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A Playbook for Transportation Projects in Pima County Communities

Grant Road
Photo: Wheat Design Group

PART 3

Green Infrastructure Design, Implementation, and Maintenance for Arid Landscape Transportation Projects

The management of stormwater as a resource within and along our roadways requires establishing new guidelines at each stage of the GI project lifecycle to ensure continued public safety and overcome perceived and real barriers and challenges. The following chapter takes a solutions-based approach to addressing common challenges when considering GI features and then lays out guidance for design, implementation, and maintenance best practices to ensure a positive return on investment. This section is supplemented by the appendices including recommended design guides, plant lists, and maintenance schedules.

Terminology

Many GI related terms are used interchangeably. The information below is provided as a cross reference between terms used in various disciplines and policies. Transportation related examples are provided.

Curbless bioswale.
Photo: Watershed Management Group

Bioretention. Described as "stormwater harvesting" in many local manuals and it is important to note that these catch-basins not only retain water but also include vegetation as part of the infrastructure and function. Also called a rain garden or rain basin by the public. A shallow landscape depression sited at a low point to collect, utilize, treat, and infiltrate stormwater. Typically designed for water quality treatment; can also provide minor flood storage with enough space. Specifically, a bioretention basin design includes vegetative ground cover, organic mulch as a surface cover, and, when conditions allow, native shade trees. Pima County RFCD and City of Tucson manuals limit use of this term to GI management practices that include engineered soils.

Best management practices (BMPs). Activities, practices, or prohibitions of practices designed to prevent or reduce pollution.

Bioswale. A swale is described in local manuals as a depression that is cut into the soil for the purpose of conveying stormwater and it is important to note that although "bio" is not in those terms, in GI/LID guidance it is implied. A bioswale, or vegetated swale, is a linear vegetated landscape feature which promotes stormwater infiltration while facilitating drainage such as along roads with narrow rights-of-ways. May consist of a runnel or an earthen V-ditch if used to promote infiltration with checkdams, meanders and vegetation.

Complete Streets. An approach to transportation planning and design that guides the development of a safe, connected, and equitable transportation network for everyone - regardless of who they are, where they live, or how they get around.

Intersection bumpout with green infrastructure.
Photo: Watershed Management Group

Curb extension. A curb extension is a term for street design features where the existing curb line is extended into the parking lane of a street creating lane narrowing which may provide space for green infrastructure to manage street runoff. They can reduce impervious surfaces, reduce pedestrian crossing distances, and slow traffic as well as stormwater. Examples include bump outs, which when used with a meander is known as a chicane.

Curb inlets. Curb inlets, cuts, or cores are openings created in the curb to allow stormwater from the street or other adjacent impervious surface (e.g. parking lot) to flow into a depressed infiltration and planting area.

Crescent berms. Sometimes called "tree eyebrows" by Trees for Tucson, these round or boomerang shaped mounds of rock and soil are created perpendicular to runoff flow and may have a shallow excavation to hold water uphill of the berm. The berm is often placed outside the drip line of the tree and helps to detain the water and increase soil moisture.

Crescent berms create tree planting areas in a gravel lot previously used for parking.
Photo: Hans Huth

Daylight. To bring stormwater or street stormwater flow to the surface, exposed to open air and visible to the public.

First flush. The delivery of a highly concentrated pollutant loading during the early stages of a storm due to the washing effect of runoff on pollutants that have accumulated on drainage surfaces.

First-flush retention. Defined in the Pima County RFCD's Design Standards for Stormwater Detention and Retention as the capturing and retaining of the stormwater runoff volume from 0.5 inch of rainfall on all newly disturbed or impervious areas for new development or redevelopment. Often, requirements can be readily achieved through GI practices.

Sugar Hill neighborhood green alley during construction.
Photo: Watershed Management Group

Green Alley. Converted alleys from underutilized infrastructure into open space amenities using GI such as permeable pavement or bioswales. Benefits include reduced crime, encouraging people to walk, and creating connections between neighborhood destinations. (See Sugar Hill neighborhood in Tucson for an example).

Hardscape. Impermeable surfaces, such as concrete or stone, used in the landscape environment along sidewalks or in other areas used as public space

Infiltration Trenches and Drywells. Infiltration trenches are linear, rock-filled features that promote infiltration by providing a high ratio of sub-surface void space in permeable soils. Dry wells are typically distinguished by being deeper than they are wide but may not be applicable for the ROW depending on the jurisdiction. Dry wells are useful in densely developed areas. Any site with potential for previous underground contamination should be investigated and causes major restrictions. These features can be part of a GI system if the water is used by vegetation and can be accompanied by vegetation filter strips to treat contaminants prior to infiltration.

