City of Phoenix, City of Tempe and Maricopa County

Integrating Green Infrastructure and Low Impact Development Tools into Hazard Mitigation Plans

Summary Report of Research Findings

Prepared by Skeo Solutions
November 2019

FINAL

Introduction

Local Hazard Mitigation Plans (HMPs) offer a unique opportunity to institutionalize green stormwater infrastructure (GI)/Low Impact Development (LID) strategies and leverage multiple stormwater benefits (e.g., water quality, flow control, flood risk reduction) along with additional co-benefits (e.g., recreation, mobility, habitat, heat island reduction, air quality, increased property values) that align with broader community goals. The U.S. Environmental Protection Agency (EPA) Office of Wetlands, Oceans and Watersheds (OWOW), the Office of Community Revitalization, the Urban Waters Program, EPA Region 9, and the Federal Emergency Management Agency (FEMA) Region 9 are sponsoring technical assistance to support the cities of Phoenix and Tempe and Maricopa County, Arizona in integrating Low Impact Development (LID) and GI into their 2020 HMPs and flood control documents. Consulting firm, Skeo Solutions, has been selected by EPA to facilitate this technical assistance.

The technical assistance centers around a 1.5-day technical assistance workshop scheduled for December 10-11, 2019, to facilitate stakeholder discussion resulting in recommendations on how GI/LID can be integrated into the Maricopa County Multi-Jurisdictional Hazard Mitigation Plan (MHMP) and other flood and stormwater management strategy documents. The outcomes of the workshop will be integrated into a final report, which will include updated language for the Maricopa County MHMP.

Goals for this technical assistance include the following:

1. Expand the range of tools used to mitigate flood risk to include natural and nature-based solutions (i.e., GI/LID).
2. Institutionalize GI/LID into hazard mitigation and stormwater management planning.
3. Enable co-planning management of flooding, nonpoint source water quality, and protection of areas important to the hydrologic connectivity of the local watersheds.
4. Enhance opportunities for FEMA funds to be directed to GI/LID projects.
5. Achieve co-benefits of GI/LID, including improved water quality, water conservation and drought mitigation, climate mitigation, urban heat island reduction, air quality, and quality of life.

In preparation for the workshop, Skeo has reviewed a prioritized set of local city and county studies and other documents on GI/LID in semi-arid landscapes (see pages 9 and 20 for a complete list). The findings from the review are summarized in this document to help inform workshop materials that will be used to facilitate locally developed GI/LID recommendations for the 2020 Maricopa County MHMP update. The following sections of the document include:

- Maricopa County: Flood Control and HMP Documents
- Benefits of Integrating GI/LID
- Menu of GI/LID Technologies
- Relative Benefits of GI/LID Technologies
- Considerations for a Semi-Arid Climate
- Operations and Maintenance Considerations

Maricopa County: Flood Control and HMP Documents

The 2015 Maricopa County MHMP[1] identifies the following risks for mitigation strategies by participating jurisdictions:

- Dam inundation
- Drought
- Extreme heat
- Fissure
- Flood
- Levee failure
- Severe wind
- Subsidence
- Wildfire

GI/LID technologies are most suitable to address three of the risks identified in the Maricopa County MHMP: **drought, extreme heat, and flood[2].** Green stormwater infrastructure technologies could potentially be integrated with many of the mitigation strategies that the City of Phoenix, City of Tempe and Unincorporated Maricopa County included in the 2015 Maricopa County MHMP. Table 1 outlines mitigation strategies from the 2015 MHMP that could be adapted to include GI/LID technologies. The table sorts the current mitigation strategies into the following four implementation categories with considerations for how GI/LID could be integrated into each category:

- Planning
- Capital projects
- Development requirements
- Stewardship (education and voluntary programs)

Similarly, GI/LID technologies also support the 2015 Floodplain Management Plan for Unincorporated Maricopa County.[3] See Tables 4 through 7 in Appendix A for a more detailed list of mitigation strategies from the 2015 Maricopa County MHMP and the 2015 Floodplain Management Plan for Unincorporated Maricopa County.

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[1] Maricopa County. 2015 Multi-Jurisdictional Hazard Mitigation Plan. Prepared by JE Fuller/ Hydrology & Geomorphology, Inc. November 2015.

[2] Managing stormwater at or near its source in the upper portions of a watershed can also help mitigate other flood related hazards like levee failure and dam inundation, if overall volume and peak are reduced. Also, fissure and subsidence issues can have a significant impact to flood control facilities reducing flood risk effectiveness. Addressing over pumping of groundwater and mitigating water demand for outdoor uses via GI/LID water conservation and recharge strategies can help mitigate this risk.

[3] Unincorporated Maricopa County. 2015 Floodplain Management Plan. Prepared by LTM Engineering, Inc. November 2015.

Table 1. Mitigation Strategies from the 2015 MHMP by Jurisdiction That Could Integrate GI/LID

Jurisdiction	Planning	Capital Projects	Development Requirements	Stewardship and Education
	Options to integrate GI/LID technologies to mitigate for drought, flood, and extreme heat.			
	Include GI/LID technologies where appropriate in relevant planning documents.	Consider GI/LID approaches to capital improvement projects.	Consider integrating GI/LID options into development requirements.	Provide education about how to implement voluntary GI/LID projects.
City of Phoenix (Table 6-8-18, 2015 MHMP)	Updates to the Drought Response Plan. Policies in the General Plan that designate areas for open space.	Drainage facilities to mitigate flooding hazard.	Building permits for compliance with floodplain regulations. Revisions to existing building codes.	Water use awareness outreach program.
City of Tempe (Table 6-8-24, 2015 MHMP)	Development of water infrastructure master plan to identify vulnerabilities in the water supply. 2002 Water Resources Plan, the 1999 Tempe Integrated Water System Master Plan, and the 2002 Drought Management Strategy Plan.	Projects to increase groundwater storage and recovery. Projects to mitigate flooding affecting freeways. Projects related to flood control and storm drainage.	Building permits for compliance with floodplain regulations.	Education on the hazards of extreme heat. Workshops and conferences on hazard mitigation.
Unincorporated Maricopa County (Table 6-8-26, 2015 MHMP)	Area Drainage Master Studies/Plans. Updates to the framework of hazard mitigation in the 2009 Comprehensive Floodplain Management Plan.	Projects to mitigate flooding hazards through the Flood Control Capital Improvement Program.	Building permits for compliance with floodplain regulations. Revisions to existing building codes.	Public education program about flooding hazards and water conservation. Outreach to highlight renewable water uses for subdivision developers.

