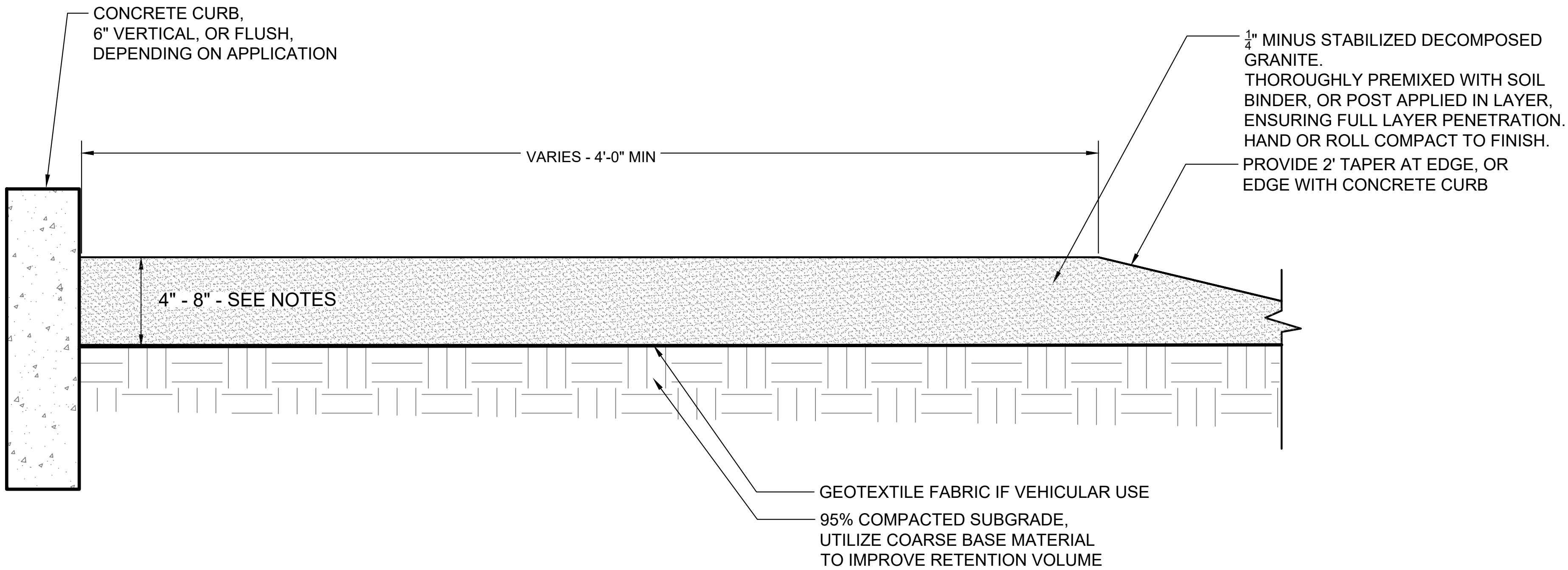


SECTION A-A

NOTES:

1. DIMENSIONS OF SEDIMENT TRAP SHOULD BE ADJUSTED BASED ON CONTRIBUTING WATERSHED SIZE AND SEDIMENT LOAD.
2. SEDIMENT TRAP CAN BE PRECAST OR CAST IN PLACE CONCRETE.
3. DEBRIS PAD SHOULD BE DESIGNED TO CONTAIN HYDRAULIC JUMP (IF POSSIBLE).
4. EXPANSION/CONTRACTION JOINT
5. RIPRAP SIZE BASED ON DESIGN REPORT.
6. DETAIL IS MODIFIED FROM GREATER PHOENIX METRO GREEN INFRASTRUCTURE HANDBOOK (GPMGIH).
7. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION.

CURB MODIFICATION - SEDIMENT TRAP	DATE: 2022	DETAIL NO. LHC-LID-07



NOTES:

1. DEPTH OF APPLICATION IS DEPENDANT UPON ANTICIPATED USE. VEHICULAR USE WILL REQUIRE A DEEPER APPLICATION.
2. STABLIZED DG PAD OR PATHWAY SHOULD BE EDGED WITH A TAPERED EDGE, CONCRETE EDGE, OR SIMILAR METHOD TO CONTAIN AND SUPPORT THE SURFACE

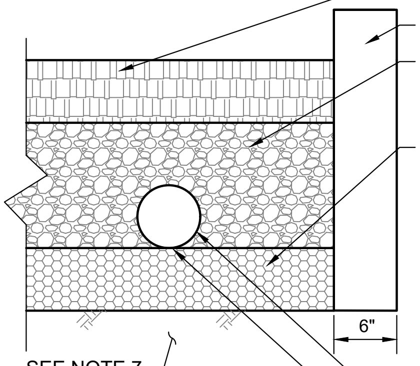
PERMEABLE HARDSCAPE - STABILIZED AGGREGATE

DATE: 2022

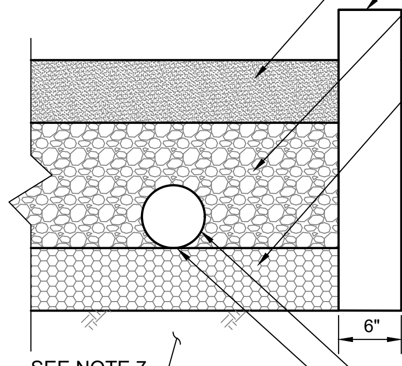
DETAIL NO. LHC-LID-08

RECOMMENDED PAVEMENT THICKNESS

PAVEMENT ITEM	CLASS A	CLASS B
PERVIOUS PORTLAND CEMENT CONCRETE	6"	8"
RESERVOIR LAYER	6", SEE NOTE 3	12", SEE NOTE 3
SUBBASE LAYER	4"	4"



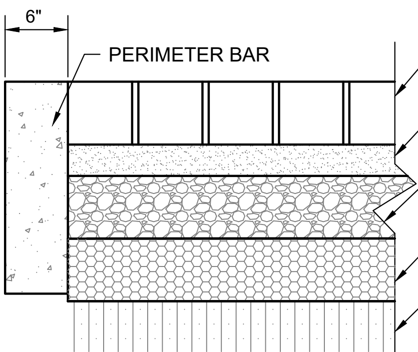
PERMEABLE CONCRETE



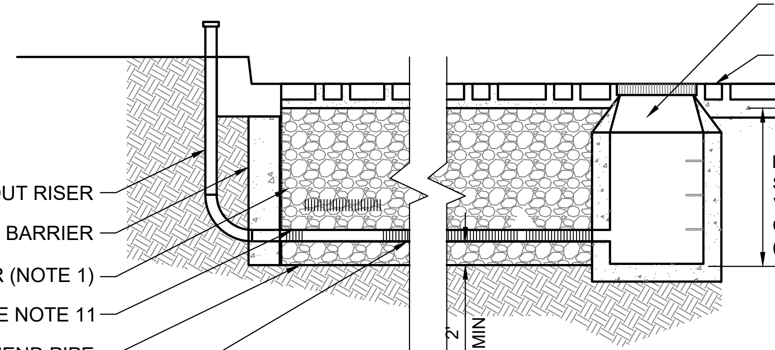
PERMEABLE ASPHALT

NOTES:

1. AGGREGATE LAYERS SHALL MEET SPECIFIED SIZE AND MATERIAL STANDARDS.
2. GEOSYNTHETIC TO BE USED TO PROTECT PIPES FROM CLOGGING.
3. DEPTH OF RESERVOIR LAYER AS SHOWN ON DESIGN PLANS SHOULD BE SIZED TO DRAIN WITHIN LOCAL TIME REQUIREMENTS.
4. TOP OF PAVEMENT SHOULD BE DESIGNED TO ACHIEVE 1% MAXIMUM SLOPE IN ANY DIRECTION.
5. WHEN FILTER LAYER IS OMITTED, PROVIDE GEOSYNTHETIC CLASS-A MATERIAL BENEATH RESERVOIR LAYER.
6. UNDERDRAIN RECOMMENDED FOR LOW PERCOLATING SOILS.
7. UNCOMPACTED SUBGRADE FOR AREAS DESIGNED FOR INFILTRATION FEATURES ONLY.
8. GEOSYNTHETIC MATERIAL.
9. COMPACTION REQUIREMENTS IF ANY WILL BE DESIGNED BY GEOTECHNICAL ENGINEER.
10. SOLID PAVERS CAN BE USED (OPTIONAL).
11. MINIMUM COVER OVER THE UNDERDRAIN PER MANUFACTURER RECOMMENDATION.
12. DETAIL IS MODIFIED FROM GREATER PHOENIX METRO GREEN INFRASTRUCTURE HANDBOOK (GPMGIH).
13. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION.

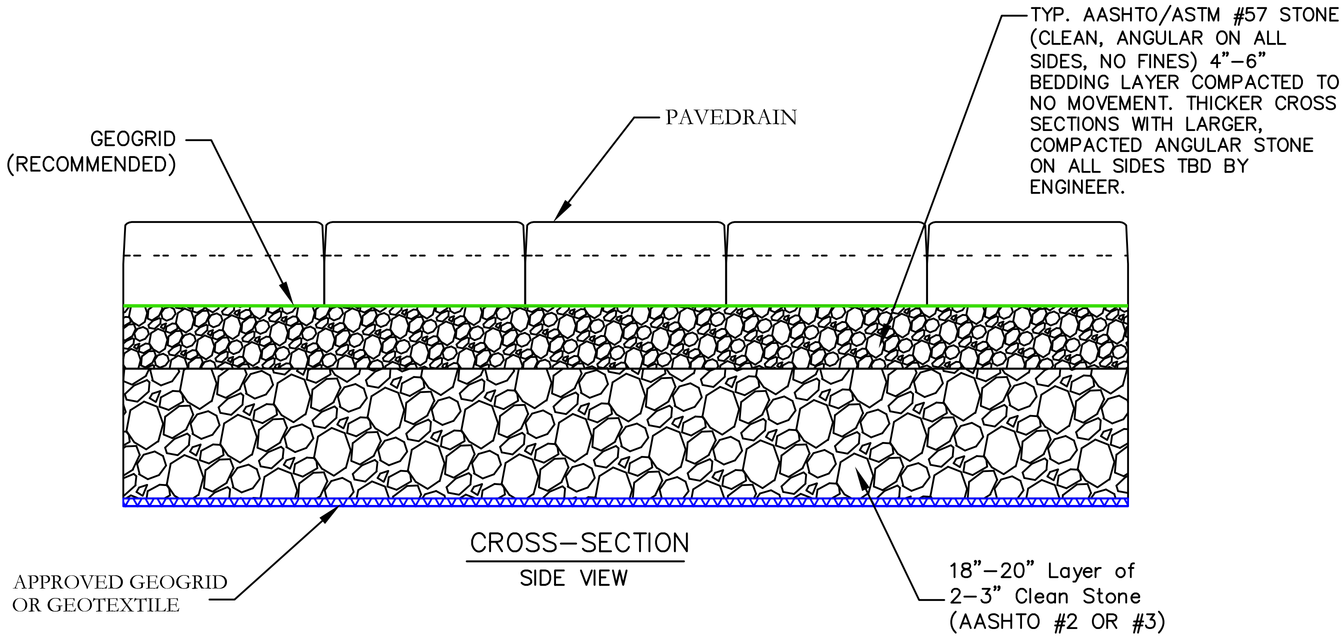


PERMEABLE CONCRETE PAVERS



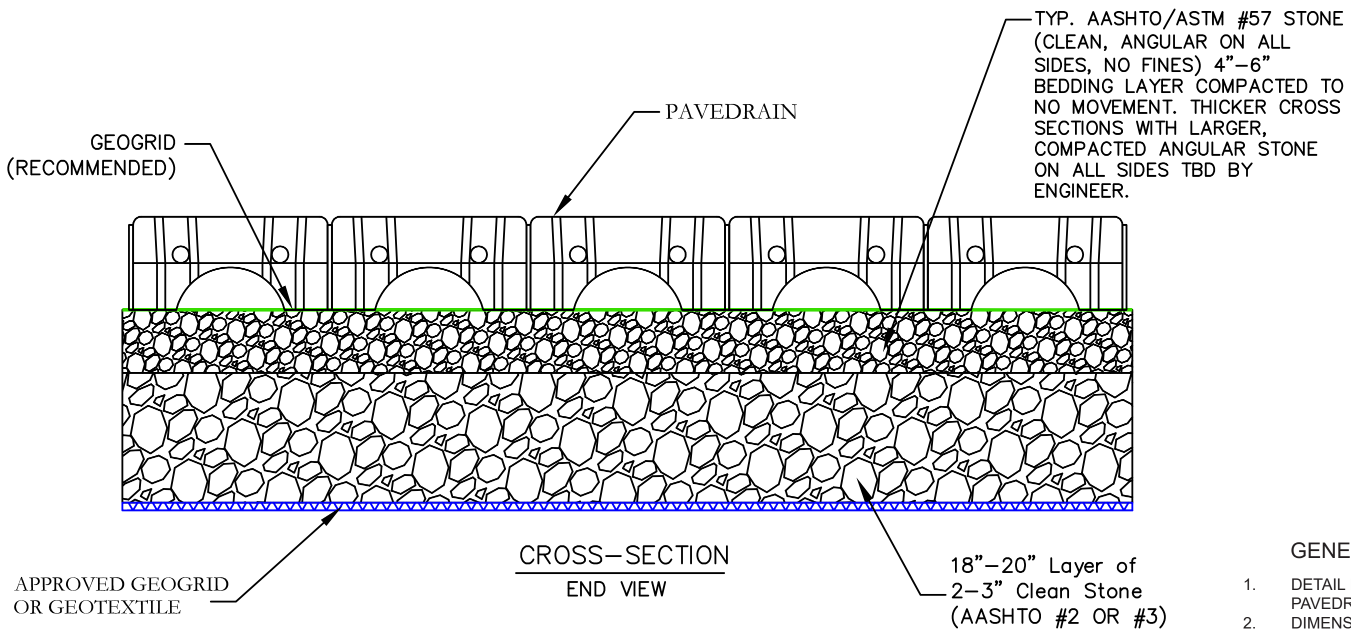
PERMEABLE PAVEMENT WITH UNDERGROUND RESERVOIR AND UNDERDRAIN (OPTIONAL)

PERMEABLE HARDSCAPE - PERMEABLE PAVEMENT	DATE: 2022	DETAIL NO. LHC-LID-09



CROSS-SECTION

SIDE VIEW



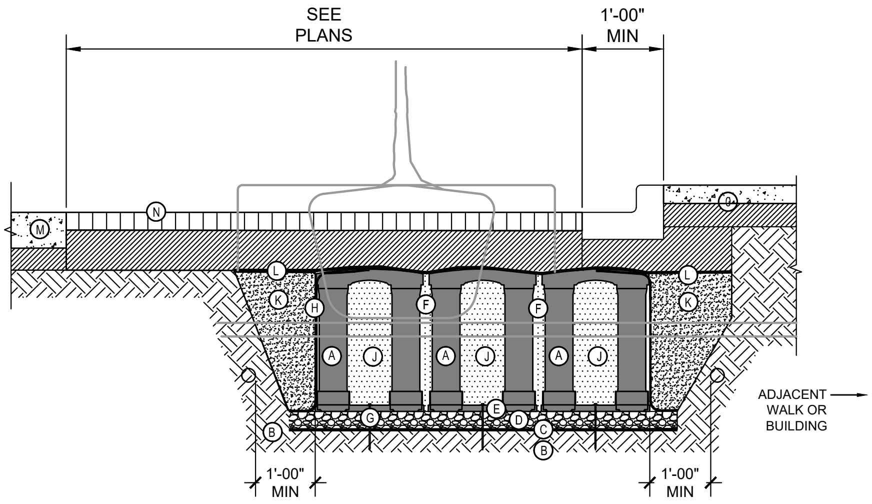
CROSS-SECTION

END VIEW

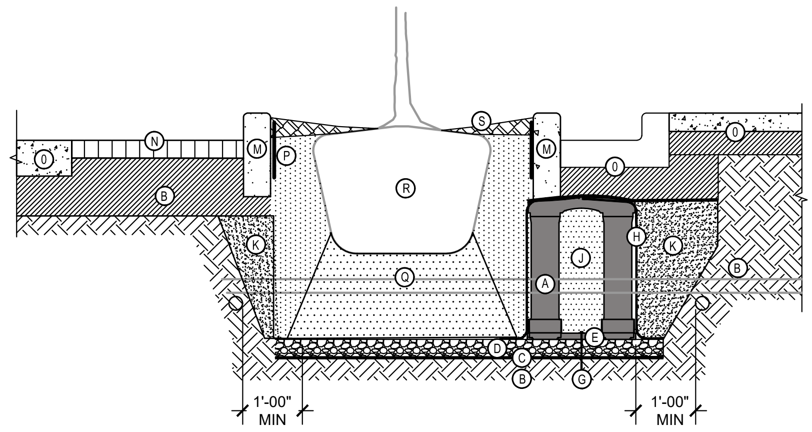
GENERAL NOTES

1. DETAIL IS DRAWN FROM MANUFACTURER, PAVEDRAIN
2. DIMENSIONS AND PERFORMING STANDARDS BU ENGINEER AND LOCATION OF APPLICATION

PERMEABLE HARDSCAPE - PERMEABLE ARTICULATING CONCRETE BLOCK (P-ACB)	DATE: 2022	DETAIL NO. LHC-LID-10



TYPICAL CELL LAYOUT SECTION



TYPICAL LAYOUT SECTION
AT CURB PLANTER

KEY PLAN

- (A) SILVA CELL SYSTEM 2X (DECK, BASE, AND POSTS)
- (B) SUBGRADE, COMPACTED
- (C) GEOTEXTILE FABRIC, PLACED ABOVE SUBGRADE
- (D) 4" MIN AGGREGATE SUB BASE, COMPACTED TO 95% PROCTOR
- (E) SILVA CELL BASE SLOPE, 10% MAX
- (F) 1" TO 6" SPACING BETWEEN SILVA CELLS AT BASE
- (G) ANCHORING SPIKES, CONTACT DEEPROOT MANUFACTURER FOR ALTERNATIVE. P: 415 781 9700
- (H) GEOGRID, WRAPPED AROUND PERIMETER OF SYSTEM, WITH 6" TOE (OUTWARD FROM BASE) AND 12" EXCESS (OVER TOP OF DECK)
- (I) CABLE TIE, ATTACHING GEOGRID TO SILVA CELL AT BASE OF UPPER LEG FLARE, AS NEEDED
- (J) PLANTING SOIL, PER PROJECT SPECIFICATIONS, PLACED IN LIFTS AND WALK-IN COMPACTED TO 75-85% PROCTOR
- (K) COMPACTED BACKFILL, PER PROJECT SPECIFICATIONS
- (L) GEOTEXTILE FABRIC TO EDGE OF EXCAVATION
- (M) CURB AT TREE OPENING
- (N) SILVA CELL PAVERS
- (O) PAVEMENT AND AGGREGATE BASE PER PROJECT *
- (P) DEEPROOT ROOT BARRIER, 12" OR 18", DEPTH DETERMINED BY THICKNESS OF PAVEMENT SECTION, INSTALL DIRECTLY ADJACENT TO CONCRETE EDGE RESTRAINT
- (Q) PLANTING SOIL BELOW ROOT BALL, COMPACTED WELL TO PREVENT SETTLING
- (R) ROOT BALL
- (S) TREE OPENING TREATMENT, PER PROJECT SPECIFICATIONS
- (T) DEEPROOT WATER AND AIR VENT, ROOTBALL, WHEN REQUIRED
- (U) DEEPROOT WATER AND AIR VENT, WHEN REQUIRED