Low Impact Development (LID) – 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 (holistic LID, or LID integrated management practices) and individual small-scale stormwater management practices (isolated LID practices) that promote the use of natural systems for infiltration, evapotranspiration and the harvesting and use of rainwater. Sometimes the term is used interchangeably with GI.

Permeable pavers reduce impervious surface areas and aid in heat island mitigation.
Photo: Watershed Management Group

Permeable Pavement. Permeable pavements include a variety of methods for paving roadways, bikepaths and pedestrian pathways to enable infiltration of stormwater runoff. Permeable pavement methods include pervious concrete, porous asphalt, paving stones, porous recycled tire products, and interlocking pavers

Pretreatment. A feature incorporated into a stormwater conveyance system to remove sediment, oil, grease, and other pollutants before they enter a stormwater basin, drywell or are discharged to receiving waters. May consist of a biological filtration.

Retention vs Detention. Retention collects and stores runoff while Detention is the temporary storage of stormwater to control discharge rates and allow for infiltration or discharge.

Stormwater Harvesting Basin. Both Pima County and City of Tucson regulatory and guidance manuals use this term to comprehensively include many GI retention practices, including bioretention basins, and roadside basins.

Urban Heat Island. An urban heat island is a metropolitan area which is significantly warmer than its surroundings. The urban heat island effect occurs as a result of buildings, roads, and other impervious surfaces absorbing the heat during the day and releasing it back slowly at night, thus increasing temperatures in urban areas. Shade-producing GI projects can reduce heat island impacts.

Common GI design challenges and potential solutions

Site characteristics can present design challenges which must be considered early in the design process. A CSS framework as outlined earlier may help overcome site challenges and foster a solution-oriented design process. When challenges are identified the project team may need to select alternate strategies or make slight design modifications to achieve the desired performance goals identified at the beginning of the project. A list of common challenges and potential solutions follows.

Underground utilities

Below ground utilities can impede green infrastructure installation but there are common solutions (see the checklist on Page 47 on early coordination and bundling lines near utilities). Excavation near utility lines is a primary concern for both project construction safety and the long-term health of the associated GI feature. Early identification of utility locations is critical to facilitate a smooth planning process for identification of GI opportunity areas and then the selection and placement of specific GI features.

It may be possible to modify the GI design to accommodate utility infrastructure situated over, under, or adjacent. For example, a basin area could transition to a shallow bioswale supporting herbaceous understory if there is concern for deeper excavation or tree roots. Alternatively, the GI features could shift in location or integrated with a meandering pedestrian and/or cycling paths to better accommodate basin areas and tree placement.

Additionally, it is recommended to coordinate with utility companies to assess when planned maintenance may occur to coordinate timing of the GI feature installation. This will prevent damage to the GI feature or potential sediment contribution into the infiltration basin area.

Prevent tree root damage to infrastructure (sidewalks, pipes, streets)

The selection and placement of appropriate trees is critical to avoid infrastructure damage. Tree roots naturally will grow to available water sources which when paired with GI will be the stormwater infiltration areas. Each tree should be paired with an ample infiltration area where pipes, sidewalks, or roadways do not need to be crossed by the tree roots. Selection of tree species with less aggressive root systems is recommended when there is concern (see recommended tree list in Appendix B). Additionally, root barriers can be installed along critical infrastructure when additional protection is desired.

Minimize flood risk

GI enables transportation engineers to avoid risks associated with traditional grey infrastructure including preventing flooding that is caused by impervious surfaces. GI can be designed to not increase flood risk, but also to reduce it.

The standard design details in the Green Infrastructure for Desert Communities developed by Watershed Management Group and reviewed by the City of Tucson Department of Transportation and Mobility highlights flow-neutral design strategies. General characteristics to allow for flow-neutral features include flush curbs where the curb is perpendicular to flow direction. Raised curbs on the street side of the GI feature are only located parallel to flow direction and used to protect from vehicles entering the structure to maintain flow-neutrality.

Common stormwater risks identified within the City of Tucson are flooding, erosion, sediment transport, and flash flood events.[45] The City of Tucson requires the following design criteria for all newly constructed or substantially improved roadways: Runoff from a ten-year storm must be contained within the curbs of

CASE STUDY

Urban runoff can be valued as a resource.
Photo: Watershed Management Group

A 2017 drainage memorandum[47] by Kimley-Horn Associates (planning and design engineering consultants) regarding a drainage analysis for the Glenn Street Neighborhood Improvement Project from Columbus Blvd to Country Club Road reviewed the potential flood risk of adjacent properties associated with the design of GI chicane (bump-out) features. Kimley-Horn assessed the additional flood risk for two design scenarios based on the concern that GI features increased the street roughness thus impeding flood flows on the street.

