Mohave County
LOW IMPACT DEVELOPMENT GUIDE
for Flood Protection and Water Sustainability

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MohaveCounty Flood Control District

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HELM

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"The true foundation of all culture is the knowledge and understanding of water"

~Viktor Schauberger

"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"

~Federal Emergency Management 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"

~Environmental Protection Agency

1 Introduction

1.1 Low Impact Development for Stormwater Management

Stormwater is an important and underutilized water resource in arid, desert environments, such as Mohave County. Typically, development and drainage infrastructure treat stormwater runoff as a nuisance or a waste to be disposed of as quickly as possible. This guide is intended to serve as a complement to conventional drainage infrastructure including the existing county drainage manuals and is intended to provide guidance for how to use stormwater as a community resource as a part of a long-term program to build resilience in drainage infrastructure.

For desert communities to thrive in the face of coming environmental and development challenges, new approaches are necessary to maximize all the benefits of stormwater resources. Stormwater can:

- Provide the necessary irrigation to establish and maintain native landscapes;
- Infiltrate into the ground to replenish aquifer supplies; and
- Create enjoyable public and private spaces that celebrate water and the natural beauty of the desert environment.

Mohave County is a part of the Mohave Desert, as well as the northern Sonoran Desert and southern Great Basin Desert. This area typically receives 4 to 10 inches of rain annually[1], while pan evaporation is 154 inches per year according to the Arizona Department of Water Resources (ADWR). As a result, much of this water resource is lost through evaporation. The runoff produced in the few rainfall events greater than 0.1-inch must be utilized as a precious water resource to protect local groundwater resources, reduce reliance on the over-allocated Colorado River, and increase the resilience of local communities in the face of drought and Colorado River shortages.

In Mohave County, the approximate average annual rainfall of 5 inches is equivalent to 3.59 million acre-feet (MAF) per year of water, based on a land surface area of 13,461 square miles. **If 2% of this water resource**, about 72,000 acre-feet (ac-ft), were beneficially utilized, it is roughly equivalent to **90% of the County's municipal water demand projected in 2050** of approximately 80,000 ac-ft in a **high population growth scenario**[2].

Left unmanaged or managed poorly, stormwater can cause damage and degradation to communities from flooding and erosion. Desert soils and ecosystems are fragile and are not well suited to handle increased stormwater discharges produced by impervious urban environments. Conventional development will continue to degrade urban and rural environments unless new methods that embrace the potential benefits of stormwater are implemented. Decentralized stormwater infrastructure provides a range of practices to address the significant challenges of stormwater management in Mohave County.

1.2 What is Decentralized Stormwater Infrastructure?

Decentralized stormwater infrastructure utilizes natural systems of soil and plants to harvest stormwater for flood protection, irrigation benefits, and treatment of stormwater pollutants.

[1] Results from major cities in Mohave County from www.usclimatedata.com
[2] Arizona Department of Water Resources, Mohave County Water Authority Demand and Supply Assessment, June 2015.

Conventional drainage infrastructure typically focuses on flood mitigation alone by conveying away the maximum amount of water as quickly as possible. Multi-benefit decentralized drainage infrastructure is necessary to address community flooding, water supply, and quality of life improvements. There are many different terms utilized for decentralized practices. The two commonly utilized throughout the southwest are Green Stormwater Infrastructure (GSI) and Low Impact Development (LID). These terms are often utilized interchangeably and are defined below.

Green Stormwater Infrastructure (GSI) and Low Impact Development (LID) techniques are considered local stormwater management opportunities.

LID as defined by FEMA 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 is more than on-site infiltration of storm water (e.g., through rain gardens and pervious surfaces). LID also captures and stores water for later reuse, filters out pollutants, and reduces water velocities during storm events. Thus, even where infiltration is not feasible, other LID techniques are still able to be used."*

GSI/LID is defined by the U.S. Environmental Protection Agency (EPA) as "*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.*"

For this guide, LID will be utilized to refer to decentralized stormwater infrastructure practices.

1.3 Why is Decentralized Stormwater Infrastructure Important?

Given the challenges associated with developing and implementing regional flood control measures, there is a significant need for decentralized stormwater management infrastructure. For the purpose of this LID Guide, decentralized stormwater management opportunities are intended to meet the following objectives:

- Mitigate nuisance flooding/drainage issues associated with high frequency storm events and reduce overall stormwater runoff volumes.
- Provide stormwater management alternatives at a scale for residents to implement/construct with limited resources.
- Promote water conservation through groundwater recharge.
- Improve stormwater quality.
- Reduce erosion and sedimentation.
- Improve soil health and increase soil moisture.

As communities develop and increase impervious surfaces, along with the increasing intensity of storms, additional drainage strategies are required to ensure public safety and improve quality of life. Decentralized drainage infrastructure captures rainfall runoff close to where it falls from the sky. This maximizes the potential of water to provide multiple benefits by slowing water down, spreading it out and sinking it into the ground. When this occurs throughout entire watersheds, large areas of healthy, established native vegetation can be irrigated by rainfall runoff alone, and with the right conditions, allow for groundwater recharge. Given limited resources to manage stormwater and limited water resources in the desert environment, it is essential to maximize the multiple benefits of stormwater. If the typical conventional management of stormwater continues, stormwater will be a waste that requires ongoing costs to manage. If LID practices are utilized, stormwater can be transformed into an asset that communities can invest in and receive a return on that investment.

1.3.1 Return on Investment

LID features present an opportunity to capture water close to where the storm flows originate, as well as an opportunity to bundle multiple benefits, such as:

- reducing flood risk;
- conserving water;
- increasing shade;
- improving water quality;
- reducing the urban heat island;
- increasing property value;
- reducing building cooling costs from well-placed shade trees; and
- reducing air pollution.

Each individual practice has a small impact; however, when aggregated throughout a watershed, LID features can have an impact on both peak flows and volume in larger washes and watersheds, while also creating significant community benefits.

The City of Phoenix conducted a study to quantify a broad range of benefits from LID. In the *Triple Bottom Line Cost Benefit Analysis of Green Infrastructure/Low Impact Development (GI/LID) in Phoenix, AZ* report (provided in Appendix C on the external hard drive, herein referred to as *Phoenix CBA*), the results clearly show the positive net benefits of LID.

For example, for every 1,000 square feet of rain garden, $9,960 of net positive value is created over the 50-year study period, equivalent to approximately $200 in average annual benefits, resulting in an overall Benefit/Cost Ratio of 2.3. This Benefit/Cost Ratio of $2.3/$1 is a result of the financial benefits mentioned in being greater than the cost of installing and maintaining the LID feature over the life of the infrastructure. These *Phoenix CBA* results were enhanced to include the addition of water conservation values based on the assumption that 50 percent of plant material water needs are met by stormwater during a 3-year establishment period and 100% of water needs are met by irrigation from stormwater after year three. For a full explanation of each category, with the exception of water conservation (explained above), see the *Phoenix CBA* report provided in Appendix C on the external hard drive.

Table 1-1 Net Present Values from the *Phoenix CBA* report for 1,000 square feet of rain garden.

Costs	
Capital Cost	$ (3,022)
Maintenance	$ (3,170)
Replacement Costs	$ (1,662)
Total Costs	*$ (7,854)*
Benefits	
Residual Value	$ 227
Heat Island Reduction	$ 10,375
Flood Risk	$ 1,151
Property Value	$ 129
Water Quality	$ 2,629
Air Pollution	$ 1,150
Energy Reduction	$ 521
Water Conservation	$ 1,632
Total Benefits	*$ 17,814*
Cost/Benefit Summary	
50 year Net Present Value	**$ 9,960**
Annual Net Benefits	**$ 199**
Benefit/Cost Ratio	**$ 2.3/$1**

Based on the monetary values and results above, Table 1-2 below was developed for LID financial benefits for rural properties in Mohave County for different levels of participation by property owners installing rain gardens. Rain gardens were selected as the only feature for this analysis given that they are easiest for homeowners to install and they will likely be the most widely used and representative features of LID benefits.

An example rural area comprising of 1,500 parcels, with an average parcel area of 1.5 acres, was evaluated for LID potential. Based on an aerial assessment of un-vegetated areas, approximately 25 percent of each parcel could be available for LID practices, however, for this analysis, we conservatively designated 2,500 square feet or about five (5) percent of the total parcel area for LID.

Table 1-2 Summary of financial benefits created by LID

Project Area % Parcels Participating	# of Parcels	LID Feature Area (sq ft)	LID Capital Costs	Project Life Net Benefits	Approximate Storage Volume (ac-ft)
5%	75	187,500	$562,500	$37,349	3.23
10%	150	375,000	$1,125,000	$74,697	6.46
15%	225	562,500	$1,687,500	$112,046	9.68
20%	300	750,000	$2,250,000	$149,394	12.91
25%	375	937,500	$2,812,500	$186,743	16.14

LID capital costs are based on an average of $3 per-square-foot as utilized in the *Phoenix CBA* report. For rain gardens and swales constructed on rural property with easy access for construction equipment by a contractor, these costs are likely high. **If the labor is done by residents or volunteers, costs drop to approximately $1 per-square-foot or less.**

Storage volume is calculated with an average LID feature depth of 0.75 feet.

The spreadsheet utilized to calculate these results can be found on the accompanying external hard drive (Appendix C). This tool can be adapted easily to model benefits for LID throughout the region by changing the cost for water and energy for each region.

Based on previous experience in Maricopa County (see *Concept Investigation for Drainage Improvements in Vicinity of 44th Street and Dynamite Boulevard* in Appendix C on the external hard drive) at least 25 percent of parcels would have to participate in LID projects to achieve a significant impact on peak discharges for large storm events. In *Improving the Resilience of Best Management Practices in a Changing Environment* (located in Appendix C on the external hard drive), the US Environmental Protection Agency found that equivalent (based on storage volume) **conventional infrastructure was more expensive than LID** over the life of the infrastructure in a modeling example in Maricopa County ($4.79 million vs. $3.98 million). Based on the data in Table 1-1, Flood Risk reduction represents approximately 6 percent of the total net benefits ($1,151/$17,814 = 6%). As a result of costs being greater for equivalent volume storage for conventional infrastructure, while only having 6 percent of the benefits given the single flood protection goal of conventional infrastructure, LID is a sound investment for community infrastructure. Figure 1-1 shows the benefits of investing in LID practices like rain gardens.

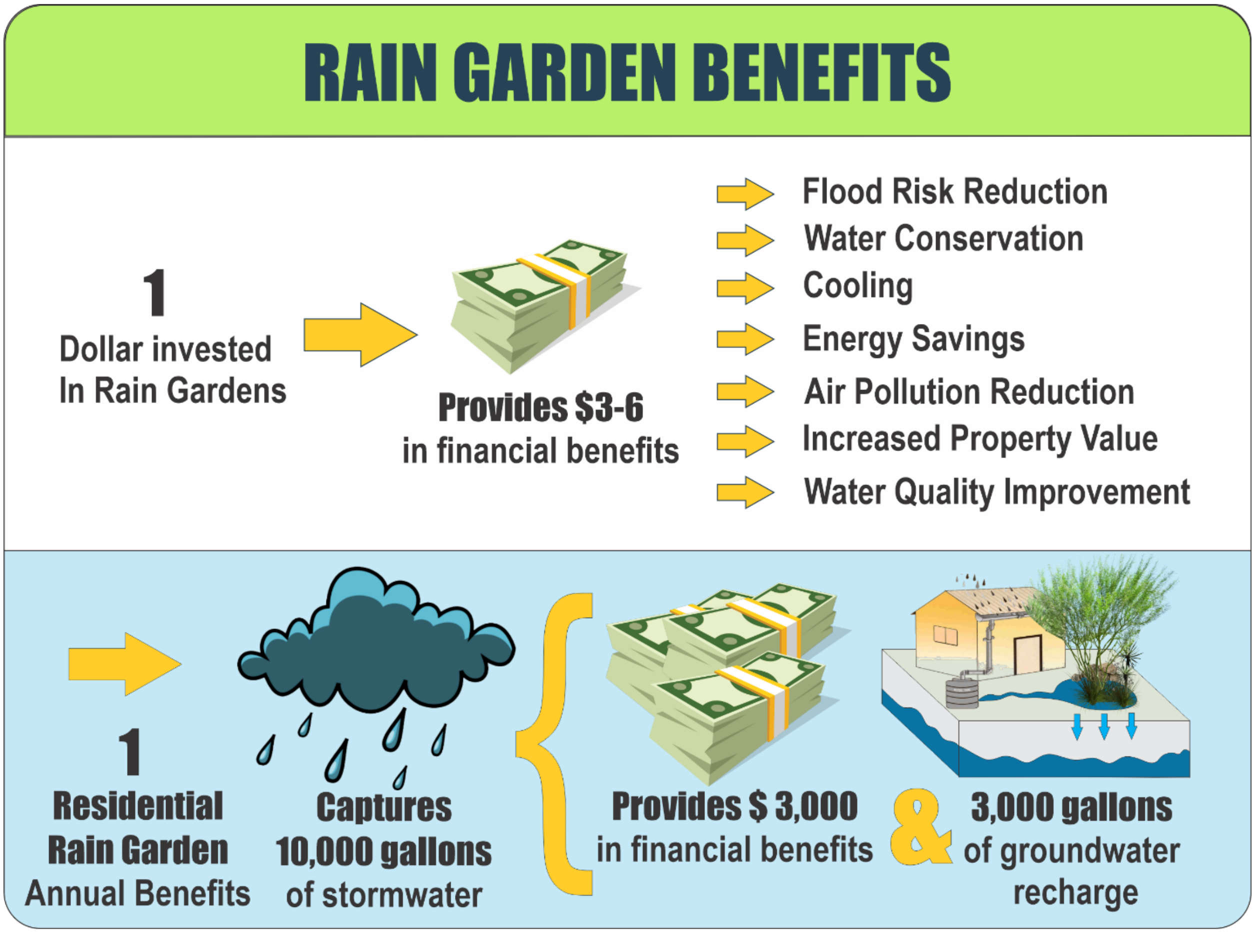


Figure 1-1 Rain garden financial and environmental benefits in Mohave County.

Given the significant benefits relative to the costs, the potential difficulty of siting and funding regional projects, and the distributary nature of flows often found in desert environments, implementation of LID on both public and private property can be an important component of a flood mitigation and erosion control program for the County.

1.3.2 Who Benefits?

There is a diversity of benefits created by LID projects as outlined above. These benefits are received by a variety of stakeholders. In order to ensure a successful LID program, it is important to involve all relevant entities impacted by LID. Within government entities, professional disciplines can include engineering, hydrology, architecture, landscape architecture, sustainability, economic development, forestry, ranching, farming, and community development. Two broad beneficiary categories – Regional and Individual Resident - represent the range of stakeholders and are described further below. Some benefits can be categorized as both regional and individual resident.

1.3.2.1 *Regional Benefits*

Regional benefits include impacts from increased water conservation, improved water quality, reduced flood risk, reduced urban heat island (Photograph 1-1), and increased tax revenues as a result of increased property values and decreased drainage maintenance. Other regional benefits not included in the *Phoenix CBA* report include improved traffic calming and reduced asphalt and street maintenance.

Photograph 1-1 LID project without an irrigation system shading a Phoenix sidewalk. Photo courtesy of Watershed Management Group.

1.3.2.2 *Individual Resident Benefits*

Individual resident benefits include reduced costs for energy and water, as well as reduced flood risk. Additional benefits not quantified in the *Phoenix CBA* report include increased water security through water harvesting and storage for potable and non-potable uses, improved erosion control, and the value of food production.

2 Low Impact Development Practices

A variety of LID practices are necessary to address the diverse challenges of stormwater management in rural and urban environments. Specific LID challenges and solutions (Section 3), common LID concerns (Section 4), design best practices (Section 5), and maintenance best practices and considerations (Section 6) are presented in the sections below. A complete set of Mohave County LID Details can be found in Appendix A. These details are intended to be a simple, yet complete detail that includes the best practices appropriate to the arid climate of Mohave County. A summary of LID best practices and pictures in two outreach brochures can be found in Appendix B. Supporting documents developed by other agencies throughout the Southwest are provided electronically on the external hard drive in Appendix C.

2.1 Local LID Practices Applicable Within Mohave County

Within Mohave County there are many flooding and drainage challenges. Implementation of LID techniques may reduce the adverse impacts associated with these challenges.

With the supporting documents found in Section 11 and in Appendix C on the external hard drive, along with the Mohave County LID Details found in Appendix A, serving as a foundation for implementation of LID techniques, the following sections provide discussion regarding the practices necessary for long-term LID function, maximizing benefits, and reducing maintenance. With a focus on the flooding and drainage challenges within the County, the following LID techniques are discussed below:

1. Rain Garden
2. Curb Cut
3. Sediment Trap
4. Berm
5. Bioretention
6. Swale
7. Zuni Bowl
8. One Rock Dam
9. Rain Tank

Photograph 2-1 Rain garden harvesting parking lot runoff for native grasses and trees in the City of Las Cruces, NM.

Photo courtesy of City of Las Cruces.

2.1.1 Rain Garden

A rain garden may mitigate flooding/drainage challenges associated with roadway flooding, sheet flow across residential parcels, and on-parcel runoff from impervious residential surfaces. Rain gardens (see Figure 2-1 and Figure 2-2) provide optimal areas to increase vegetation for both soil stabilization and shade benefits. Areas of ponding are ideal places to locate rain gardens to create conditions for greater infiltration by ripping compacted soils, adding organic mulch, planting grasses that thrive in periodic inundation conditions, and allow tree roots to establish in basin areas. Where possible, use native trees with healthy tap roots grown in "tall pots" or "tree pots" to ensure a robust root system is intact for the health of the tree and enhanced LID performance.

In sheet flow conditions, care must be taken to manage sediment in rain gardens to ensure long-term infiltration capabilities. Rain garden edges should ideally be four (4) to six (6) inches higher than the highest expected sheet flow depths to ensure ground cover materials do not float away and sediment does not deposit in the low areas. If it is not possible to keep the rain garden edges from being overtopped, the following planning and maintenance is recommended:

- Minimize unstabilized soil upstream of rain garden.
- Provide areas for sediment to deposit upstream of rain garden with Zuni Bowls and One Rock Dams.
- Remove sediment after large flows pass through rain garden.
- Utilize a layer of large organic mulch that is at least three (3) inches thick underneath a layer of rock mulch that is at least three (3) inches thick and with minimal fines. The rock layer will ensure mulch does not float and the organic mulch will decompose over time increasing the soil organic matter to improve water holding capacity and infiltration.

Best practices for rain gardens can be found in the Mohave County Rain Garden detail in Figure 2-2 as well as the list below. The Rain Garden detail as well as the complete set of Mohave County LID details can be found in Appendix A.

- Rip basin bottoms 12 to 24 inches to improve infiltration.
- Use organic mulch (3-plus inches) as ground cover in addition to bunchgrasses to improve soil health and water holding capacity in basins where there is not a risk of mulch floating away in large events.
    - If mulch floating away is a risk, utilize organic mulch underneath rock (4-plus inches) to hold the mulch in place.
- Planting native bunchgrasses is strongly encouraged in basin bottoms to ensure long-term function of basin. A few examples known to work well in Mohave County based on field observations are: sideoats grama, purple three awn, and bear grass.
- Allow leaves and any other native vegetation detritus that falls in the basins to decompose.
- Never rake, spray or mow rain gardens or basin bottom areas.
- If basins bottoms are greater than eight (8) feet wide, tree planting is encouraged in the basin or rain garden bottom to increase infiltration rates and shade canopy. Trees should be planted on raised shelves that elevate the root crown above the maximum ponding depth.

Rain Garden - Rain gardens are sunken garden areas where the existing soil has been replaced or mixed with mulch or rocks. It is then planted with deep-rooted plants that capture, absorb, and help infiltrate storm water.