Benefits of Integrating GI/LID

GI/LID can enhance existing strategies to address drought, extreme heat, and flood risks by providing the following benefits:[4]

- **Drought mitigation** through localized stormwater water storage/use and lower potable water demand
- **Extreme heat mitigation** through reduced urban heat island effect by reducing impervious surface, increasing moisture storage in the soils and providing shading through trees and understory vegetation.
- **Flood mitigation** by reducing peak flows and volumes through diversion, infiltration, storage distributed throughout watershed (localized solutions at multiple scales and quantities).

GI/LID technologies can provide additional co-benefits, including:

- Improved water quality
- Improved air quality
- Lower carbon emissions
- Enhanced pedestrian safety and amenities, including canopy shade, pedestrian-scale cooling
- Enhanced community values
- Improved property values
- Long-term cost savings

This section describes each of these benefits in more detail. A comparison of benefits by GI/LID technology is included in Table 2 on page 16.

Drought mitigation through greater water storage and lower potable water demand

Many GI/LID features contribute to drought mitigation by increasing infiltration so that a greater volume of rainfall can be recharged at or near its source, helping keep rainfall where it falls, reducing the need for supplemental irrigation. GI/LID features also provide water-efficient landscaping with proper placement of native and low water use plants. For example, a 2017 modeling study estimated that xeriscaping in Phoenix, Arizona, would result in water savings equivalent to 19.8% of the projected annual water

[4] The benefits of GI and LID included in this section were primarily obtained from "Low Impact Development and Green Infrastructure Guidance Manual," "A review of green infrastructure performance in arid environments," and "Arid Green Infrastructure for Water Control and Conservation: State of the Science and Research Needs for Arid/Semi-Arid Regions" with supplementary information cited in subsequent footnotes.

consumption in 2050.[5] In addition, many GI features harvest rainfall for use as outdoor irrigation, reducing the demands for potable water. According to the Arizona Department of Water Resources, "the largest use of potable water in Arizona is for landscaping and as much as 70% of residential water use is outdoors."[6] A four-year study of a single-family household in Tucson, Arizona, found that rainwater water harvesting reduced the household's municipal water use by 66%.[7]

Extreme heat mitigation through reduced urban heat island effect

GI/LID features can mitigate extreme surface temperatures through shade and evapotranspiration from vegetation. Studies have shown vegetation (including trees, shrubs, grasses and groundcovers) can lower local temperatures in open terrain by 9° Fahrenheit (F) and in suburbs without trees by 4 to 6°F.[8] GI/LID features such as green roofs also provide similar cooling effects at the scale of an individual building. Green roofs reflect more solar radiation than conventional roof surfaces, leading to less solar radiation absorbed by buildings and lower roof temperatures. For instance, a study of green roofs on University of Central Florida buildings found that the average maximum temperature for green roofs was 86°F, while the average maximum temperature for conventional roofs was 134°F.[9] Similarly, a 2017 modeling study found ground air temperatures in Phoenix, Arizona, would decrease by up to 35.6°F if green roofs were present throughout the city.[4] When incorporated into large open green space, GI/LID can help cool extensive urban areas. Studies have found that temperatures in urban parks can be 2.7 to 7.2°F lower than their surroundings.[8] This cooling effect can extend well past park boundaries. In some cases, lower temperatures have been observed at distances of over half a mile from parks.

Flood mitigation through diversion, infiltration, storage

The benefits of GI/LID features for stormwater management are well-documented in the literature. GI/LID can mitigate floods by using vegetation, soils and other engineered materials to increase the infiltration, evapotranspiration, interception, and management of rainfall. Vegetation intercepts rainfall through their leaves and branches, reducing the volume of water that reaches the ground. Engineered soils and established landscape areas absorb rainfall that reaches the ground and flows into the designed water-harvesting elements. As the water moves through GI/LID features, it is slowed by check dams, plant materials, and other components. Through these mechanisms, GI/LID features reduce the overall volume and rate of runoff downstream.

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[5] Yang, J., and Wang, Z. H. (2017). Planning for a sustainable desert city: The potential water buffering capacity of urban green infrastructure. *Landscape and Urban Planning*, 167, 339-347.

[6] Arizona Department of Water Resources Conservation Program. Retrieved November 21, 2019, from https://new.azwater.gov/conservation/landscaping.

[7] Jiang, Y., Yuan, Y., and Piza, H. (2015). A review of applicability and effectiveness of low impact development/green infrastructure practices in arid/semi-arid United States. *Environments*, 2(2), 221-249.

[8] The Trust for Public Land. "The benefits of green infrastructure for heat mitigation and emissions reductions in cities." June 2016.

[9] U.S. Environmental Protection Agency. 2008. Reducing urban heat islands: Compendium of strategies. https://www.epa.gov/heat-islands/heat-island-compendium.

Several field studies and models demonstrate these stormwater benefits in arid environments. Following large storms with over 2 inches in rainfall, a 2010 study found that permeable pavement in restrictive soils reduced discharge volumes by approximately 46%.[10] Likewise, a 2015 study found that GI in Tucson, Arizona, reduced peak flows after intense rainfall events by 10% to 24%.[11] Similarly, a 2016 study demonstrated that bioretention systems, bioswales, cisterns and permeable pavement in three areas in Tempe, Arizona reduced peak flows between 58% to 86%.[12] A 2012 modeling study in Phoenix, Arizona, estimated that bioswales and bioretention basins can capture up to 98.4% of rainfall from 95th percentile (one inch) storm.[13]

Additional co-benefits

Improved water quality

GI/LID features can improve water quality by filtering, absorbing and dissolving pollutants in stormwater. Studies found that bioswales reduce the concentrations of total suspended solids between 76% to 99%, lower nitrogen and phosphorous loads to levels below those of undeveloped areas and capture an average of almost 25% of heavy metals.[14,15]

Improved air quality

Vegetation in GI/LID features can contribute to improved outdoor air quality from plants and soils intercepting particulate matter. According to the study, "The Effectiveness of Green Infrastructure for Improvement of Air Quality in Urban Street Canyons" published in *Environmental Science & Technology* in august 2012, the "judicious placement of grass, climbing ivy and other plants in urban canyons can reduce the concentration at street level of Nitrogen Dioxide by as much as 40 percent and particulate matter by 60 percent." Vegetation can also indirectly discourage the formation of smog through cooler temperatures.

Lower carbon emission

By mitigating extreme temperatures, GI/LID can reduce energy consumption and contribute to lower carbon emissions. Some studies estimate that green roofs can reduce annual building energy consumption

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[10] Fassman, E. A., & Blackbourn, S. (2010). Urban runoff mitigation by a permeable pavement system over impermeable soils. *Journal of Hydrologic Engineering*, 15(6), 475-485.