OPTION 1
Included a 4-ft wide opening adjacent to the existing curb to allow street runoff to flow into and out of the depressed buffer-yard with use of a vertical curb extending from the opening, around and including the parallel curb section.

OPTION 2
Eliminated all vertical curbs except the portion parallel to the existing curb. The Manning's Normal Depth calculations assumed a street with full flow.

Both design options resulted in a potential rise in flow depth within the street of less than the maximum allowable of 0.1 feet. The drainage memo recommended Option 2 to minimize drainage impacts on adjacent parcels compared to existing conditions as it would divert less than 3% of the street flow into adjacent properties compared to 15% for Option 1. Additionally, they alleviated concerns of flooding by recommending plants that will not impede runoff such as "... thin plants like grasses that would lay down during a flow event, or a small trunked tree with foliage well above the top of curb elevation. Bushes, shrubs, or other plants that increase roughness and potentially block flow should be avoided." The City ultimately allowed the use of GI chicanes and chose option 2 for the design and implementation of the Glenn Street chicanes.

the street. On multi lane roadways, at least one travel lane in each direction shall be free from flooding during a 10-year flood. Otherwise storm drains, drainage channels, or other acceptable infrastructure shall be provided to comply with all-weather access requirements. In order to meet the above design criteria, Tucson employs a mix of traditional drainage practices and water harvesting/ GI methods.[46]

Wilson Drainage flooding creates road danger.
Photo: Watershed Management Group

Mitigate peak flood flows

The ability of distributed GI to mitigate peak regulatory flood events relies largely on the scale of the intervention across a target subwatershed. Taking an integrative approach to treat both private parcels and public rights-of-way (ROWs) can substantially reduce peak flow volumes and flood depths. Two flood model case studies highlight the potential of GI under different treatment scenarios. A 2015 report by Watershed Management Group in partnership with Pima County Regional Flood Control District (RFCD) and the City of Tucson Ward 1 Council Office indicated that GI implemented broadly (25% level of adoption by residential front yards with select green streets retro-fits) across an urban subwatershed can have a significant reduction ranging from 10% to 24%) by subwatershed for a 100-year 3-hour event.[48]

A Tempe, AZ area Drainage Master Study reviewed the implications of LID interventions by type and at different adoption levels. The model results indicated the Green Street treatment scenario reduced peak flows by 58%, on-lot treatments had the highest impact to reducing peak flow (86% reduction), and Green Parking (77% reduction) the next highest. [49]

Enhanced mobility and safety

GI is compatible with enhancing the safety of alternative mobility modes. Enhanced safety often is the result by means of calming vehicular traffic, narrowing pedestrian crossing points, or providing a physical buffer to vehicles. Additional safety benefits may also include more efficiently drained pedestrian and bicycle travel lanes, reducing flood flow depths, shading and cooling the streetscape, and improving air quality. As mentioned in following sections it is important to maintain planting setbacks from travel areas and lines of sight for general visibility.

Often the GI feature can be placed and aligned to help physically buffer pedestrians and cyclists from vehicles. When creating a visually meandering roadway with chicanes or other features be sure that ample signage or reflectors are in place for nighttime safety.

Vehicle safety

While GI should enhance vehicle safety, however, design of GI is often limited by a fear of what might happen to the unsafely operated vehicle. It should be accepted that if GI is used as a vehicle buffer for bicycling and pedestrian travel lanes then vehicle encounters with the GI feature may occur. GI features should follow generally accepted roadway safety guidelines based on the road type in place by the local jurisdiction/authority and the context of the frequent user modes. See the GI feature standard designs found in Appendix A. The PAG Road Safety Assessment process has resulted in discoveries that even following all design standards doesn't guarantee the safest outcome necessarily. The standards need to take into account the impacts their application will have on performance. The answer is context sensitive, not a one size fits all distinction. Training and experience of those addressing or interpreting the standards are typically the biggest factors in this contextual approach.

Sight visibility requirements

GI features should maintain site visibility requirements associated with turn lanes, ingress and egress points, and even residential driveways. A recommended understory plant list for use in GI features is included (see Appendix B). Plants which can maintain clear site lines should be allowed in associated GI features even if adjacent to intersections or turn lanes.

By way of example see Sec. 25-52.1(4) of the Tucson City Code, 5-01.7.0 Unified Development Code STANDARDS FOR TREES IN SIGHT VISIBILITY TRIANGLES, and 10-01.5.0 Tucson Technical Standards Manual SIGHT VISIBILITY.

Soil stability

GI features if installed properly should not compromise soil stability or impair adjacent roadway infrastructure. Typically, the header curb with a depth of at least 12" in the soil profile is sufficient to protect instreet roadway surfaces or other infrastructure. GI infiltration areas are typically limited to an 8" ponding depth which facilitates rapid infiltration and minimizes the potential of full saturation of the surrounding soil or seepage underneath a compacted and well prepared roadbed.