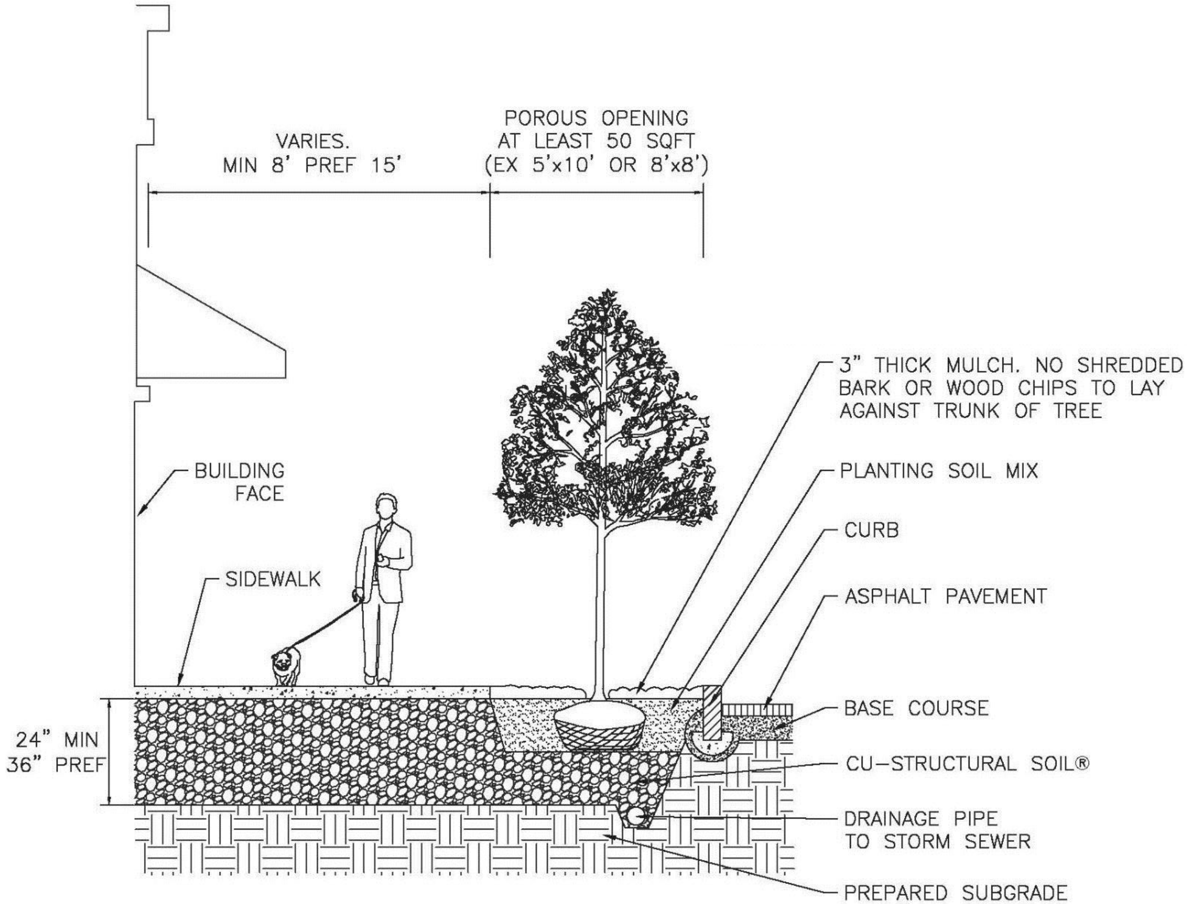
*MINIMUM PAVEMENT PROFILE OPTIONS TO MEET H-20 LOADING

PAVEMENT	+ AGGREGATE BASE COURSE
4" CONCRETE	+ 4" AGGREGATE
3" PAVER	+ 12" AGGREGATE
4" ASPHALT	+ 12" AGGREGATE
2.6" PAVER	+ 5" CONCRETE

SUSPENDED PAVEMENT - PERVIOUS STORAGE MEDIA

DATE: 2022

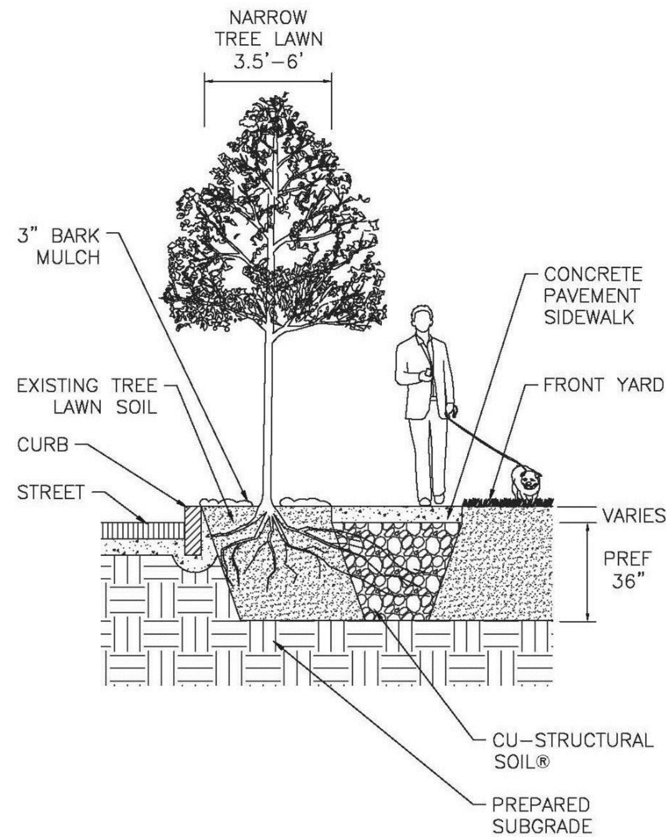
DETAIL NO. LHC-LID-11



GENERAL NOTES

1. DETAIL IS DRAWN FROM MANUFACTURER CU-STRUCTURAL SOIL
2. DIMENSIONS AND PERFORMING STANDARDS BU ENGINEER AND LOCATION OF APPLICATION

TYPICAL TREE PLANTING PIT ALONG SIDEWALK



GENERAL NOTES

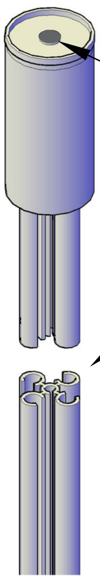
1. DETAIL IS DRAWN FROM MANUFACTURER CU-STRUCTURAL SOIL
2. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION

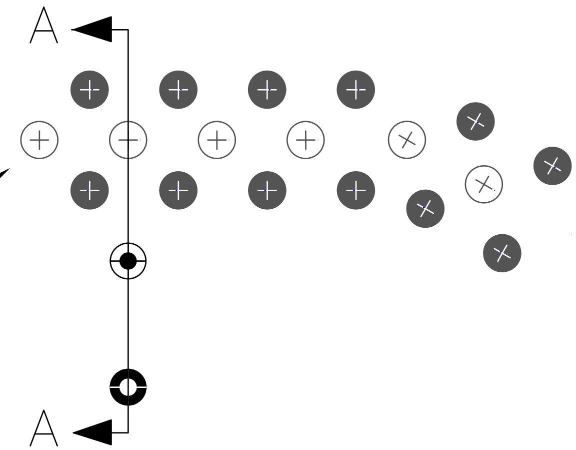
MANUFACTURER NOTES

1. BREAK-OUT ZONES SHOULD BE CONSIDERED WHEN TREE LAWN IS LESS THAN 6' WIDE
2. FOR EACH TREE, TWO 5'X5' SIDEWALK SLABS ARE TO BE REMOVED AND RECONSTRUCTED WITH A BASE OF 24" MIN (36" PREF) CU-STRUCTURAL SOIL TO ALLOW TREE ROOTS TO SAFELY GROW UNDER SIDEWALK AND INTO ADJACENT PROPERTY WITHOUT HEAVING SIDEWALK.

BREAK-OUT ZONE FROM NARROW TREE LAWN TO ADJACENT PROPERTY

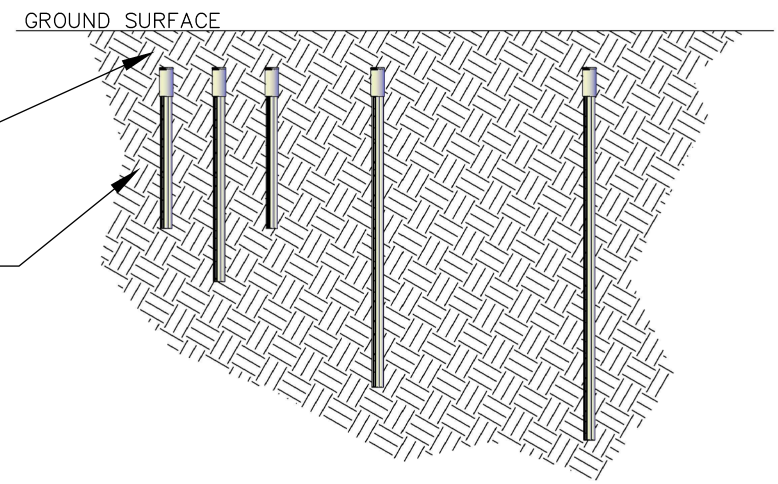
SUSPENDED PAVEMENT - STRUCTURAL SOIL	DATE: 2022	DETAIL NO. LHC-LID-12





TOP VIEW

(NOT TO SCALE)



SECTION A–A VIEW

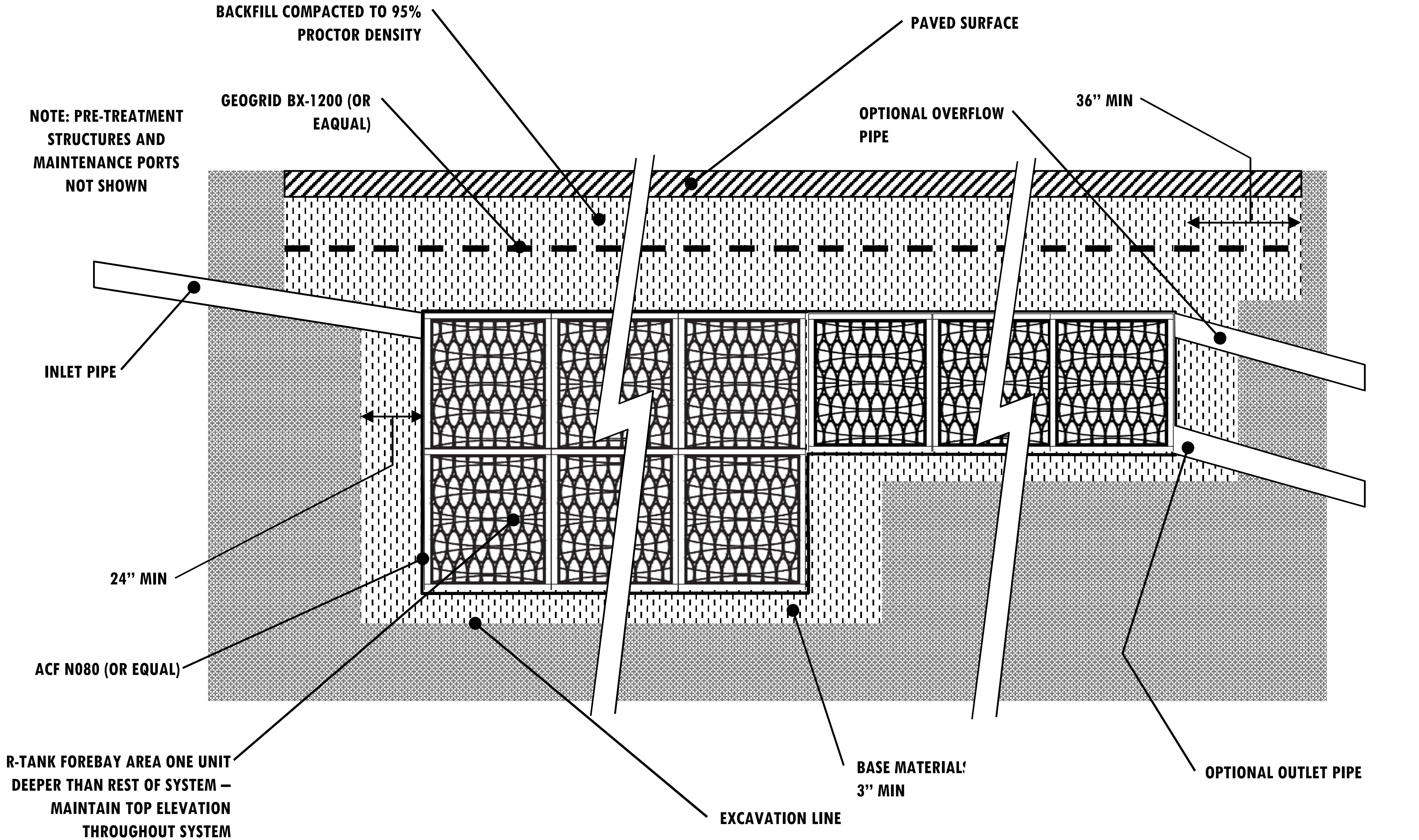
(NOT TO SCALE)

SPECIFICATIONS	
DIAMETER	1.25 INCHES
BASE LENGTH	5 TO 40 FEET
MATERIAL	POLYETHYLENE
INSTALATION DEPTH	1 TO 3 FEET BELOW GROUND SURFACE
DRILL HOLE DIAMETER	1.75 INCHES
SPACING BETWEEN DEVICES	2 TO 75 FEET

GENERAL NOTES

1. DETAIL IS DRAWN FROM MANUFACTURER PRAJANA EGRP
2. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION

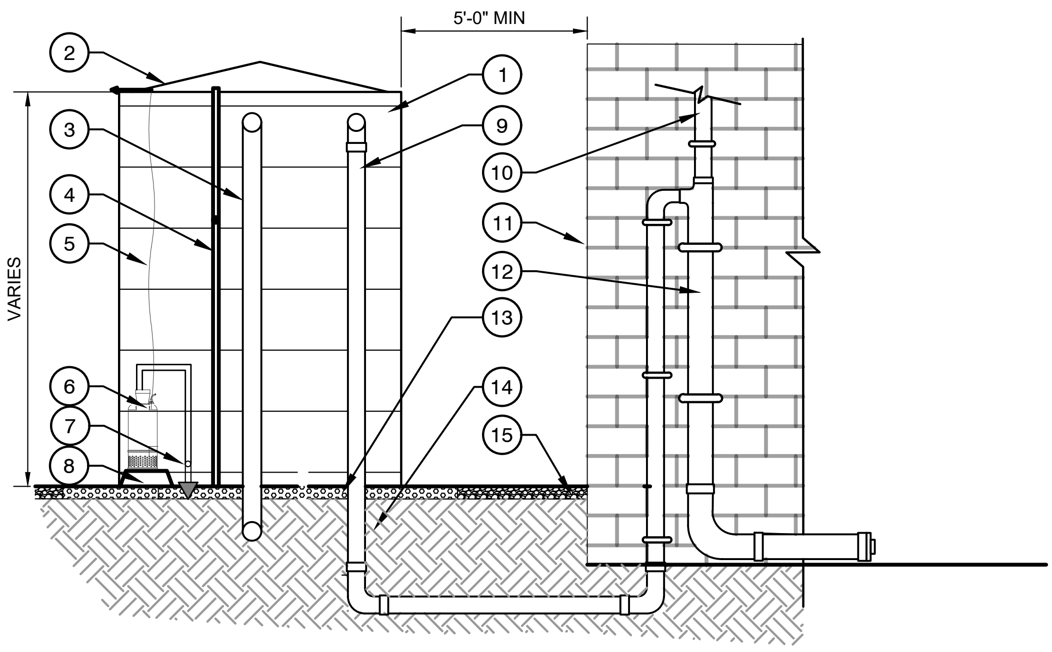
SOIL MODIFICATION - ENERGY-PASSIVE GROUNDWATER RECHARGE (EGRP)	DATE: 2022	DETAIL NO. LHC-LID-13



GENERAL NOTES

1. DETAIL IS DRAWN FROM MANUFACTURER ACF ENVIRONMENTAL
2. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION

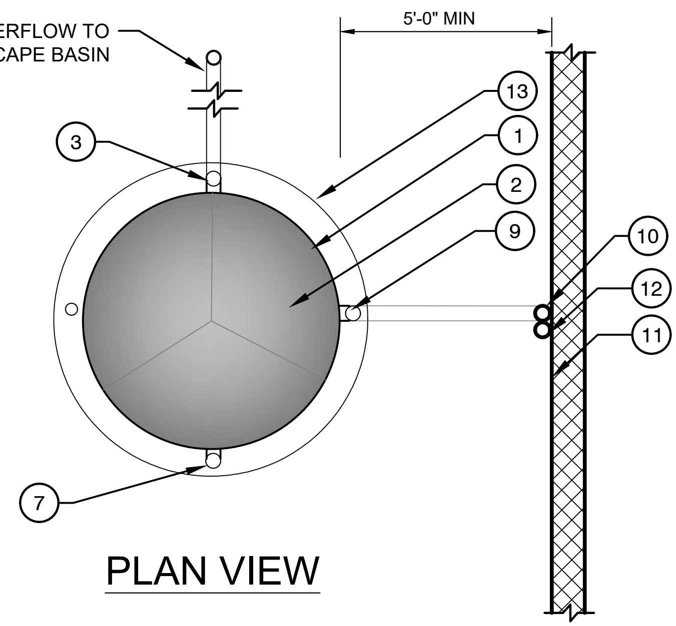
MODULAR UNDERGROUND STORAGE - R-TANK	DATE: 2022	DETAIL NO. LHC-LID-14



ELEVATION

1	ABOVE GROUND WATER STORAGE CISTERN. MATERIAL, SIZE, HEIGHT, AND APPERANCE VARY
2	CISTERN COVER
3	OVERFLOW, DRAIN INTO LANDSCAPE AREA.
4	LEVEL INDICATOR
5	PUMP POWER CORD
6	PUMP
7	PREDRILLED 1" BULKHEAD FITTING, AC-4 ONLY
8	PUMP STAND
9	INLET
10	CONNECT TO ROOF DRAIN
11	BUILDING EXTERIOR
12	FIRST FLUSH DIVERTER CHAMBER
13	CRUSHED ROCK DRAINAGE AGGREGATE - TAMP AND LEVEL PRIOR TO INSTALLATION
14	COMPACTED SUBGRADE
15	LANDSCAPE TOPDRESS - SEE LANDSCAPE PLANS

NOTES:
1. SEE ALL MANUFACTURER'S INSTALLATION REQUIREMENTS PRIOR TO INSTALLATION.
2. INSTALL TANK WITH FIRST FLUSH SYSTEM.
3. ALL ABOVE GROUND PIPING SHALL USE SCHEDULE 40 PVC PIPE.



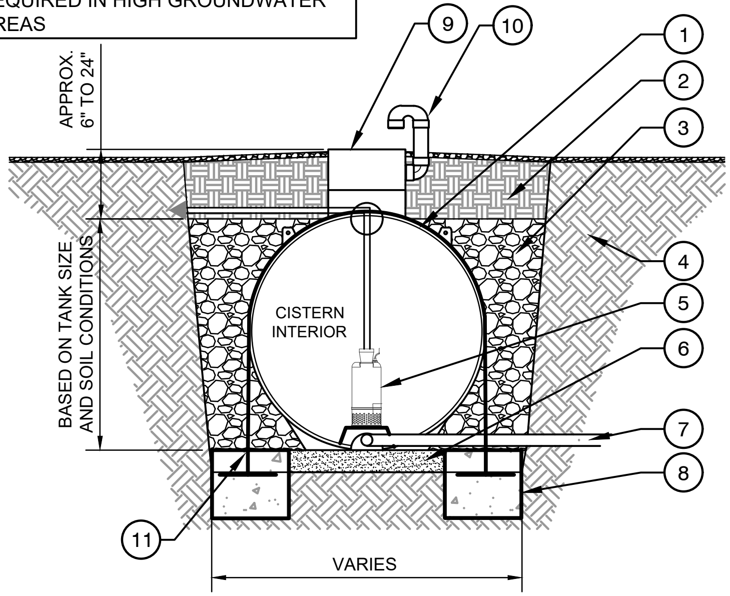
PLAN VIEW

CISTERN - ABOVEGROUND

DATE: 2022

DETAIL NO. LHC-LID-15

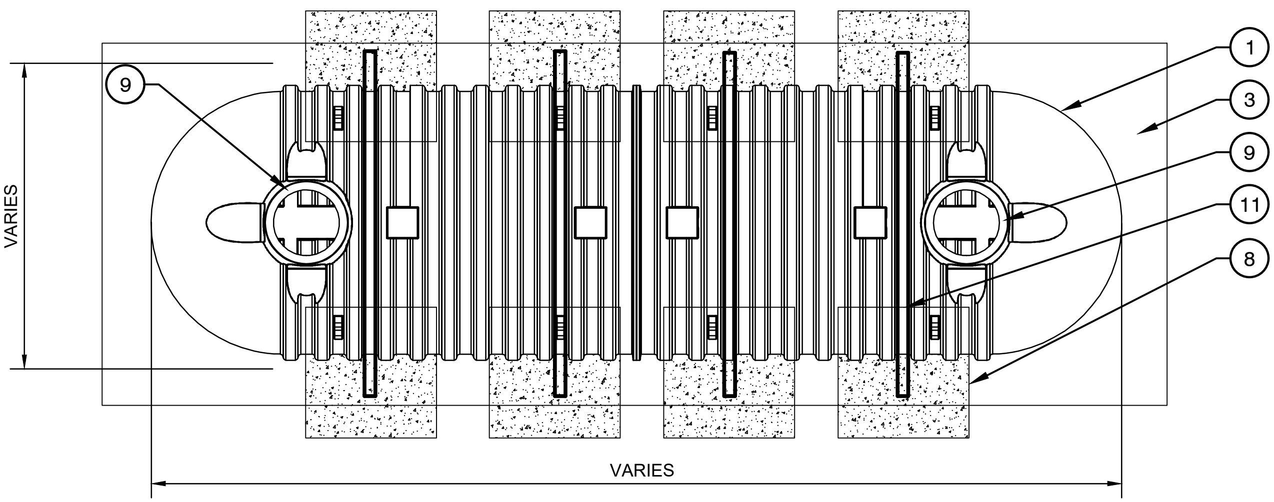
NOTE:
CISTERN ANCHORING MAY BE REQUIRED IN HIGH GROUNDWATER AREAS



SECTION VIEW

1	UNDERGROUND CISTERN. MATERIAL, SIZE, CAPACITY, AND DEPTH VARIES, BASED ON WATERSHED, AVAILABLE AREA, AND BUDGET.
2	BACKFILL SOIL - MOUND SOIL ON TOP OF TANK TO DIRECT SURFACE WATER AWAY FROM TANK
3	BACKFILL MATERIAL - PER GEOTECHNICAL ENGINEER'S RECOMMENDATION
4	UNDISTURBED SOIL / SUBGRADE
5	PUMPS AND FITTINGS AS NEEDED.
6	WELL-PACKED SAND BEDDING - 12" MINIMUM SAND, SEE MANUFACTURER INSTALLATION INSTRUCTIONS.