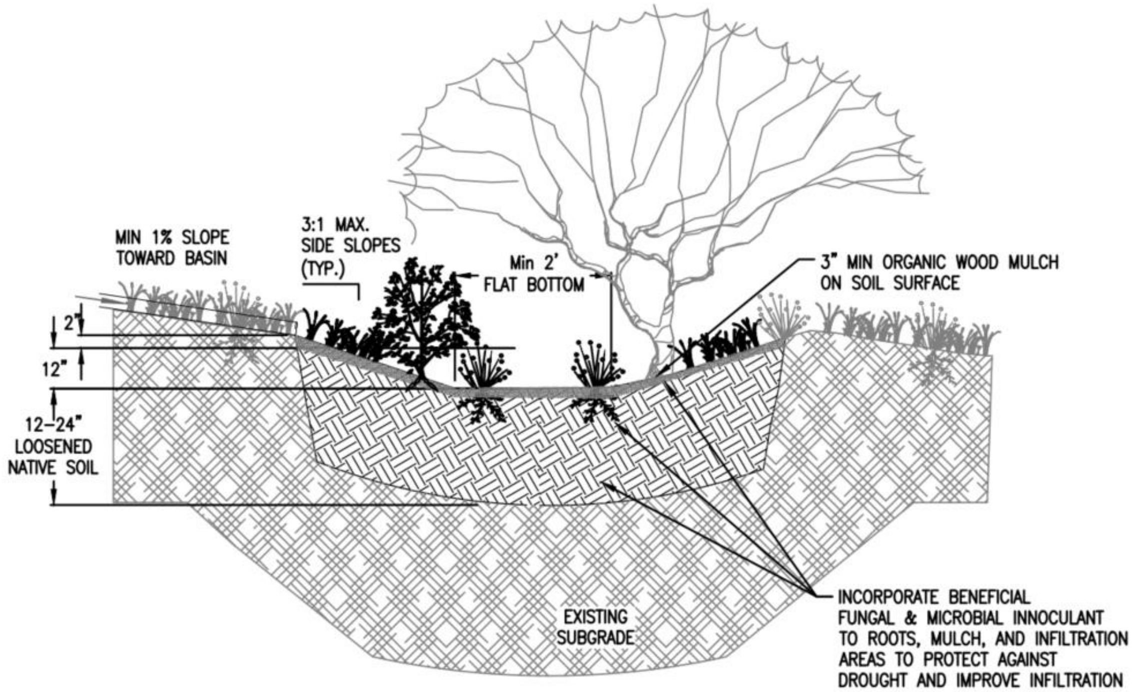
Benefits:

- Collect and holds runoff
- Filters pollutants
- Low maintenance
- Collected water supports more vegetation

Considerations:

- The first few years require higher maintenance while plants become established, weeding, and watering
- In later years, plants may require thinning

Figure 2-1 Conceptual Rain Garden (Excerpt from *Reduce Your Flood Risk: A Resource Guide*).



NOTES:

1. PROVIDE PROTECTION FROM ALL VEHICLE TRAFFIC, EQUIPMENT STAGING, AND FOOT TRAFFIC IN PROPOSED INFILTRATION AREAS PRIOR TO, DURING, AND AFTER CONSTRUCTION.
2. LOOSEN SOILS IN INFILTRATION AREAS 12–24" TO BREAK UP ANY COMPACTION.
3. SURFACE WATER MUST DRAIN WITHIN 36 HOURS.
4. 8–12" PONDING DEPTH FOR WELL DRAINING SOILS SUGGESTED, 4–6" DEPTH CAN BE USED IN POOR DRAINING SOILS OR WHERE MAXIMIZING IRRIGATION OF NATIVE VEGETATION IS A PRIORITY.
4. RAIN GARDEN MUST BE 10' AWAY FROM FOUNDATIONS AND 5' AWAY FROM PROPERTY LINES. IT IS RECOMMENDED TO AVOID INSTALLATION OVER UNDERGROUND OR BELOW ABOVE GROUND UTILITIES. ENSURE POSITIVE DRAINAGE AWAY FROM ALL STRUCTURES.
5. DESIGN AN OVERFLOW ROUTE THAT ALLOWS STORMWATER TO SAFELY ESCAPE THE RAIN GARDEN AWAY FROM BUILDING FOUNDATIONS AND ADJACENT PROPERTIES IN HIGH FLOWS. ESCAPE ROUTE SOILS SHOULD BE STABILIZED WITH VEGETATION OR ROCK TO PREVENT EROSION.
6. THE USE OF SAND IN PLANTING OR INFILTRATION SOIL MEDIA CAN CAUSE PLANT DEATH IN DRY PERIODS. USE COMPOST IN INFILTRATION AREAS TO INCREASE INFILTRATION. PLANTING AREAS SHOULD MAINTAIN NATIVE SOIL CHARACTERISTICS FOR OPTIMAL ESTABLISHMENT PERIOD AND LONG–TERM PLANT HEALTH.
7. PROVIDE A TOP COVER OF AT LEAST 3" OF WOOD MULCH IN RETENTION AREAS OUTSIDE OF FLOW PATHWAYS WHERE MULCH CAN FLOAT AWAY.
8. MULCH, PLANT ROOTS, AND INFILTRATION AREAS SHOULD BE INOCULATED WITH BENEFICIAL FUNGAL AND MICROBIAL COMMUNITIES TO IMPROVE RAIN GARDEN AND VEGETATION PERFORMANCE
9. NATIVE BUNCH GRASSES SHOULD BE ESTABLISHED INITIALLY BY SEED AND IN SMALLEST COMMERCIALLY AVAILABLE CONTAINERS TO QUICKLY PROVIDE GROUND COVER TO SUPPORT INFILTRATION AND MULCH IN STABILIZING SOILS AFTER PLANTING WITH MINIMAL WATER NEEDS. GRASSES THAT RESEED CAN BE HELPFUL IN ENHANCING GROUND COVER AND LONG–TERM SOIL HEALTH AND INFILTRATION RATES.
10. PROVIDE A DIVERSITY OF PLANT MATERIAL SPECIES, SIZES, SHAPES AND LOCATIONS FOR HABITAT.
11. USE TALL POT NATIVE TREES WHERE POSSIBLE TO ENSURE HEALTHY ROOT SYSTEMS FOR ENHANCED INFILTRATION AND STABILITY DURING STORMS.
12. USE ROCK OR CONCRETE AT INLET PER LID–04 TO DISPERSE FLOWS, CAPTURE SEDIMENT AND PREVENT EROSION.
13. FOR LID DESIGN AND MAINTENANCE BEST PRACTICES SEE THE MOHAVE COUNTY LID GUIDE.

– DRAWING NOT TO SCALE –

SEAL OF MOHAVE COUNTY ARIZONA, DITAT DEUS, 1864	RAIN GARDEN LOW IMPACT DEVELOPMENT TYPICAL DETAILS	NUMBER LID–01 12–1–19

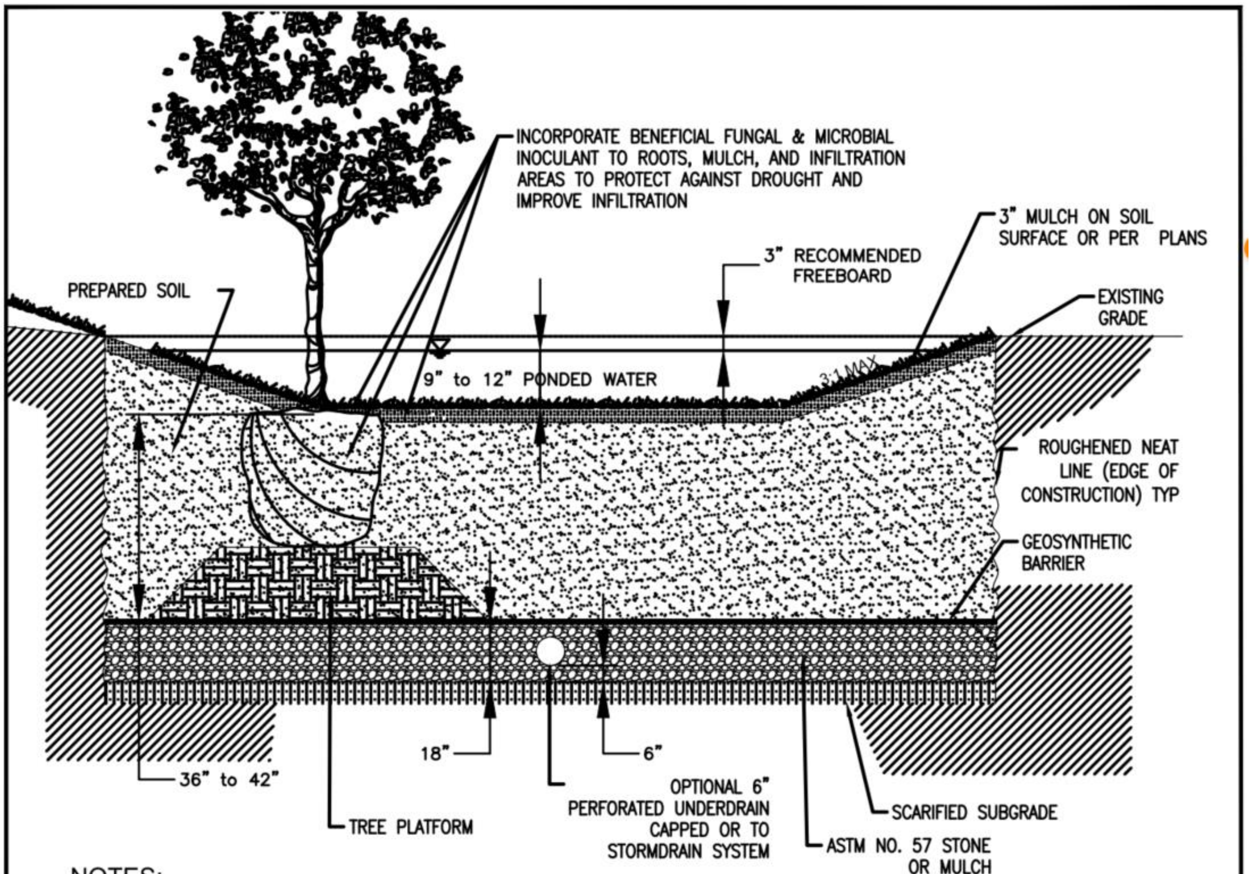
Figure 2-2 Mohave County Rain Garden LID Detail.

2.1.2 Bioretention

Bioretention is a LID technique that can be implemented to increase infiltration, particularly in excessive, long-duration ponding areas. The following best practices for bioretention systems in arid environments should be considered/implemented to maximize performance:

- Prepared soil should be reviewed by an Engineer or Landscape Architect with LID experience. This will ensure the prepared soil is appropriate for infiltration goals while also maintaining soil health that will ensure plants can survive dry periods.
- Sand content in excess of 40 percent is not recommended in prepared soil for plants to survive dry periods in between watering. Appropriate soil organic matter content from native soil and compost amendment will ensure water retention for plants to survive dry conditions.

These and other soil health best practices are incorporated in the Mohave County Bioretention LID Detail in Figure 2-3. A complete set of Mohave County LID Details can be found in Appendix A.



NOTES:

1. PROVIDE PROTECTION FROM ALL VEHICLE TRAFFIC, EQUIPMENT STAGING, AND FOOT TRAFFIC IN PROPOSED INFILTRATION AREAS PRIOR TO, DURING, AND AFTER CONSTRUCTION.
2. SURFACE PONDED WATER MUST PERCOLATE WITHIN 36-HOURS.
3. MINIMUM DEPTH OF 36 TO 42 INCHES TO ACCOMMODATE 48-INCH BOX TREE PLANTING.
4. BASIN MUST BE 10' AWAY FROM FOUNDATIONS AND 5' AWAY FROM PROPERTY LINES. IT IS RECOMMENDED TO AVOID INSTALLATION OVER UNDERGROUND OR BELOW ABOVE GROUND UTILITIES. ENSURE POSITIVE DRAINAGE AWAY FROM ALL STRUCTURES.
5. AN OVERFLOW ROUTE THAT ALLOWS STORMWATER TO SAFELY ESCAPE THE BASIN AWAY FROM BUILDING FOUNDATIONS AND ADJACENT PROPERTIES IN HIGH FLOWS. ESCAPE ROUTE SOILS SHOULD BE STABILIZED WITH VEGETATION OR ROCK TO PREVENT EROSION.
6. 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.).
7. INSTALL FILTER FABRIC BETWEEN TREE PLATFORM AND NO.57 STONE/MULCH.
8. PREPARED SOIL SHOULD NOT EXCEED 40 PERCENT SAND CONTENT AND UNCOMPACTED NATIVE SOILS SHOULD BE MAINTAINED IN PLANTED AREAS FOR PLANTS TO SURVIVE DRY PERIODS. ENSURE SUFFICIENT SOIL ORGANIC MATTER CONTENT BY UTILIZING ORGANIC WOOD MULCH ON THE SURFACE AND COMPOST MIXED INTO THE PREPARED SOIL AS RECOMMENDED BY LID PROFESSIONAL.
9. NATIVE BUNCH GRASSES SHOULD BE ESTABLISHED INITIALLY IN 1 GALLON CONTAINERS TO QUICKLY PROVIDE GROUND COVER TO SUPPORT INFILTRATION AND AID MULCH IN STABILIZING SOILS AFTER PLANTING. GRASSES THAT RESEED CAN BE HELPFUL IN ENHANCING GROUND COVER AND LONG-TERM SOIL HEALTH AND INFILTRATION RATES.
10. MULCH, PLANT ROOTS, AND INFILTRATION AREAS SHOULD BE INOCULATED WITH BENEFICIAL FUNGAL AND MICROBIAL COMMUNITIES TO IMPROVE WATER QUALITY AND VEGETATION PERFORMANCE.
11. PROVIDE A DIVERSITY OF PLANT MATERIAL SPECIES, SIZES, SHAPES AND LOCATIONS FOR HABITAT.
12. USE TALL POT NATIVE TREES WHERE POSSIBLE TO ENSURE HEALTHY ROOTS FOR IMPROVED INFILTRATION AND STABILITY DURING STORMS.
13. USE ROCK OR CONCRETE AT INLET PER LID-04 TO DISPERSE FLOWS, CAPTURE SEDIMENT AND PREVENT EROSION.
14. FOR LID DESIGN AND MAINTENANCE BEST PRACTICES SEE THE MOHAVE COUNTY LID GUIDE.

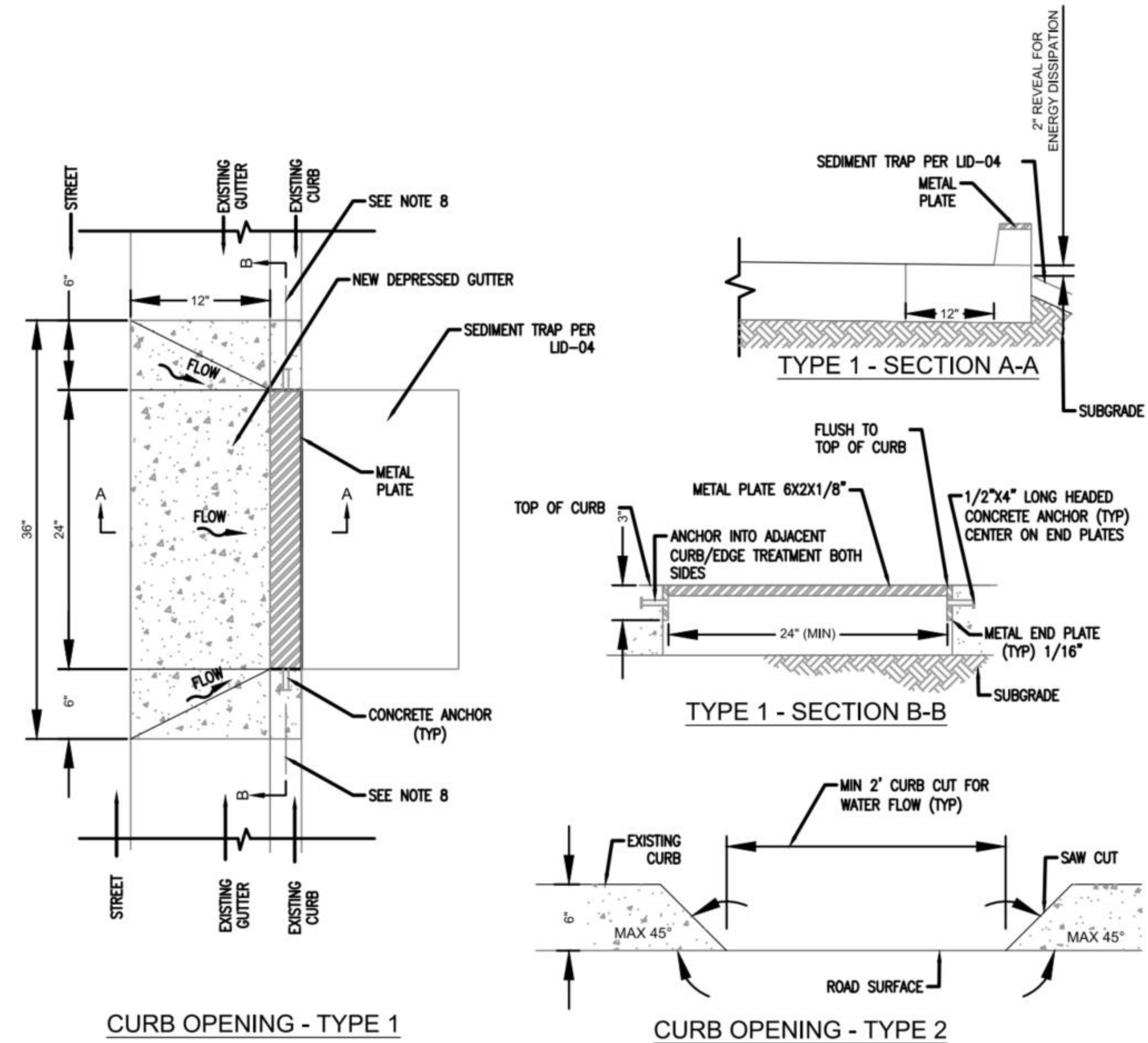
- DRAWING NOT TO SCALE -

SEAL OF MOHAVE COUNTY ARIZONA, DITAT DEUS, 1864	BIORETENTION LOW IMPACT DEVELOPMENT TYPICAL DETAILS	NUMBER LID-02 12-1-19

Figure 2-3 Mohave County Bioretention LID Detail.

2.1.3 Curb Cut

Curb cuts are important features in areas with curb and gutter. This is true for incorporation into new development as well as for retrofitting developed communities. Mohave County Curb Cut LID-03 in Figure 2-4 and Figure 2-5 summarizes over two decades of curb cut detail development based on experiences in Tucson, Phoenix, and other arid communities throughout the southwest. Mohave County Curb Cut Detail LID-03 can be found in Appendix A.



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 MAG SPECIFICATION 341 FOR MATERIAL AND CONSTRUCTION INFORMATION.
7. REFER TO AASHTO ROADWAY DESIGN GUIDE FOR CLEAR ZONE REQUIREMENTS FOR SPEED DESIGNS.
8. ALL CURB OPENINGS SHALL BE MADE BY SAW CUT METHOD.
9. GRIND EXPOSED METAL AND SEAL TO PROTECT FROM CORROSION.
10. FOR LID DESIGN AND MAINTENANCE BEST PRACTICES SEE THE MOHAVE COUNTY LID GUIDE.

- DRAWING NOT TO SCALE -

SEAL OF MOHAVE COUNTY ARIZONA · DITAT DEUS · 1864	CURB CUTS TYPE 1 & 2 LOW IMPACT DEVELOPMENT TYPICAL DETAILS	NUMBER LID-03 12-1-19

Figure 2-4 Mohave County LID-03 Curb Cuts 1 & 2 Detail.