[11] City of Tucson and Pima County Regional Flood Control District. Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area. Prepared by Watershed Management Group. May 2015.

[12] Tempe Area Drainage Master Study, LID Application Review and FLO-2D Modeling, Revised April 2016.

[13] Meerow S., Natarajan M., and Krantz D. "A review of green infrastructure performance in arid environments." Unpublished manuscript. October 14, 2019.

[14] Sansalone, J., Raje, S., Kertesz, R., Maccarone, K., Seltzer, K., Siminari, M., Simms, P. and Wood, B. (2013). Retrofitting impervious urban infrastructure with green technology for rainfall-runoff restoration, indirect reuse and pollution load reduction. Environmental pollution, 183, 204-212.

[15] Evans, Z., Van Ryswyk, H., Los Huertos, M., & Srebotnjak, T. (2019). Robust spatial analysis of sequestered metals in a Southern California Bioswale. *Science of The Total Environment*, *650*, 155-162.

by as much as 60%.[7] Because of their cooling effect, GI/LID features can help indirectly reduce carbon emissions by decreasing energy consumption. When implemented at larger scales, many GI/LID features may also directly remove carbon from the atmosphere. Trees and other vegetation take in carbon dioxide during photosynthesis and store carbon as biomass in their branches, leaves, roots and stems. Through carbon sequestration, vegetation in urban areas may offset activities that release atmospheric carbon. For example, a 2018 modeling study estimated that trees in Phoenix, Arizona store approximately 57,800 tons of carbon.[16]

Enhanced pedestrian safety and amenities

GI/LID can enhance street access for pedestrians and bicyclists by calming car traffic. GI/LID features such as curb extensions discourage cars from speeding, reducing the risk for traffic accidents. Planted bioswales can also improve the aesthetic quality of the streetscape and provide shade which can have positive benefits for residents, such as increased physical activity through biking and walking and reduced stress through time spent outdoors.[17]

Enhanced community wellness

GI/LID supports overall community wellness through increased access to green space. By providing attractive natural green space, GI/LID encourages the community to spend more time outdoors, a measure that has been linked to positive mental and cognitive health benefits such as improved attention and mood.[18] GI/LID features can provide venues for social interaction among neighbors. Well-maintained landscaping can also contribute to neighborhood beautification, strengthening a neighborhood's sense of place, safety and trust.

Improved property values

GI/LID features are often integrated in parks and provide recreational amenities for communities. Because of these desirable amenities, GI/LID features can contribute to increased property values. Some studies have documented increases of up to 30% in properties near parks.[19] Other studies suggest that even individual trees may benefit property values.[20]

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[16] Kim, G., & Coseo, P. (2018). Urban park systems to support sustainability: The role of urban park systems in hot arid urban climates. Forests, 9(7), 439.

[17] Roe, J. (2016). Cities, Green Space, and Mental Well-Being. *Oxford Research Encyclopedia of Environmental Science*. https://oxfordre.com/environmentalscience/view/10.1093/acrefore/9780199389414.001.0001/acrefore-9780199389414-e-93.

[18] Polonsky H., Cohen-Cline H., and Wolf K. Green Infrastructure and Health Guide. Willamette Partnership and Oregon Public Health Institute. Prepared by the Oregon Health and Outdoors Initiative. January 2018.

[19] Pima County and City of Tucson. Low Impact Development and Green Infrastructure Guidance Manual. March 2015.

[20] Landry S., Koeser, A., Northrop, R., McLean, D., Donovan, G., Andreu, M., and Hilbert, D. (2018). City of Tampa Tree Canopy and Urban Forest Analysis 2016. Tampa, FL: City of Tampa, Florida.

Long-term cost savings

Several studies have quantified the financial, environmental and social benefits of GI/LID features and found that their overall benefits outweigh upfront costs and maintenance costs. Net benefits from GI/LID are often much greater than conventional infrastructure. For instance, according to a 2018 cost-benefit analysis in Phoenix, Arizona, bioswales and bioretention basins generate about $15,000 greater net value (the difference between costs and benefits over a period of time, taking into account long-term operational costs) per 1,000 square feet than conventional concrete.[21] Similarly, a 2014 cost-benefit analysis in Tucson, Arizona, found that GI features at two sites – one commercial property and one road segment – generated net values of $12,941 and $322,525, respectively.[22] Another Tucson study estimated in 2015 that GI features in three watersheds would result in over $2.5 million dollars in annual community benefits (such as reduced water use, energy savings, mitigated flood risk, traffic calming and reduced heat island impacts).[11]

Menu of GI/LID Technologies

GI/LID technologies are all rooted in design principles that mimic natural processes and achieve multiple functions. GI/LID technologies differ in their target outcomes and specifications. This section provides a brief overview of common GI/LID technologies, including:[23]

- Infiltration trench
- Dry well
- Vegetated or rock bioswale
- Bioretention system
- Stormwater harvesting basin
- Sediment trap
- Permeable pavement
- Green roof
- Conservation area
- Cistern
- Curb extension

The effectiveness and benefits of GI/LID features can be increased by designing GI/LID features in a treatment train (a series of consecutive features within the water flow.) In addition, performance can be

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[21] City of Phoenix. Triple Bottom Line Cost Benefit Analysis of Green Infrastructure/Low Impact Development (GI/LID) in Phoenix, AZ. Prepared by Autocase. June 2018.

[22] Pima County Regional Flood Control District and Pima Association of Governments. Evaluation of GI/LID Benefits in the Pima County Environment. Prepared by Infrastructure, LLC and Stantec. July 2014

[23] The GI and LID technologies included in this section were primarily obtained from "Low Impact Development and Green Infrastructure Guidance Manual" and "Greater Phoenix Metro Green Infrastructure Handbook: Low-Impact Development Details for Alternative Stormwater Management."

increased by including accessory elements such as curb cuts, rock check dams, sediment traps and dome overflow structures.

Infiltration Trench

Infiltration trenches are long, narrow channels that are filled with gravel to retain stormwater or transfer it to another location.

Applications

Infiltration trenches are appropriate for commercial, industrial or high-density residential sites. However, unlike stormwater harvesting basins or bioretention systems, vegetation cannot be grown on the infiltration trenches.

Figure 1: Illustration of an infiltration trench (Source: Flood Control District of Maricopa County. Reduce Your Flood Risk: A Resource Guide. June 2019.)