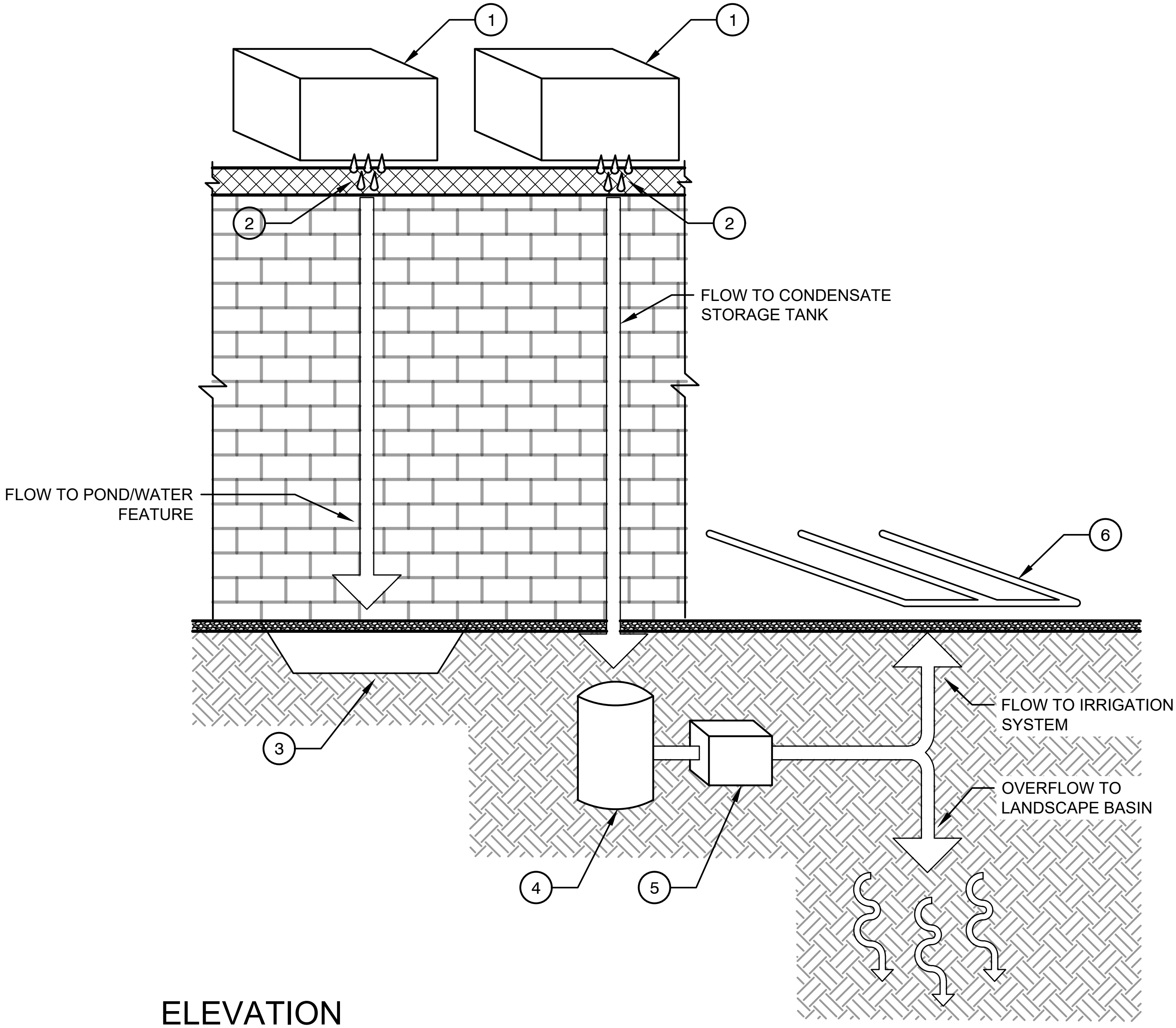
7	EQUALIZER LINE FOR USE TO JOIN MULTIPLE TANKS INSTALLED NEAR ONE ANOTHER.
8	CONCRETE ANCHOR BLOCKS, IF REQUIRED. SIZE AND QUANTITY PER STRUCTURAL ENGINEER.
9	CISTERN ACCESS RISER - INSTALL PER MANUFACTURER RECOMMENDATIONS
10	6" PVC VENT, REQUIRED BY MANUFACTURER. INSTALL PER MANUFACTURER SPECIFICATIONS.
11	ANCHOR STRAP, IF REQUIRED



PLAN VIEW

NOTES:
1. SEE ALL MANUFACTURER'S INSTALLATION REQUIREMENTS PRIOR TO INSTALLATION.
2. FILL TANK WITH WATER DURING BACKFILL OPERATIONS. SEE MANUFACTURER'S RECOMMENDATIONS.
3. PIPING IS GENERALLY PVC, THOUGH OTHER MATERIALS MAY WORK

CISTERN - UNDERGROUND	DATE: 2022	DETAIL NO. LHC-LID-16



1	BUILDING COOLING SYSTEM
2	CONDENSATE FROM BUILDING COOLING SYSTEM
3	ONSITE POND OR WATER FEATURE
4	CONDENSATE STORAGE TANK
5	FILTRATION AND IRRIGATION PUMP
6	SITE IRRIGATION SYSTEM

NOTES:
1. SEE ALL MANUFACTURER'S INSTALLATION REQUIREMENTS PRIOR TO INSTALLATION.
2. DETAIL IS MODIFIED FROM BIOHABITATS

ELEVATION

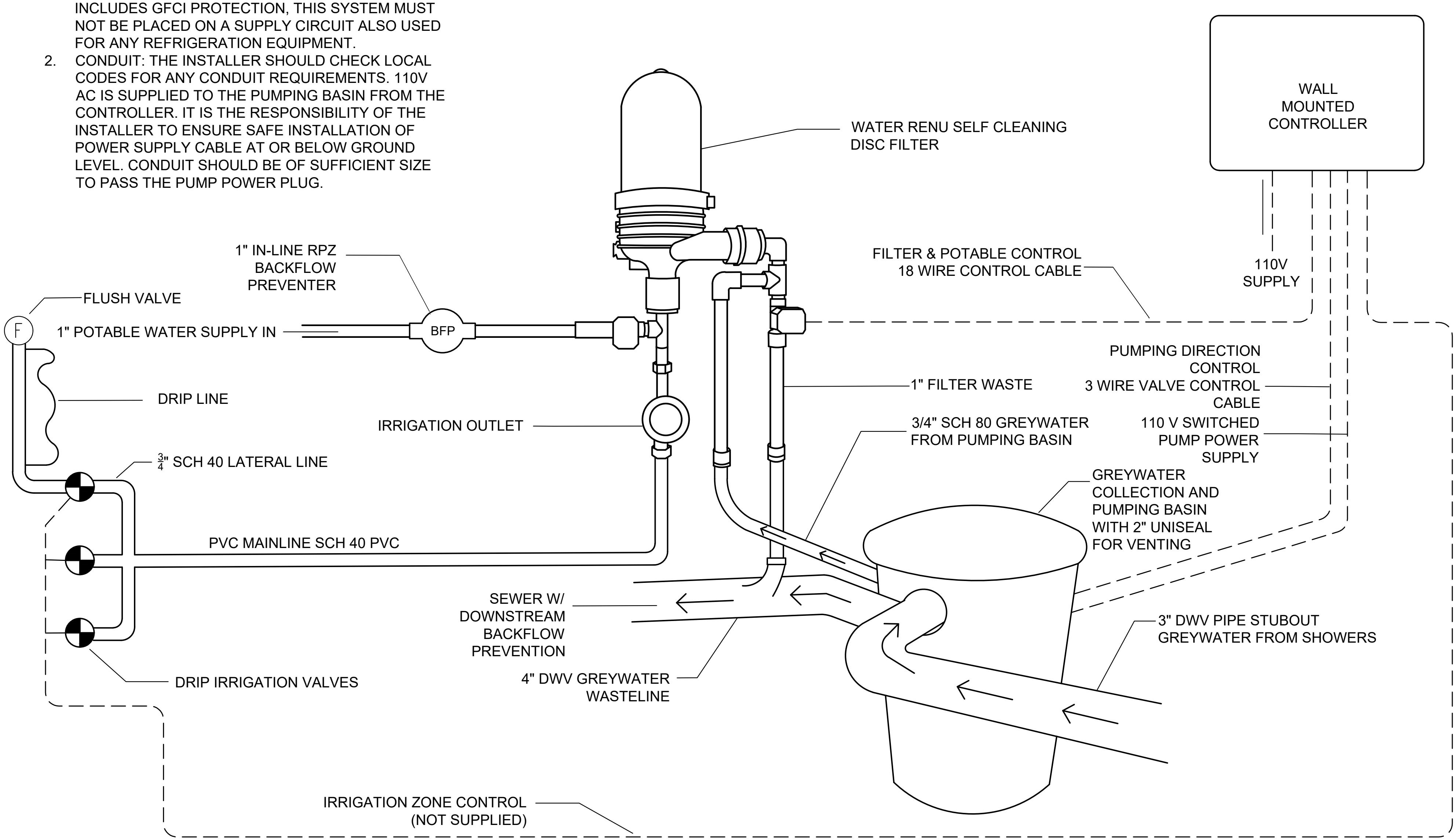
GREYWATER COLLECTION - AC CONDENSATE

DATE: 2022

DETAIL NO. LHC-LID-17

NOTES:

1. POWER: 110V AC 10 AMP SUPPLY. IRRIGRAY IS SUPPLIED WITH A 3' POWER LEAD, MALE 3 WIRE PLUG. ALTHOUGH THE IRRIGRAY SYSTEM INCLUDES GFCI PROTECTION, THIS SYSTEM MUST NOT BE PLACED ON A SUPPLY CIRCUIT ALSO USED FOR ANY REFRIGERATION EQUIPMENT.
2. CONDUIT: THE INSTALLER SHOULD CHECK LOCAL CODES FOR ANY CONDUIT REQUIREMENTS. 110V AC IS SUPPLIED TO THE PUMPING BASIN FROM THE CONTROLLER. IT IS THE RESPONSIBILITY OF THE INSTALLER TO ENSURE SAFE INSTALLATION OF POWER SUPPLY CABLE AT OR BELOW GROUND LEVEL. CONDUIT SHOULD BE OF SUFFICIENT SIZE TO PASS THE PUMP POWER PLUG.

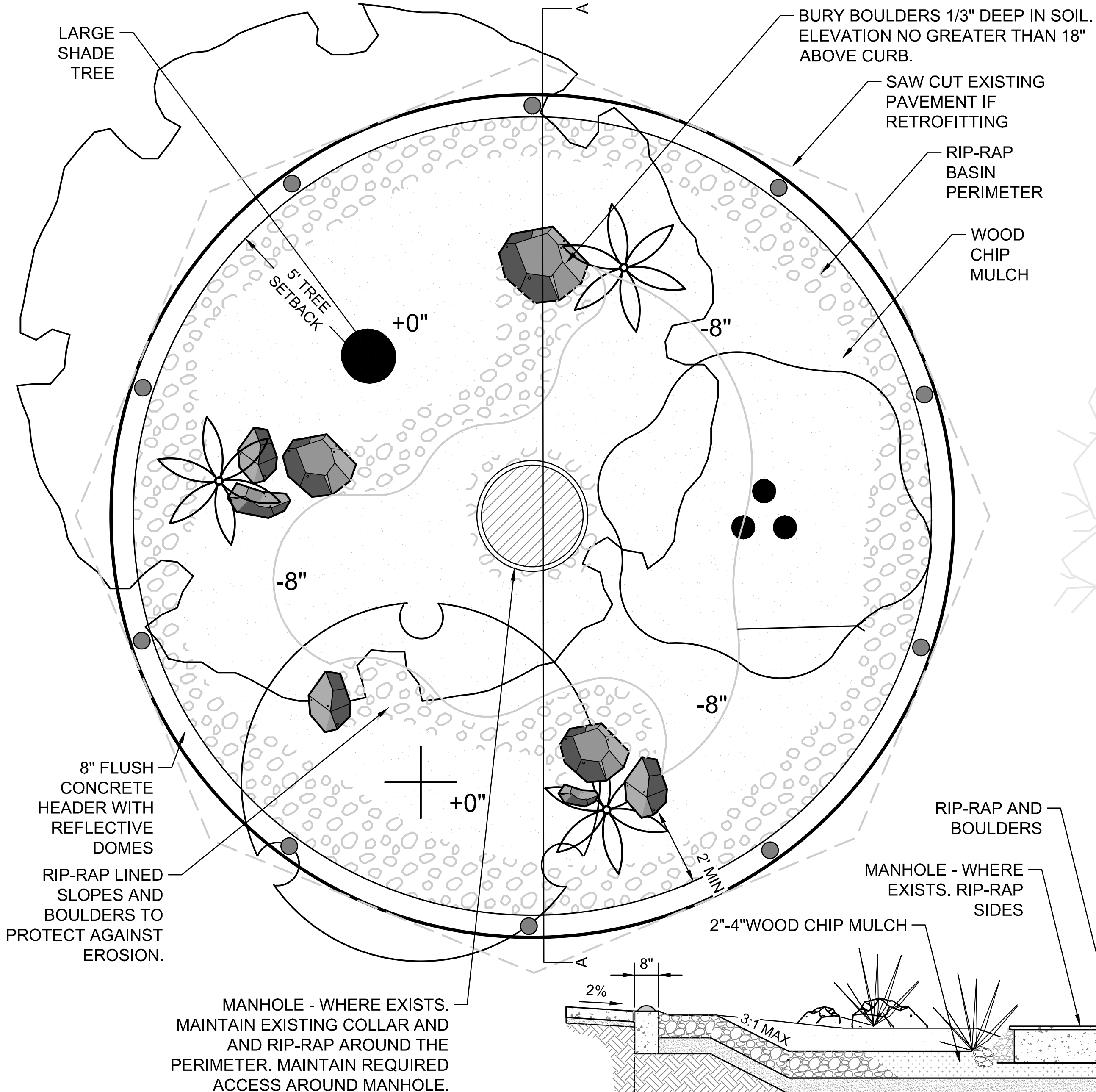


IRRIGRAY SYSTEM PLUMBING

GREYWATER COLLECTION - SHOWER WATER RECYCLING	DATE: 2022	DETAIL NO. LHC-LID-18

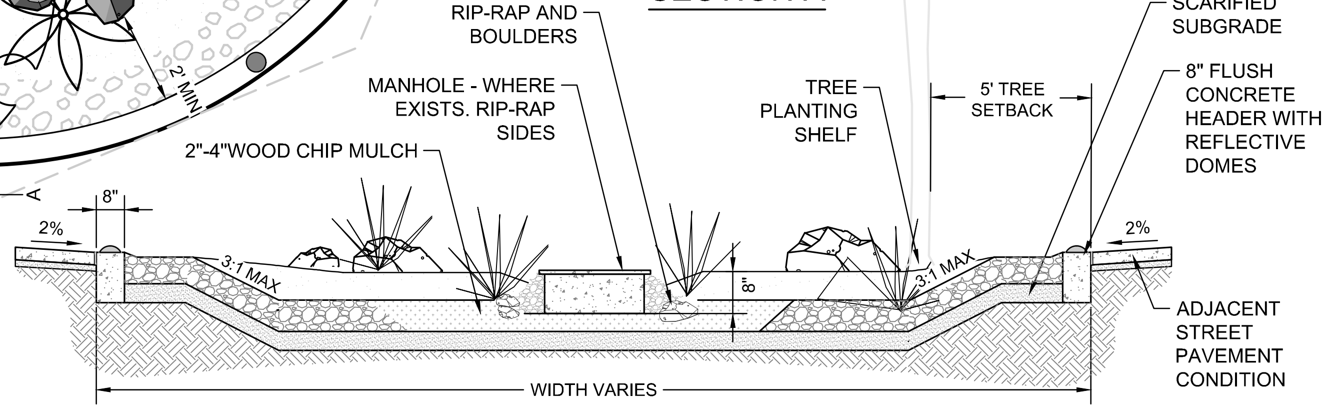
GENERAL NOTES:

1. DETAIL IS MODIFIED FROM GREEN INFRASTRUCTURE FOR DESERT COMMUNITIES BY WATERSHED MANAGEMENT GROUP.
2. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION.



PLAN VIEW

SECTION A

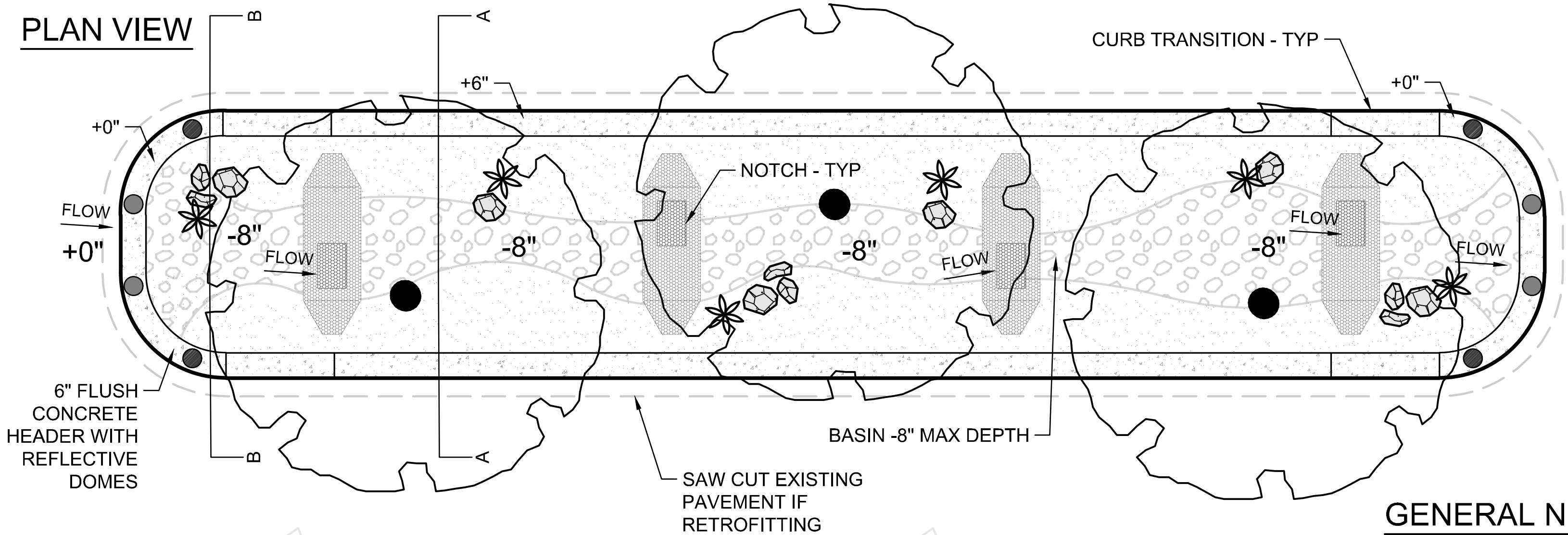


TRAFFIC CIRCLE - INVERSE CROWN STREET

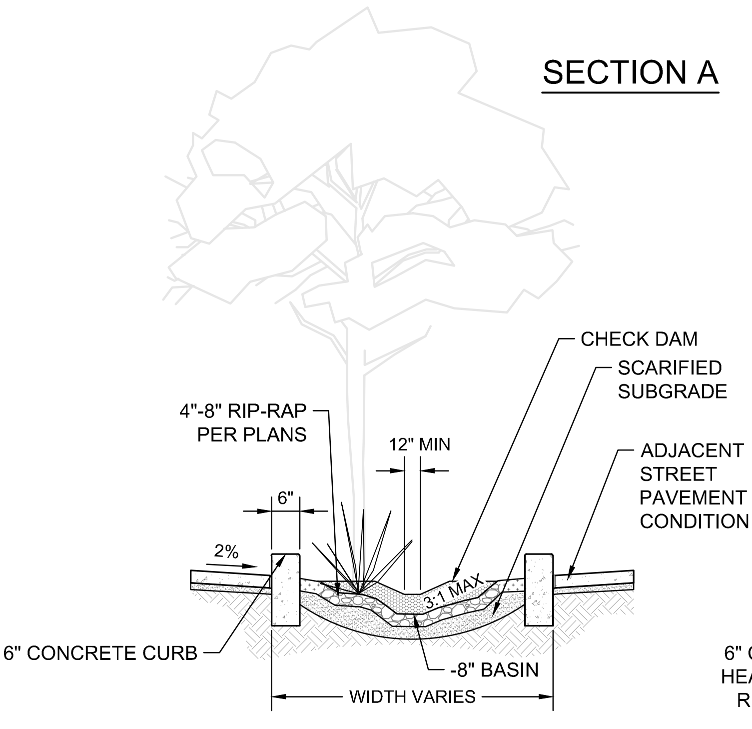
DATE: 2022

DETAIL NO. LHC-LID-19

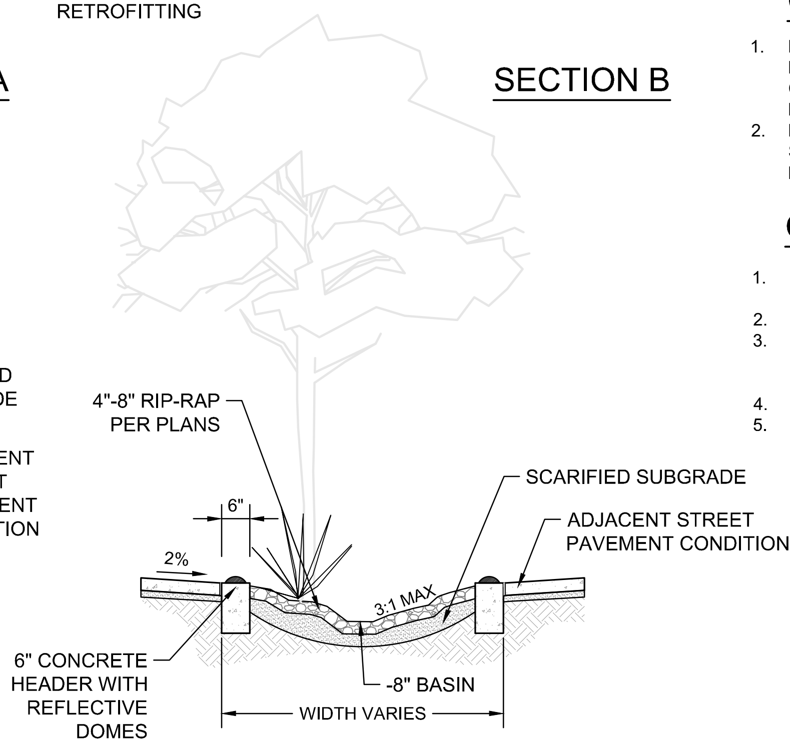
PLAN VIEW



SECTION A



SECTION B



GENERAL NOTES:

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2. DIMENSIONS AND PERFORMING STANDARDS BY ENGINEER AND LOCATION OF APPLICATION.