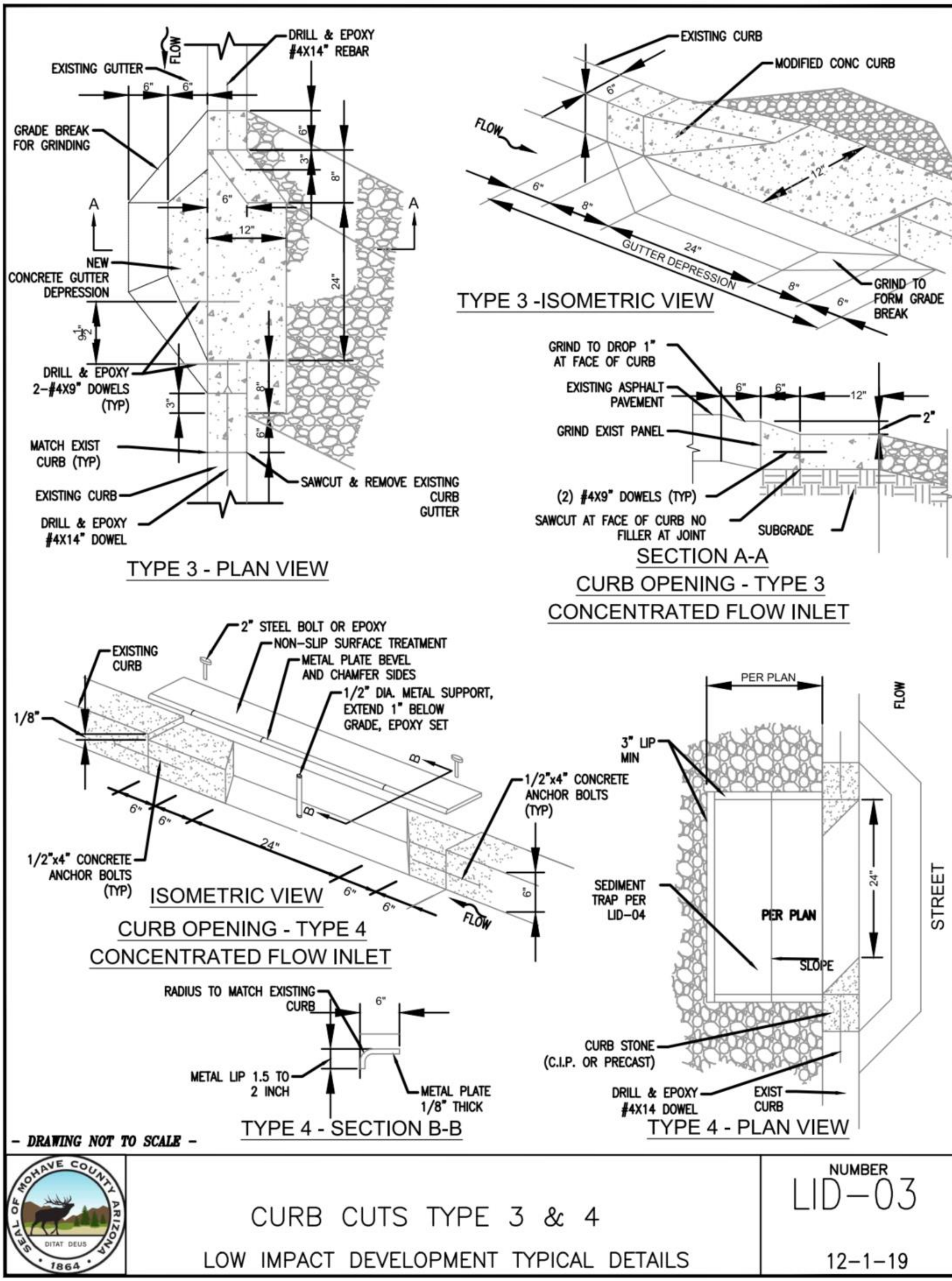


Figure 2-5 Mohave County LID-03 Curb Cuts 3 & 4.

2.1.4 Sediment Trap

Sediment traps in Mohave County Detail LID-04 (Figure 2-6) are one of the most important and overlooked components of LID. Managing sediment in arid environments is especially important given the occurrence of sediment laden stormwater and the potential impact on LID functionality. A poorly designed or non-existent sediment trap can lead to reduced LID feature capacity, decrease infiltration rates and even complete elimination of stormwater infiltration. Designing for ease of maintenance, and sizing for retention of sediment based on stormwater characteristics and watershed size, is critical.

A complete set of Mohave County LID Details can be found in Appendix A.

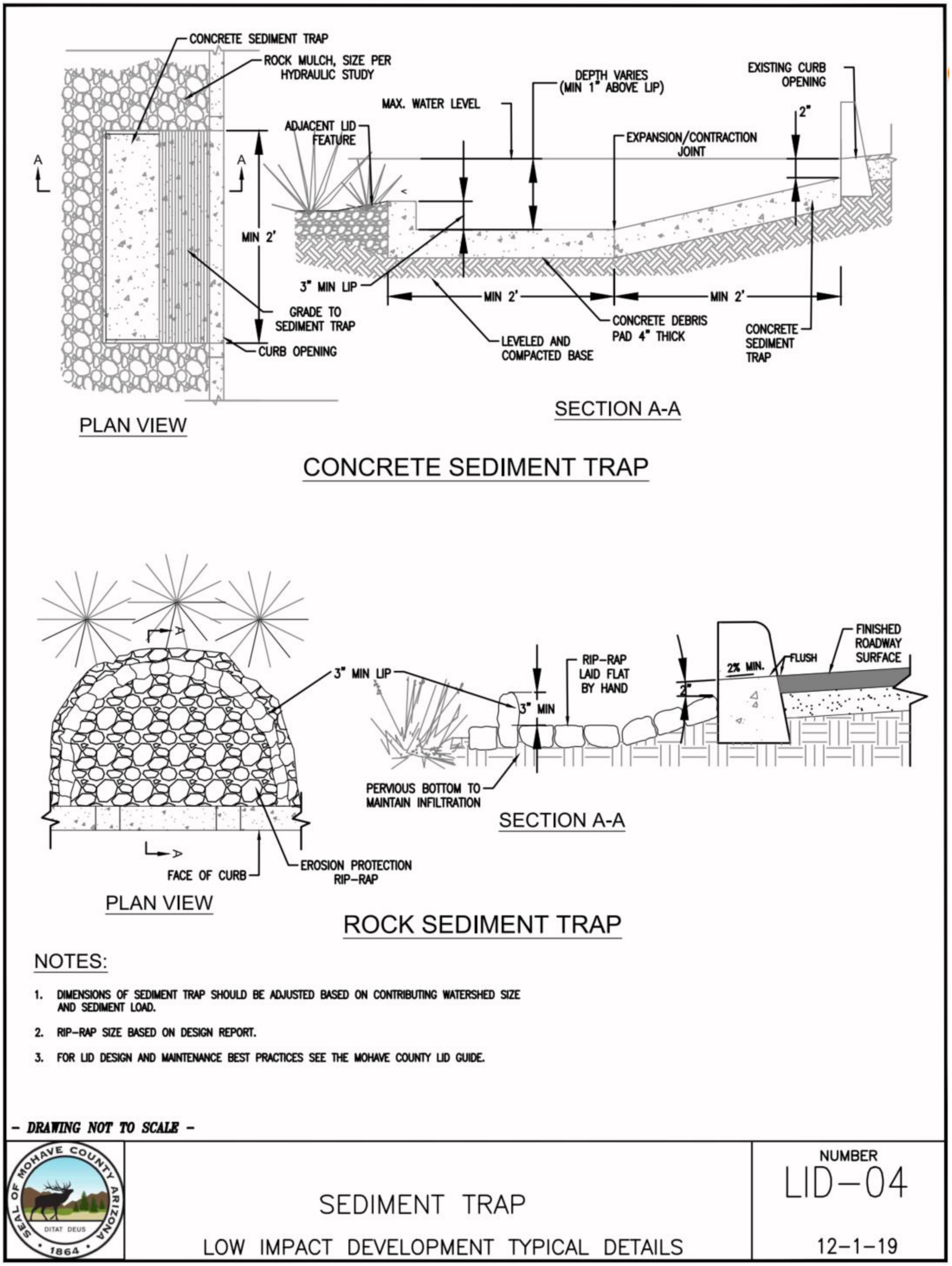


Figure 2-6 Mohave County Sediment Trap LID Detail.

2.1.5 Berm

A berm (Figure 2-7 and Figure 2-8) can be placed to retain water for landscape irrigation benefits and/or redirect stormwater flows away from property and structures. Berms are often constructed on contour, perpendicular to the slope of the land to slow water down and promote infiltration. Slopes should be no steeper than 3H:1V on the upstream side and no steeper than 4H:1V on the downstream side. In sandy soils, more gentle slopes of 5H:1V or greater are preferred to avoid steep slopes that may erode easily, and the slope should be compacted as directed by an Engineer.

Berms - Berms are mounds of earth with sloping sides that direct runoff.

Benefits:
- Directs water flow to basins or other landscape areas
- Upper layer of soil can be planted
- Adds interest to a flat landscape

Considerations:
- Can be strengthened by inlaying aggregate along the banks

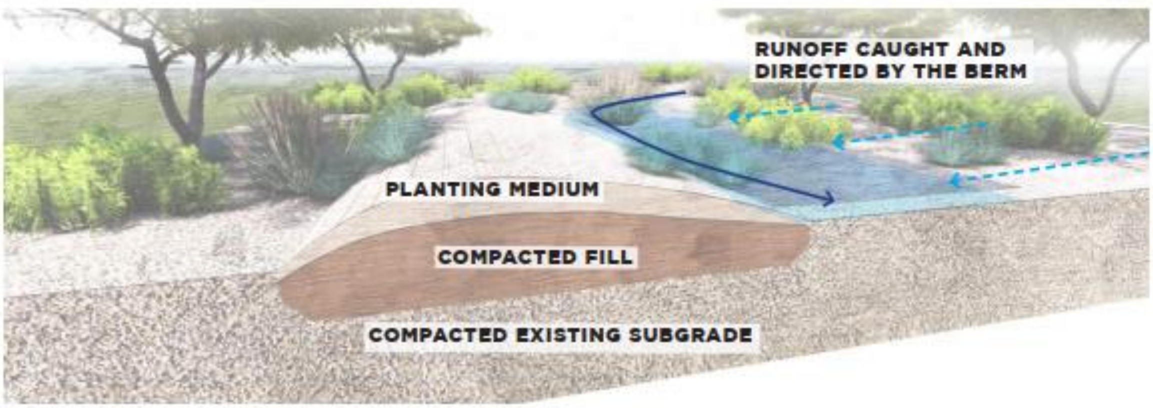
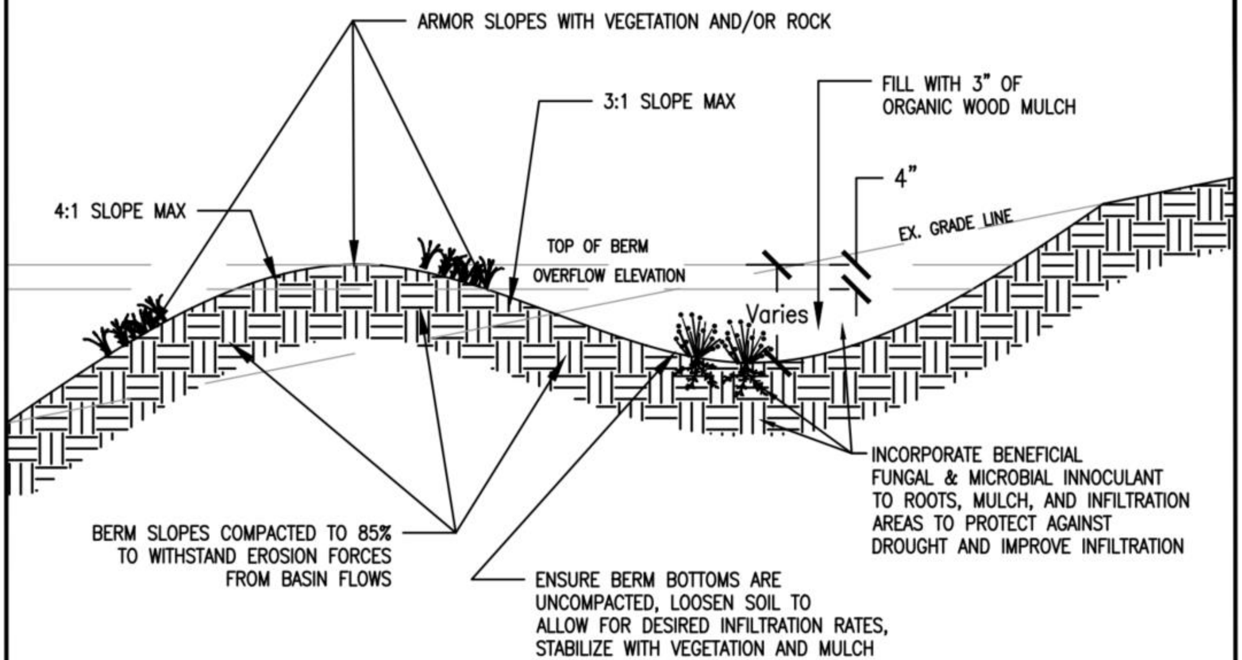


Figure 2-7 Conceptual Berm (Excerpt from *Reduce Your Flood Risk: A Resource Guide*).



NOTES:

1. PROVIDE PROTECTION FROM ALL VEHICLE TRAFFIC, EQUIPMENT STAGING, AND FOOT TRAFFIC IN PROPOSED INFILTRATION AREAS PRIOR TO, DURING, AND AFTER CONSTRUCTION.

2. LOOSEN SOILS IN INFILTRATION AREAS 12–24" TO BREAK UP ANY COMPACTION.

3. SURFACE WATER MUST DRAIN WITHIN 36 HOURS.

4. 8–12" PONDING DEPTH FOR WELL DRAINING SOILS SUGGESTED, 4–6" DEPTH CAN BE USED IN POOR DRAINING SOILS OR WHERE MAXIMIZING IRRIGATION OF NATIVE VEGETATION IS A PRIORITY.

4. BERM RETENTION AREAS SHOULD BE 10' AWAY FROM FOUNDATIONS AND 5' AWAY FROM PROPERTY LINES. IT IS RECOMMENDED TO AVOID INSTALLATION OVER UNDERGROUND OR BELOW ABOVE GROUND UTILITIES. ENSURE POSITIVE DRAINAGE AWAY FROM ALL STRUCTURES.

5. DESIGN AN OVERFLOW ROUTE THAT ALLOWS STORMWATER TO SAFELY ESCAPE THE BERM AWAY FROM BUILDING FOUNDATIONS AND ADJACENT PROPERTIES IN HIGH FLOWS. ESCAPE ROUTE SOILS SHOULD BE STABILIZED WITH VEGETATION OR ROCK TO PREVENT EROSION.

6. THE USE OF SAND IN PLANTING OR INFILTRATION SOIL MEDIA CAN CAUSE PLANT DEATH IN DRY PERIODS. USE COMPOST IN INFILTRATION AREAS TO INCREASE INFILTRATION. PLANTING AREAS SHOULD MAINTAIN NATIVE SOIL CHARACTERISTICS FOR OPTIMAL ESTABLISHMENT PERIOD AND LONG–TERM PLANT HEALTH.

7. PROVIDE A TOP COVER OF AT LEAST 3" OF WOOD MULCH IN RETENTION AREAS OUTSIDE OF FLOW PATHWAYS WHERE MULCH CAN FLOAT AWAY.

8. NATIVE BUNCH GRASSES SHOULD BE ESTABLISHED INITIALLY IN 1 GALLON CONTAINERS TO QUICKLY PROVIDE GROUND COVER TO SUPPORT INFILTRATION AND AID MULCH IN STABILIZING SOILS AFTER PLANTING. GRASSES THAT RESEED CAN BE HELPFUL IN ENHANCING GROUND COVER AND LONG–TERM SOIL HEALTH AND INFILTRATION RATES.

8. MULCH, PLANT ROOTS, AND INFILTRATION AREAS SHOULD BE INOCULATED WITH BENEFICIAL FUNGAL AND MICROBIAL COMMUNITIES TO IMPROVE RAIN GARDEN AND VEGETATION PERFORMANCE

9. PROVIDE A DIVERSITY OF PLANT MATERIAL SPECIES, SIZES, SHAPES AND LOCATIONS FOR HABITAT.

10. USE TALL POT NATIVE TREES WHERE POSSIBLE TO ENSURE HEALTHY ROOT SYSTEMS FOR ENHANCED INFILTRATION AND STABILITY DURING STORMS.

11. FOR LID DESIGN AND MAINTENANCE BEST PRACTICES SEE THE MOHAVE COUNTY LID GUIDE.

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BERM

LOW IMPACT DEVELOPMENT TYPICAL DETAILS

NUMBER LID–05

12–1–19

Figure 2-8 Mohave County Berm LID Detail.

2.1.6 Swale

A swale presents an opportunity to provide conveyance of flows while minimizing erosion with native vegetation and rock. Basic construction details for constructing a vegetated or rock swale can be found in Figure 2-9 and in Appendix A. The following details should be considered/implemented to maximize performance:

- In most residential applications, rock is not necessary unless flows and/or slope are significant. Consult an Engineer to determine if rock is necessary, and if so, determine appropriate rock sizing based on expected high-flow conditions.
- Alternate low-flow notches in rock check dams with native bunch grasses on the downstream side to provide meandering flows while protecting from erosion, as shown in the isometric view.
- Ensure rock check dams direct the force of water away from check dam edges/swale banks by raising rock that interfaces with the soil banks above the main level of the check dam.

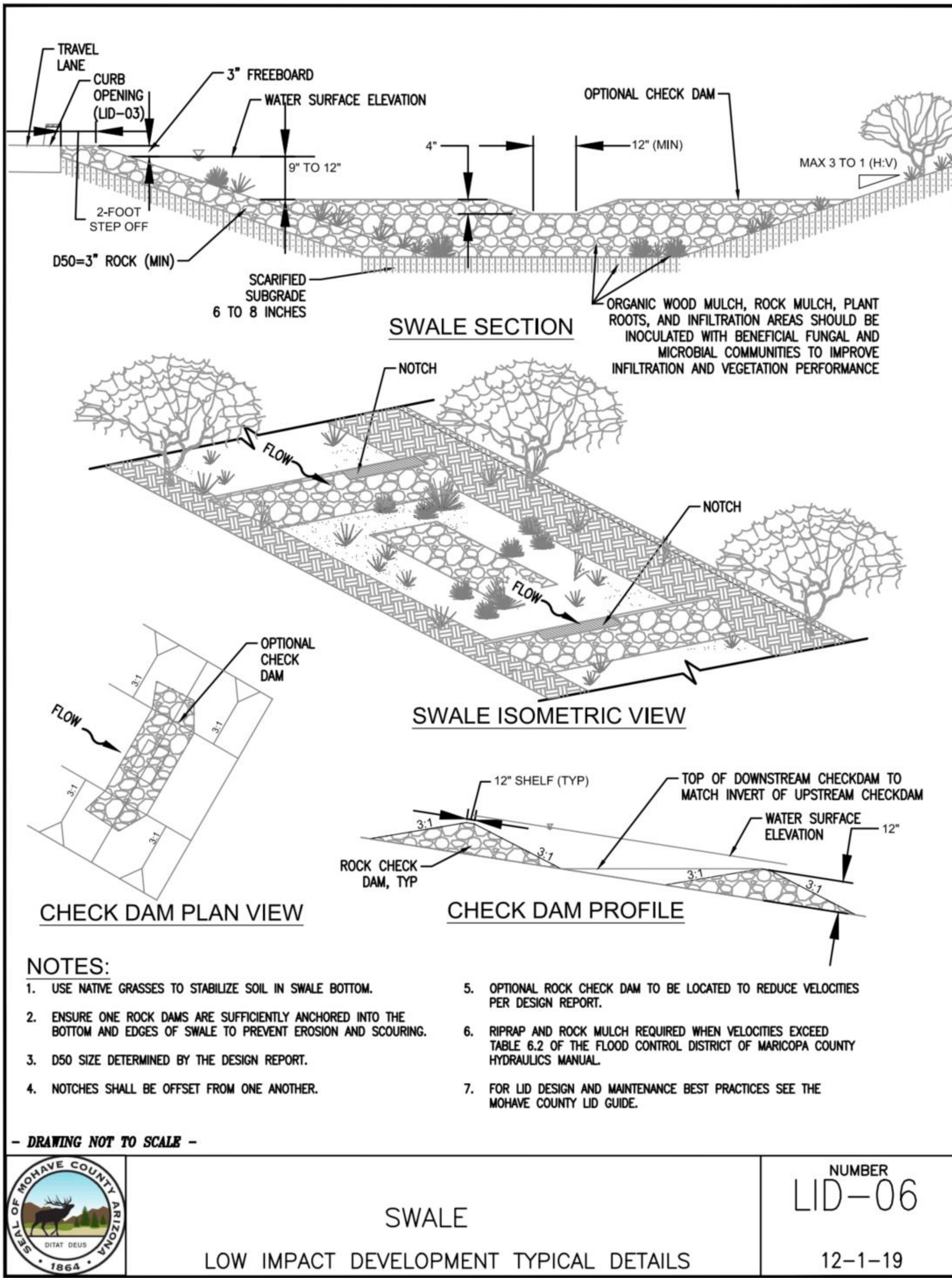


Figure 2-9 Mohave County Swale LID Detail.