Dry Well

Dry wells are excavations that are only a few feet in diameter and are filled with gravel.

Applications

Dry wells are appropriate for multi-family residential and commercial sites. They are not suitable for areas with potential hazardous materials.

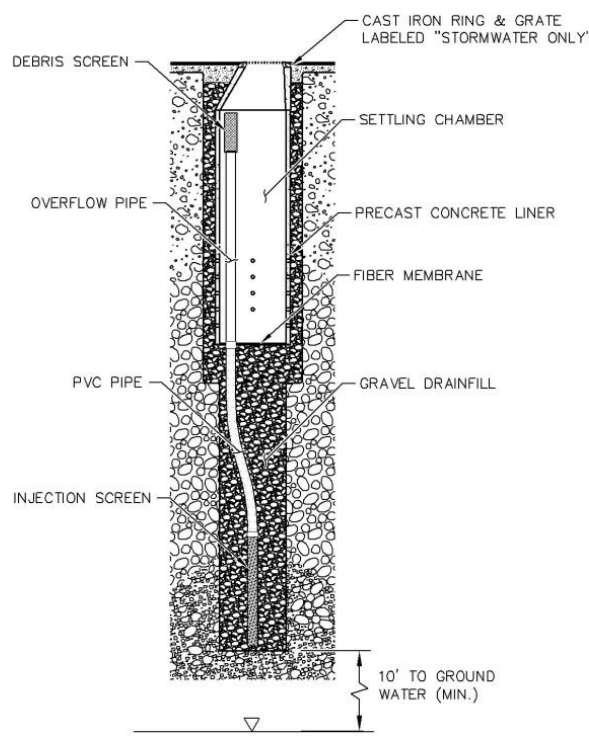

Figure 2: Diagram of a dry well. (Source: Pima County and City of Tucson. Low Impact Development and Green Infrastructure Guidance Manual. March 2015.)

Vegetated or Rock Swale

Swales are elongated, shallow channels covered by vegetation and pervious rock or gravel. Vegetated swales provide many of the co-benefits of GI/LID including those associated with drought (reduce potable water use), flood risk (higher infiltration, slowed flows), and urban heat. For all vegetated features, plants helps slow and infiltrate water, reduce water through uptake and drop sediment loads.

Figure 3: Bioswale in Phoenix, Arizona (Source: City of Phoenix. Study: Effectiveness of Existing Green Infrastructure in Phoenix. Prepared by Coe & Van Loo Consultants, Inc. December 2018.)

Applications

Swales are an alternative to storm drain systems as well as curbs and gutters along streets. They can be used where no storm drain system is present but they may also be a companion (with curb cuts and sediment basins) to help take water off the street, infiltrate it closer to its source, slow flows, and reduce reliance solely on the storm drain system. They are best implemented together with other GI/LID technologies, such as sediment traps, infiltration trenches, rock check dams, and curb cuts. Swales slow water flows compared to a concrete-lined channel, so they require a larger area.

Bioretention System

Bioretention systems are a basin or planter that includes over excavation and placement of bio-engineered soils for increased storage potential along with vegetation to remove pollutants from stormwater.

Figure 4: A bioretention system at a parking lot. (Source: Pima County and City of Tucson. Low Impact Development and Green Infrastructure Guidance Manual. March 2015.)

Applications

Bioretention systems are appropriate along roadways and for residential, commercial, industrial sites and parking lots. They are especially suitable for areas that require high infiltration rates in a limited space. They are best implemented together with other GI/LID technologies, such as sediment traps, infiltration trenches, rock check dams, and curb cuts. The strong vegetation component provides multiple co-benefits associated with drought, flood risk, and urban heat.

In areas that have a drainage collection system downstream (e.g., storm drains, basins, channels or natural washes), bioretention systems can connect to domed overflow structures. Domed overflow structures provide outlets for water that exceeds the pond capacity during larger storms.

Stormwater Harvesting Basin

Stormwater harvesting basins are shallow depressions that effectively collect store, infiltrate and redirect runoff along with planted vegetation to treat stormwater.

Applications

Stormwater harvesting basins are suitable in sites where vegetation would benefit from additional water. They are often placed next to impervious areas such as parking lots to help support landscaped features.

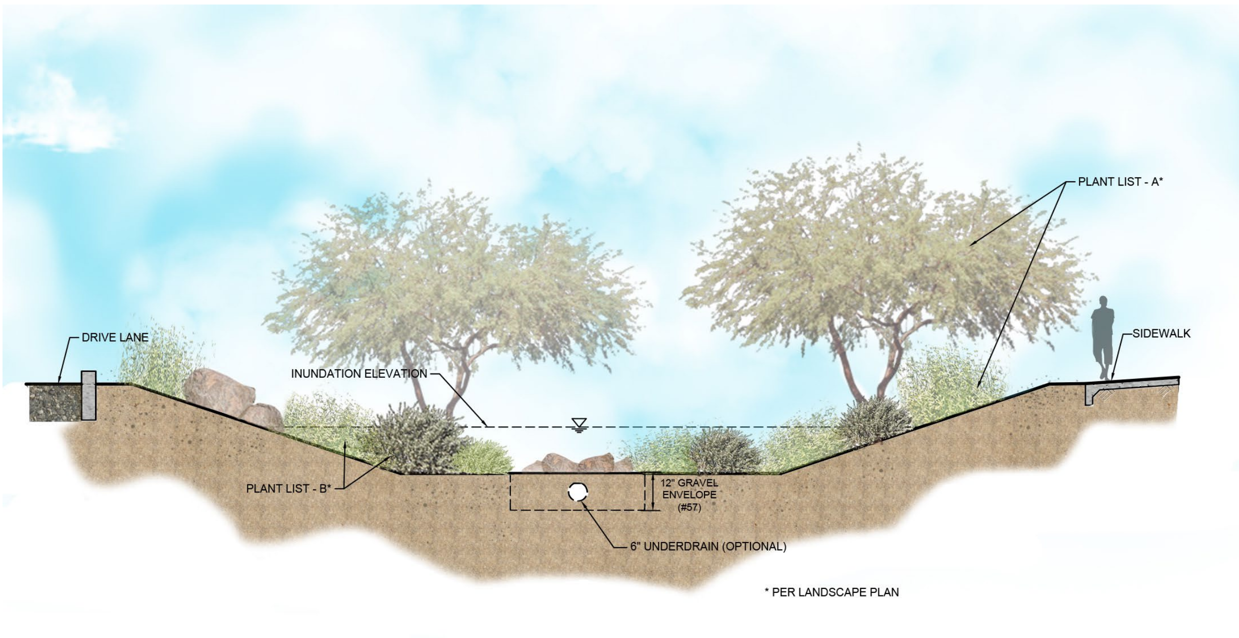

Figure 5: A rendering of a stormwater harvesting basin. (Source: City of Scottsdale and Arizona State University. Greater Phoenix Metro Green Infrastructure Handbook: Low-Impact Development Details for Alternative Stormwater Management. Prepared by Dibble Engineering and Logan Simpson. January 2019.)