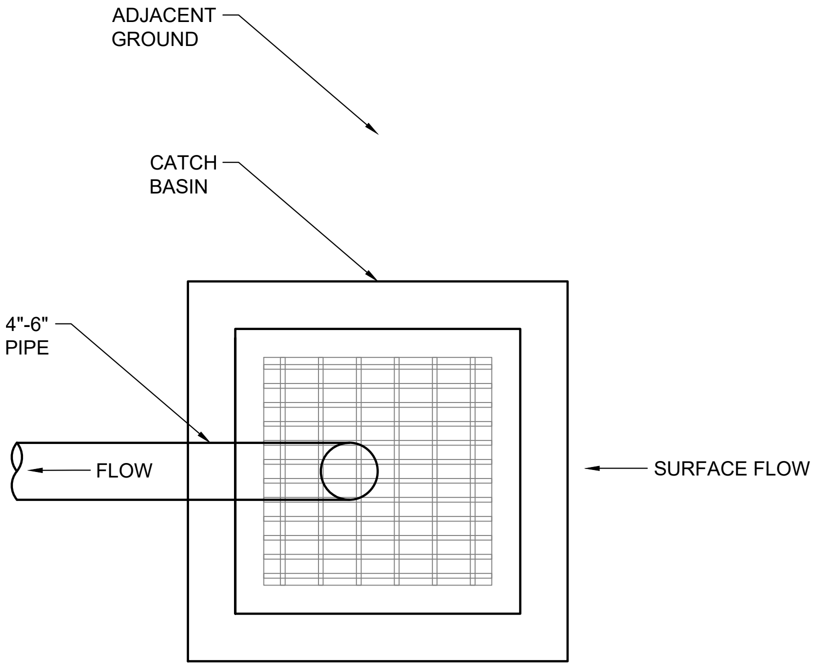
CHECK DAM NOTES

1. OPTIONAL CHECK DAM IS MEANT TO SLOW FLOWS DURING HIGH FLOW EVENTS.
2. D50 SIZE DETERMINED BY THE DESIGN REPORT.
3. NOTCHES SHALL BE LATERALLY OFFSET FROM ONE ANOTHER TO INCREASE THE WATER PATH OF TRAVEL.
4. REDUCE VELOCITIES PER DESIGN REPORT.
5. TOP OF DOWNSTREAM CHECKDAM TO MATCH INVERT OF UPSTREAM CHECKDAM.

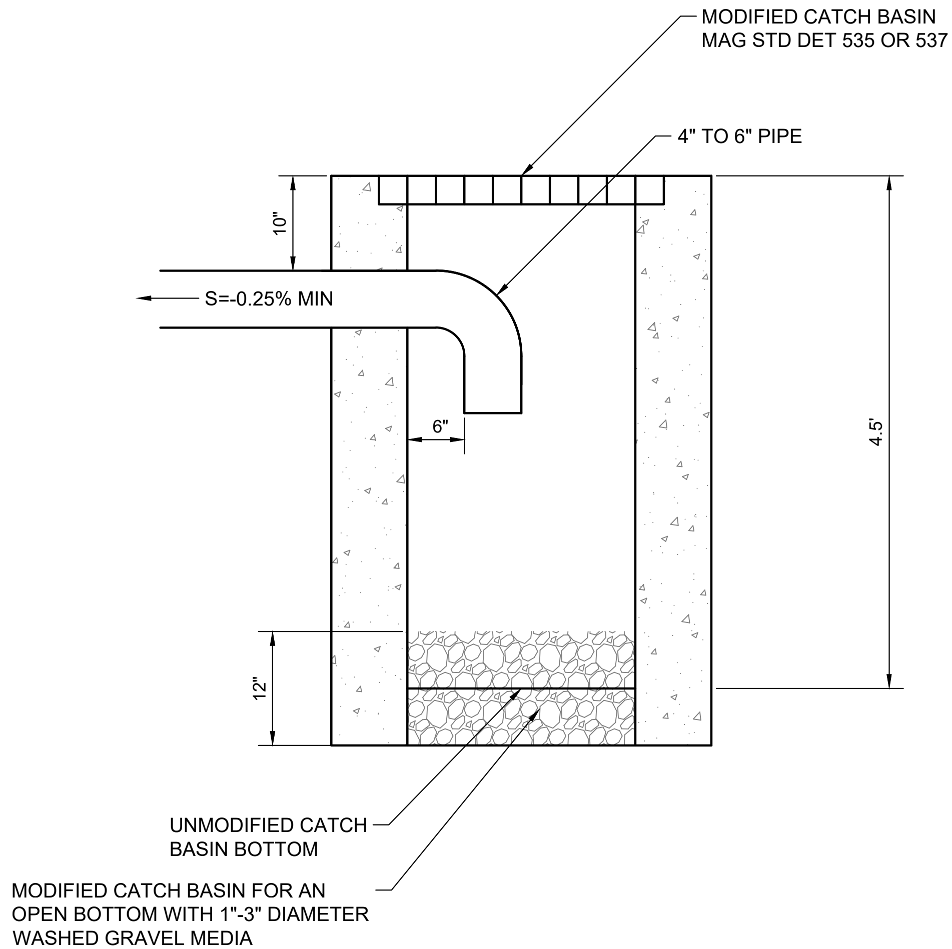
LANDSCAPE MEDIAN - INVERSE CROWN STREET	DATE: 2022	DETAIL NO. LHC-LID-20

NOTES:

1. CATCH BASIN PER MAG STD DET 535 OR 537 MAY BE MODIFIED WITH AN OPEN BOTTOM TO FACILITATE DRAINAGE OF RESIDUAL WATER.
2. GRATE TO BE FLUSH WITH GROUND
3. EXCAVATION SHOULD BE DONE TO AS NEAT A LINE AND GRADE AS POSSIBLE. UPON EXCAVATION THE EXPOSED SOIL SHOULD NOT BE COMPACTED TO PROMOTE PERCOLATION



SUMP CATCH BASIN
PLAN VIEW (N.T.S.)

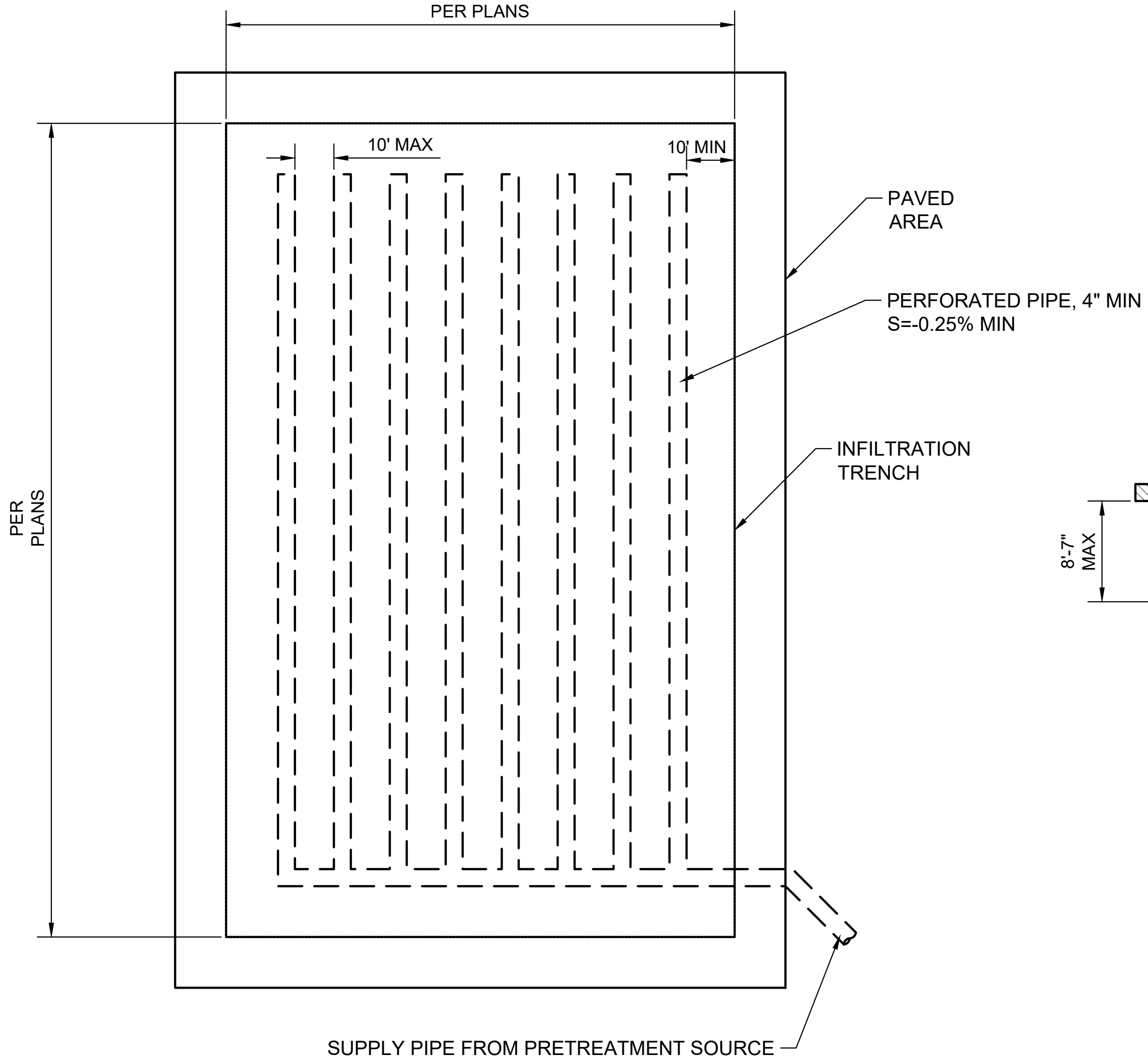


SUMP CATCH BASIN
TYPICAL SECTION (N.T.S.)

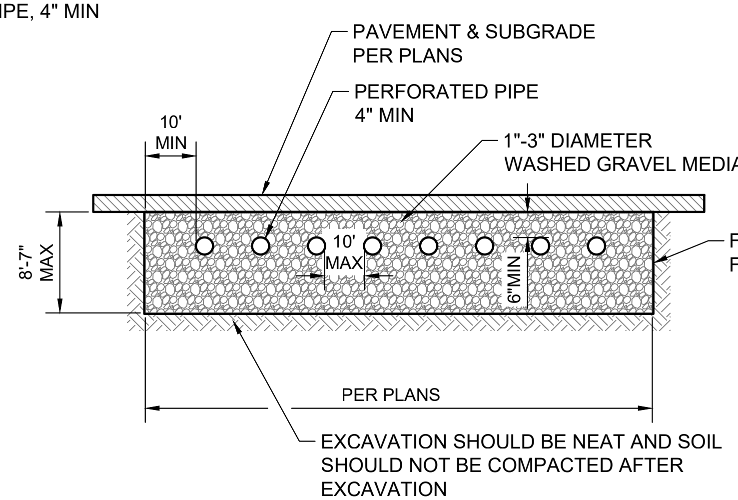
DRAIN INLET (SUMP)	DATE: 2022	DETAIL NO. LHC-LID-21

NOTES:

1. FILTER FABRIC TO WRAP ALL GRAVEL (TOP-SIDES-BOTTOM)
2. PLACE GRAVEL MEDIA WITH VIBRATORY PLATE COMPACTION ONLY
3. PLACE 4' PERFORATED PIPES MINIMUM 10' APART FROM OUTSIDE DIAMETER
4. ALL PIPES SHALL HAVE A MINIMUM SLOPE OF 0.25%
5. EXCAVATION SHOULD BE DONE TO AS NEAT A LINE AND GRADE AS POSSIBLE. UPON EXCAVATION THE EXPOSED SOIL SHOULD NOT BE COMPACTED TO PROMOTE PERCOLATION



INFILTRATION TRENCH
PLAN VIEW (N.T.S.)



INFILTRATION TRENCH
PLAN VIEW (N.T.S.)

INFILTRATION TRENCH	DATE: 2022	DETAIL NO. LHC-LID-22

APPENDIX D

Master Plan Exhibits

LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY
900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Recommended BMP Locations
- Priority Maintenance Street
- High Conveyance Street
- LID Focus Area
- Priority Maintinance Detail Area*

***See Prioirtiy Maintinance Detail Areas exhibit for additional detail.**

N
0 400 800
Feet

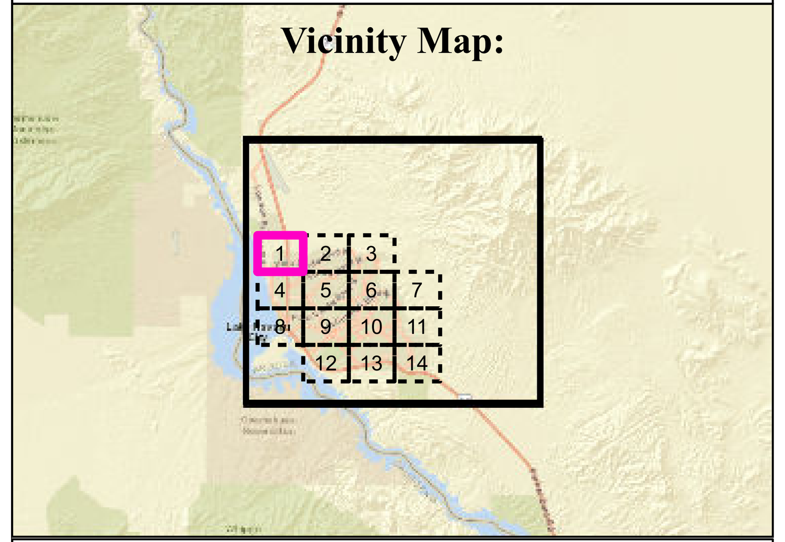
Notes:

- Lake Havasu City Low Impact Development Master Plan and Modeling Update; Mapping Activity Statement No. 2020-09-Mohave; FEMA Case No. 20-09-0058S

- NAVD 88 Vertical Datum

- Aerial Imagery Dated 2010

Vicinity Map:



Proposed BMP Locations

Sheet 1 of 14

April 2022

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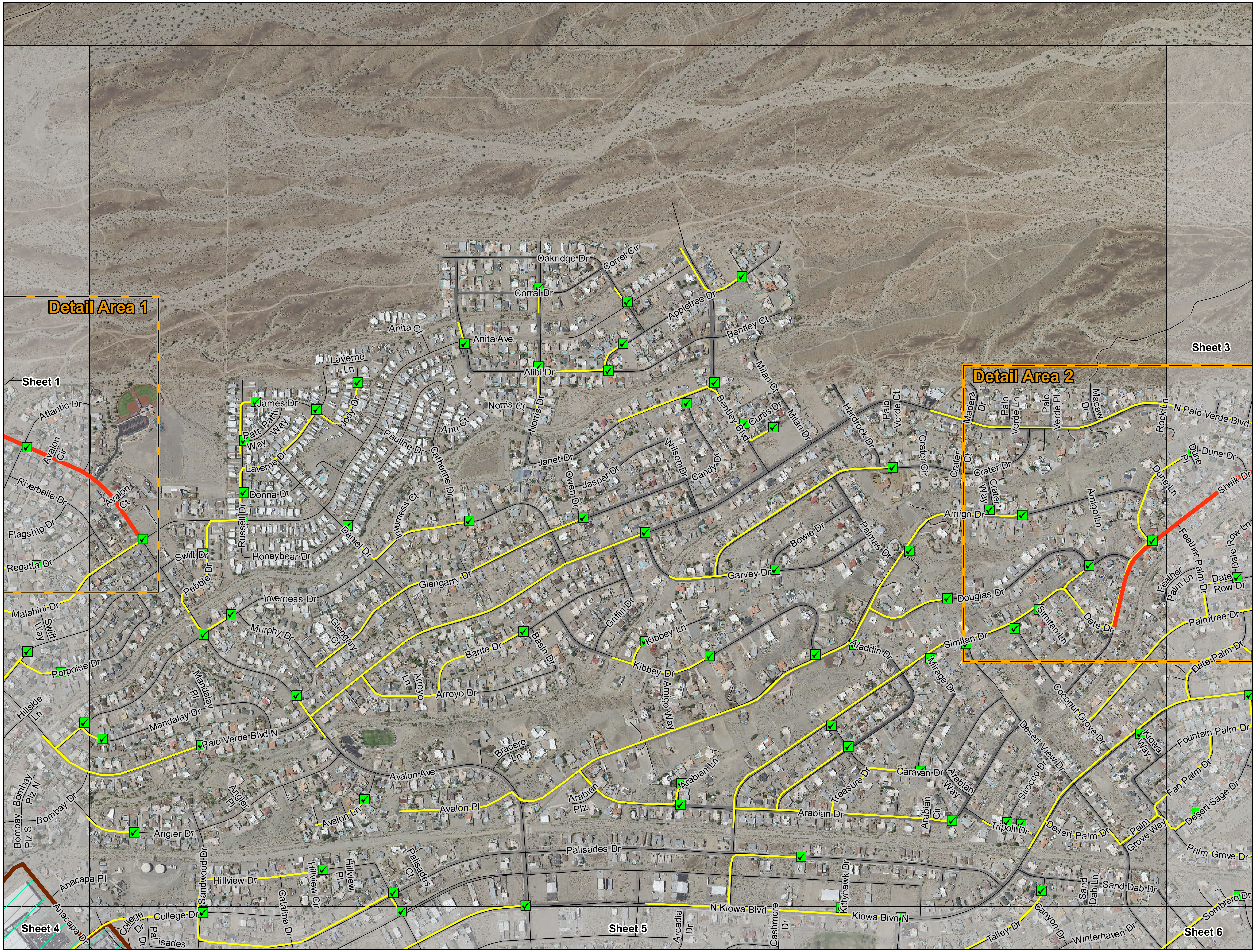
14040 North Cave Creek Road, Ste. 104
Phoenix, Arizona 85022



LAKE HAVASU CITY
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LAKE HAVASU CITY
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Lake Havasu City, Arizona 86404

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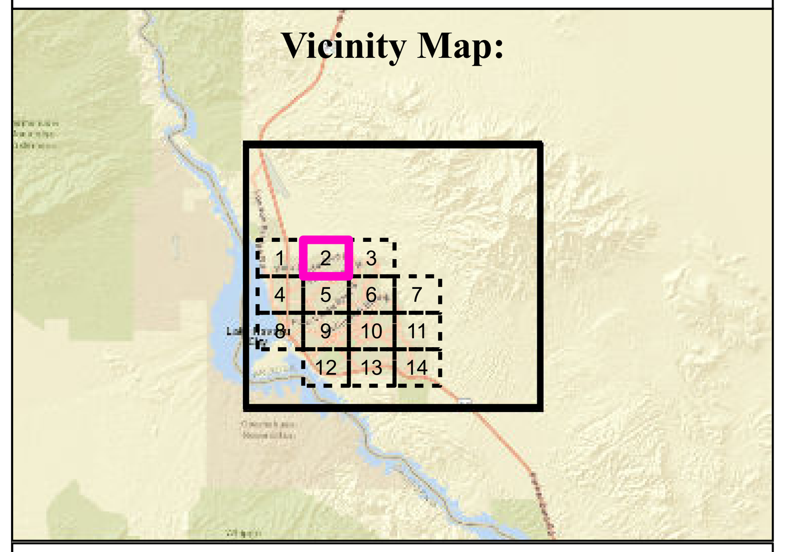