2.1.7 Zuni Bowl

Zuni Bowls can be used in washes/channels or in the uplands to dissipate energy, manage sediment, and stop erosion and head cutting. It is important to use experienced, skilled labor to effectively place rock to resist the forces of flows and to ensure large rock are keyed in at the bottom of the bowl and the edges of the banks where erosive forces will be greatest. A typical Zuni Bowl detail is shown in Figure 2-10, Figure 2-11, and Appendix A. Additional information on the Zuni Bowl can be found in the *Rio Verde Area GI/LID Report* and the *Quivira Coalition Erosion Control Field Guide*.

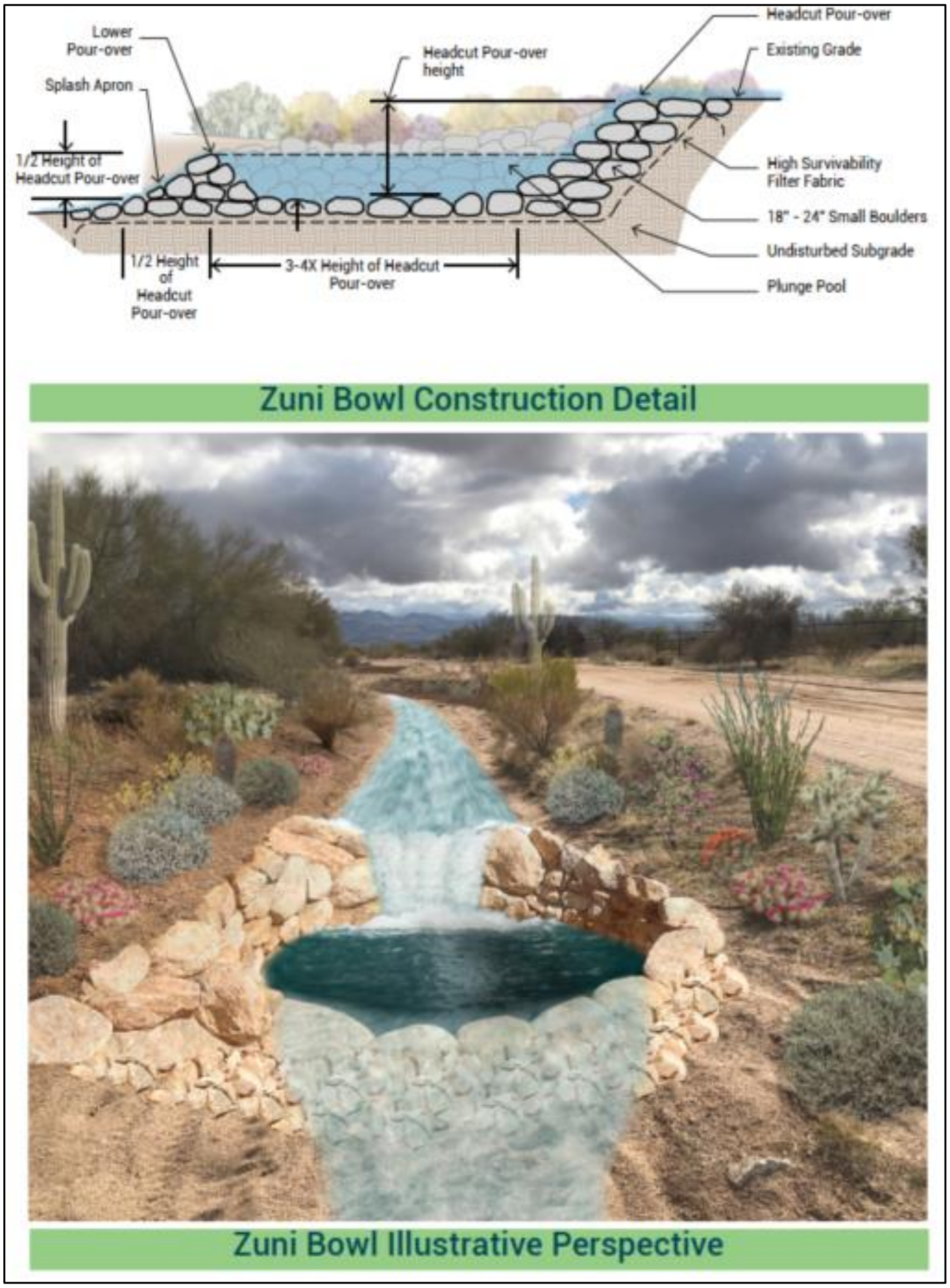


Figure 2-10 Zuni Bowl Detail (Excerpt from *Rio Verde Area GI/LID Report*).

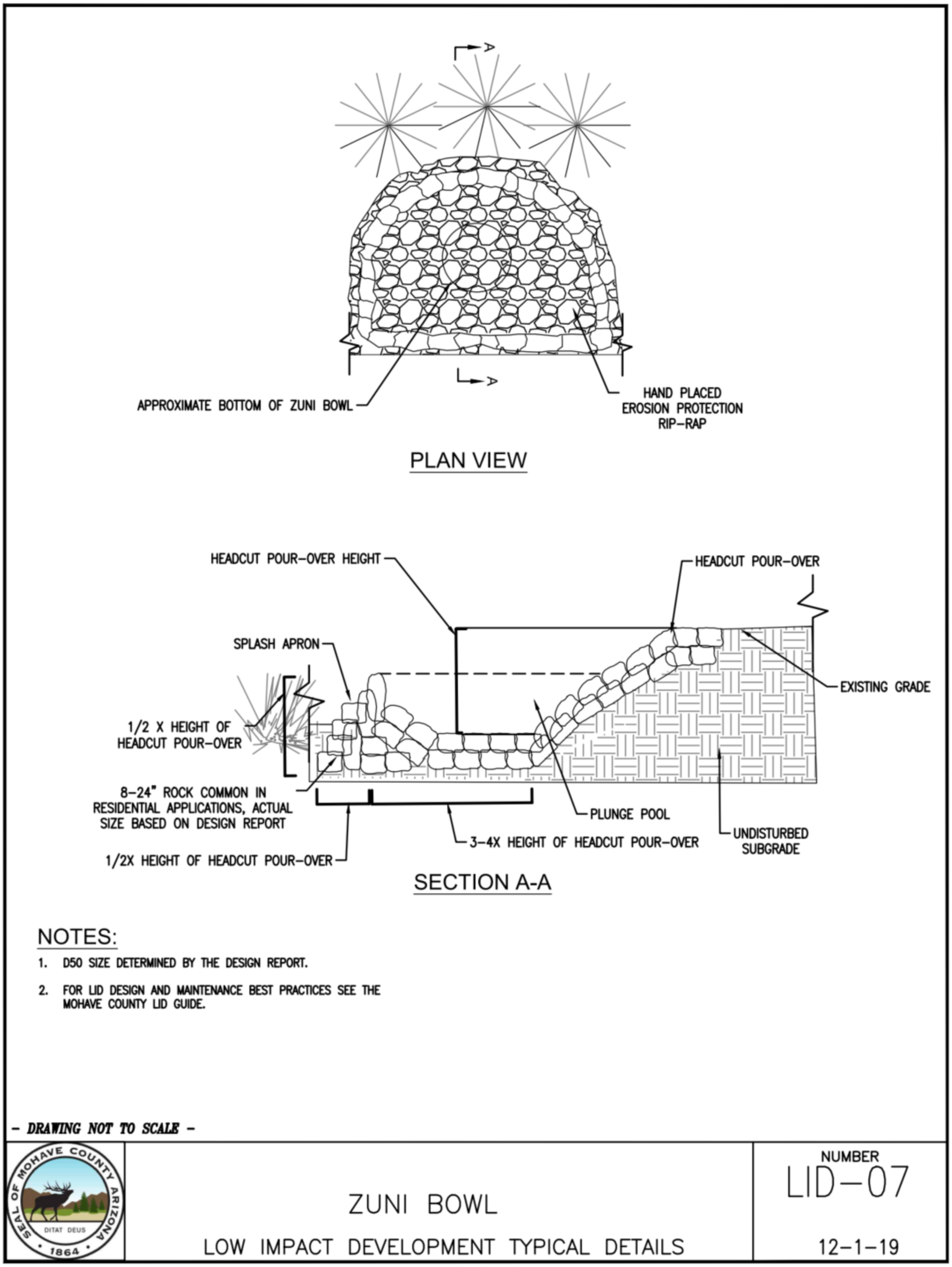


Figure 2-11 Mohave County Zuni Bowl LID Detail.

2.1.8 One Rock Dam

One Rock Dams are an important tool for residential scale erosion control, especially as an alternative to a check dam. A series of well-built One Rock Dams in a wash or erosive flow path can be much more effective than check dams, especially given the relative difficulty of constructing check dams and the potential for failure and increasing erosion and flood risks.

A well-constructed One Rock Dam will tie rock into the adjacent banks and secure the low flow rock below the channel bed to create sufficient strength to resist the expected scour/erosion forces. Rock should be sized for the largest expected flows to ensure features remain in place to minimize erosion in all expected design conditions. A *Quivira Coalition Erosion Control Field Guide* detail for a One Rock Dam is shown in Figure 2-12. Similar to a One Rock Dam, a typical Cross-Vane Weir detail from Dave Rosgen's *Stream Stabilization White Paper* is shown in Figure 2-13. The Mohave County One Rock Dam Detail can be found in Figure 2-14 and Appendix A.

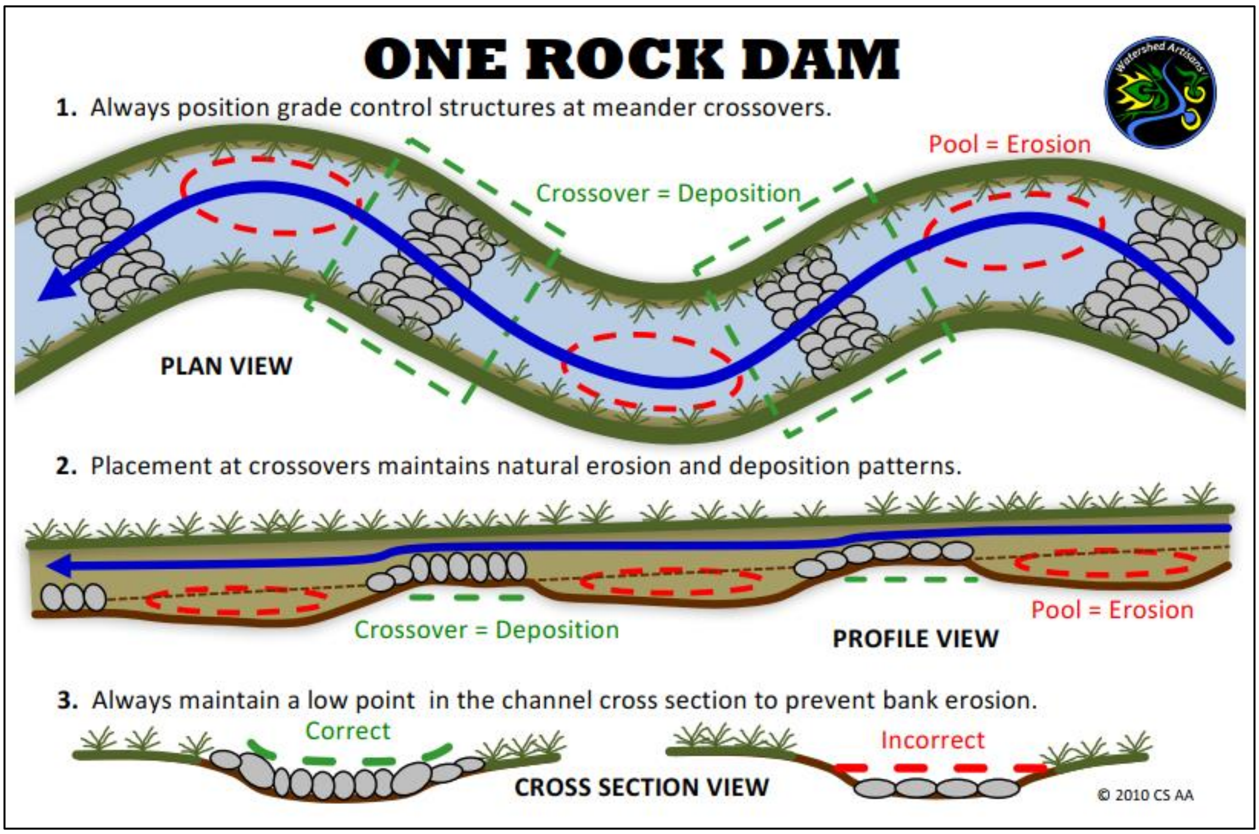


Figure 2-12 One Rock Dam Conceptual Detail (Excerpt from Quivira Coalition Erosion Control Field Guide).

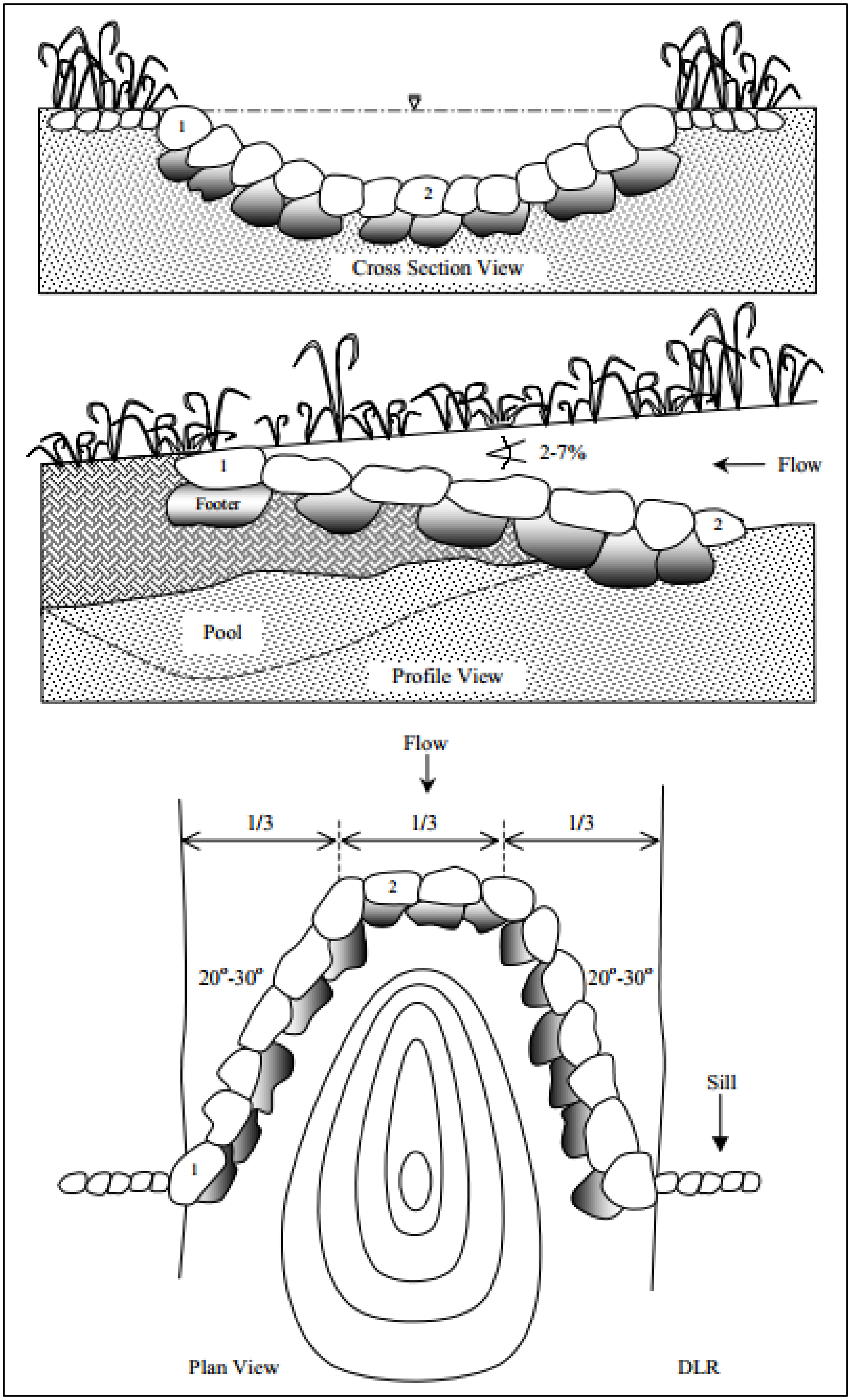
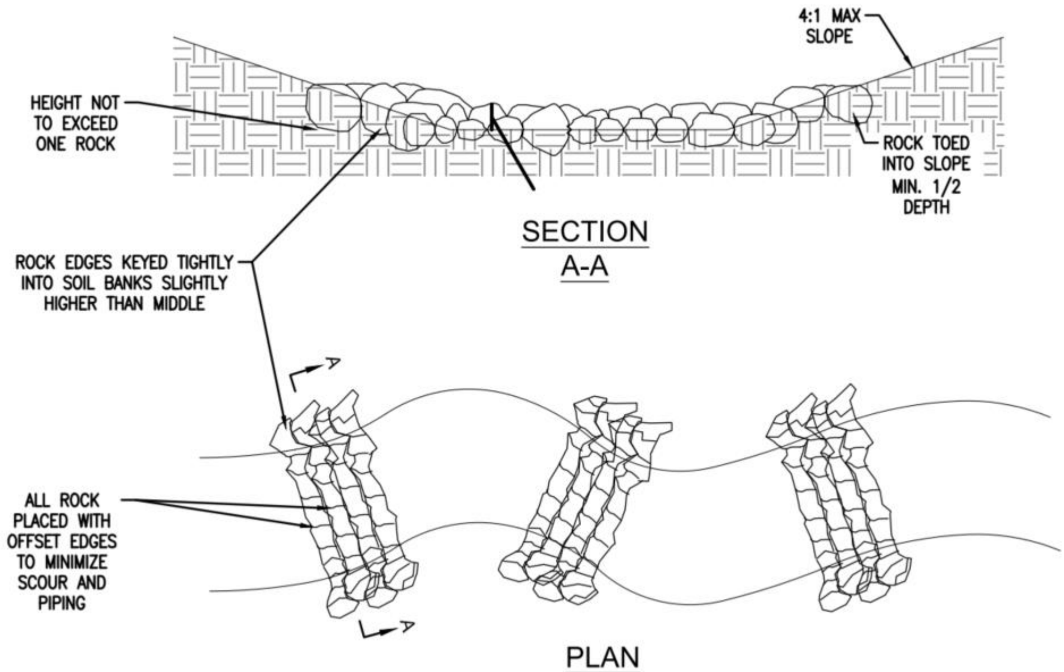


Figure 2-13 Cross-Vane Weir Detail (Excerpt from *Stream Stabilization White Paper)*.

One Rock Dams (Photograph 2-2) were recently constructed in a study reach located at the Heard Scout Pueblo - Boy Scouts of America Facility under the Hydrologic Research Pre- and Post-Grade Control Structure Installations Study (GCS Installations Study), sponsored by the Bureau of Reclamation (BOR). As part of the GCS Installations Study, the hydrologic impact of grade control structure (GCS) installations on storm flows, soil moisture, and sediment transport will be assessed. Research results will be used to inform water management policy regarding techniques used to optimize integrative management on surface water, groundwater, and eco-hydrologic resources.

Photograph 2-2. Installed One Rock Dam Per GCS Installations Study. Looking Downstream. April 12, 2019.



NOTES:

1. D50 SIZE DETERMINED BY THE DESIGN REPORT.
2. ALL ROCK IS HAND PLACED AND KEYED IN PLACE TO USE THE FORCE OF FLOWS TO BUILD STRENGTH IN THE FEATURES.
3. FOR LID DESIGN AND MAINTENANCE BEST PRACTICES SEE THE MOHAVE COUNTY LID GUIDE.

– DRAWING NOT TO SCALE –

SEAL OF MOHAVE COUNTY ARIZONA · DITAT DEUS · 1864	ONE ROCK DAM LOW IMPACT DEVELOPMENT TYPICAL DETAILS	NUMBER LID–08 12–1–19

Figure 2-14 Mohave County One Rock Dam LID Detail.