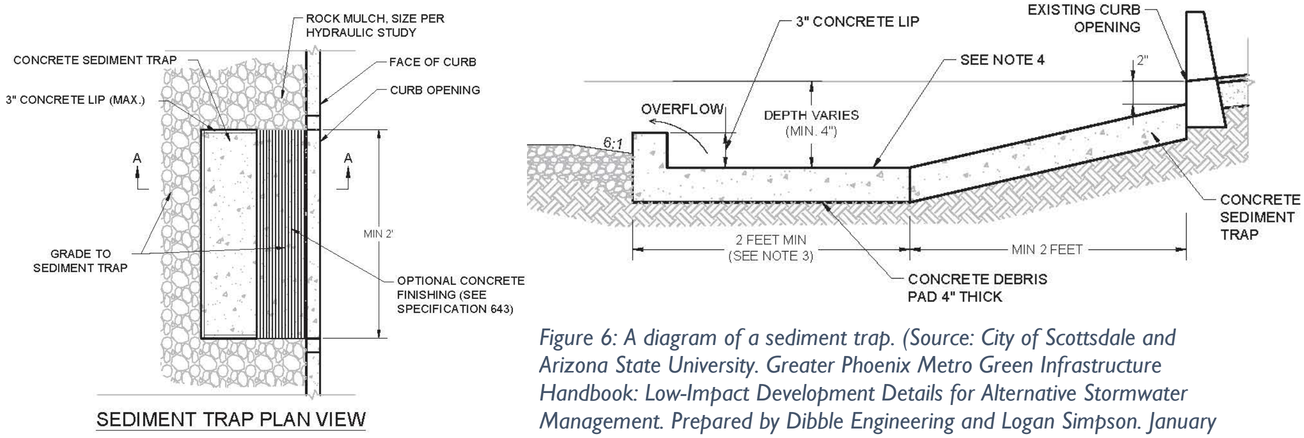

Figure 6: A diagram of a sediment trap. (Source: City of Scottsdale and Arizona State University. Greater Phoenix Metro Green Infrastructure Handbook: Low-Impact Development Details for Alternative Stormwater Management. Prepared by Dibble Engineering and Logan Simpson. January 2019.)

Sediment Trap

Sediment traps are depressions at inlets with debris pads to collect sediment from concentrated stormwater flows. They provide some pretreatment before stormwater enters a stormwater capture feature.

Applications

Sediment traps are used as accessory features to other GI/LID technologies that store stormwater, such as stormwater harvesting basins and bioretention systems.

Permeable Pavement

Permeable pavement includes surfaces with small voids to allow water to infiltrate or drain into a reservoir below the pavement. Permeable pavers, pervious concrete, porous gravel, porous asphalt and grid asphalt are typical surfaces used for permeable pavement.

Figure 7: Permeable pavement. (Source: Pima County and City of Tucson. Low Impact Development and Green Infrastructure Guidance Manual. March 2015.)

Applications

Permeable pavement is appropriate for driveways, parking lots, sidewalks, and residential streets with vehicle travel speeds of less than 30 miles per hour. Permeable pavement is not suitable for streets with higher vehicle travel speeds or areas with high expected pollutant loading. These areas include industrial sites, gas stations or vehicle storage areas.

Green Roof

Green roofs use vegetation and soils on building rooftops to retain stormwater.

Applications

Green roofs are suitable for buildings with relatively flat roofs. They require irrigation in arid and semi-arid climates.

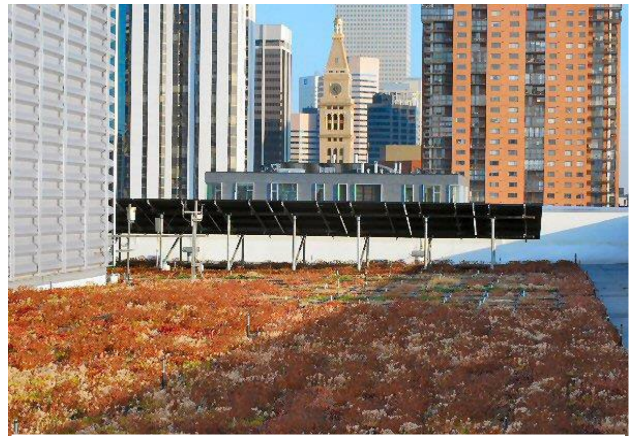

Figure 8: A green roof in Denver, Colorado. (Lee, J., & Fisher, C. (2016). Arid green infrastructure for water control and conservation. State of the Science and Research Need for Arid/Semi-arid Regions. Environmental Protection Agency.)

Conservation Area

Conservation areas protect undeveloped drainage areas to tap into their natural infiltration and storage capacity. Undeveloped drainage areas often have established vegetation and undisturbed soils with high infiltration rates. Natural meandering flow paths also slow the stormwater flows. Conserved areas can potentially offer more co-benefits than constructed GI/LD features.

Applications

Conservation areas provide a less costly alternative to flow structures and can accept post-development flows especially when integrated into property retrofits. They are most readily implemented in larger sites such as lower density residential developments and open space.

Figure 9: Natural areas in a semi-arid environment. (Source: Pima County and City of Tucson. Low Impact Development and Green Infrastructure Guidance Manual. March 2015.)

Cisterns

Cisterns are metal, plastic or concrete containers that collect rain for non-potable use such as for irrigation or flushing toilets. Cisterns typically can hold several thousand gallons.

Applications

Cisterns are suitable for residential and commercial properties.

Figure 10: A cistern. (Source: Pima County and City of Tucson. Low Impact Development and Green Infrastructure Guidance Manual. March 2015.)

Curb Extensions

Also known as chicanes, curb extensions are landscaped areas built out from a vehicle travel or parking lane.

Applications

Curb extensions are suitable for low-speed roadways, driveways or parking lots.