Proposed BMP Locations

Sheet 2 of 14

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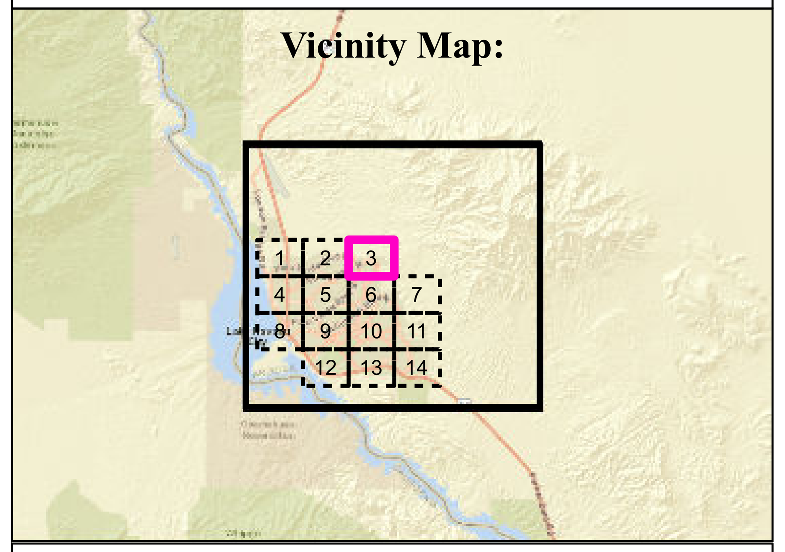

Proposed BMP Locations

Sheet 3 of 14

April 2022

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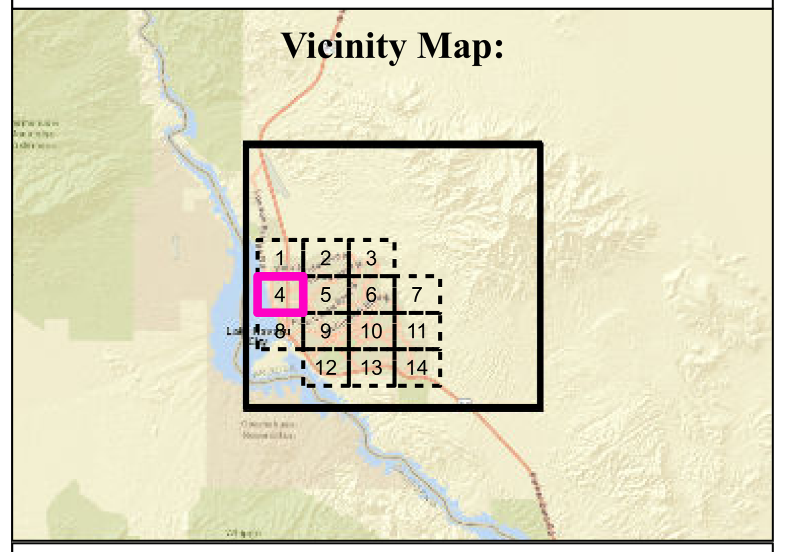

Proposed BMP Locations

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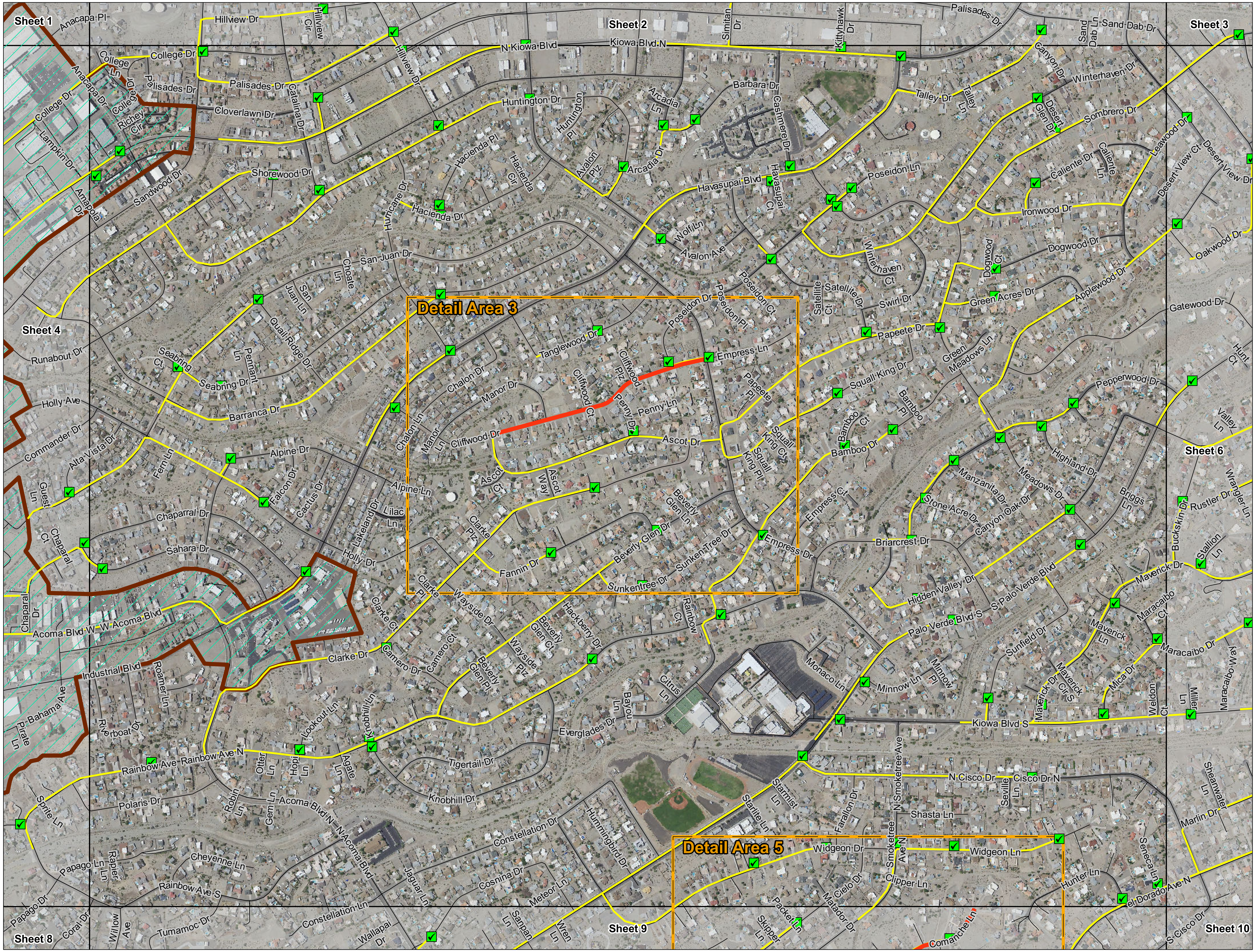

LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

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N

0 400 800
Feet

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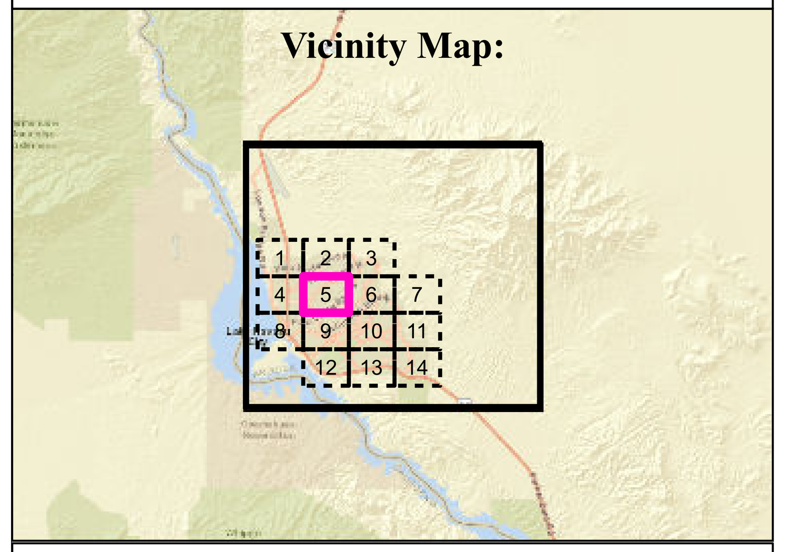

Proposed BMP Locations

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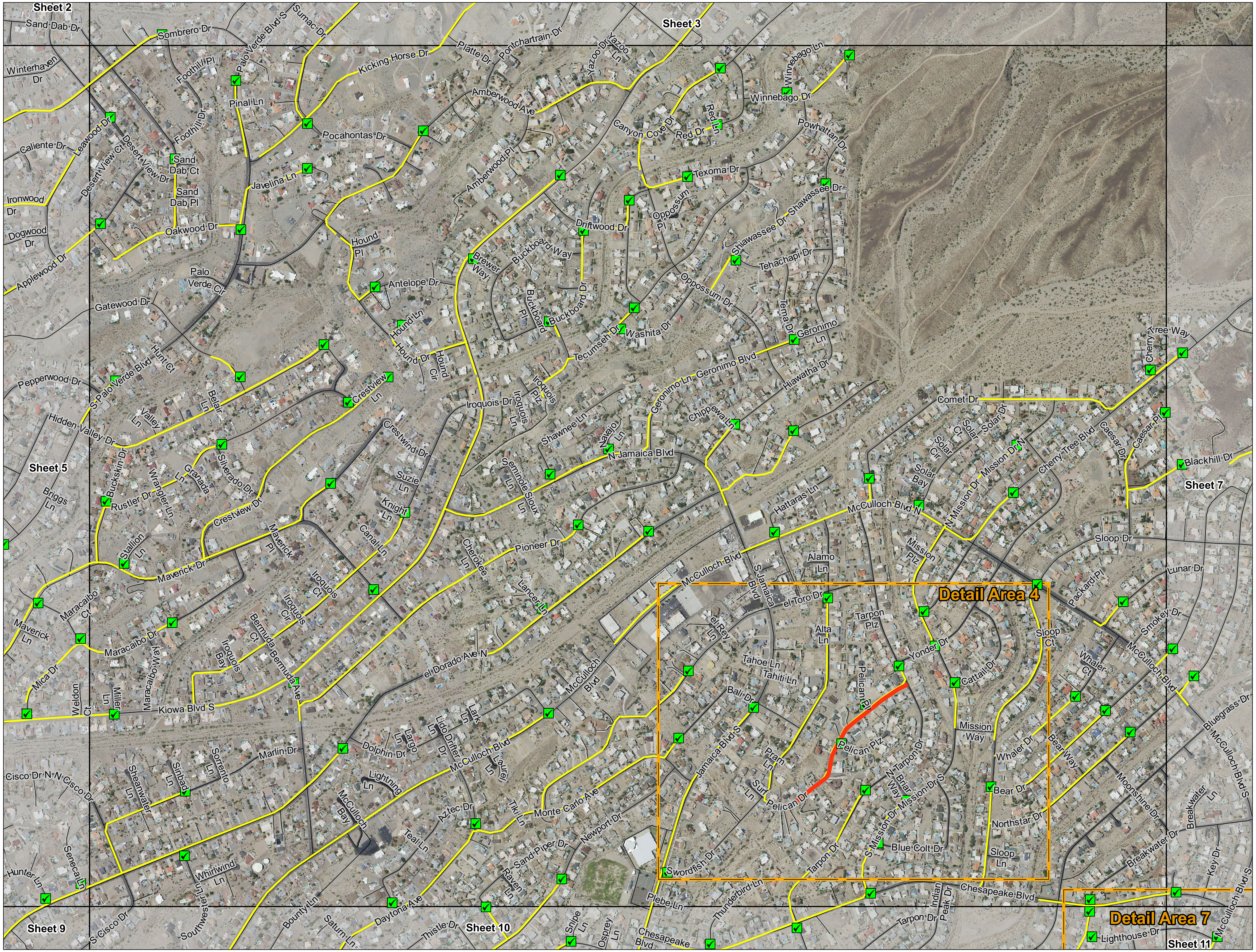

LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

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N

0 400 800
Feet

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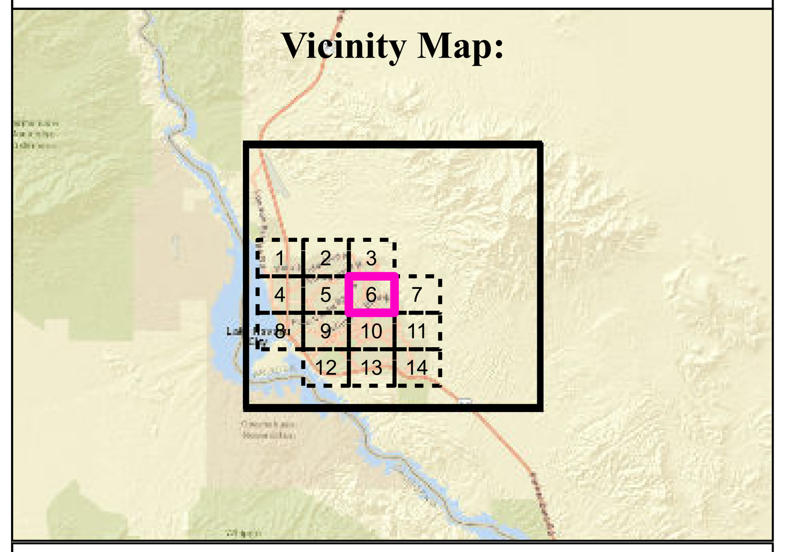

Proposed BMP Locations

Sheet 6 of 14

April 2022

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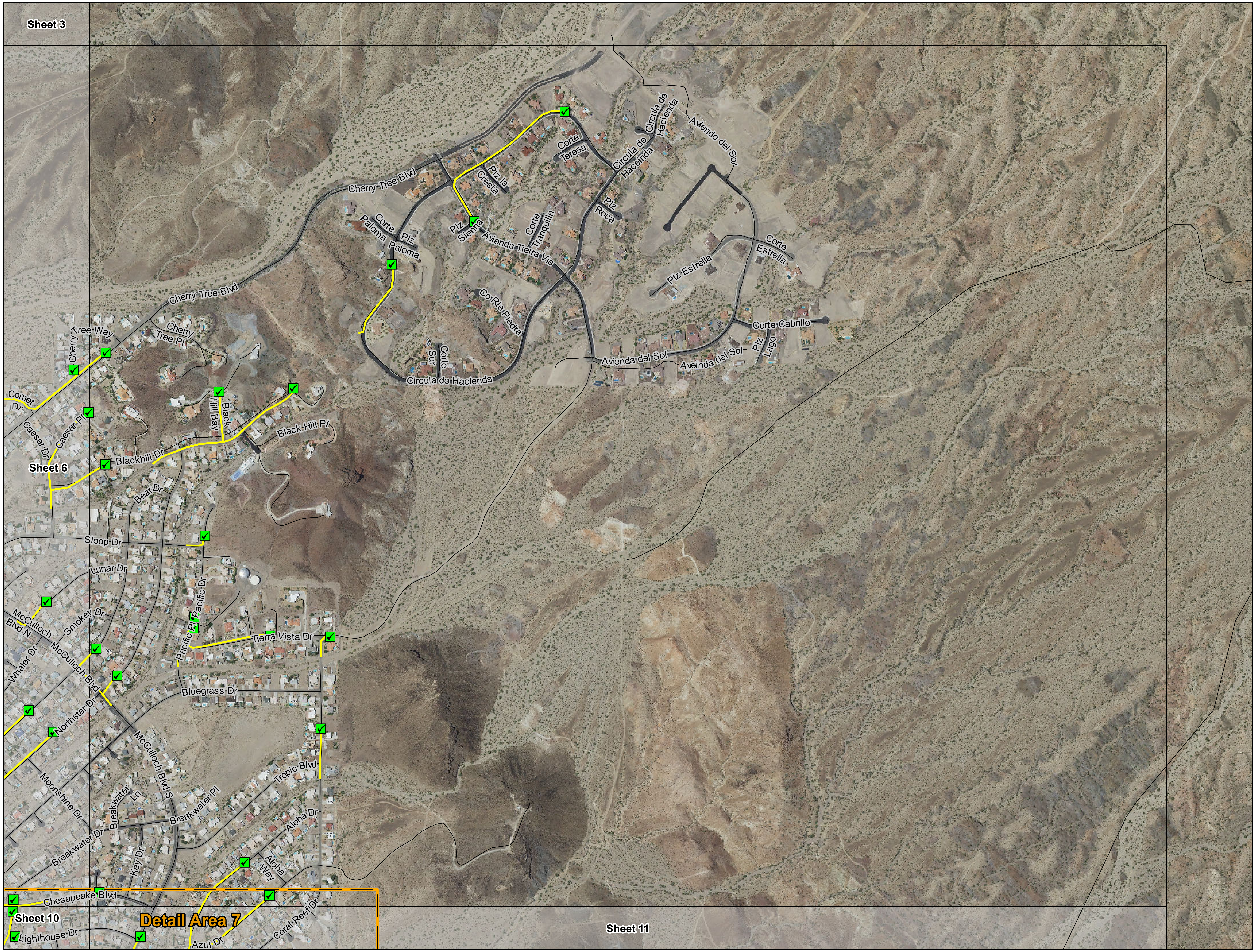

LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

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N

0 400 800
Feet

Notes:

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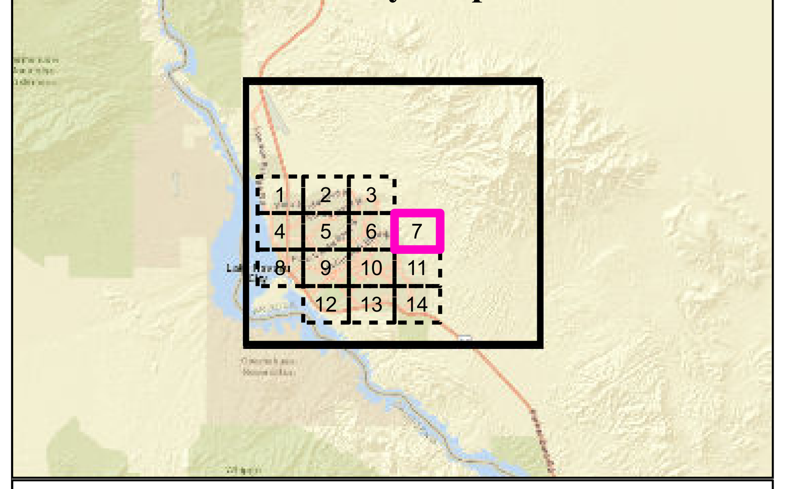
- NAVD 88 Vertical Datum

- Aerial Imagery Dated 2010

Vicinity Map:



Proposed BMP Locations

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LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

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N

0 400 800
Feet

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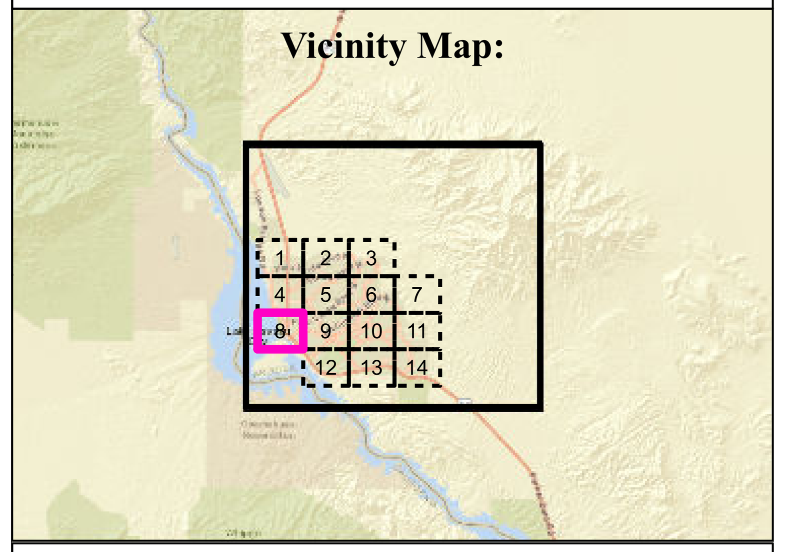

Proposed BMP Locations

Sheet 8 of 14

April 2022

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LAKE HAVASU CITY
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LID MASTER PLAN

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N

0 400 800
Feet

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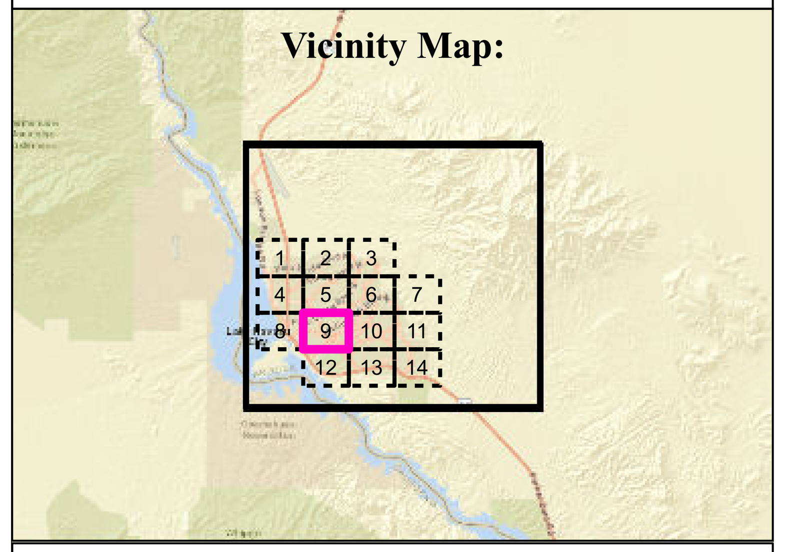