2.1.9 Rain Tank

In arid regions, rain tanks (Figure 2-15, Figure 2-16, and Appendix A) are an important method of storing water during dry periods for outdoor water use and indoor uses if treated appropriately. Typical indoor rainwater treatment systems utilize a combination of sand, carbon, and ultraviolet processes. When installing a rain tank, follow these guidelines to ensure optimal system function:

- Design first flush systems and debris filters to be self-cleaning and easily accessible.
- Remove internal debris screens included in any plumbing or tank fitting. Any screens that are not visible to the homeowner will eventually clog and create a flood risk.
- Locate tank overflow popup at least 10 feet away from any structures and rain tanks.
- Do not modify existing drainage patterns with overflow location.
- Use the above LID practices to effectively manage tank overflow and maximize benefits.
- If flood risk mitigation is a primary goal, install a bleed off pipe to ensure a minimum flood storage capacity is available when back-to-back storms occur.

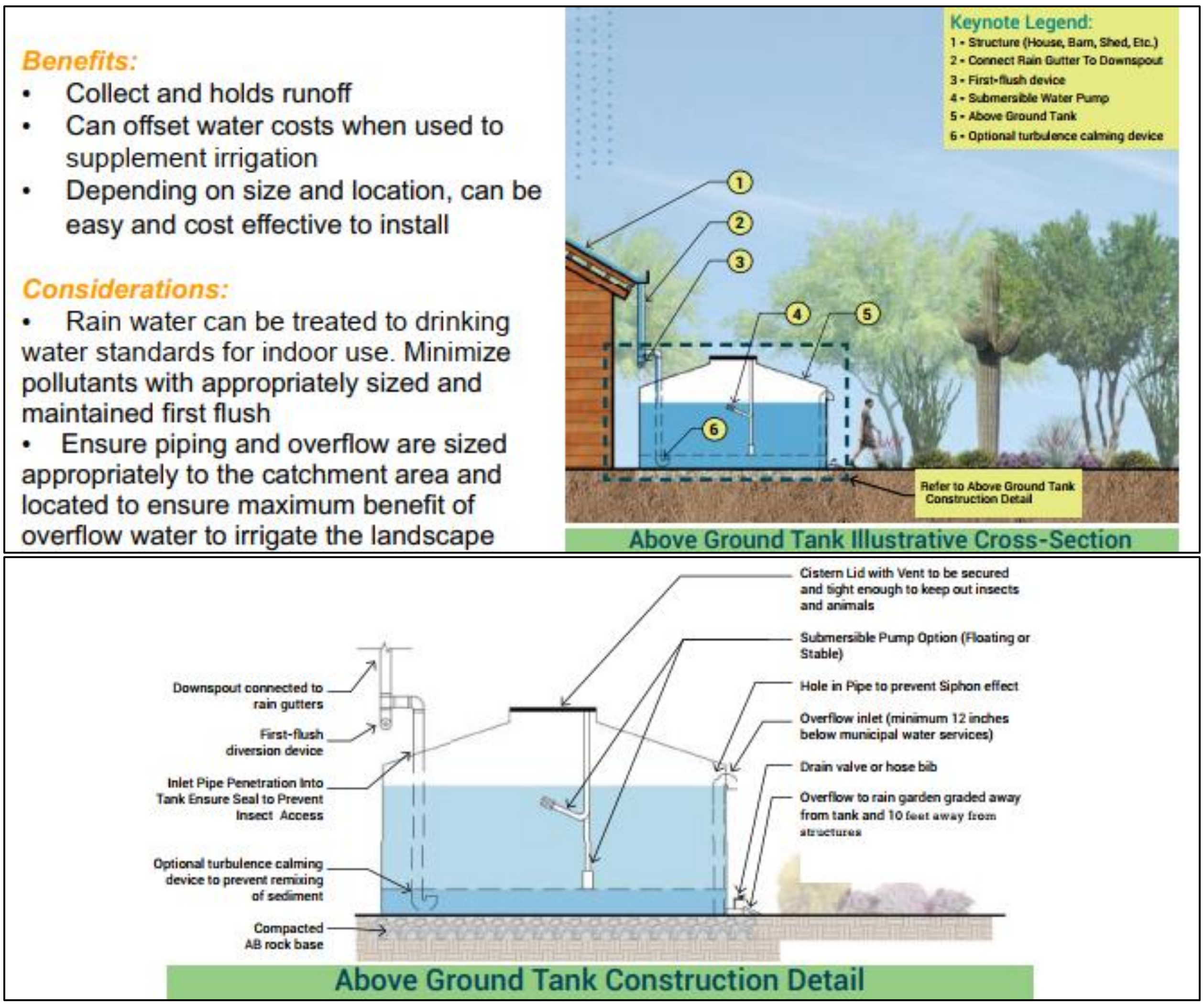


Figure 2-15 Tank Detail (Excerpt from *Reduce Your Flood Risk: A Resource Guide*).

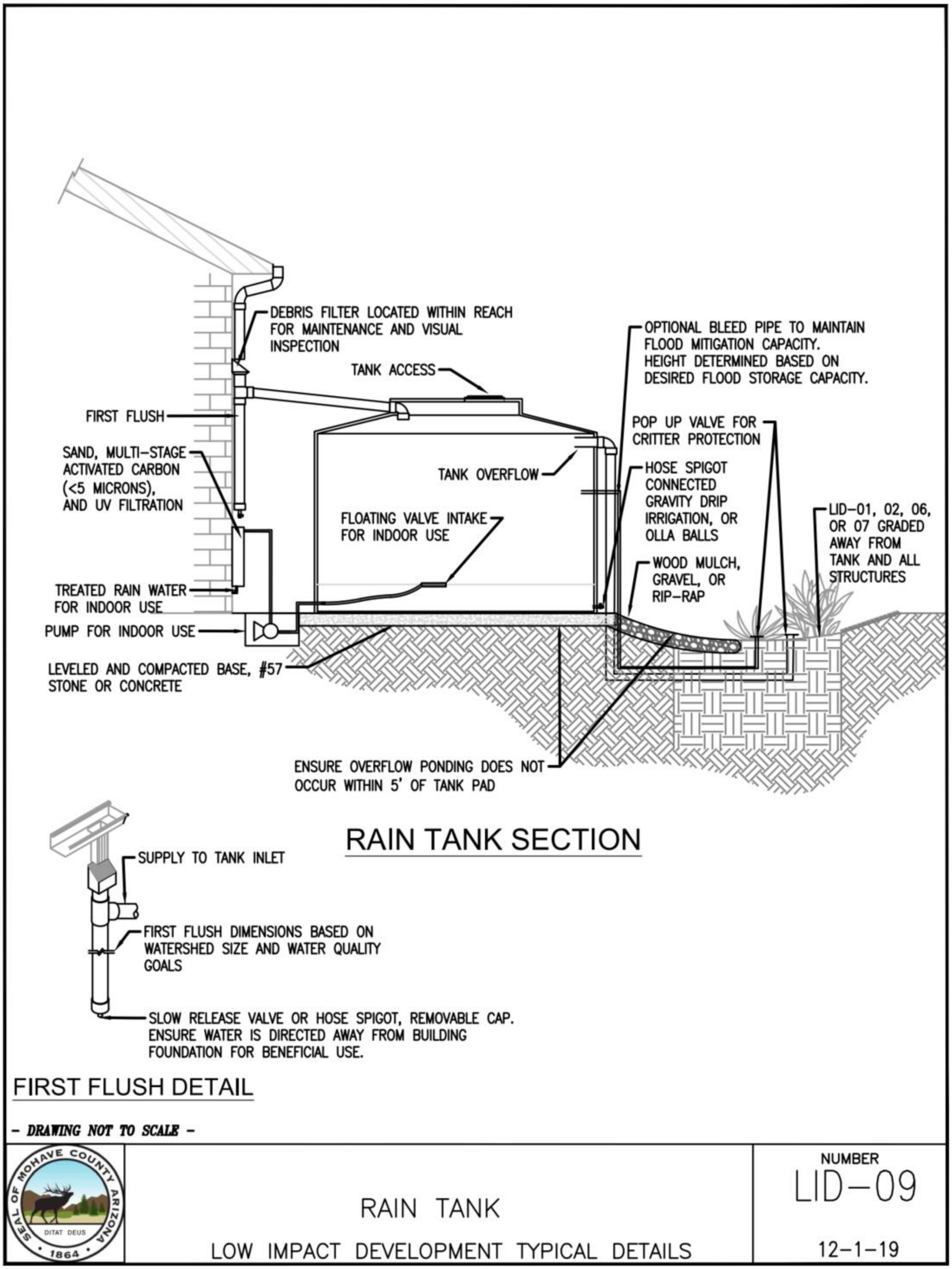


Figure 2-16 Mohave County Rain Tank LID Detail.

3 LID Solutions for Stormwater Management Challenges

Stormwater left unmanaged can create strains on public infrastructure and is a risk to public safety. The cost of inaction is greater than the cost of actively managing stormwater. As outlined in Section 1.3.1, LID practices provide important values to manage stormwater as an asset that can provide a return on investment not possible with conventional stormwater practices. Section 3.1 provides a discussion of the opportunities to apply LID techniques. Section 4 addresses common concerns about LID based on experience developing LID programs throughout the Southwest over the last 10 years.

An important aspect of the LID techniques discussed below is that they are relatively simple when compared to other stormwater management strategies, such as permeable pavements. The LID practices below are relatively easy to plan, design, install and maintain compared to other strategies and practices. These LID practices also help ensure that maximum passive irrigation benefit is achieved by maintaining water higher in the landscape. Permeable materials (asphalt, blocks, pavers, etc.) often infiltrate water below ground that then require subsurface conveyance typically out of reach from landscapes, especially newly planted landscapes that require additional potable water for establishment. Permeable materials require specialized installation and maintenance crews. An important component of any LID installation is minimizing maintenance and preventing failure. The techniques selected here can all be inspected quickly by visual inspection and are not subject to unknown failure due to inability to easily inspect, as all features are above ground.

3.1 Problems and Opportunities

All LID techniques can be utilized to address the various problems created by stormwater either directly (a berm can mitigate sheet flow) or indirectly (a curb cut reduces the volume of downstream erosive forces but does not directly address erosion). However, some practices are relevant to mitigating specific stormwater challenges, as shown in Table 3-1. For more detail on the application of the techniques, see Section 2.

Table 3-1 Applications of LID techniques to address problems created by stormwater.

	Sheet Flow	Erosion	Unstabilized Soil	Roof Runoff	Ponding	Driveway/Road Culvert Obstruction
Rain Garden	X		X	X	X	
Curb Cut	X		X			X
Sediment Trap		X	X			
Berm	X	X	X		X	X
Bioretention	X		X	X	X	
Swale	X	X	X	X	X	X
Zuni Bowl	X	X	X	X		X
One Rock Dam	X	X	X	X		X
Rain Tank	X			X		

3.1.1 Sheet flow

Sheet flow is uniform, shallow flow that occurs overland with no defined channels. This typically occurs on roads, driveways and flat yards. Sheet flow sources on residential properties include roofs, patios, driveways and other hardscape surfaces, and can include runoff from adjacent properties. Sheet flow can be mitigated through infiltration and storage practices. All LID techniques are relevant for sheet flow. Central to the success of LID applications for sheet flow is improving soil organic matter as outlined in Sections 10, 5.1, and establishing vegetation in Section 5.3.

3.1.2 Erosion

Erosion occurs when sediment loads in stormwater are below the load the flow can carry or when the flow exceeds the soil's resistance to detachment. LID works in several ways to address erosional forces by reducing stormwater volume and discharge velocities while also stabilizing vulnerable soil surfaces with rock and vegetation.

One Rock Dams and Zuni Bowls are the rock features that work to dissipate the energy of water to reduce erosion. Over time these features will facilitate the establishment of vegetation by slowing water down and dropping sediment that contains nutrients, organic matter and seeds, while also retaining water under rock. One Rock Dams can be placed upstream of rill erosion and also in rills when placed appropriately and tied into the edges of the rill banks. Use caution when placing rock in rills and follow the practices outlined in Section 5.2. Failing to follow all applicable best practices outlined in Section 5.2, can result in making erosion worse than no action at all.

Zuni Bowls are best utilized to dissipate energy over changes in elevation where One Rock Dams may not be strong enough to withstand the erosion and scour forces of water. A series of Zuni Bowls can be utilized to move water down a slope. It is always important to consult an erosion control professional, or an engineer with experience utilizing LID practices for erosion control, to ensure techniques are applied appropriately and safely.

Berms and swales can direct stormwater flows away from areas of erosion to where the water can be harvested in a rain garden or bioretention area. Berms and swales can also be utilized to slow the velocity of water before reaching an area impacted by erosion.

3.1.3 Unstabilized soil

Soils without vegetation, organic ground cover, or undisturbed soil crusts are susceptible to erosion. While similar to the erosion issues presented in Section 3.1.2, unstabilized soil is important to note separately due to the occurrence of properties and areas without any cover, that result in major dust and erosion hazards. Areas that drain on to roadways and adjacent to roads are of particular concern given the potential for sediment deposition on roadways or in roadway drainage structures. In many right-of-way landscapes adjacent to roadways in arid environments, soil is unstabilized due to lack of ground cover, insufficient ground cover planted at the time of construction, or complete mortality of vegetation and removal of mulch or other ground cover as a result of maintenance or wind/water erosion. Curb cuts, rain gardens and bioretention areas, adjacent to roadways, provide the benefit of managing stormwater while creating ground cover that can survive extreme arid climates. These LID practices can mitigate sediment deposition in streets.

Medium to large scale LID (Photograph 3-1) can provide solutions to large expanses of unstabilized soil. LID practices can provide creative solutions needed for challenging soil stabilization where resources do not permit other means of broad scale revegetation. Finding opportunities to utilize stormwater effectively for revegetation and plant irrigation can be accomplished by directing storm flows with curb cuts (if applicable) or rock work practices like One Rock Dams and Zuni Bowls to slow water down as vegetation is established. Starting at the top of the watershed-of-interest is key. Once areas have been revegetated at the top of a watershed with native plants, the seedbank and water flowing from those features will facilitate revegetation downstream.

Photograph 3-1 Pima County Regional Flood Control District LID restoration site.
Photo courtesy of Pima County Regional Flood Control District

Photograph 3-1 shows the potential to harvest runoff from a major roadway, before stormwater enters the storm drain system, to stabilize barren soil and to re-establish riparian vegetation in a historic floodplain that had lost its vegetation due to downcutting and groundwater pumping.

3.1.4 Roof runoff

Unmitigated roof runoff from homes and buildings can be a significant contributor to local flooding if the drainage around building foundation is not well designed. Often landscape retrofits have unintended consequences on drainage and inappropriately located berms and slopes can cause roof runoff to collect near structures. Roofs have very high run coefficients (0.9) and have a higher potential to create damage as a result of the runoff being generated high off the ground, creating an impact force when it lands. Both sheet flow and concentrated flows from a roof can create significant erosion and flooding problems, depending on the roof size and the condition of the ground below.

There is no clear answer of whether having gutters or not is better. It depends on the goals of the property owner, shape of the roof and house, and the conditions of the landscape around. It is important that gutters are adequately sized to handle the intensity of large flow events and should be upsized if budget allows. Often gutter sizing is overlooked and can create unexpected new problems if they are not sized appropriately. Areas where two rooflines meet and concentrated flows occur (Photograph 3-2) should have gutters with a lip to ensure those flows are captured and do not spill over the edge of the gutter. With gutters, steps must be taken to dissipate the energy of concentrated flows coming from the downspouts.

Photograph 3-2 Waterfall created by concentrated flows from two rooflines.

If water storage is a goal, appropriately sized and located rain tanks with an appropriately located overflow is ideal. Sizing can be constrained by budget, as rain tanks are the most expensive form of residential LID; available area for a tank is typically another main constraint. Locating a tank so it achieves multiple goals such as water storage, shading a part of the yard or house, and blocking an undesirable view is ideal and will be further expanded upon in Section 7. Locating the overflow for maximum benefit of the excess stormwater, while also protecting structures, is critical. Rain gardens or bioretention areas are ideal features to receive rain tank overflow. If storage is not desired, energy dissipation can be achieved by an appropriately sized Zuni Bowl. Typical downspout splash pads are often not adequately sized to effectively capture flow from gutters and direct it to a water harvesting landscape. It is recommended that flows be conveyed at least 5-10 feet away from a structure, depending on soil type, before any form of rain garden or bioretention feature is located and constructed. An additional strategy could be to use a painted PVC or ABS downspout, place it underground, and ensure it has at least a 2% slope to reach an overflow area at least 5-10 feet away from structures. This downspout would then have a pop-up, with a small hole in the bottom, to allow any ponded water to drain out of the pipe after the end of the rain event.

Roof areas without gutters or concentrated flows can be captured by swales and directed away from foundations to rain gardens and bioretention areas. Holistic Management (Section 10) of the landscape can support infiltration and water storage in the soil for passive irrigation of the landscape, while also reducing the potential for erosion.

3.1.5 Ponding

Ponding can be mitigated or eliminated by increasing the potential for infiltration as well as spreading flows out to vegetation more evenly throughout an area to maximize the potential irrigation benefit and minimize the risks of future ponding issues. Increasing infiltration can be accomplished by use of a rain garden, bioretention area and Holistic Management (Section 10) practices. Flows can be distributed more evenly throughout an area by utilizing a system of berms, swales, and rain gardens. Berms and swales can keep flows away from areas where infiltration is not possible or desired.

Ponding within 5-10 feet of foundations (Photograph 3-3) should be redirected with positive drainage of 2% away from structures. Infiltration trenches or French drains are also potential tools, but they should be considered last resorts as underground drainage features are harder to inspect and assess maintenance needs.

Photograph 3-3 Ponding adjacent to a home foundation and rammed earth wall.

3.1.6 Road/Driveway Culverts

Sediment loads from unstabilized ground can accumulate and obstruct roadway and driveway culverts. Curb cuts, berms, and swales can mitigate flows from entering drainage channels that lead to road and driveway culverts. These features can minimize sediment loads and stormwater from entering the drainage channel by slowing, spreading, and sinking the water in order to establish vegetation to create long-term stabilization and improve soil health. Zuni Bowls and one rock dams can be utilized in the drainage way to dissipate energy of flows and reduce sediment loads before entering the culverts. These will still require maintenance but will increase the culvert capacity to handle sediment and shift the maintenance work from the culverts to the rock features, reducing the potential for loss of road/driveway access as well as culvert and roadway damage.

Photograph 3-4. Road culverts with reduced capacity due to sedimentation.

3.1.7 Common mistakes

A common practice is not using hand placed rock that is securely tied into the bottom and sides of eroded areas as described in Section 5.2 for erosion control. This practice only worsens erosion as it concentrates flows around the rocks, spreading the erosive forces laterally. For more information on best practices for rock work, consult Sections 11.4 and 5.2 and you can also enlist the help of a trained water harvesting professional or licensed engineer with experience designing, installing and maintaining loose rock structures.

Obstruction of inlets can occur by poor design of sediment traps or excessive rock ground cover. A common occurrence in the City of Tucson, when the commercial rainwater harvesting ordinance was first passed, was the creation of low areas fed by curb cuts in landscapes filled with rock piled up above the elevation of the curb cut inlet. Requiring a minimum 2” drop from the edge of curb to the start of the sediment trap will ensure a safety factor for any clogging by rain garden material settling or sediment build up from lack of maintenance.

Placement of rain gardens in locations higher than the adjacent areas has been observed throughout the southwest. While less common, occasional LID rain gardens have been observed at high points in watersheds where no water flows. This has occurred in roadway projects as well as parking lot projects. It is important to observe existing topography to ensure stormwater will flow as designed and make any feasible corrections or relocate features to ensure stormwater will enter LID facilities as planned.

4 LID Common Concerns

LID practices have been implemented throughout the arid southwest and United States for over two decades. However, it is only recently that LID practices have become more commonly used as complementary techniques to manage stormwater along with conventional infrastructure. Despite the increase in LID, there are still common concerns expressed by communities regarding LID practices. The US Environmental Protection Agency (EPA) has produced a series of LID Barrier Busters[3] addressing common concerns about LID. Below are the most common concerns that have been expressed and suggestions for how to address them. Appendix C on the external hard drive contains the US EPA Barrier Busters that specifically address the concerns in each section below.