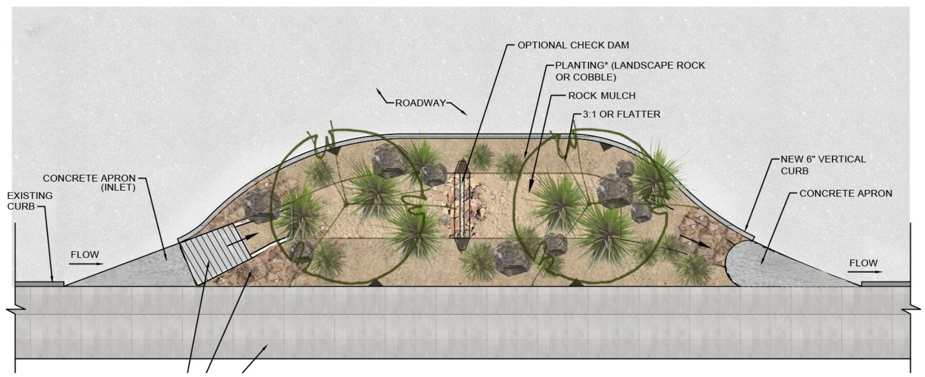

Figure 11: A rendering of a curb extension. (Source: City of Scottsdale and Arizona State University. Greater Phoenix Metro Green Infrastructure Handbook: Low-Impact Development Details for Alternative Stormwater Management. Prepared by Dibble Engineering and Logan Simpson. January 2019.)

Relative Benefits of GI/LID Technologies

Table 2 on the following page outlines relative benefits of GI/LID technologies for hazard mitigation as well as other benefits.

Table 2. Relative Benefits of GI/LID Technologies

Technology	Relative Cost	Mitigates the Following HMP Risks					Quality of Life Benefits
		Flooding	Drought: Water Demand	Drought: Water Storage	Urban Heat Island	Water Quality	
Infiltration trench	$	●	◓	●	○	●	
Curb extension	$$	◓	●	○	◓	◓	Habitat, planting feature, traffic calming, aesthetics, trash capture
Sediment trap	$	◓	○	○	○	◓	Important O&M feature to include with bioswales and basins.
Vegetated or rock bioswale	$$	●	●	○	●	●	Habitat, planting feature, aesthetics, trash capture, traffic calming, air quality
Bioretention system	$$	●	●	●	●	●	Wildlife habitat, planting feature, aesthetics, air quality
Stormwater harvesting basins	$$	●	●	●	●	●	Wildlife habitat, planting feature, aesthetics, air quality
Permeable pavement	$$-$$$	●	◓	◓	◓	●	Traffic calming
Green roof	$$$	◓	○	○	●	◓	Wildlife habitat, planting feature, aesthetics
Conservation area	$	●	◓	●	●	●	Wildlife habitat, planting feature, aesthetics, air quality
Cistern	$	◓	●	◓	◓	◓	
Dry well	$	●	◓	◓	○	●	

Key: Benefits ● = high; ◓ = medium; ○ = low

Relative Costs (Capital and O&M) $$$=high; $$=medium; $=low

Applicability of GI/LID approaches

The following table outlines general applicability of GI/LID approaches across different land use types.

Table 3. Applicability of GI/LID approaches across land use types

	Street	Open space	Parking lot	Commercial/ institutional	Residential lot	Residential subdivision
Infiltration trench	x	x	x	x	x	
Curb extension	x		x	x		x
Sediment trap	x		x	x		
Bioswale	x	x	x	x	x	x
Bioretention system	x	x	x	x		
Stormwater harvesting system	x	x	x	x	x	x
Permeable pavement	X*		x	x	x	x
Green roof				x		
Conservation Area		x		x	x	x
Cisterns				x	x	x
Dry well			x	x	x	x

**in limited applications*

Considerations for a Semi-Arid Climate

GID/LID features are most effective in terms of both performance and cost savings when they are planned with the local climate and geology in mind.[24] The following environmental factors are critical to consider:

- Rainfall
- Temperature
- Soils

Local rainfall, temperatures and soils may affect design specifications such as:

- Plant species selection
- Sizing

Rainfall and Temperature

Local rainfall and temperatures inform both the size of the GI/LID feature and the appropriate plants for landscaping. In Maricopa County, the climate is considered semi-arid with long periods of dry, hot conditions punctuated by high-intensity, short-duration storms during monsoon season (generally July through September). In the winter, fronts often bring lower-intensity storms to the area. Based on rainfall data from over 300 rain gauges in Maricopa County, the city of Scottsdale determined that 90% to 95% of

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[24] The climate considerations included in this section were primarily obtained from "Low Impact Development and Green Infrastructure Guidance Manual and "Greater Phoenix Metro Green Infrastructure Handbook: Low-Impact Development Details for Alternative Stormwater Management."

all storms were less than 1.5 inches which is well suited to effective stormwater management through GI/LID applications.[25]

Soil

Soil characteristics heavily influence the rate of infiltration at a site, which is a crucial component of GI/LID technologies. Like rainfall or temperature, soil characteristics also determine which plants are most suitable for GI/LID technologies. Soils in Maricopa County tend to be loamy sand or sandy loam in texture.[20] They generally exhibit higher permeability and alkalinity but have lower organic matter content. Some soils in Maricopa County may also contain clay or caliche layers.[15] Caliche layers consist of hardened concrete-like material formed by mineral deposits. If not removed or punctured, both clay and caliche layers can inhibit infiltration and plant growth.

Plants

Appropriate plant selection will minimize costs and increase long-term success while achieving desired performance levels. When selecting plants, consider the following factors:

- Suitability for semi-arid environments
- Mature size and natural shape of plant species
- Proximity to public roads or streets and sensitive underground utilities
- Tolerance for periodic inundation and long periods with low to no water
- Placement of plant material within GI/LID feature – “right plant in the right place”

Native plant species are well-adapted to the unique conditions of a semi-arid environment. The following documents include lists of native plant species recommended for GI/LID features:

- Pima County and City of Tucson Low Impact Development and Green Infrastructure Guidance Manual[19]
- Greater Phoenix Metro Green Infrastructure Handbook: Low-Impact Development Details for Alternative Stormwater Management[25]
- Phoenix Active Management Area’s Drought Tolerant Plant List[26]

Sizing

The size of a GI/LID feature primarily depends on local rainfall events. The American Society of Civil Engineers recommends sizing GI/LID features based on the rainfall event that occurs in 85% of all storms. Pima County’s 2015 Low Impact Development and Green Infrastructure Guidance Manual suggests that GI/LID features should accommodate between 0.5 and 1.5 inches of rainfall. Maricopa County

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[25] City of Scottsdale and Arizona State University. Greater Phoenix Metro Green Infrastructure Handbook: Low-Impact Development Details for Alternative Stormwater Management. Prepared by Dibble Engineering and Logan Simpson. January 2019.