Proposed BMP Locations

Sheet 9 of 14

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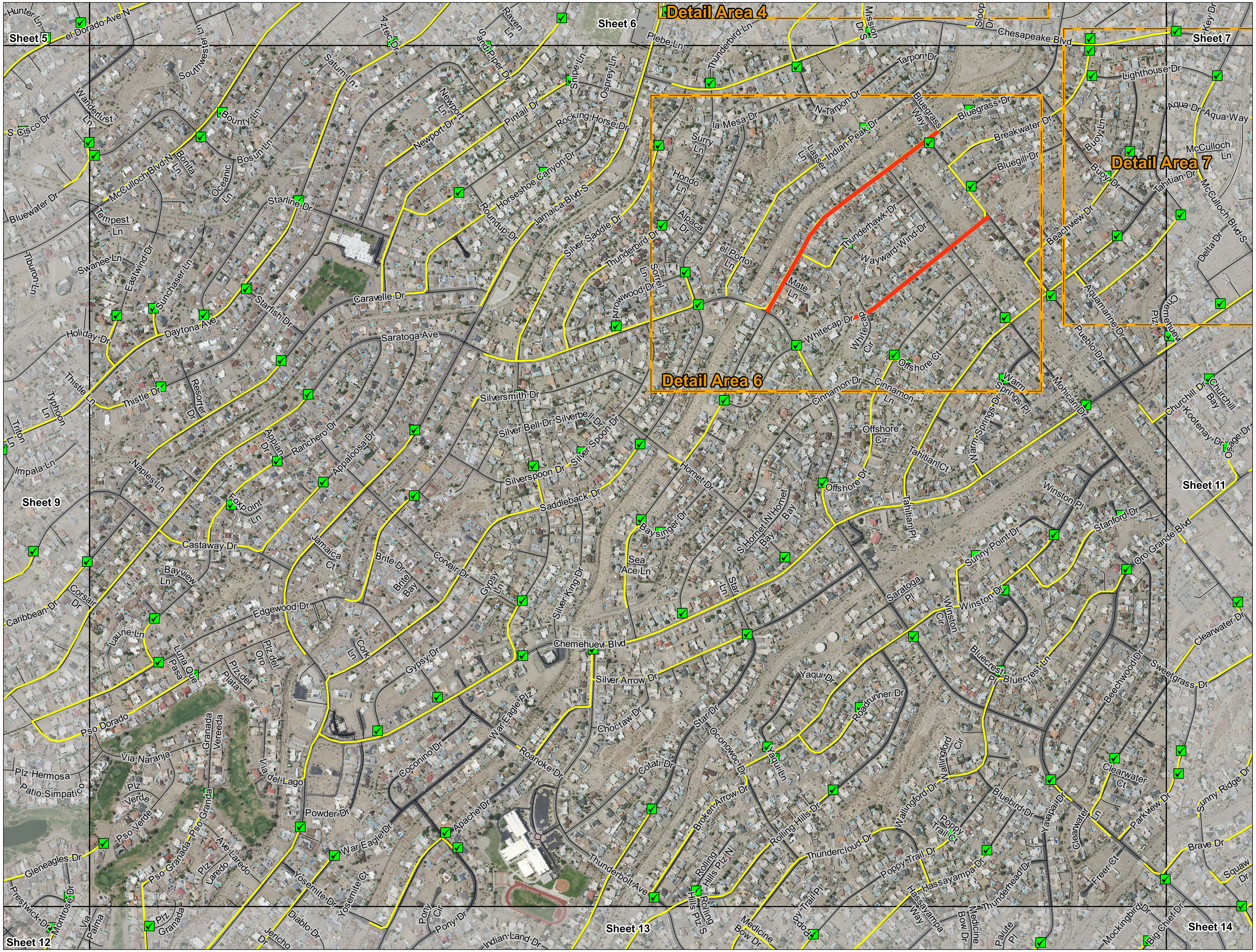

LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY
900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

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N

0 400 800
Feet

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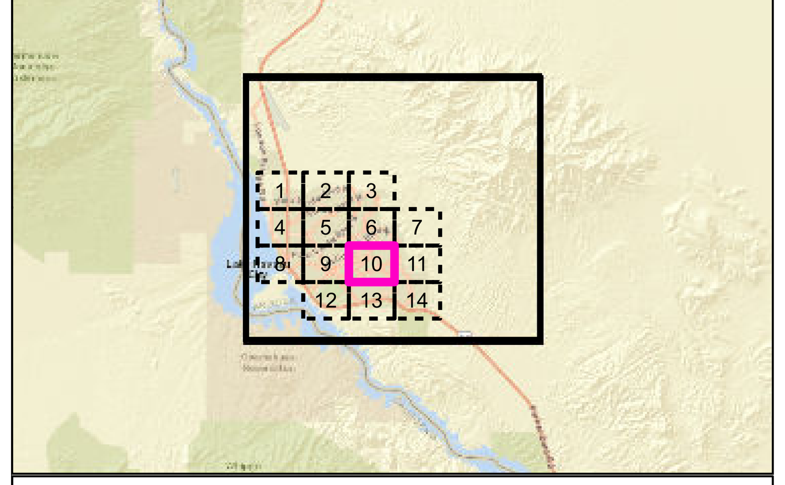
Vicinity Map:



Proposed BMP Locations

Sheet 10 of 14

April 2022

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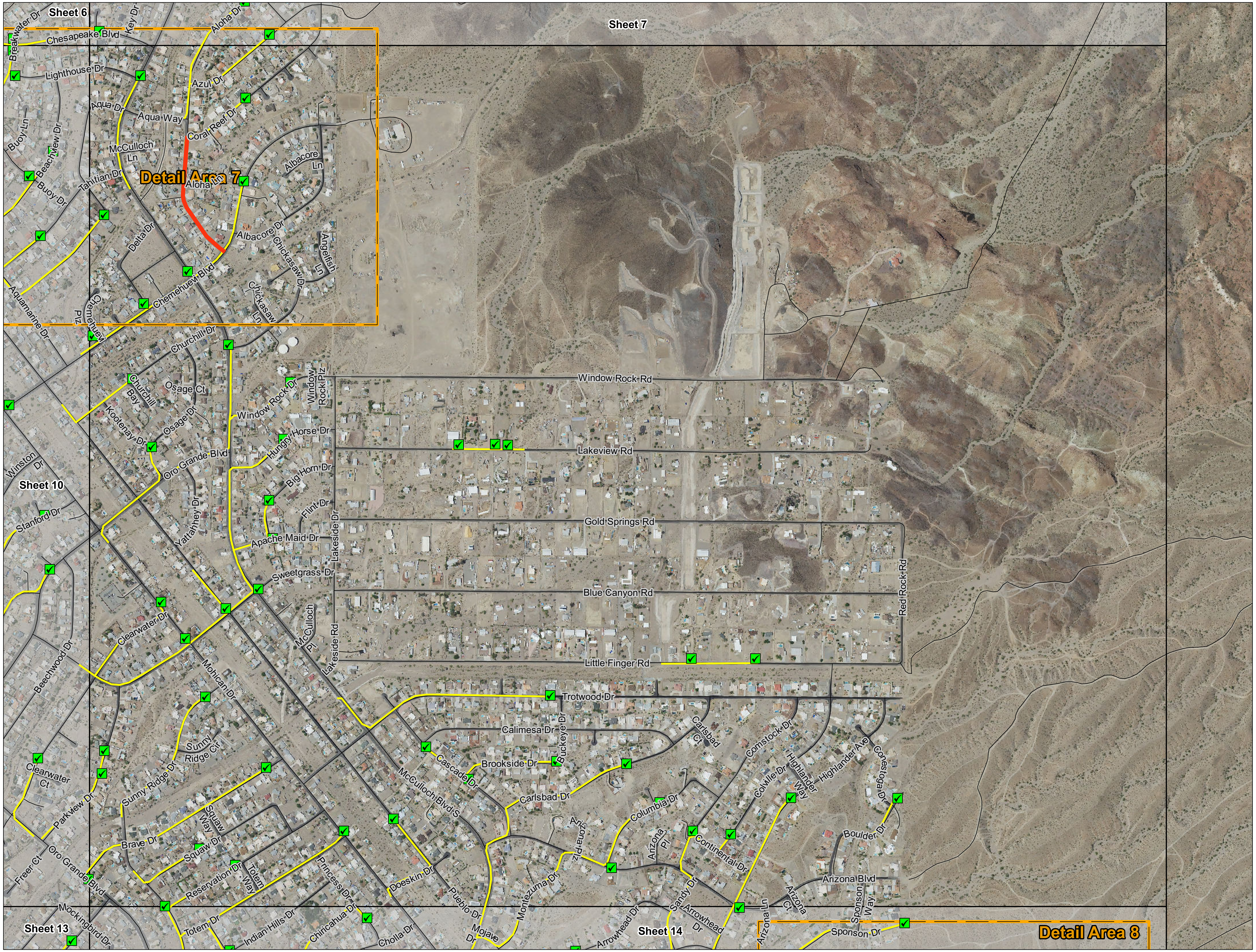

Legend

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N

0 400 800
Feet

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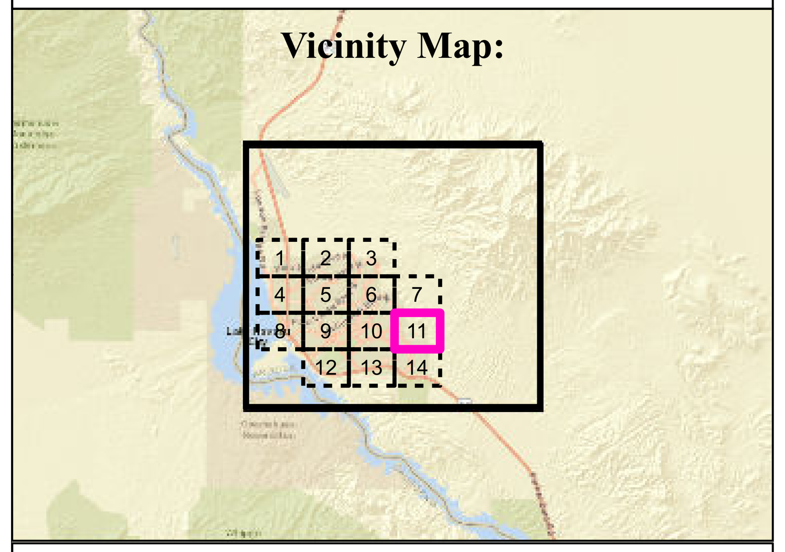
- Aerial Imagery Dated 2010

Vicinity Map:



Proposed BMP Locations

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April 2022

Revisions:

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14040 North Cave Creek Road, Ste. 104
Phoenix, Arizona 85022

LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Recommended BMP Locations
- Priority Maintenance Street
- High Conveyance Street
- LID Focus Area
- Priority Maintinance Detail Area*

***See Prioirtiy Maintinance Detail Areas exhibit for additional detail.**

N

0 400 800
Feet

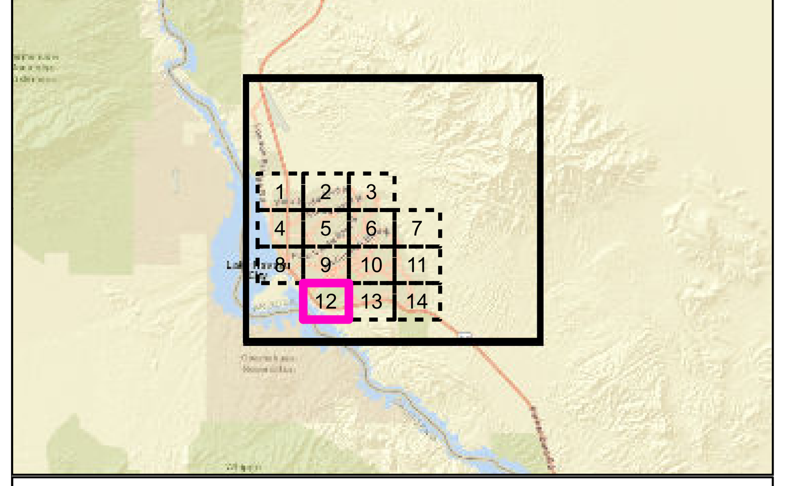
Notes:

- Lake Havasu City Low Impact Development Master Plan and Modeling Update; Mapping Activity Statement No. 2020-09-Mohave; FEMA Case No. 20-09-0058S

- NAVD 88 Vertical Datum

- Aerial Imagery Dated 2010

Vicinity Map:



Proposed BMP Locations

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April 2022

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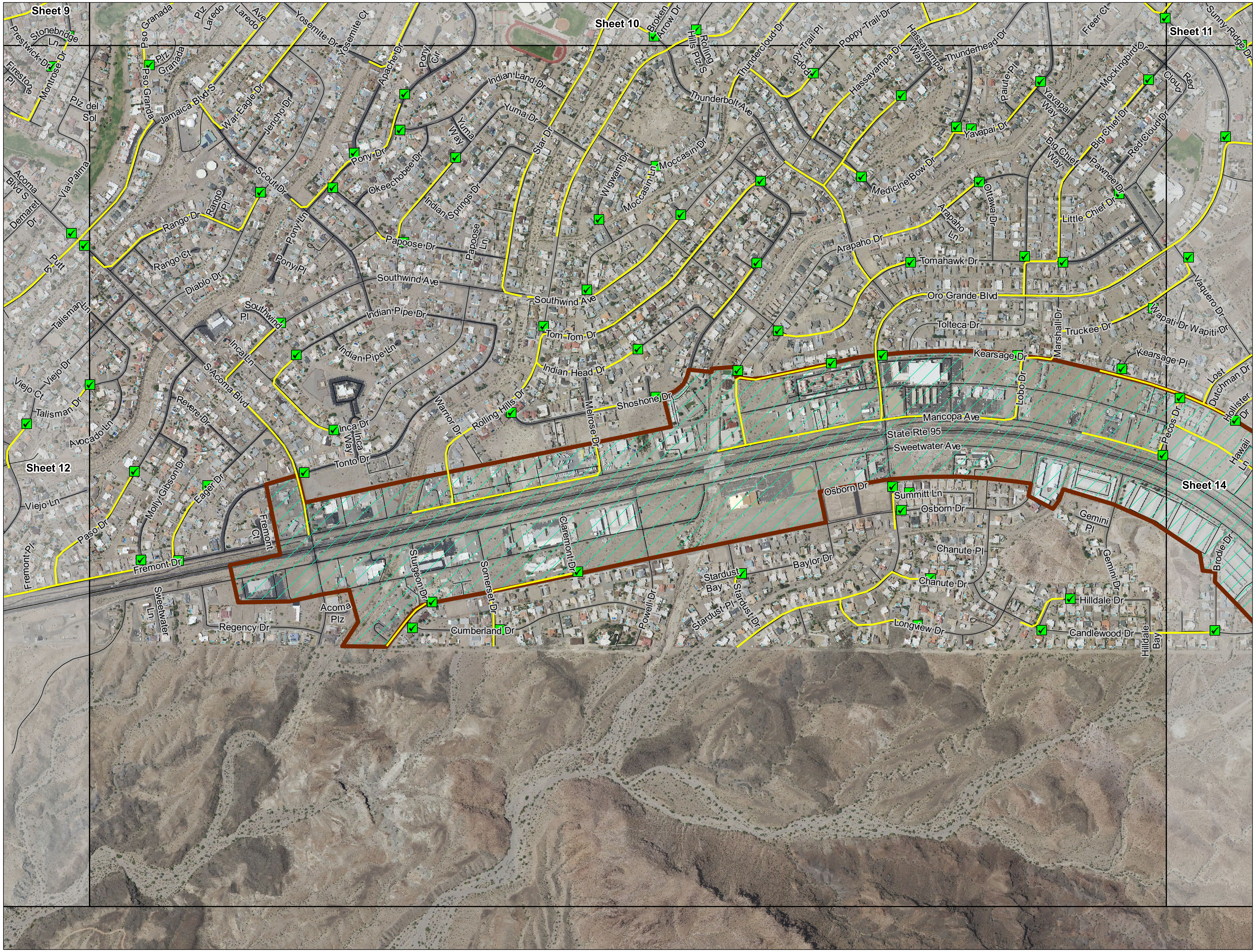
Phoenix, Arizona 85022



LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Recommended BMP Locations
- Priority Maintenance Street
- High Conveyance Street
- LID Focus Area
- Priority Maintinance Detail Area*

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N

0 400 800
Feet

Notes:

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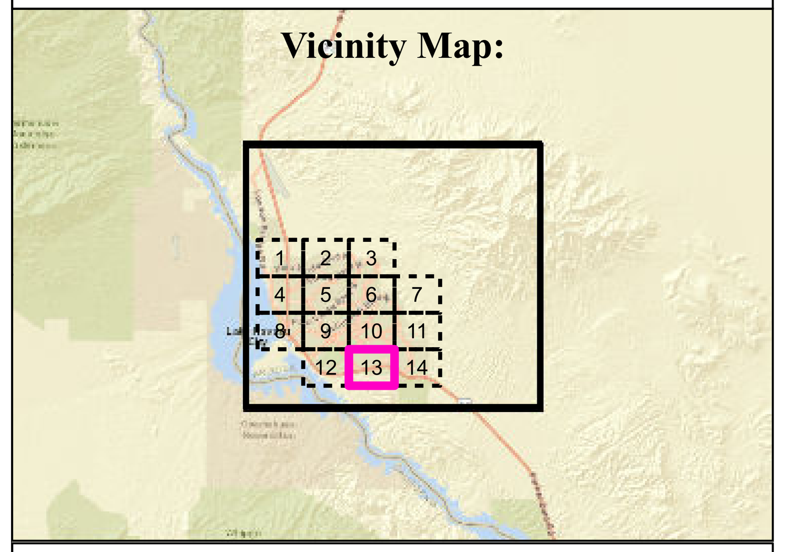
- NAVD 88 Vertical Datum

- Aerial Imagery Dated 2010

Vicinity Map:



Proposed BMP Locations

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April 2022

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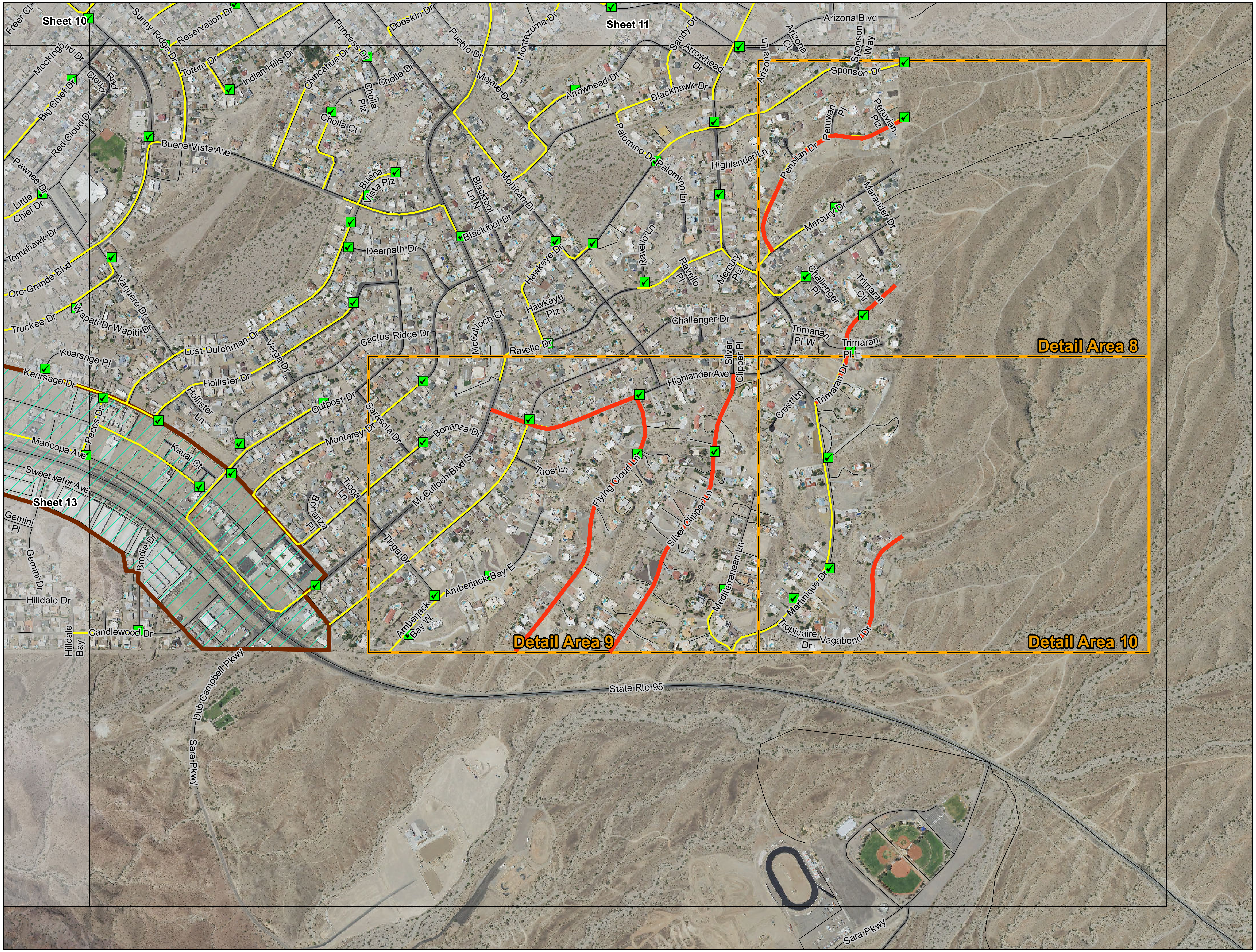
14040 North Cave Creek Road, Ste. 104
Phoenix, Arizona 85022



LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Recommended BMP Locations
- Priority Maintenance Street
- High Conveyance Street
- LID Focus Area
- Priority Maintinance Detail Area*

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N

0 400 800
Feet

Notes:

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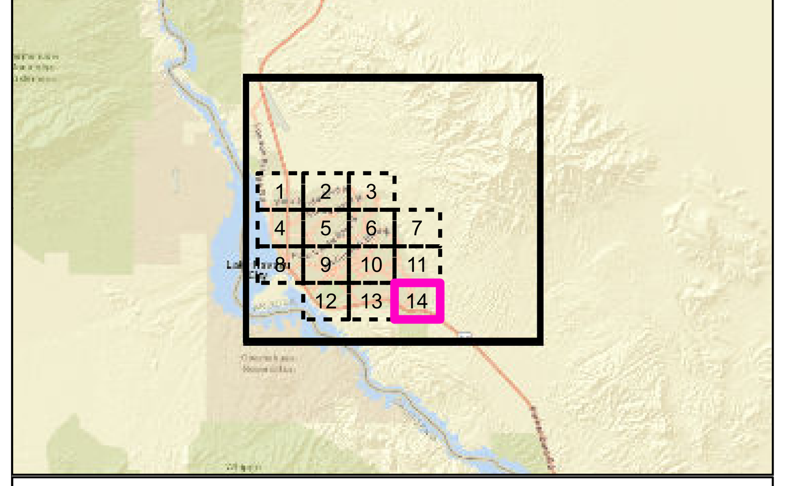
- NAVD 88 Vertical Datum

- Aerial Imagery Dated 2010

Vicinity Map:



Proposed BMP Locations

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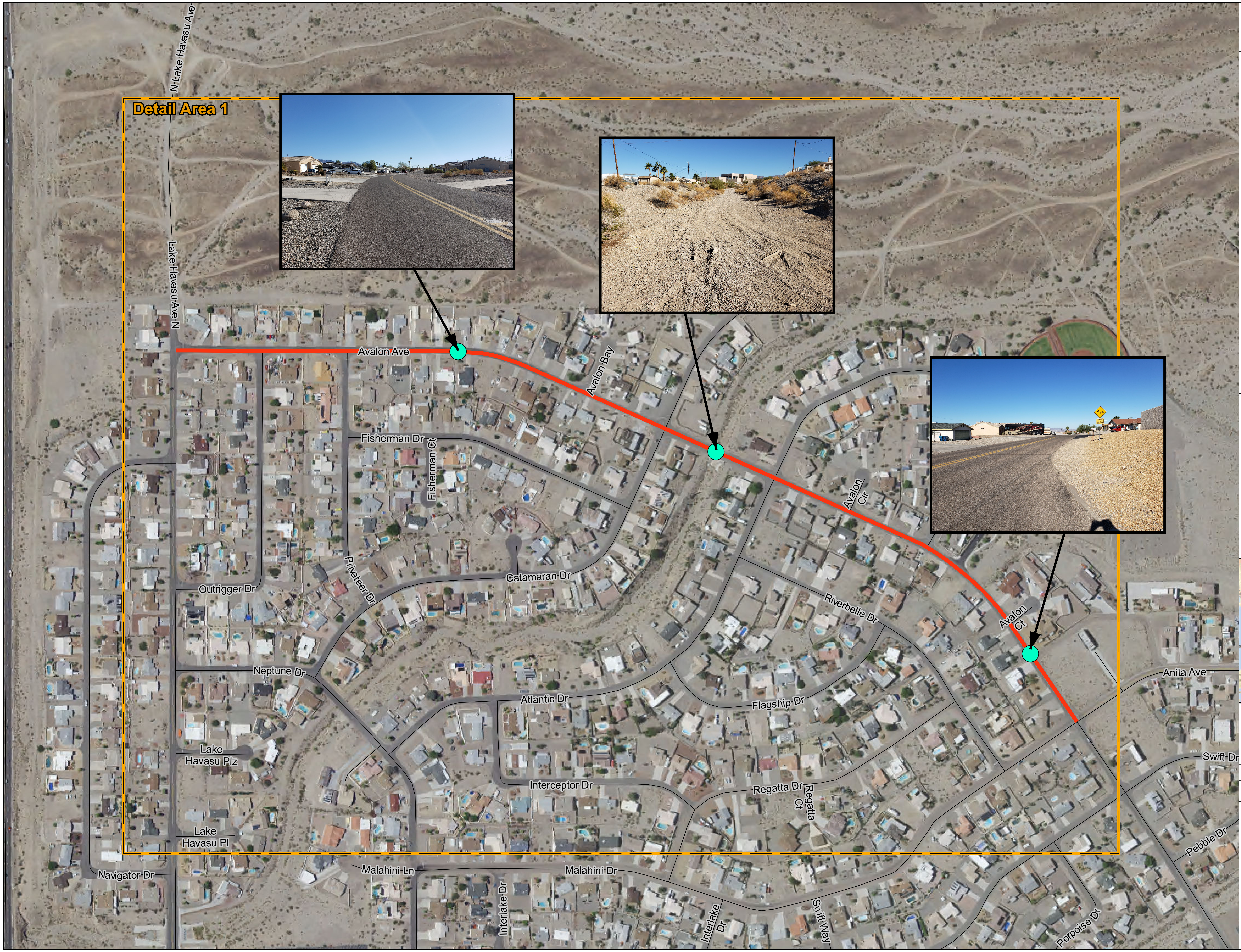
Phoenix, Arizona 85022



LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Photo Locations
- Priority Maintenance Street
- Priority Maintinance Detail Area*

***See Proposed BMP Locations Exhibit for locations whithin the City limits.**

N

0 200 400
Feet

Notes:

- Lake Havasu City Low Impact Development Master Plan and Modeling Update; Mapping Activity Statement No. 2020-09-Mohave; FEMA Case No. 20-09-0058S

- Aerial Imagery Dated 2010

- Priority Maintenance Streets as identified by Lake Havasu City maintenance staff

Vicinity Map:

1 2 3 4 5 6 7 8 9 10

Priority Maintenance Detail Areas

Detail Area 1 of 10

April 2022

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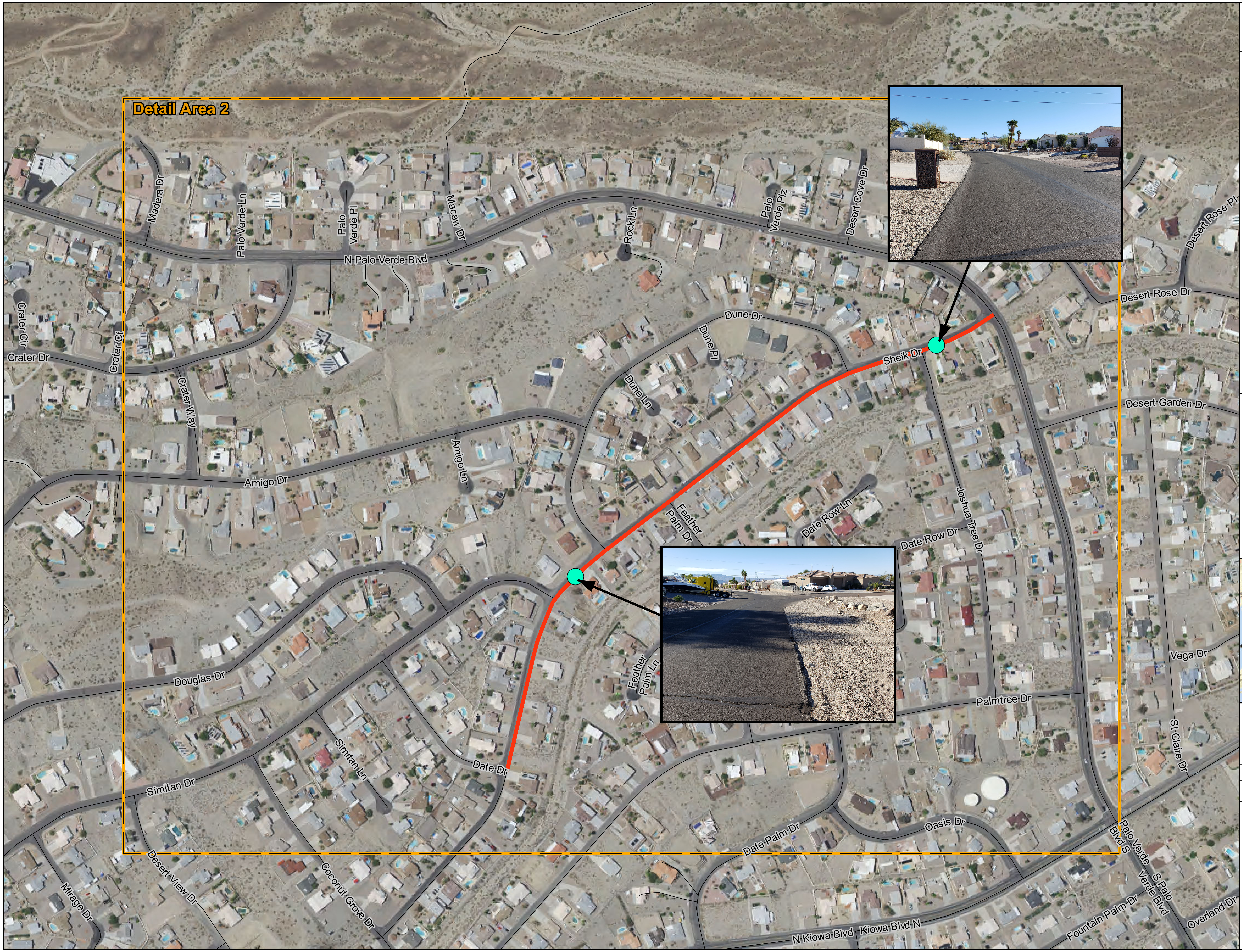
Phoenix, Arizona 85022



LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Photo Locations
- Priority Maintenance Street
- Priority Maintinance Detail Area*

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N

0 200 400
Feet

Notes:

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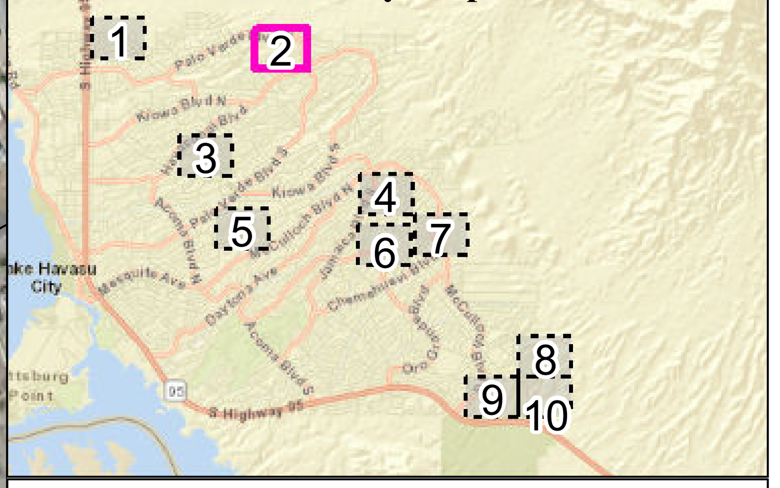
- Aerial Imagery Dated 2010

- Priority Maintenance Streets as identified by Lake Havasu City maintenace staff

Vicinity Map:



Priority Maintenance Detail Areas

Detail Area 2 of 10

April 2022

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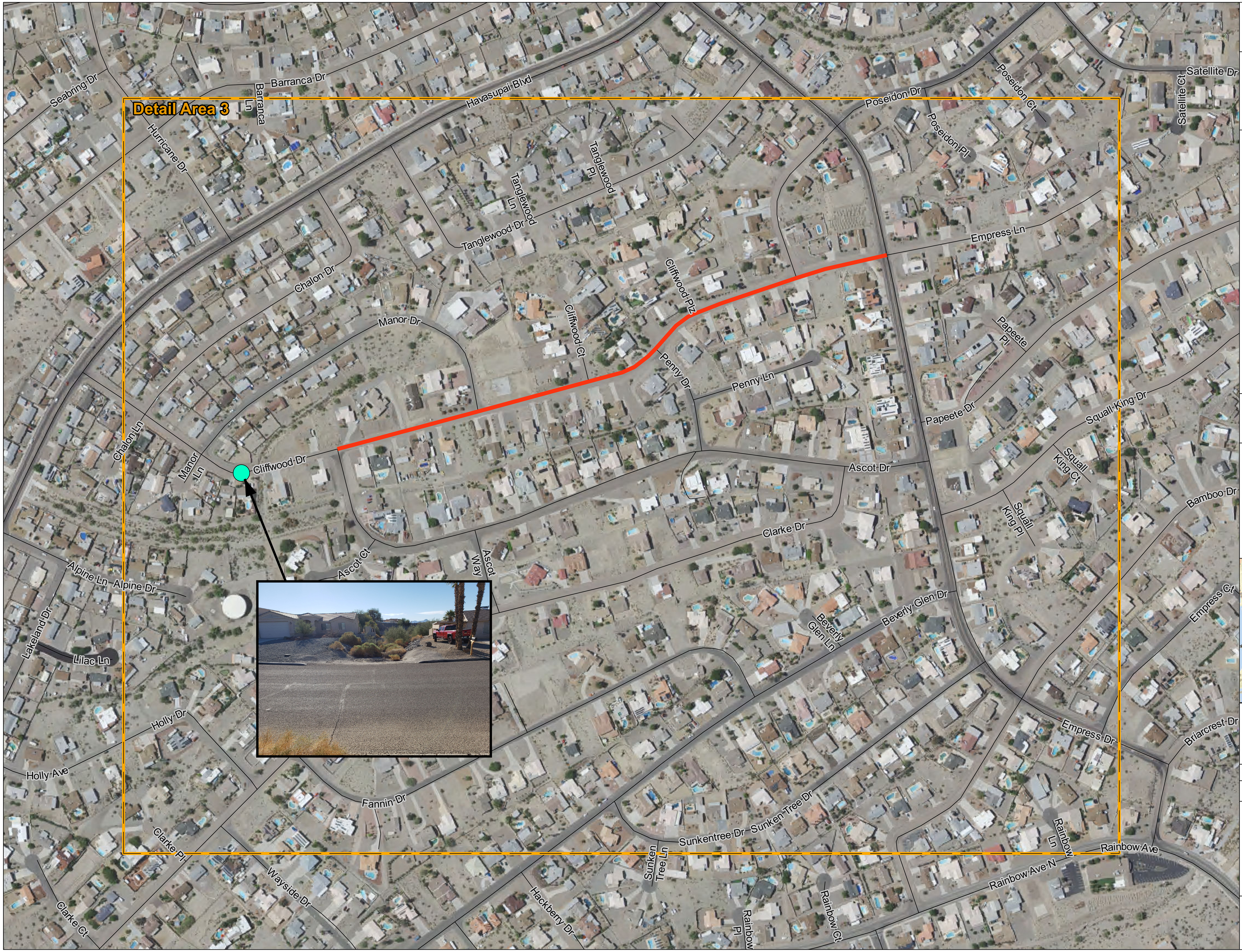
Phoenix, Arizona 85022



LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Photo Locations
- Priority Maintenance Street
- Priority Maintinance Detail Area*

***See Proposed BMP Locations Exhibit for locations whithin the City limits.**

N

0 200 400
Feet

Notes:

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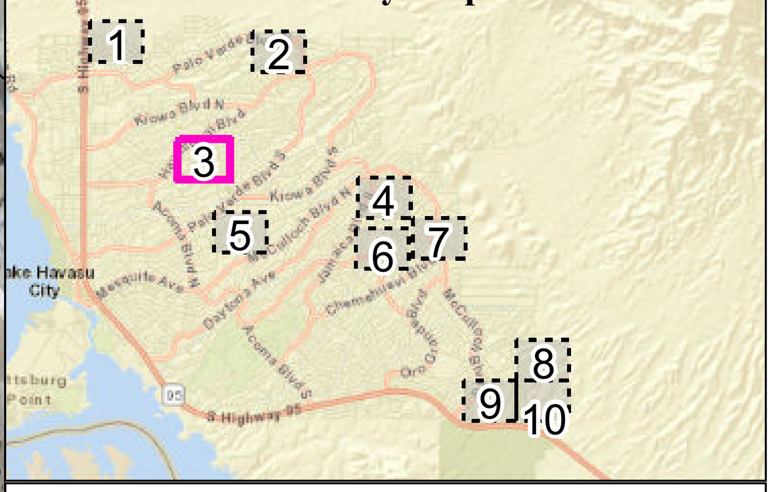
- Aerial Imagery Dated 2010

- Priority Maintenance Streets as identified by Lake Havasu City maintenace staff

Vicinity Map:



Priority Maintenance Detail Areas

Detail Area 3 of 10

April 2022

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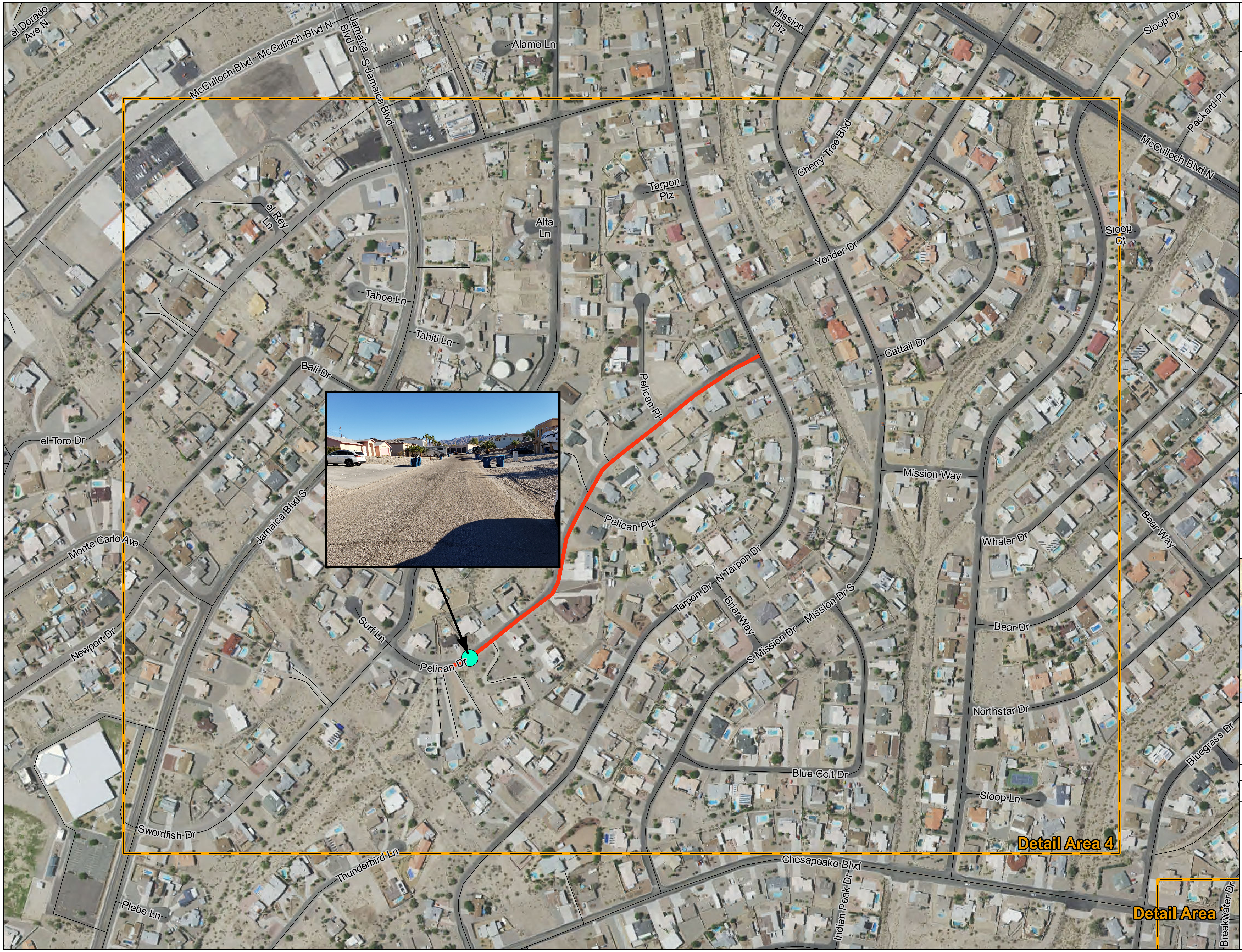
Phoenix, Arizona 85022



LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Photo Locations
- Priority Maintenance Street
- Priority Maintinance Detail Area*

***See Proposed BMP Locations Exhibit for locations whithin the City limits.**

N

0 200 400
Feet

Notes:

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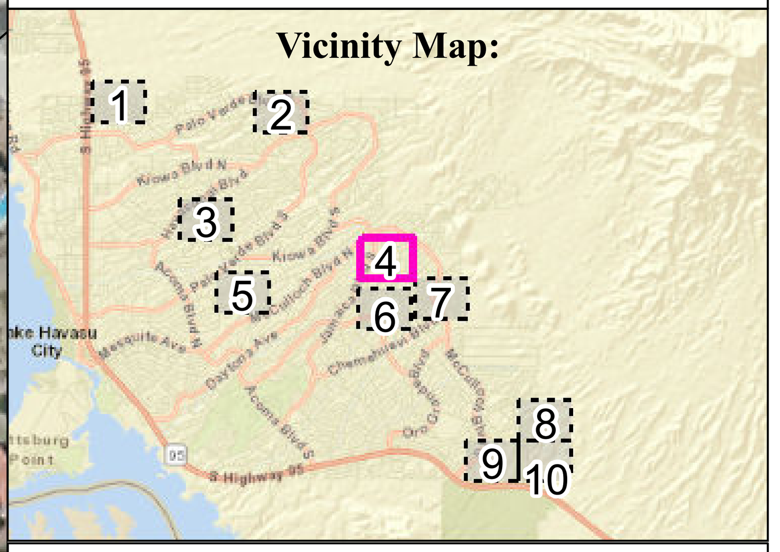
- Aerial Imagery Dated 2010

- Priority Maintenance Streets as identified by Lake Havasu City maintenance staff



Priority Maintenance Detail Areas

Detail Area 4 of 10

April 2022

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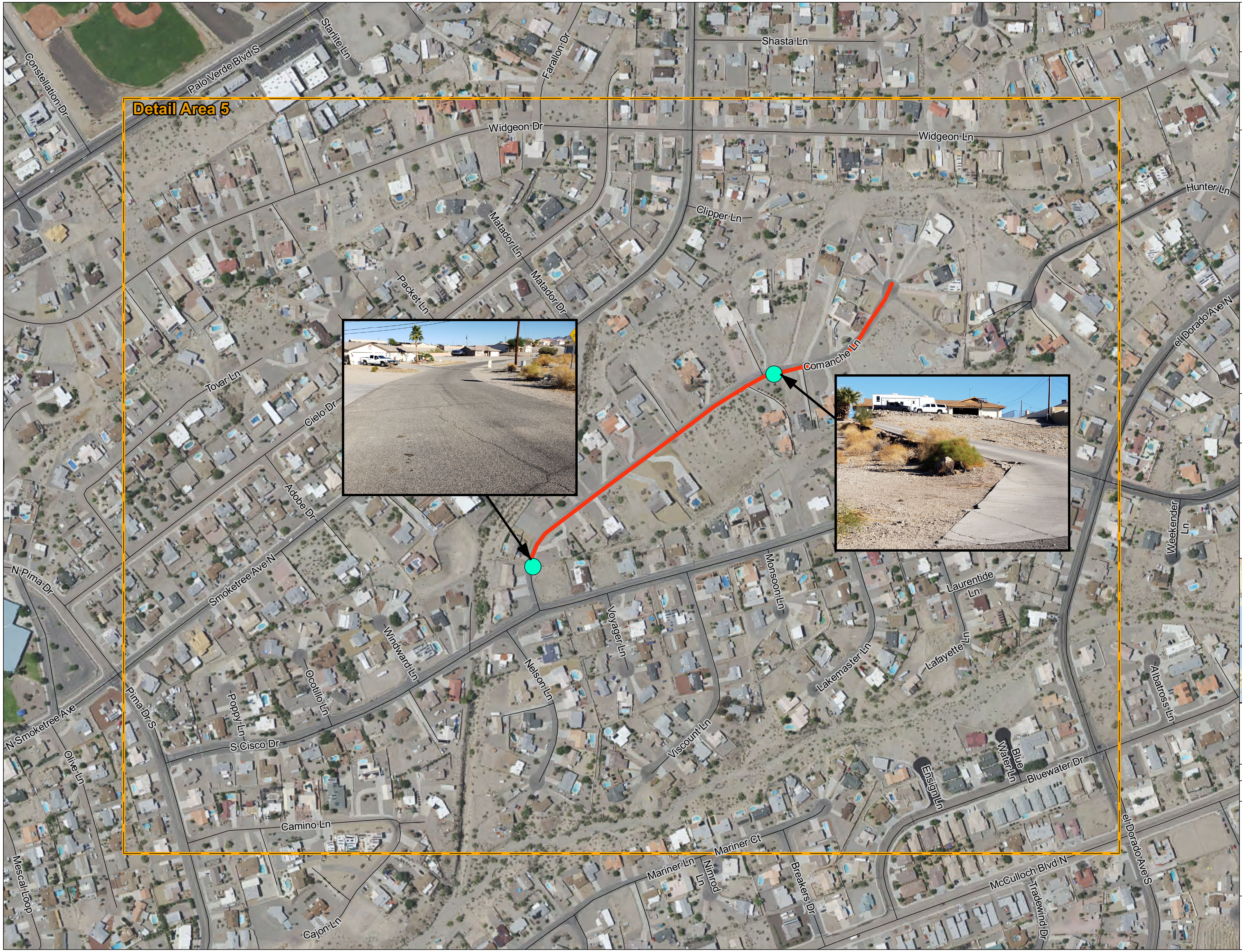
Phoenix, Arizona 85022



LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Photo Locations
- Priority Maintenance Street
- Priority Maintinance Detail Area*

*See Proposed BMP Locations Exhibit for locations whithin the City limits.

N

0 200 400
Feet

Notes:

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- Aerial Imagery Dated 2010

- Priority Maintenance Streets as identified by Lake Havasu City maintenance staff

Vicinity Map:

1 2 3 4 5 6 7 8 9 10

Priority Maintenance Detail Areas

Detail Area 5 of 10

April 2022

Revisions:

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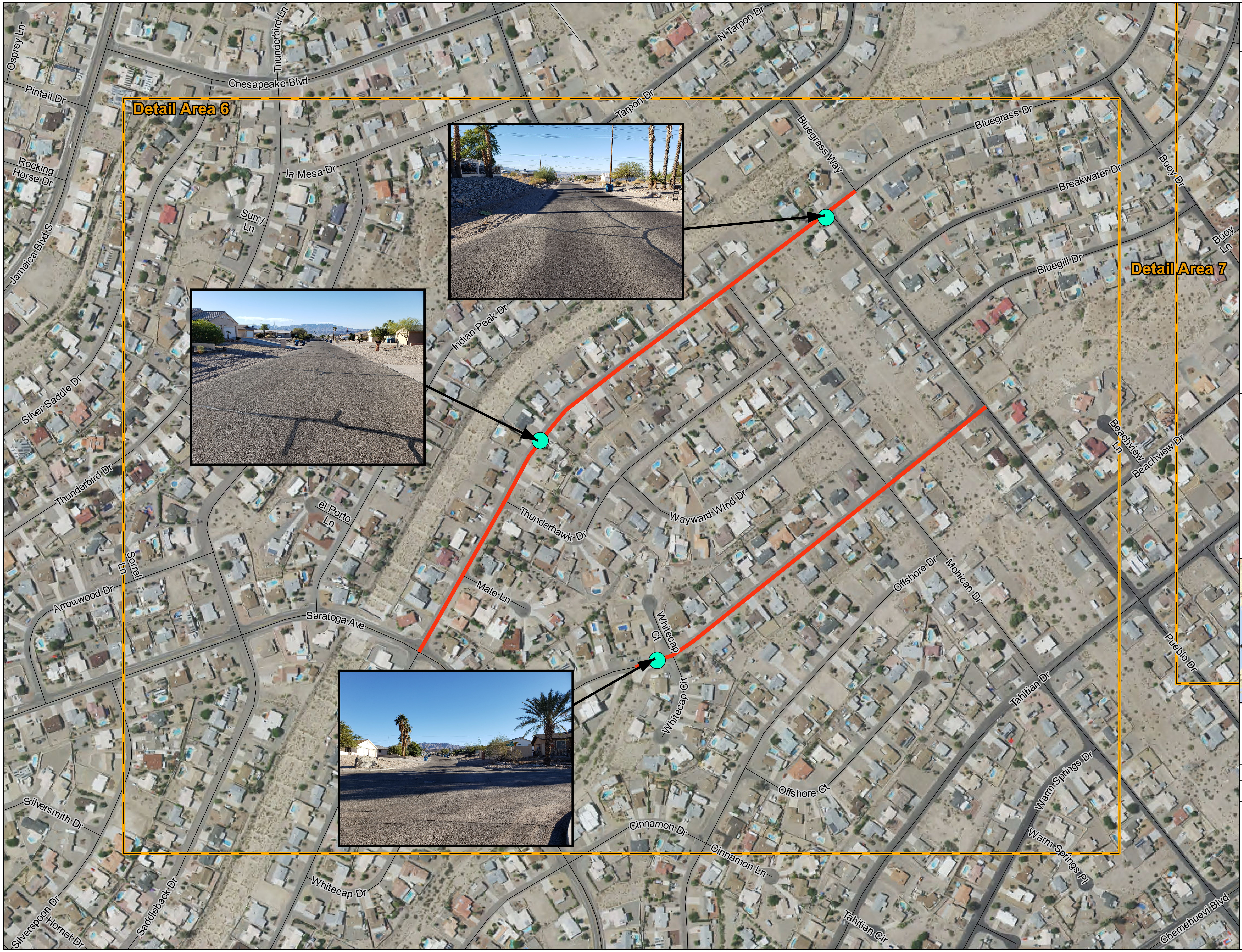
Phoenix, Arizona 85022



LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Photo Locations
- Priority Maintenance Street
- Priority Maintinance Detail Area*

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N

0 200 400
Feet

Notes:

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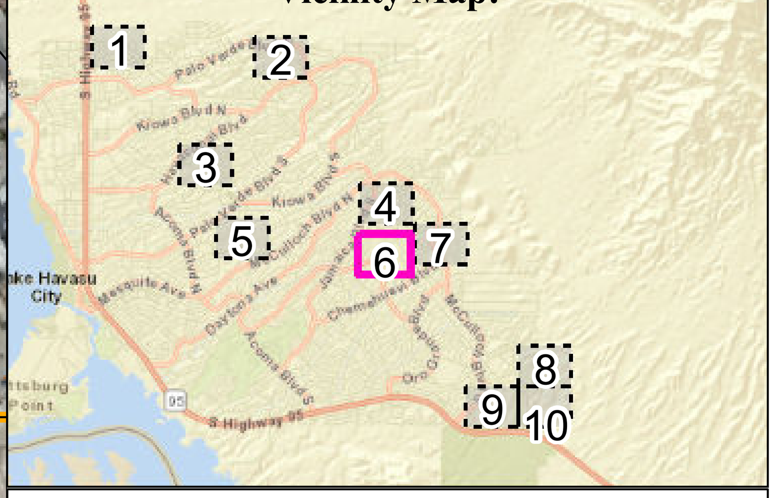

Priority Maintenance Detail Areas

Detail Area 6 of 10

April 2022

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Phoenix, Arizona 85022

LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Photo Locations
- Priority Maintenance Street
- Priority Maintinance Detail Area*

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N

0 200 400
Feet

Notes:

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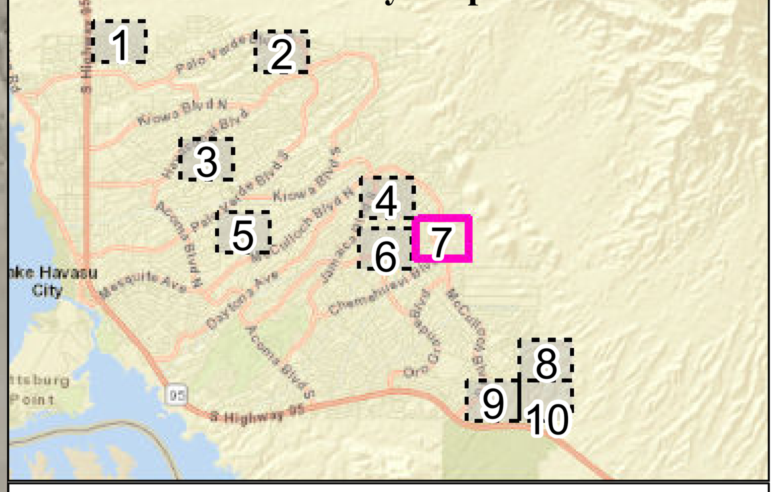

Priority Maintenance Detail Areas

Detail Area 7 of 10

April 2022

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Phoenix, Arizona 85022

LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Photo Locations
- Priority Maintenance Street
- Priority Maintinance Detail Area*

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N

0 200 400
Feet

Notes:

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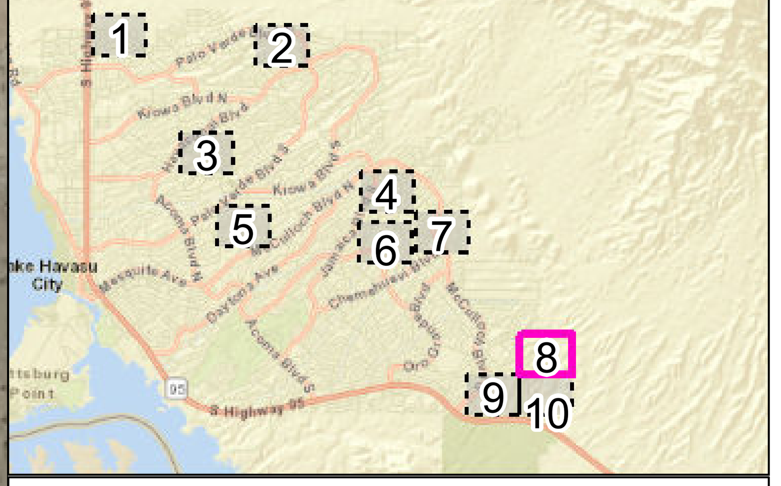

Priority Maintenance Detail Areas

Detail Area 8 of 10

April 2022

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14040 North Cave Creek Road, Ste. 104
Phoenix, Arizona 85022

LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Photo Locations
- Priority Maintenance Street
- Priority Maintinance Detail Area*

***See Proposed BMP Locations Exhibit for locations whithin the City limits.**

N

0 200 400
Feet

Notes:

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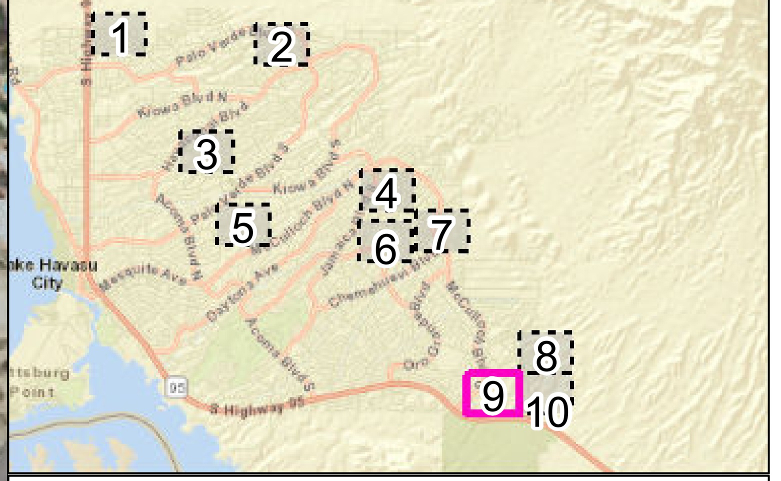

Priority Maintenance Detail Areas

Detail Area 9 of 10

April 2022

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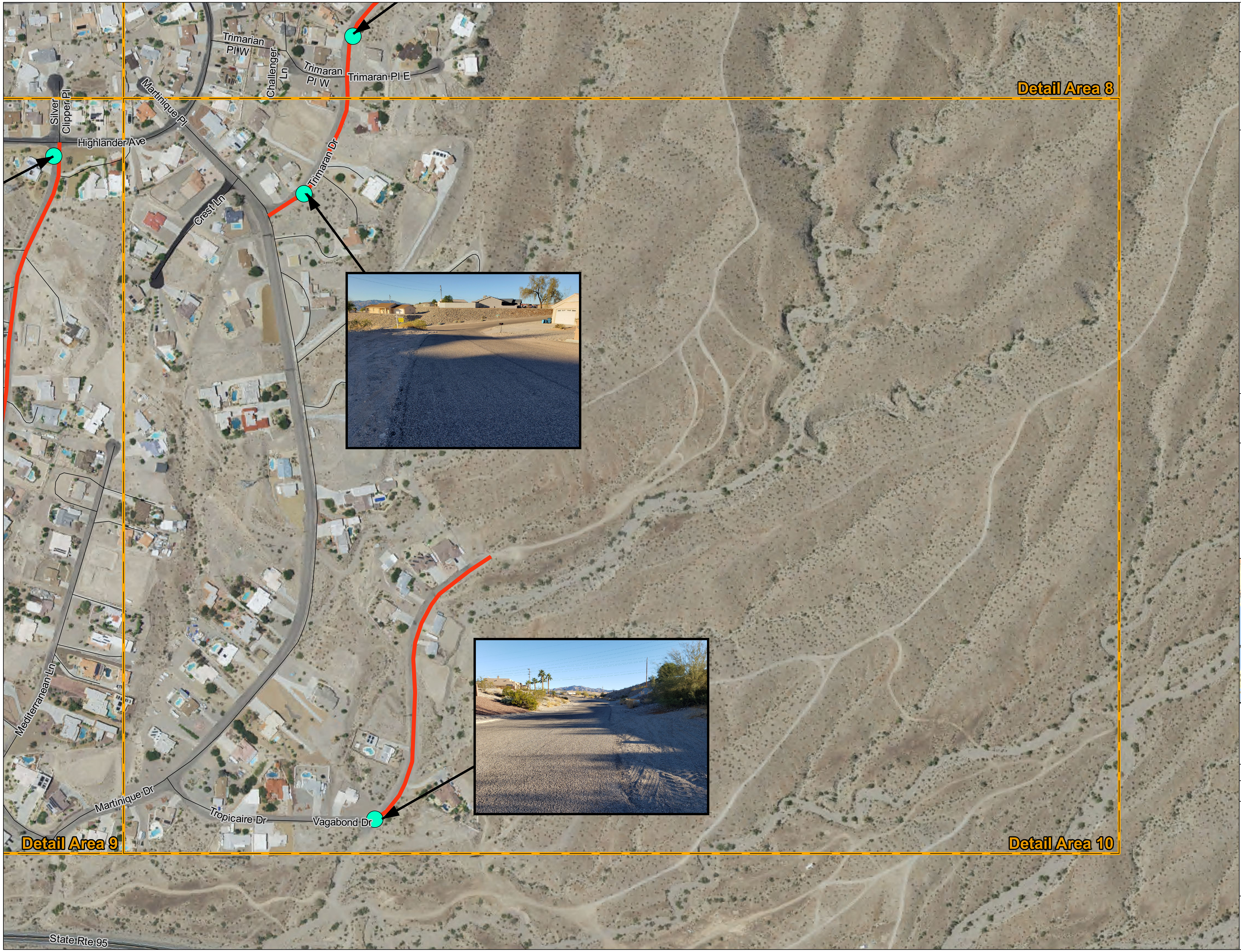
14040 North Cave Creek Road, Ste. 104
Phoenix, Arizona 85022



LAKE HAVASU CITY
FEMA RISK MAP PROJECT
LID MASTER PLAN

LAKE HAVASU CITY

900 London Bridge Rd
Lake Havasu City, Arizona 86404

Legend

- Photo Locations
- Priority Maintenance Street
- Priority Maintinance Detail Area*

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N

0 200 400
Feet

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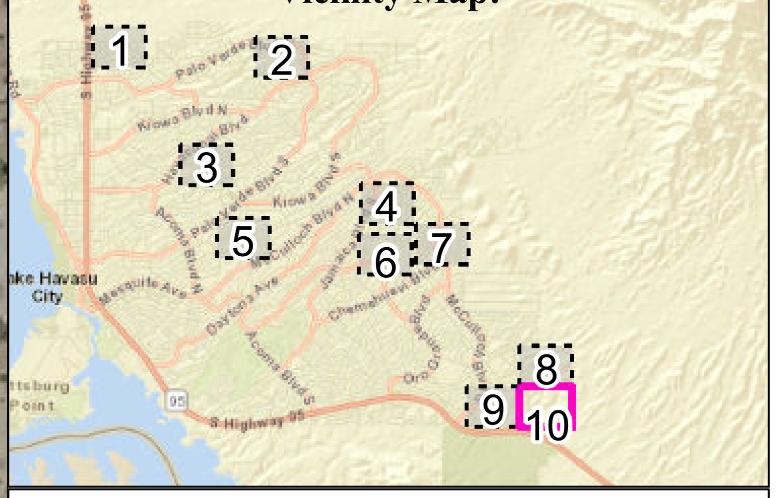

Priority Maintenance Detail Areas

Detail Area 10 of 10

April 2022

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