4.1 Maintenance

The most common concern about LID is maintenance. The Return on Investment achieved in Section 1.3.1 is based on appropriate maintenance and includes the necessary costs. Thus, LID maintenance is one of the few maintenance practices for stormwater infrastructure that has a positive return on investment and creates benefits beyond conventional stormwater management activities.

Many LID programs and installations have been developed without adequate concern for maintenance, and thus, a common criticism is that maintenance for LID is not cost effective. This is true for scenarios where maintenance is deferred and/or conducted inappropriately, creating a much greater long-term maintenance burden. The large one-time maintenance need is often perceived as the necessary ongoing maintenance needs. With a small up-front investment to ensure native plants are well established and the soil is healthy, the long-term maintenance burden significantly decreases. Planning for appropriate financial, technical, and educational resources is critical. Conventional maintenance practices do not support healthy natural systems. Knowledge and experience working with and understanding natural systems is critical for long-term performance of LID. Section 6 will go into greater detail for maintenance best practices.

4.2 Cost Effectiveness and Funding

The US Environmental Protection Agency did an assessment in Maricopa County showing the cost effectiveness of LID practices compared to conventional stormwater management. As stated in Section 1.3.1, equivalent (based on storage volume) conventional infrastructure was more expensive than LID, over the life of the infrastructure, in a modeling example in Maricopa County ($4.79 million vs. $3.98 million). The US EPA published guidance documents titled, *Fund LID/GI Projects with FEMA Grants for Flood Mitigation* and *Get Flood Insurance Discounts with Low Impact Development, Open Space Protection Plans, and Stormwater Management Regulations*, found in Appendix C on the external hard drive. These reports describe how LID can be funded through FEMA grant programs as well as the NFIP and CRS benefits of LID projects and programs respectively. See Section 8 for more details regarding successful LID funding programs from around the country.

4.3 Technical Effectiveness

A common thought regarding LID is that it does not reduce flooding, especially large events. Both LID modeling and practices show that LID can be implemented to mitigate local flooding, and if LID practices are implemented throughout a large watershed, modeling shows reductions in peak

[3] US EPA LID Barrier Buster Brochures: https://www.epa.gov/nps/urban-runoff-low-impact-development

flows for the 100-year storm. In FEMA's report, *Innovative Drought and Flood Mitigation Projects* (provided in Appendix C on the external hard drive), a chapter section is dedicated to LID successes for flood protection, modeling results, feasibility and effectiveness, benefits and costs, and other considerations. The US EPA's *Res Benefits of Green Infrastructure for Stormwater Management* (provided in Appendix C on the external hard drive) details floodplain area reductions with LID for a variety of storm events, as well as estimates of losses avoided.

In *Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area* (provided in Appendix C on the external hard drive), the City of Tucson, in collaboration with the Pima County Regional Flood Control District and Watershed Management Group, used FLO-2D to model flood reduction potential. Depending on the assumed level of LID implementation for the 100-year, 3-hour event, reductions in peak discharge between 10% and 40% and reductions in runoff volume between 10% and 25% were shown in the modeling results.

The Flood Control District of Maricopa County Tempe Area Drainage Master Study (ADMS) found LID can address localized flooding at the neighborhood scale in the 100-year, 6-hour storm. Figure 4-1 shows the decrease in peak discharges from a neighborhood in the Tempe ADMS based on the percentage of parcels installing street harvesting LID features.

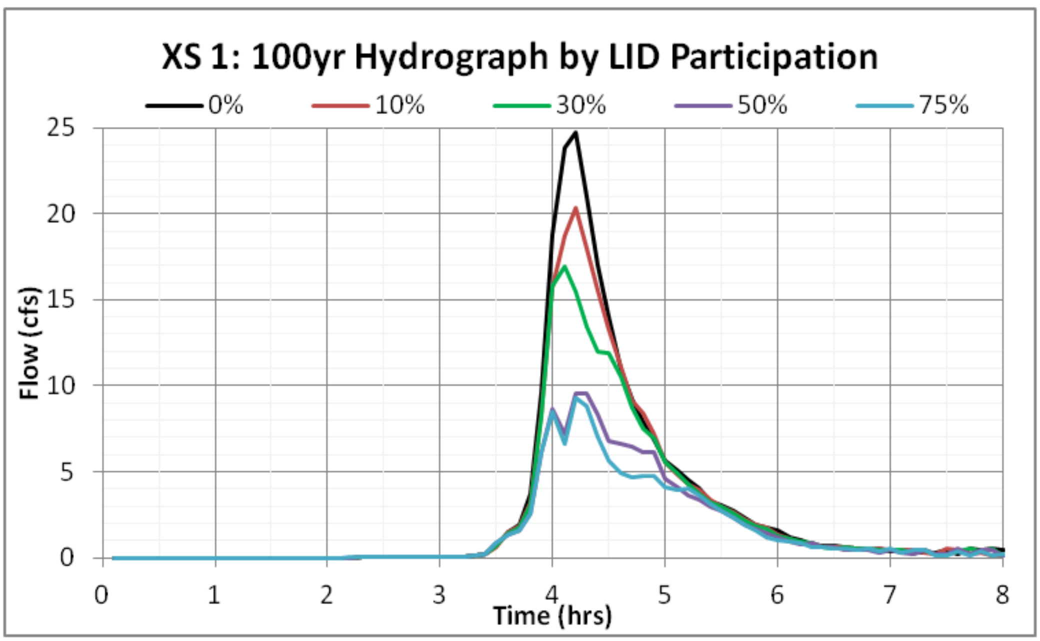


Figure 4-1 100-year flood mitigation by percentage of parcel participation.

4.4 Education and Training

LID practices have been utilized throughout the arid southwest for over two decades, however, they are not fully integrated into development and drainage standards. Education and training are necessary for all relevant professional communities and disciplines, decision makers, and the general public interested in implementing LID on private property to gain an understanding of best practices. Planning and design needs have been met in many places through development of standard details and guides that have been refined by each region over time, as experience provides greater insight into best practices. It is important to have a well-organized group of designers, planners and installers to advance regional LID practices and inform policy development.

Educating and training the general public and the LID maintenance community are two critical areas that need more attention. Hands-on training workshops are essential for all those interested in LID. Training workshops can be used to build demonstration projects to further reinforce and promote LID through general educational activities. For example, a workshop to train community members and professionals in LID practices could build a project on public property in an area that is highly traveled by pedestrians. Participants will learn by doing and community members can benefit from seeing the LID site mature over time and learn about the practices through signage.

Throughout the southwest, landscape contracting is a difficult business with low wages, high turnover and few training resources. Creating new training opportunities for field crews and incentives for LID crews is essential. Contracting for maintenance appropriately is key. Conventional landscape maintenance contracts have led to the demise of many LID projects.

5 Best Practices in LID Design

A variety of LID design guidance and manuals exist for the arid southwest (Section 11). The sections below outline relevant existing materials while highlighting and expanding upon important best practices.

5.1 Soil Health

Soil health is the single most important component of LID. It is also the most commonly overlooked part of LID projects in arid environments. It is imperative that healthy soil best practices are central to LID projects and that communities learn what are the most appropriate practices for local climate, vegetation, and LID goals.

LID goals across the southwest and the nation are diverse and sometimes do not work well together. For example, managing large volumes of water in LID for flood control or water quality benefits with high flow soil mixes will not allow for vegetation to thrive in the face of drought or even regular dry periods due to low moisture holding capacity. Technologies exist to address this challenge, but often exceed project budgets of arid communities that do not have well-funded stormwater or LID programs and/or the regulatory drivers of communities with combined sewers.

Given the importance of shade and water conservation needs of the arid southwest, an emphasis on simple improvements to soil, that can establish and maintain a healthy tree canopy as well as deep rooted grasses and shrubs, is essential. This allows for improved infiltration rates, increased water pollution reductions, and can improve moisture retention for the right plant palette. It is important to address soil health in both design and maintenance of LID. Our model for soil health is based on healthy forest and grassland desert ecosystems that create major benefits for humans beyond the often-degraded landscapes created as a result of past human activities. These systems thrive with healthy nutrient cycles that create a thick layer of topsoil rich in organic matter from decomposing plant and animal litter. Evidence of healthy soils can be observed with the presence of mosses, lichens, fungi, and mycelium. Fungi and mycelium have shown the potential to improve water quality in LID practices with little or no additional costs[4,5].

Photograph 5-1 Mulch shown with a white mat of mycelium
Photo courtesy of Fungi Perfecti

[4] Stamets, P., Taylor, A. Implementing Fungal Cultivation in Biofiltration Systems. USDA Forest Service Proceedings, RMRS-P-72. 2014

[5] Taylor, A., Flatt, A., Beutel, M., Wolff, M., Brownson, K., Stamets, P. Removal of Escherichia coli from synthetic stormwater using mycofiltration. Ecological Engineering. Volume 78, May 2015, Pages 79-86.

Soil health benefits can be maximized in design and construction with the following practices.

1. Compaction is minimized by avoiding infiltration and planting areas with heavy equipment while also breaking up physical compaction by ripping soils 12-24" below the basin bottom depth.
2. Healthy native plants, especially bunchgrasses or other native grasses, are planted in basin bottoms that can thrive with periodic inundation and have significant root mass to improve infiltration rates and provide a substrate for microbial treatment of stormwater pollutants.
3. Organic mulch ground cover is utilized where possible. Wood mulch is critical to jumpstarting soil health and is preferred over rock mulch. Larger mulch can be used in basin/rain garden bottoms. The depth can be varied based on local conditions and design goals, but typical depths are 2-4 inches. Rock should only be used in areas where mulch will float away and/or hydrology dictates the need for rock to eliminate scour. Overuse of rock in basin bottoms and as ground cover increases urban heat island impacts and can also cause water quality issues.
4. Soil inoculants that provide healthy mycelial and microbial communities can be added to mulch, under mulch, in the soil, and on plant roots when planting to provide many benefits to soil and vegetation including improved infiltration, water retention and water quality improvements[6]. Worm castings, compost, and compost teas can be made with local organic matter to provide inoculants if purchasing commercial products is not possible. Utilizing local organic materials to produce inoculants or commercial products tailored for the local plant and soil conditions is preferred in order to jumpstart the native soil biology most effectively. MycoGrow or Bactifeed are commercial products that have worked well in arid projects in Arizona.
5. Native tree canopy coverage over entire project footprint, and ideally beyond, is created to protect the ground and plantings from the erosive forces of high intensity rainfall while providing microclimates for understory plant establishment, decreasing soil temperatures, and reducing the urban heat island impacts.

Practices to protect and enhance healthy soil during maintenance is further discussed in Section 6.

5.2 Rock Work

Rock work is important for stabilization soil in a variety of conditions. Throughout southwestern landscapes and LID, rock is overused as a primary ground cover and this creates significant water quality and infiltration challenges. Appropriate rock work in LID should focus on stabilization of soil with the long-term intention of establishing vegetation.

Rock in LID bottoms should only be utilized when water velocities create a scour potential that does not allow for vegetation to establish and organic mulch would wash away. Ensuring rock of appropriate size and quality for the context, in addition to minimizing fines, is critical to ensure long-term infiltration.

Careful rock placement is essential, otherwise the problems described in Section 3.1.7 will occur. The *Erosion Control Field Guide,* described in Section 11.4, provides several best practices for rock work.

[6] The Drought Tolerant Garden: Los Angeles County Handbook, 2012.

Best practices for rock work include:

1. ensuring rock are sized appropriately for design conditions,
2. providing adequate support for rock features where the erosive forces of water are typically most destructive (the edges and bottoms of features), and
3. utilizing skilled and experience labor for the context.

5.3 Vegetation

The right plant for the right place is an important phrase for LID. Vegetation selection and placement decisions should:

- enhance infiltration rates,
- create shade for people, other vegetation and soil,
- stabilize soils,
- block nuisance views and noises,
- maintain lines of sight for vehicle, bike and pedestrian safety,
- maintain safe access to LID facilities,
- meet plant material water demands, and
- maintain a safe distance from other infrastructure.

A well-developed example of a LID plant list, developed for the City of Tucson[7], is included in Appendix C on the external hard drive. A LID database with native plants could be created for Mohave County.

In the *Greater Phoenix Metro Green Infrastructure Handbook – Low-Impact development Details for Alternative Stormwater Management* (referred herein as the *GI Handbook*) found in Appendix C, plant lists are broken down into "Above the inundation elevation" and "Below the inundation elevation". It is important to develop and refine a list of local, native plants that thrive in the conditions created by LID features. Given that evaporation is a major source of water loss, native plants that can thrive with periodic inundation, create shade, and provide a source of organic matter over time to the soil are critical to improve moisture holding capacity while also decreasing long-term maintenance needs and costs. Work with local nurseries to select native seed, propagate, and establish plants in a way that will maximize their success in the harsh conditions of the desert and unique conditions of LID infrastructure. Pots that allow native trees to establish a healthy tap root are critical to healthy trees in LID projects that can withstand drought, maximize infiltration and water quality benefits, and withstand strong winds with saturated soils.

5.4 Installation

The difference between success and failure for LID can be a matter of inches. Construction observation and contractor training and/or experience are critical for the success of LID projects. The art and act of LID construction must embrace all the best practices of design as outlined in this section. Having an experienced contractor and/or construction observer involved in LID

[7]Brad Lancaster, Plant list resources for Arizona, www.harvestingrainwater.com.

projects, programs and processes, who understands how to communicate these best practices in ways that address needs and knowledge of equipment operators, general contractors, laborers, and community members, is critical. In many arid areas where LID has not been broadly accepted and implemented, there is the challenge to bring the planning, design, installation and maintenance professionals up to a common baseline of LID best practices. Education, training and demonstration sites are critical to building support for LID and to create the knowledge and tangible understanding of best practices through hands-on training.

6 Maintenance

It is important that communities reassess the value of - and need for - the typical neat and tidy landscape. Conventionally maintained landscapes have tremendous direct and indirect negative impacts on communities. Pollution from noises, chemicals, dust, runoff, and fossil fuels are some of the results of having manicured landscapes that are not healthy for nature or people. Research shows the lack of nature in urban environments is having detrimental impacts on human physical and emotional health. Additionally, the negative public health impacts and many lawsuit rulings against the use of chemicals like glyphosate, found in the commonly used weed killer Round Up, have resulted in many bans and commitments to eliminate the use of those chemicals in cities and countries across the globe[8]. Conventional maintenance practices will guarantee the need for chemical based practices that negatively impact community health while ensuring long-term costs will increase over time. Alternatives to conventional chemical management, that are cost-effective and decrease over time while building soil and human health, are necessary.

Maintenance practices that are closer to the fun of gardening in your lush garden are needed to change the perception of maintenance and change the aesthetic to a more natural beauty that will decrease the direct costs of maintenance over time and will decrease the indirect costs of health impacts created by conventional maintenance.

Often overlooked and under or unfunded, maintenance is critical to successful LID programs in arid environments. The only offense greater than deferred maintenance is inappropriate maintenance, as shown in Photograph 6-1. Education and training programs are critical to ensure the LID knowledge base in a region is healthy and can grow with the demand for projects and maintenance needs. The *GI Handbook* outlines the basic, standard maintenance practices necessary for each LID practice. The City of Tucson created a maintenance guidelines video found here:

https://www.tucsonaz.gov/newsnet/green-infrastructure-maintenance-guidelines-video

Critical best practices and common practices that need to be avoided are presented below. This is an important challenge to address early in the development of a LID program. LID must be maintained as infrastructure within an asset management program. Often, LID is treated as a typical landscape with the result looking like this:

Photograph 6-1. A commercial LID installation sprayed for weeds and excessively pruned.

[8] https://www.baumhedlundlaw.com/toxic-tort-law/monsanto-roundup-lawsuit/where-is-glyphosate-banned/

With the organic mulch removed, native bunch grasses and shrubs sprayed, native trees severely pruned into a lollipop, all the infrastructure functions of the LID feature have been impaired, and if continued, will eliminate all functionality. LID managed with current conventional landscape maintenance techniques, will result in a stormwater hazard and nuisance that will pond, creating mosquito habitat while also decreasing water quality by negating the beneficial functions of the soil and plant root ecosystem. When practices that impact soil health negatively are employed, maintenance needs will remain consistent and will lead to higher longer-term costs over time.

Holistic Land Management, as described in Section 10, is a tool that can be utilized as part of an LID maintenance program to target invasive species and unmaintained LID features as well as prepare a site for an LID project with the use of animals to graze unwanted vegetation and fertilize the soil with their dung and urine.

It is important to understand the function of weeds in nature. They are intended to protect and heal soil. When we continue to damage soil through conventional maintenance practices, we guarantee weeds will persist and increase long-term maintenance needs. By creating conditions for healthy soil, native plants will thrive as the presence of weeds decreases with time. The weeds that do appear in LID features will be easier to eradicate with healthy soils. Weeds will likely not be eliminated given that, primarily by stormwater, seeds will be brought into LID features; however, with a mature tree canopy and a healthy native understory and groundcover, weeds will no longer be needed to protect the soil and germination rates will diminish over time. The ease of removal will also improve as soil is naturally aerated by root growth and organic mulch decomposition.

6.1 Best Practices: Avoid Conventional Landscape Management

Design best practices for healthy soil are outlined in Section 5.1. In order to maintain healthy soils, ensure the guidelines below are followed:

- Utilize physical removal of undesired plants. Animals can be an advantageous way to remove undesirable weeds and invasive plants, while building soil health as described in Section 10.
- Do not use chemicals.
- Minimize raking where possible and do not use leaf blowers.
- Use trimmings from native vegetation as soil cover/mulch replacement after chopping it to an acceptable size to drop where needed.

It is important that maintenance guidance be developed with simple language that appeals to the contractor industry, community decision makers, and private property owners. An example of a simple guide is the *Field Guide for Rain Garden Care* found in Appendix C on the external hard drive. An introduction to desirable and undesirable plants in the desert, pruning, and regular rain garden care activities is presented.

When addressing a problem site or a LID feature than has not been maintained adequately or at all, ensure adequate time and resources are allocated to address the issue up front. LID features are too often blasted with chemicals and then weed wacked to remove the nuisance vegetation growth. However, this only destroys any soil life and resets the conditions for new weed growth. If problem plants, like Bermuda grass, are chocking features, it is important to try physical removal with a hoe. If a nuisance plant like Bermuda grass is well-established, a major retrofit of the LID soil may be necessary with heavy equipment. Ensure tree roots are adequately protected by using an experienced operator and involving a certified arborist as needed.

The conventional landscape maintenance company is not typically equipped or trained for appropriate LID maintenance. For example, the Sustainable Landscape Management (SLM) certification provided by the Arizona Landscape Contractors Association does not fully meet the needs of LID. Often the certification is possessed by someone behind a desk who doesn't always impart the relevant knowledge to crew leaders and landscape technicians.

7 Integrated Design

Integrated design provides an opportunity to blend the full range of LID practices based on observations of existing conditions to address the needs and constraints of a site. When possible, work with an engineer, designer, landscaper, contractor, or consultant who has appropriate experience and accreditation for LID design and implementation in the arid southwest.

A common phrase among experienced LID practitioners is "slow, spread, and sink stormwater." Integrated design is the process of examining flows of water across a landscape and looking for the best opportunities to utilize that water to achieve the design goals by implementing LID practices to slow, spread, and sink stormwater. Rain tanks, berms, curb cuts, bioretention and rain gardens can be used to slow water. Berms, One Rock Dams, and Zuni bowls can spread water. Rain gardens, berms, bioretention, One Rock Dams, Zuni bowls and Holistic Land Management (Section 10) can sink and infiltrate water.

For more details on the integrated design process, the books *Rainwater Harvesting for Drylands and Beyond vols 1 & 2,* are excellent resources for homeowners and design professionals. The website associated with the books[9] has many useful resources freely available.

The principles of integrated design from Brad Lancaster follow the steps below:

1. Long and thoughtful observation
2. Start at the top of the watershed
3. Start small and simple
4. Spread and infiltrate the flow of water
5. Plan to manage all overflows as a resource where possible
6. Maximize living and organic ground cover
7. Maximize benefits and efficiency
8. Continually reassess and improve system

This process can be utilized by residents and professional designers. A critical component, whose importance should not be overlooked, is #1: Long and thoughtful observation. Many flaws in LID projects could have been avoided by better understanding the context and problem. While the design process can be sped up by working with a trained professional, utilizing observations from a property owner, who has spent multiple rainy seasons observing water flows, is ideal.