[26] Arizona Department of Water Resources. Low Water Use/Drought Tolerant Plant List: Official Regulatory List for the Arizona Department of Water Resources, Phoenix Active Management Area. May 2007. https://repository.asu.edu/attachments/148177/content/Low%20Water%20Use%20Plant%20List.pdf.

recommends the 0.5-inch event as the minimum sizing requirement for GI/LID features. This depth of rainfall represents the first flush rainfall, which typically accumulates the highest levels of pollutants.

Operations and Maintenance Considerations

Like all stormwater features, appropriate maintenance of GI/LID features is required to perform at optimum levels. For example, a 2018 assessment of existing GI features in Phoenix, Arizona, observed that pervious concrete at a site performed poorly in infiltration because of sediment build-up on the surface, likely from insufficient maintenance.[27] In most cases, GI/LID features do not necessarily require more maintenance but a different style of maintenance that respects the functions of the natural features. Thoughtful selection of plants, soil, mulch and irrigation can reduce standard landscape maintenance practices.

Maintenance generally includes:

- Removing debris and sediments
- Removing weeds
- Temporarily watering vegetation during establishment or drought periods
- Proper pruning of trees and shrubs, if required
- Replacing dead plants
- Repairing any damage from erosion or human activity
- Replacing mulch

[27] City of Phoenix. Study: Effectiveness of Existing Green Infrastructure in Phoenix. Prepared by Coe & Van Loo Consultants, Inc. December 2018.

Bibliography

Hazard Mitigation Plans

Maricopa County. 2015 Multi-Jurisdictional Hazard Mitigation Plan. Prepared by JE Fuller/ Hydrology & Geomorphology, Inc. November 2015.

Unincorporated Maricopa County. 2015 Floodplain Management Plan. Prepared by LTM Engineering, Inc. November 2015.

Flood Management

City of Phoenix. Floodplain Management Plan. Prepared by HDR Engineering Inc. May 2016.

Flood Control District of Maricopa County. Reduce Your Flood Risk: A Resource Guide. June 2019.

Drainage Studies

Flood Control District of Maricopa County. Tempe Area Drainage Master Study, LID Application Review and FLO-2D Modeling, Revised April 2016.

Rio Verde Area Alternative Stormwater Management, Water Conservation, Green Infrastructure/Low Impact Development Analysis Tools and Development Summary Report. 2018.

Arid Climate GI/LID Manuals

Arizona Department of Water Resources Conservation Program. Retrieved November 21, 2019, from https://new.azwater.gov/conservation/landscaping.

Arizona Department of Water Resources. Low Water Use/Drought Tolerant Plant List: Official Regulatory List for the Arizona Department of Water Resources, Phoenix Active Management Area. May 2007.
https://repository.asu.edu/attachments/148177/content/Low%20Water%20Use%20Plant%20List.pdf.

City of Scottsdale and Arizona State University. Greater Phoenix Metro Green Infrastructure Handbook: Low-Impact Development Details for Alternative Stormwater Management. Prepared by Dibble Engineering and Logan Simpson. January 2019.

Jiang, Y., Yuan, Y., and Piza, H. (2015). A review of applicability and effectiveness of low impact development/green infrastructure practices in arid/semi-arid United States. Environments, 2(2), 221-249.

Lee, J., and Fisher, C. (2016). Arid green infrastructure for water control and conservation. State of the Science and Research Need for Arid/Semi-arid Regions. Environmental Protection Agency. EPA/600/R-16/146.

Meerow S., Natarajan M., and Krantz D. "A review of green infrastructure performance in arid environments." Unpublished manuscript. October 14, 2019.

Pima County and City of Tucson. Low Impact Development and Green Infrastructure Guidance Manual. March 2015.

Pima County Regional Flood Control District and Pima Association of Governments. Evaluation of GI/LID Benefits in the Pima County Environment. Prepared by Infrastructure, LLC and Stantec. July 2014.

Watershed Management Group. Green Infrastructure Manual for Desert Communities. January 2017.

Yang, J., and Wang, Z. H. (2017). Planning for a sustainable desert city: The potential water buffering capacity of urban green infrastructure. *Landscape and Urban Planning*, 167, 339-347.

GI/LID Evaluation

City of Phoenix. Study: Effectiveness of Existing Green Infrastructure in Phoenix. Prepared by Coe & Van Loo Consultants, Inc. December 2018.

Fassman, E. A., & Blackbourn, S. (2010). Urban runoff mitigation by a permeable pavement system over impermeable soils. *Journal of Hydrologic Engineering*, *15*(6), 475-485.

Sansalone, J., Raje, S., Kertesz, R., Maccarone, K., Seltzer, K., Siminari, M., Simms, P. and Wood, B. (2013). Retrofitting impervious urban infrastructure with green technology for rainfall-runoff restoration, indirect reuse and pollution load reduction. Environmental pollution, 183, 204-212.

Cost Benefit Studies

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

City of Tucson and Pima County Regional Flood Control District. Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area. Prepared by Watershed Management Group. May 2015.

Landry S., Koeser, A., Northrop, R., McLean, D., Donovan, G., Andreu, M., and Hilbert, D. (2018). City of Tampa Tree Canopy and Urban Forest Analysis 2016. Tampa, FL: City of Tampa, Florida.

GI/LID and Health Benefits

Kim, G., & Coseo, P. (2018). Urban park systems to support sustainability: The role of urban park systems in hot arid urban climates. Forests, 9(7), 439.

Polonsky H., Cohen-Cline H., and Wolf K. Green Infrastructure and Health Guide. Willamette Partnership and Oregon Public Health Institute. Prepared by the Oregon Health and Outdoors Initiative. January 2018.

Roe, J. (2016). Cities, Green Space, and Mental Well-Being. *Oxford Research Encyclopedia of Environmental Science.* https://oxfordre.com/environmentalscience/view/10.1093/acrefore/9780199389414.001.0001/acrefore-9780199389414-e-93.

The Trust for Public Land. "The benefits of green infrastructure for heat mitigation and emissions reductions in cities." June 2016.

U.S. Environmental Protection Agency. 2008. Reducing urban heat islands: Compendium of strategies. Draft. https://www.epa.gov/heat-islands/heat-island-compendium.