[9] Rainwater Harvesting for Drylands and Beyond, Brad Lancaster, http://www.harvestingrainwater.com/.

7.1 Simplified Design Calculations

For a homeowner or project designer to quickly assess the potential for LID and size features, the following sections outline simplified calculations for rapid initial LID sizing.

7.1.1 Rain gardens

Sizing rain gardens based on roof runoff can be done with this simple calculation: for every 1,000 square feet of roof, 600 gallons of water are produced per inch of rainfall, which roughly translates to 100 square feet of rain garden based on a depth of 9 inches. See the Table 7-1 for a range of rain garden areas for different roof areas and rainfall events.

Table 7-1. The approximate rain garden area needed for various rainfall events and roof areas.

Roof Area (sf)	500	1,000	2,500	3,500
Rainfall	**Rain Garden Area (sf)**			
0.25”	13	25	63	88
0.50”	25	50	125	175
0.75”	38	75	188	263
1.00”	50	100	250	350
1.50”	75	150	375	525
2.50”	125	250	625	875
3.50”	175	350	875	1,225
5.00”	250	500	1,250	1,750

7.1.2 Rain tanks

Rain tank sizing should be based on the appropriate goals defined by the property owner and can include:

- supplemental irrigation needs for fruit trees and vegetable gardens,
- primary/sole irrigation source for food production,
- supplemental water source for indoor and outdoor water needs, and
- primary/sole water source for property.

These various goals will require sizing based on available water from roof surfaces, budget, space for tanks, topography and roof height. Supplemental irrigation needs and indoor/outdoor water needs can be met as project budget allows. In order to meet the needs of all irrigation for food, it is important to ensure food production has been planned and sized appropriately. Given the amount and pattern of rainfall in Mohave County, it is important to reduce water consumption through water conservation measures in order to maximize the use of rainwater and minimize the cost of storage needed. Given the interest and available budget ($20K+) for storing, treating, and utilizing rainwater as the sole water source for a property, sizing a tank or tanks to capture half the annual rainfall for the area is recommended.

Table 7-2. Rain tank capacity for different rain events and roof sizes.

Roof Area (sf)	500	1,000	2,500	3,500
Rainfall	**Rain Tank Capacity (gal)**			
0.25”	75	150	375	525
0.50”	150	300	750	1,050
0.75”	225	450	1,125	1,575
1.00”	300	600	1,500	2,100
1.50”	450	900	2,250	3,150
2.50”	750	1,500	3,750	5,250
5.00”	1,500	3,000	7,500	10,500
10.00”	3,000	6,000	15,000	21,000

Exact rain tank capacity and dimensions will vary depending on the brand and type of material. It is not recommended to plan or utilize rain tanks to harvest water off surfaces other than roofs as the maintenance and pre-treatment of water makes tanks cost prohibitive for most residential users. Roofs typically supply more water than needed for the goals of a property owner.

7.1.3 Zuni Bowls and One Rock Dams

In most residential applications, rock work can be accomplished with rock 6-12”. If a natural drainage crosses a property, consult a professional engineer to determine peak discharges for large events to size rock appropriately. Zuni bowls have been designed for peak discharges over 8,000 cubic feet per second in the arid southwest[10].

7.2 Water Budget

Central to water conservation practices with LID is ensuring water demands of plant material can be met through stormwater runoff after establishment. This can be accomplished by following the practices in Sections 5.1, 5.2, and 5.3.

A well-designed street harvesting LID feature stormwater supply will easily exceed plant demand, given the large watersheds relative to plant demand. A 100-square-foot LID basin with two native trees, 4 grasses, 2 groundcovers, and 2 shrubs would consume approximately 6,000 gallons of water per year at maturity. 6,000 gallons of water would be produced for every inch of rainfall over 10,000 square feet. This is equivalent to a 400’ asphalt roadway, with two 12’ lanes, and 1’ of gutter.

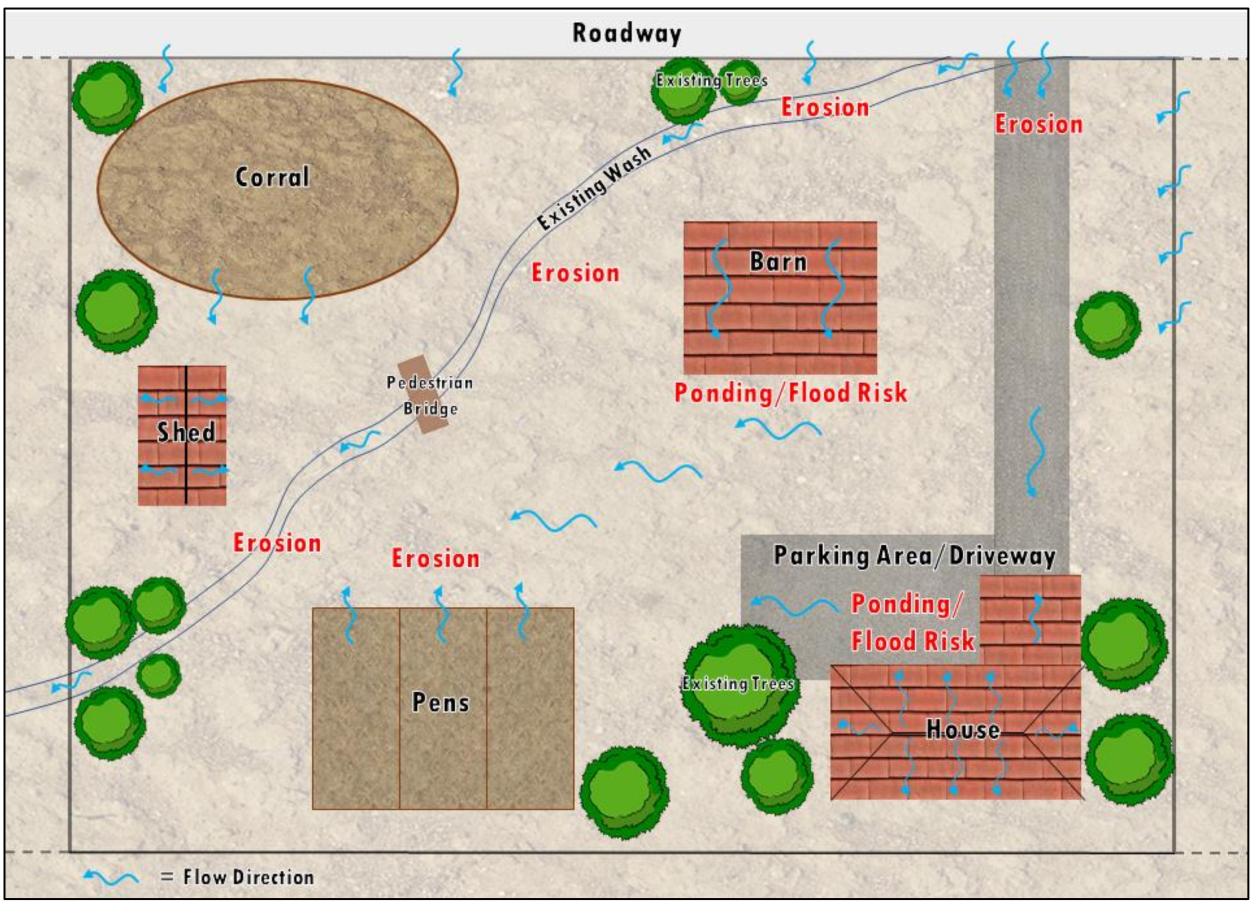
Given the two rainy seasons that often occur in Mohave County, it is possible to design LID projects without irrigation systems, as long as monitoring is done to ensure plants are watered with water trucks during dry periods while plants are establishing (2-3 years after planting). With appropriate design and construction planning to account for ideal planting time to receive winter rainfall, long-term maintenance costs and cost benefit ratios can be maximized by not investing in irrigation systems.

[10] Stream Dynamics, Arroyo San Vicente, http://streamdynamics.us/blog-entry/san-vicente-creek-project-action.

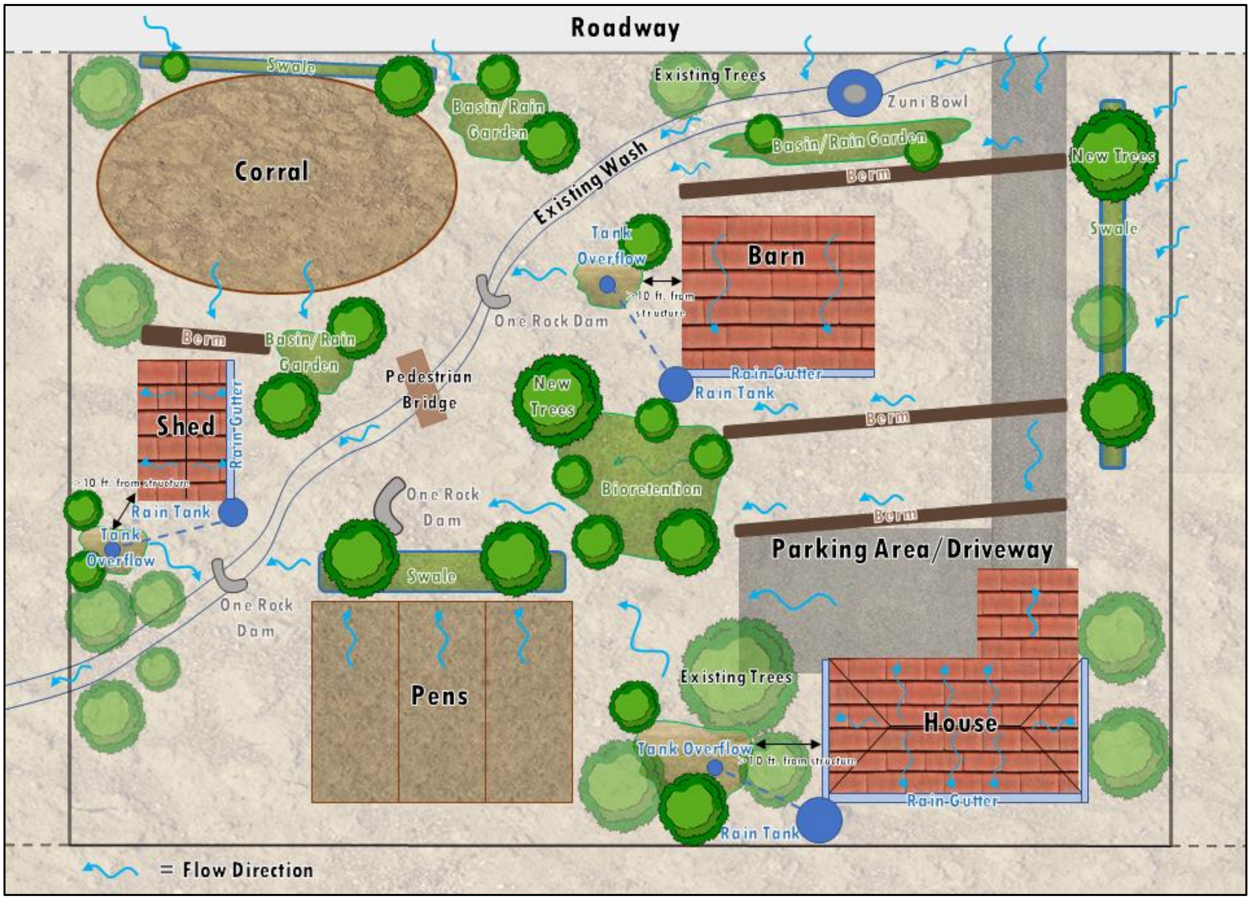
7.3 Conceptual Residential Drainage Plan

It should be noted that the above listed LID practices function best in combination with each other to harvest stormwater close to where it falls, slow runoff, maximize irrigation benefits, and minimize erosion and flood risks. Photograph 7-1 and Photograph 7-2 illustrate how LID techniques may reduce flooding and sediment-related issues on a conceptual parcel.

Photograph 7-1 shows existing flow patterns across a conceptual residential parcel. Photograph 7-2 shows implementation of many of the LID features discussed above (Section 2.1) to mitigate flooding on the conceptual residential parcel, while maximizing the benefits of stormwater. Berms are utilized to direct flows to areas for infiltration and to redirect conveyance away from driveways, walkways, and structures. Berms can concentrate flows and erosional forces should be mitigated with One Rock Dams and Zuni Bowls. Rain tanks provide water storage; however, when full, rain tanks also concentrate flows from roofs. Rain tank overflows must be located and designed with great care, as mentioned in Section 2.1.9. Overflow can be directed as shown through rain gardens, swales, berms, and one rock dams to move water away from structures, minimize risks, and maximize the irrigation benefit.



Photograph 7-1 Existing Flow Patterns Across Conceptual Residential Parcel.

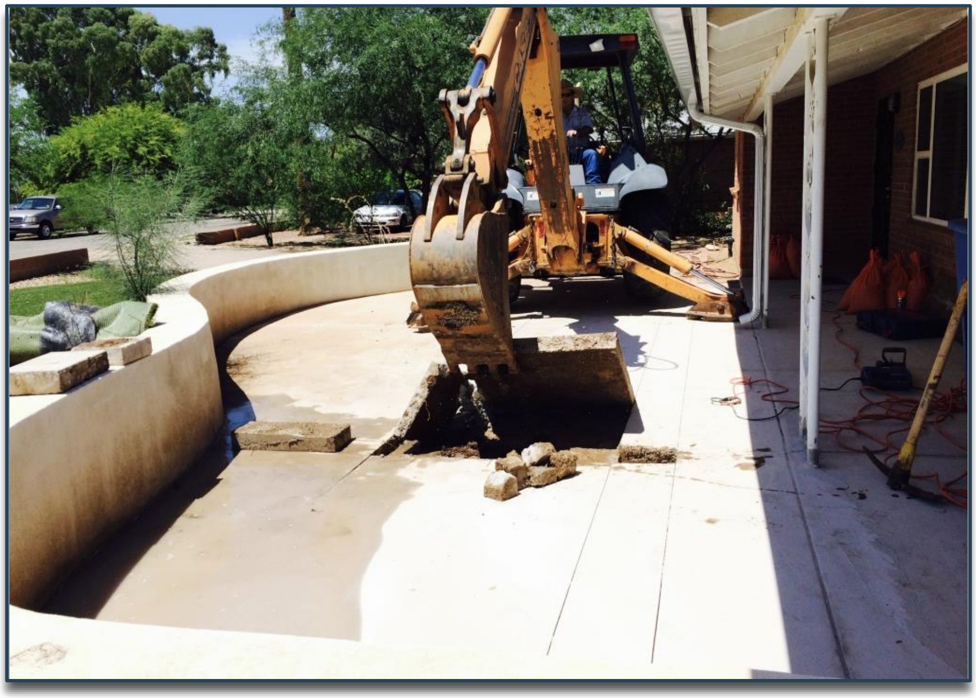


Photograph 7-2 Conceptual LID Flood Mitigation Opportunities.

7.4 City of Tucson Residential Case Studies for Flood Protection

Two case studies are presented below to show the potential for LID practices to protect homes against flooding. The first home experienced flooding from roof runoff in combination with stormwater overflowing from street conveyance. When water overtopped the curb, it would flow through the floodwall weep holes, if they had been cleared, and would flood one home. If the weep holes were blocked, flows would spread to the same home at a different location, as well as to an adjacent neighbor. By utilizing LID to direct flows away from both residential structures with berms and rain gardens, these homes were protected from frequent flooding in small storms as well as larger flood events. Additionally, the floodwall structure was better protected from being undermined by creating positive drainage away from the wall foundation.

Photograph 7-3 Stormwater overtopping the curb does not flood the adjacent homes after project. Photo courtesy of Watershed Management Group.



Photograph 7-4 The hardscape receiving roof runoff from downspouts that drained toward the foundation was removed and replaced with rain gardens and swales. Photo courtesy of Watershed Management Group.

Photograph 7-5 After LID retrofit, the yard was lowered to provide drainage and retention capacity away from the home foundation. Photo courtesy of Watershed Management Group.

Photograph 7-6 The rain gardens in action providing an irrigation benefit while protecting the residential structure. Photo courtesy of Watershed Management Group.

This home in Photograph 7-7 experienced flood risks in both small and large rain events from water ponding adjacent to the foundation. The flood risk was getting worse over time as the soil infiltration rates were decreasing due to removal of organic matter by stormwater and sun exposure from lack of ground cover and tree canopy. The top layer of soil became almost impervious as small rain events would create ponding as seen in Photograph 7-8 and Photograph 7-9. This LID retrofit employed rain gardens, berms, and rain tanks to protect the home from flooding.

Photograph 7-7 This home, before LID retrofits, experienced flood risks from compacted soils and drainage toward the home's foundation in the back yard.

Photograph 7-8. Concentrated roof runoff creates a waterfall that ponds adjacent to the porch and drains toward the home's foundation.

Photograph 7-9 Ponding adjacent to a rammed earth wall experiencing degradation from repeated moisture exposure.

Photograph 7-10 The first step in the LID retrofit was to remove all non-native vegetation in order to improve shade, reduce water consumption, and increase soil infiltration rates.

Photograph 7-11. The asphalt driveway hardscape was removed.

The asphalt from the driveway was replaced with large wood chip mulch to reduce the ambient air temperature of the property, while providing additional soil moisture for tree root zones, without creating a soggy driveway in large rain events.

Photograph 7-12 Rain gardens, harvesting water from the roof and the street, harvest large volumes of water for native shade trees, grass and shrub irrigation.

Photograph 7-13 Over 40 cubic yards of wood mulch.

The wood mulch was added in rain garden bottoms and across the surface of the yard on this quarter acre lot in order to reduce erosion, conserve water, improve soil health, increase habitat for beneficial wildlife and cool temperatures.

Photograph 7-14 Four years after the LID retrofit.

The front yard has not used any potable water for over two years. A major shade producing vegetation canopy was created with little cost, watered primarily by stormwater that significantly reduced cooling needs and even eliminated many days of using the home cooling system due to the significantly cooler yard, while also eliminating the mosquito producing ponds created at the end of the street by harvesting water off the street into the right-of-way.

7.5 City of Phoenix Residential Case Study

This residential home converted its barren front yard to a cooling, water saving oasis by utilizing only roof runoff to establish native vegetation. The organic mulch cover also helps to regulate the hot summer temperatures, especially during the night when many yards in Phoenix stay above 100 degrees, this yard will always be cooler as a result of the vegetation and mulch.

Photograph 7-15 A typical barren desert yard ready for an LID retrofit.
Photos courtesy of Watershed Management Group.

Photograph 7-16 The earth works for the LID project are in progress.

The yard was shaped with berms and rain gardens to slow, spread, and sink the water, in as many areas as possible, to maximize the irrigation benefit.

Photograph 7-17 The yard right after the LID retrofit
Photos courtesy of Watershed Management Group.

Photograph 7-18 Native vegetation has established with effective use of stormwater with LID.

8 Decentralized Flood Protection Funding Programs

The funding programs summarized below focus on local stormwater management (GI/LID) improvements on private property.

8.1 City of Tucson

8.1.1 Water Harvesting Rebate Program

Tucson Water, the local public water utility, runs several conservation programs, including the Water Harvesting Rebate Program. Two types of rebates are offered for private property owners to fund residential-scale flood protection projects: - Level 1 and Level 2. Level 1 rebates are for passive water harvesting structures, such as basins, berms, and swales, to harvest stormwater on private residential property. The Level 1 rebate was expanded to include curb cut basins constructed in the public right-of-way adjacent to residential private property. Level 2 rebates are for rain tanks/cisterns, to store stormwater runoff from roof surfaces. Level 1 rebates can fund 50 percent of relevant project costs up to $500. Level 2 rebates can pay for up to $2,000 for a cistern project. An important component of this program is the educational requirement. Residents must attend a three-hour informational and design focused session to learn about water conservation and flood mitigation. More information can be found at: https://www.tucsonaz.gov/water/rainwater-harvesting-rebate

8.1.2 Neighborhood GSI Grant & GSI Fund

Tucson Clean and Beautiful administers the City of Tucson/Tucson Water Neighborhood Stormwater Harvesting Grant Program. Neighborhoods can apply for funds to implement stormwater harvesting projects in the right-of-way adjacent to private property. Currently $350,000 is distributed evenly throughout the six (6) City Wards. This creates challenges from both an administrative and community need perspective. Administratively, funds are divided evenly by Ward and then by neighborhood to fund small- to medium-scale projects. Although even division of funding may seem equitable, the severity of nuisance flooding and need for mitigation projects across the six Wards is not even. More information about the program can be found at: https://tucsoncleanandbeautiful.org/trees-for-tucson/neighborhood-stormwater-harvesting

The Green Stormwater Infrastructure Fund is a funding source being considered by the City of Tucson. This program is expected to generate $3M to $5M annually and would allow for medium- to large-scale green stormwater infrastructure projects to be implemented in a more cost-effective method than current funding programs, while also creating the potential to mitigate significant local flooding on private property, where no potential regional flood mitigation solutions exist.

8.2 San Francisco Green Infrastructure Grant Program

The San Francisco Public Utilities Commission recently launched a new program for funding green infrastructure on public and private property. This program's initial funding will generate $6.4M over the next two years. The intention is to encourage owners of large impervious parcels to apply for grants to better manage stormwater to mitigate combined sewer overflows in wet weather. Grantees are eligible to receive $765,000 per acre of impervious surface managed, up to $2M per project. More information can be found at: https://sfwater.org/gigrants

8.3 New York City Green Infrastructure Grant Program

The New York City Department of Environmental Protection offers a grant program exclusively for private property. Projects are performance-based. Project types include green roofs and infiltration projects such as rain gardens and porous pavement. Green roofs are reimbursed based on soil depth per square foot. The greater the soil depth, the greater the reimbursement rate. Soil depths and area must be at least 1.5 inches and 3,500 square feet, respectively. Reimbursement rates range from $10 to $30 per square foot. Minimum criteria for infiltration projects are managing 1 inch of rainfall from the contributing area. More information can be found at: https://www1.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_grant_program.shtml

8.4 Philadelphia Greened Acre Retrofit Program for Private Property

The Greened Acre Retrofit Program is unique in that it works with contractors to bundle green stormwater infrastructure projects on private property in order to implement equivalent benefits of public right-of-way projects at a fraction of the cost. This results in reduced stormwater fees for property owners and increased property values. The program's goal is to green approximately one-third of the service area impacted by combined sewer overflows. This area is approximately 10,000 acres with two-thirds of that area being on private property. Private property owners voluntarily participate in the program, and in exchange for having retrofits constructed on their property, agree to maintain the facilities. The program currently has a $10M annual budget with a maximum expenditure of $90,000 per acre, with the goal of treating 100 acres per year. More information about the development of the program and details on encouraging private property owner participation can be found at:

https://www.nrdc.org/sites/default/files/philadelphia-green-infrastructure-retrofits-IB.pdf

8.5 Special Improvement Districts for LID Project Funding

Special improvement districts in Mohave County offer an interesting opportunity to fund LID improvements. Currently, only projects on public property (parks and streets) could be funded through special improvement districts in Mohave County[11]. However, significant improvement districts have been developed throughout the country focusing on energy, water conservation, flood mitigation, and stormwater management on individual private properties. Property owners agree to be assessed fees on their property to pay for the investment in infrastructure on their individual property. These programs were initially created with a focus on energy and have increasingly been expanded to address water conservation as well as flood resilience and mitigation. For additional details on how these programs work visit:

https://pacenation.us/what-is-pace

The momentum for these programs is growing throughout the nation as other means to fund LID projects on private property have not been sufficient to achieve long-term stormwater management needs of communities, especially in communities that are not impacted by combined sewer overflows.

The Town of Gilbert has implemented Park Improvement Districts[12] (PKID) to fund improvements to parks that, among other goals, have a goal to achieve water conservation objectives. With this funding, the Town hires a contractor responsible for the installation and maintenance of these features on public property that directly benefit the residents. An LID Improvement District could similarly be created to allow a City or County to invest in LID facilities on public property or in the future develop an LID ID for private property.

[11] https://www.mohavecounty.us/ContentPage.aspx?id=128&cid=212&page=1

[12] https://www.gilbertaz.gov/departments/parks-and-recreation/parks-facility-and-sport-field-rentals/parks-infomation/pkid/pkid-process

9 Action Plan for a Successful LID Program

The actions outlined below have been utilized in other arid southwestern communities interested in LID as a tool to address drainage challenges while providing multiple benefits. The actions are not presented in a particular order as it is important for each community to identify what is most relevant to their current needs, and these activities can be implemented concurrently as interest and capacity allows. In many cases, concurrent actions can provide important benefits such as utilizing a demonstration project as a training opportunity that provides CRS points as a part of a Hazard Mitigation Plan and showcases current LID Standard Details. See the US EPA document titled *Get Flood Insurance Discounts with Low Impact Development, Open Space Protection Plans, and Stormwater Management Regulations* found in Appendix C on the external hard drive for specific details on earning CRS points and NFIP discounts.

- Identify training topics needed and implement LID training programs
- Identify and construct demonstration projects
    - Identify characteristics for successful demonstration sites
    - Generate a list of specific demonstration project opportunities
- Incorporate LID into the Hazard Mitigation Plan
- Integrate Pest and Holistic Management Policy into vegetation management policies and contracts
- Develop LID funding programs
- Develop LID standards and details and incorporate into design standards
- Develop a native plant list for conditions throughout Mohave County to use in LID
- Integrate LID into decentralized flood protection policies & regulatory driver programs
    - CRS, NFIP, MS4 Permit, Tree and Shade Programs, other community and sustainability programs or goals

10 Holistic Land Management

Holistic Land Management (HM) is a framework for studying ecological processes and responding to challenges or land management problems with natural solutions. These natural solutions can include the practices listed above, but a unique aspect of HM is animal grazing and animal impact as a natural systems solution. Animal grazing and animal impact promote healthy soil through increasing levels of ecological succession by creating favourable conditions for native plants and animals to thrive. This is accomplished through reducing non-native vegetation, improving soil health by inoculating soil nutrients and biota with animal saliva, dung, and urine as well as improving water holding capacity by the micro basins created from hoof action. HM is not traditionally considered a LID technique, but it is included here due to the potential for use to address and mitigate flood risk while improving water security due to the large portions of Mohave County land that can benefit from HM practices. HM can be utilized as an LID design practice to prepare a site for LID facility installation, a process for managing vegetation in larger scale LID, and/or for addressing deferred maintenance where physical removal with human labor is not available or is too costly.

HM is not conventional grazing. It is about selecting the right animal, for the appropriate amount of time, at the right time, in the right place, in the right density, to address the goals and context of a project. A range of goals could include:

- managing invasive species,
- improving soil health,
- reducing fire risk,
- promoting native plant and animal habitat,
- reducing dust,
- improving drainage, and
- improving water quality.

Conventional methods used to remove invasive plants, including mechanical and chemical technology, are costly. These methods commonly produce negative environmental consequences including decreased soil health, water and air pollution, as well as other potential environmental and human health concerns. The evidence for the need for alternatives for glyphosate based invasive plant removal are increasing. The recent supreme court case ruled that the use of glyphosate is linked to cancer. There is also considerable evidence of glyphosate's negative impact on pollinators[13].

Alternatively, intensive animal grazing for the consumption of invasive species and vegetation management has been vetted as an effective invasive management strategy in California, New Mexico as well as across the Pacific Northwest, Midwest and Northeast. The Chicago O'Hare Airport has its own shepherd. Tucson Electric Power has utilized sheep to ensure vegetation is managed below its large solar panel installations[14]. This provided significant cost savings due to the elimination of dust creation from vegetation management activities relative to mowing. One

[13] Motta, E.V.S., Raymanna, K., Moran, N.A., National Academy of Sciences, Glyphosate perturbs the gut microbiota of honeybees.
[14] Tucson Electric Power, accessed Feb 25, 2019, https://www.tep.com/news/sheep-clear-weeds-at-tep-solar-array/

study by the Contra Costa County Flood Control and Water Conservation District in California found conventional grazing removed 47% of invasive cover with no significant impact to water quality parameters for non-recreation use. Herbicides only reduced invasive coverage by 18%[15]. Surveys of grazers using Holistic Management practices across the US showed both increases in biodiversity while also increasing profitability[16]. Research also shows appropriate grazing can have a positive impact on plant biodiversity and hydrologic function. Test plots that included grazing in the wetland ecologies grasslands with vernal pools demonstrated "a cover of native plant species 5 to 20% higher in the ungrazed plots…Ungrazed pools held water for a shorter period of time than pools grazed under historic regime"[17].

Frost and Launchbaugh found that grazing is an important tool for vegetation management without chemicals. This is an important consideration for LID maintenance, especially in facilities and areas where water quality is a concern. They found that, for invasive plants, the viability of seed in manure is anywhere from 0-60%. However, seed viability was less relevant with proper animal grazing due to the successional conditions created that tend to favor native grasses and forbs and reduce the probability of invasive seed germination. Additionally, timing of animal grazing is ideal before plants go to seed to eliminate the opportunity for animal dung to germinate invasive plant seeds[18]. Contra Costa County also found that animal waste from the goats did not impact water quality parameters tested.

Moreover, animal grazing offers multiple community benefits; as an environmentally friendly invasive plant management strategy, it improves soil health by increasing soil carbon levels of degraded desert soils, which improves ground-water quality. This may lead to the production of valuable agricultural products such as meat, milk, wool, and hides. HM practices are gaining momentum throughout Arizona through demonstration studies and sites in Cochise County, Pima County, and Yavapai County and can provide a variety of benefits and complementary tools for LID programs and projects.

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[15] Contra Costa County Flood Control & Water Conservation District, Streambank Vegetation Management Study, Walnut Creek, July 2015

[16] Stinner, D.H., Stinner, B.R., Martsolf, E., Biodiversity as an organizing principle in agroecosystem management: Case studies of holistic resource management practitioners in the USA. Agriculture, Ecosystems & Environment. Vol. 62, Issues 2–3, April 1997, Pages 199-213.

[17] Marty, J.T., Loss of biodiversity and hydrologic function in seasonal wetlands persists over 10 years of livestock grazing removal. April 18th, 2015 Restoration Ecology: The Journal o f the Society for Ecological Restoration.

[18] Rachel A. Frost and Karen L. Launchbaugh, 2003, Prescription Grazing for Wildland Weed Management A new look at an old tool to control weeds on rangelands. Rangeland 25:43-47

11 Supporting Documents

The following local stormwater management supporting documents are highlighted in the following section and can be found in Appendix C on the external hard drive:

- *Reduce Your Flood Risk: A Resource Guide* (document)
- *Rio Verde Area Alternative Stormwater Management Report* (report)
- *Greater Phoenix Metro Green Infrastructure Handbook – Low-Impact development Details for Alternative Stormwater Management* (document)
- *Quivira Coalition Erosion Control Field Guide* (field guide)
- *Cross-Vane, W-Weir and J-Hook Structures for Stream Stabilization* (white paper)
- *Pima County/City of Tucson GI/LID Guidance Manual* (document)
- *Watershed Management Group Green Infrastructure for Desert Communities* (document)

The above listed supporting documents provide LID information, standards, implementation strategies, etc. Brief discussion regarding these supporting documents is provided below; however, the reader is encouraged to read each resource in support of this LID Guide.

11.1 Reduce Your Flood Risk: A Resource Guide

The *Reduce Your Flood Risk: A Resource Guide* was prepared for the Flood Control District of Maricopa County and released June 2019. The guide provides information on the following LID techniques:

- Swales
- Infiltration Trench
- Basins
- Rain Gardens
- Berms and Earthen Embankments (Terracing)
- Vegetative cover
- Downspouts and Roof Runoff Collection
- Rainwater Cisterns
- Check Dams
- Labyrinth and Spiral Infiltrators
- Zuni Bowls

As stated in the *Reduce Your Flood Risk: A Resource Guide:*

> *"The Flood Control District of Maricopa County (FCD) has developed the resource guide to help address commonly-asked questions about flood hazards and floodplain management…In addition, the guide provides information about flood risk and steps residents can take to reduce their risk."*

The *Reduce Your Flood Risk: A Resource Guide* is provided on the accompanying external hard drive (Appendix C). Labyrinth and Spiral Infiltrators are not recommended for homeowners in Mohave County due to their construction costs and challenging maintenance needs.

11.2 Rio Verde Area Alternative Stormwater Management Report

The *Rio Verde Area Alternative Stormwater Management Report - Water Conservation, Green Infrastructure/Low Impact Development Analysis Tools and Development Summary Report* (herein referred to as the *Rio Verde Area GI/LID Report*) was prepared for the Flood Control District of Maricopa County and released September 2018. According to the *Rio Verde Area GI/LID Report*:

> *"This report is intended to introduce green infrastructure and low-impact development techniques and strategies that may be applicable to rural Maricopa County residents. Although not exhaustive in its evaluation of GI/LID techniques, this report provides a framework in which a rural homeowner or a landowner can evaluate their residence and property for possible voluntary implementation of GI/LID techniques. The overall goals and objectives of this report are as follows:*
>
> - *Define GI/LID strategies and highlight potential applications for a rural Arizona environment*

- *Promote use of stormwater as a valuable resource rather than being viewed as a nuisance or waste product*
- *Provide GI/LID methods that, slow, sink, and spread rainfall to maximize on-site infiltration*
- *Provide GI/LID techniques to assist in reducing potable water use for landscape irrigation and other outdoor uses*
- *Provide GI/LID techniques to assist in slowing and reducing erosion on residential properties*
- *Provide GI/LID techniques to assist in reducing the movement of sediment, nutrients, pollutants or debris from individual parcels into adjacent washes, arroyos, and roadways*
- *Provide GI/LID techniques and strategies for the above goals, while maintaining, or improving on, Rio Verde's rural community character and environmental health"*

The *Rio Verde Area GI/LID Report* discusses application of the following GI/LID techniques for rural arid lands:

- Above and Below Ground Tanks
- Rain Garden
- Bio-Swale
- Terrace
- Check Dam
- Infiltration Trench
- Labyrinth Infiltrator
- Spiral Infiltrator
- Zuni Bowl

The *Rio Verde Area GI/LID Report* is provided on the accompanying external hard drive (Appendix C). Labyrinth and Spiral Infiltrators are not recommended for homeowners in Mohave County due to their construction costs and challenging maintenance needs.

11.3 Greater Phoenix Metro Green Infrastructure Handbook

Released January 2019, the *Greater Phoenix Metro Green Infrastructure Handbook – Low-Impact development Details for Alternative Stormwater Management* (*GI Handbook*) was prepared for the City of Scottsdale, ASU Sustainable Cities Network, and Member Communities. Harry Cooper of the Flood Control District of Maricopa County was instrumental in the review of the document.

According to the *GI Handbook*:

> *"The purpose of this Handbook is to provide members of the design, planning, and development communities in Maricopa County, Arizona with guidance and specific techniques for low impact development (LID) that can be implemented on their projects.*
>
> *The goal of this Handbook is to advance the implementation of LID and green infrastructure (GI) by developing selected LID technical standard details and specifications (TSDS). These TSDS are expected to be used primarily on public projects associated with road and street improvements, although the concepts and techniques are equally applicable to private projects. Ultimately, it is anticipated these TSDS, or improved versions of these TSDS, will be incorporated into the design and development standards of communities across Maricopa County."*

The following nine LID technical standard details and specifications are presented in the *GI Handbook*:

1. Permeable Pavements
2. Curb Openings
3. Sediment Traps
4. Stormwater Harvesting Basins
5. Vegetated or Rock Bioswales
6. Bioretention Systems
7. Curb Extensions
8. Bioretention Planters
9. Domed Overflow Structures

In addition to the above listed LID technical standard details and specifications, the *GI Handbook* provides landscaping details and specifications. According to the *GI Handbook*:

> *"The role of vegetation is obvious and inherent to the origination and success of LID treatments. While engineering analyses establish the stormwater management needs, the selection of appropriate LID treatments requires an integrated, iterative process between drainage and landscape designers based on on-site ecological resources, design requirements, and budgetary considerations. In Maricopa County, native vegetation is generally sparse, providing limited stormwater management functions. As a result, purposely installed landscaping is needed to produce an effective vegetative cover for LID treatments. To ensure viable landscaping, a number of factors must be considered. This section of the Handbook elaborates on those factors and offers guidance and recommendations on the design, implementation, and maintenance of LID landscaping."*

The *GI Handbook* is provided on the accompanying external hard drive (Appendix C).

11.4 Quivira Coalition Erosion Control Field Guide

Written by Craig Sponholtz and Avery C. Anderson Sponholtz, the *Quivira Coalition Erosion Control Field Guide* was developed based on field-tested practices by restoration professionals, including: Bill Zeedyk, Steve Carson, Van Clothier, Brad Lancaster, Steve Vrooman, as well as many others working on rural landscapes throughout the arid southwest. It provides useful guidance relevant for homeowners in the project area with erosion challenges. The practices can be constructed with minimal cost, utilizing locally available materials. The focus of the *Quivira Coalition Erosion Control Field Guide* is to introduce the erosion control practices that regenerate soil so that it holds more water, supports more vegetation, and reduces soil erosion. The local stormwater management practices presented in the *Quivira Coalition Erosion Control Field Guide* include:

1. One Rock Dams
2. Rock Mulch Rundown
3. Zuni Bowl
4. Media Luna

The *Quivira Coalition Erosion Control Field Guide* is provided electronically on the external hard drive (Appendix C). It can also be purchased as a bound and laminated copy for field use from the Quivira Coalition (https://quiviracoalition.org/). The One Rock Dam is highlighted in Section 2.1.8 and is also relevant to Section 2.1.7 for construction best practices for the Zuni Bowl.

11.5 Rosgen White Paper

According to *The Cross-Vane, W-Weir and J-Hook Vane Structures…Their Description, Design and Application for Stream Stabilization and River Restoration* (*Stream Stabilization White Paper*) white paper, written by Dave Rosgen, P.H.:

> *"The descriptions, design specifications, placement locations, spacing and various applications of Cross-Vane, W-Weir and J-Hook Vane structures are presented. These structures were developed and subsequently applied to: 1) establish grade control, 2) reduce streambank erosion, 3) facilitate sediment transport, 4) provide for irrigation diversion structures, 5) enhance fish habitat, 6) maintain width/depth ratio, 7) improve recreational boating, 8) maintain river stability, 9) dissipate excess energy, 10) withstand large floods, 11) maintain channel capacity, 12) be compatible with natural channel design, and 13) be visually acceptable to the public."*

Excerpts from the *Stream Stabilization White Paper*, showing typical details for Cross-Vane, W-Weir, and J-Hook Vane structures, and and supporting documents are provided electronically on the accompanying external hard drive (Appendix C).

11.6 Pima County/City of Tucson GI/LID Guidance Manual

The *Low Impact Development and Green Infrastructure Guidance Manual* released March, 2015, is the first guidance manual in the southwest to provide an overview of LID while also providing guidance on integrated design and site planning. Structural Green Infrastructure Practices included in the manual are:

1. Stormwater Harvesting Basins
2. Vegetated or Rock Swale
3. Bioretention Systems
4. Infiltration Trenches
5. Cisterns
6. Permeable Pavements

7. Dry Wells

The manual also addresses common components of Green Infrastructure and provides some initial guidance to manage difficult soils utilizing compost, gypsum, and organic mulches. The guidance manual can be found in Appendix C on the external hard drive.

11.7 Watershed Management Group Green Infrastructure for Desert Communities

The *Green Infrastructure for Desert Communities* guide is an attempt to bridge between guidance manuals and design standards to provide a more accessible resource for community leaders, the general public, decision makers, and design professionals to promote LID. This resource provides significant contributions by outlining guidance on soil health and simple maintenance, as well as documenting progress on metrics for community scale LID planning, including modeling and cost benefit analyses. LID features presented here are broken into three broad categories and include:

1. Street side LID:
    a. Curb inlets
    b. Curb cuts and basin
    c. Sediment traps
2. In-street LID:
    a. Chicanes and street width reductions
    b. Medians
    c. Traffic Circles
3. Parking lot LID:
    a. Bioretention
    b. Alternative materials

A section on maintenance is presented in the guide that has also been expanded into the *Rain Garden Care Field Guide*, also found in Appendix C on the external hard drive. Simple best management practices have been outlined to promote soil health and ensure cost-effective performance of LID. This guide is suitable for public and private projects and has been utilized for training.