Appendix A: Sample Mitigation Strategies from the 2015 Maricopa County MHMP that Could Align with GI/LID

Table 4. City of Phoenix Sample Mitigation Strategies from the 2015 Maricopa County MHMP that Could Align with GI/LID

Planning	Capital Improvement Projects	Development Requirements	Stewardship and Education
Continue to include policies in the General Plan that protect the natural flow regimes of washes and designate areas for Open Space and Preserves.	Construct drainage facilities to mitigate flooding hazard to residents of the city.	Review building permits for compliance with Floodplain Ordinance and National Flood Insurance Program (NFIP) regulations. Update and adopt a revised building code.	Maintain and execute a water use awareness outreach program. Continue to provide links on the website to sources of hazard mitigation educational materials such as FEMA.gov and Ready.gov.
Approaches to integrate GI/LID into HMP to mitigate for drought, flood and extreme heat			
Include GI/LID approaches where appropriate in relevant planning and guidance documents to mitigate for drought, flood and extreme heat.	Consider GI/LID approaches to drainage facilities and other capital improvement projects to mitigate for drought, flood and extreme heat.	Consider integrating GI/LID options into development requirements to mitigate for drought, flood and extreme heat.	Include information about GI/LID technologies and how to implement voluntary projects in community education programs to mitigate for drought, flood and extreme heat.

Table 5. City of Tempe Sample Mitigation Strategies from the 2015 Maricopa County MHMP that Could Align with GI/LID

Planning	Capital Improvement Projects	Development Requirements	Stewardship and Education
Develop a water infrastructure master plan that discusses water resources and identifies vulnerabilities to long-term water supply. Tempe will continue to develop additional groundwater storage and recovery programs to significantly reduce potential drought impacts. Planning documents include the 1997 Tempe Water Resources Plan (updated in 2002), the 1999 Tempe Integrated Water System Master Plan, and the 2002 Drought Management Strategy Plan.	Miscellaneous flood control and storm drainage projects to improve drainage and reduce flooding potential in various locations. Stormwater outfall inspection – activities for both condition and capacity of outfall locations to regional waterways. Ongoing project work in cooperation with the Arizona Department of Transportation (ADOT) to identify and mitigate flooding related to freeway systems.	Review building permits for compliance with floodplain ordinance and NFIP regulations.	Seek funds for workshops and conferences. Utilization of Tempe social media platforms to educate the general public.
Approaches to integrate GI/LID into HMP to mitigate for drought, flood and extreme heat			
Include GI/LID technologies where appropriate in relevant planning and guidance documents to mitigate for drought, flood and extreme heat.	Consider GI/LID approaches to capital improvement projects to mitigate for drought, flood and extreme heat.	Consider integrating GI/LID options into development requirements to mitigate for drought, flood and extreme heat.	Include information about GI/LID technologies and how to implement voluntary projects in community education programs to mitigate for drought, flood and extreme heat.

Table 6. Unincorporated Maricopa County Sample Mitigation Strategies from the 2015 MHMP that Could Align with GI/LID

Planning	Capital Improvement Projects	Development Requirements	Stewardship and Education
Update the Flood Control District of Maricopa County 2009 Comprehensive Floodplain Management Plan and Program to set the framework in mitigating flood hazards.	Construct facilities to mitigate flooding hazards to residents of Maricopa County. Channelize an existing wash to contain flood flows and protect existing homes. Construct a basin and storm drain to mitigate flooding hazards to existing and future homes. Encourage bridge or culvert construction where roads are in locations susceptible to flooding.	Review building permits to ensure that unincorporated Maricopa County residents are safe from flooding by meeting the NFIP requirements for development within a Special Flood Hazard Area through enforcement of floodplain regulations.	Continue public education program to assist residents in recognizing potential flooding and erosion hazards and inform them on how to reduce risk to life and property. Conduct public outreach to educate the residents about water conservation. Educate/advise subdivision developers about County subdivision regulations that outline and highlight the provisions for renewable water uses.
Approaches to integrate GI/LID into HMP to mitigate for drought, flood and extreme heat			
Include GI/LID technologies where appropriate in relevant planning and guidance documents to mitigate for drought, flood and extreme heat.	Consider GI/LID approaches to capital improvement projects to mitigate for drought, flood and extreme heat.	Consider integrating GI/LID options into development requirements to mitigate for drought, flood and extreme heat.	Include information about GI/LID technologies and how to implement voluntary projects in community education programs to mitigate for drought, flood and extreme heat.

Table 7. 2015 Floodplain Management Plan for Unincorporated Maricopa County – Actions that Could Align with GI/LID

Planning	Capital Improvement Projects	Development Requirements	Stewardship and Education
Continue preparing and updating Area Drainage Master Studies/Plans (ADMS/Ps) and pursue implementation with local jurisdictions Recognize natural resource benefits (use of water and aggregate; outdoor activity) within the ADMS/P program. Identify and accommodate wildlife corridors, habitat, and recreational opportunities as part of the ADMS/P program and during the planning and construction of flood control projects. Support multi-use/multi-benefit approaches to floodplain management. Incorporate low-flow stormwater conservation and explore partnerships for best use of water.	Incorporate ongoing best management practices and emerging LID technologies in design projects. Evaluate floodplains and District-owned lands for groundwater recharge potential and explore public/private partnerships to support groundwater recharge. Promote restoration of natural habitat by replacing invasive species with native species where feasible. Explore avenues to expand the Capital Improvement Program (CIP) budget for infrastructure to meet the demands of identified flood risks. Adjust criteria for Small Projects Assistance Program (SPAP), which provides funding for drainage infrastructure, to allow projects for areas that have a	Encourage the Maricopa County Planning & Development Department to continue to propose/discuss "good ideas" at pre-application meetings for all proposed development (i.e., mitigation measures and approaches to reduce the risk of flooding).	Offer technical assistance to residents seeking information and at the request of municipalities that perform their own floodplain management. Create a nontechnical booklet with photos and illustrations of examples of good versus poor floodplain management practices and a fact sheet with resources on floodproofing for distribution by inspectors and staff. Provide annual funding for the Flood prone Properties Assistance Program (FPAP) and floodproofing activities. Partner with sand and gravel operations to implement mutually beneficial activities in the river corridors. Develop a marketing plan to promote sound floodplain

Planning	Capital Improvement Projects	Development Requirements	Stewardship and Education
	demonstrated flood risk but have not previously experienced structural flooding.		management practices. Educate the public and officials on floodplain management needs and benefits. Develop multi-hazard educational material on the effects of long- and short-term changes to the watersheds. Develop a strategy to publicize the benefits of past floodplain management practices, flood control efforts, and the potential economic benefits from reduced flood losses and disruption to commerce. Develop educational material and guidelines for fencing to promote lot-to-lot drainage functions.