If a soil test confirms presence of a high percentage of shrink-swell clays or presence of soil piping characteristics, then a geotechnical engineer should be consulted. See the best practices checklist for how to address limiting soil layers which can impair drainage. Lastly, piping or slumping may occur if a nearby or underlying utility line trench was not properly re-compacted when filled. This is a rare occurrence. The utility should be contacted and informed of the problem for coordinating and determining how to best address this. If there is further need for a soil moisture barrier based on the soil stability test, they can be installed vertically along roadway edges or other critical infrastructure to minimize saturation of soil adjacent to stormwater basin areas. Tree planting cells can also be used to minimize lateral moisture seepage.

Accumulation of sediment in the basin is typically only a problem if infiltration is affected by fines or retention volume is reduced. Otherwise sediment may act as a beneficial mulch. Sediment traps can be used if maintenance regimes support periodic clean out to help meet specified stormwater quality goals.

Rural Roads

Stormwater management on rural roads can have an impact on habitat, waterways, and erosion. Pima County has had success in addressing runoff on rural roads with water harvesting approaches. Pima County has trained employees with Bill Zeedyk and reference his manual Water Harvesting from Low-Standard Rural Roads. This manual uses the approach of improving common grade control practices to create vegetation and water quality benefits. For example, flow splitters and spreaders are common techniques used on rural roads to evenly distribute flow using a wing ditch off a road drain ditch. When using these practices, gradient, switchbacks, and spacing are key to creating benefits of water harvesting and effective sediment control. A media luna uses loose rock in a long band with ends pointed up-valley to prevent erosion on a hillside, which may be seen along a raised roadway. Crescent berms that are placed outside the drip line of the tree help to detain the water and increase soil moisture for vegetation use. One rock dams prevent erosion, capture coarse bedload particles, raise moisture levels uphill and help to establish vegetation. Zuni Bowls dissipate energy in water which prevents head cuts of erosion from progressing uphill in the flow path. They also trap water so that vegetation can grow. These can be used where flow paths have become incised or channelized such as after a culvert.

Design Best Practices

Below are design best practices that have been refined through practice and development and shown to provide successful GI performance in the Pima County region. The purpose of these best practices is to facilitate optimal GI performance in our arid environment to achieve intended benefits while reducing overall operations and maintenance.

GRADING, CRITICAL ELEVATIONS, INLETS, ROUTING AND RETENTION

- **Grading** Grading of the roadway surface will be planned and implemented to promote distribution of runoff into adjacent landscape areas and to minimize grey stormwater infrastructure. Grading within the landscape areas will ensure the ability to receive street runoff, distribute throughout the planting area, and promote infiltration through the use of bioretention basins, terraces, berms, and/or checkdams.
    - Landscape areas should be designed for water harvesting at every possible opportunity. Bioretention areas should be setback from roadway edges, sidewalks, utilities, and other critical infrastructure per standard setbacks set by a jurisdiction. Design safeguards (e.g. root guards, railing, etc.) to protect adjacent infrastructure may allow encroachment of these setbacks.
    - GI features should intersect with the lowest elevation (e.g. the curb and gutter drain) of the roadway to ensure collection of stormwater to capture the greatest flow and facilitate rapid draining of stormwater from the roadway.

- **Pedestrian Path Space** The City requires that a 5' pedestrian path be maintained and clear in the ROW. Any new GI behind the curb or at edge of pavement with no curb must maintain this 5'. If the GI basin is near the curb or edge of pavement and the 5' is behind it closer to the property line a 2' clear space from face of curb or edge of pavement to the top of basin must be maintained so that if a car parks next to the GI the passenger has a 2' space to step out onto. This is often a limiting factor when it comes to GI at roadside.

- **Critical Elevations** Set the inlet to a GI bioretention basin at the upstream side of a basin and ensure each basin has an associated stormwater inlet to allow collection even with the smallest of rain events. This will ensure thorough soaking to support associated plants with each rainfall runoff event.
    - Provide for a minimum of 2" drop from curb inlet to top of rock or mulch in the receiving basin to direct passage of stormwater into the basin.
    - Incorporate a sediment trap (bowl feature with rip-rap lining and a downstream rocked lip) if routing concentrated flow into and through a landscape feature. Unless annual sediment removal is available or to design to meet a specific water quality goal, GI basins do not require a sediment trap. Often the first basin in a series can function as the sediment trap for subsequent basins. It should be considered that since maintenance does not typically remove accumulated sediment in the GI basin the sediment trap becomes an added cost for little to no value added.
    - Ensure that if a sediment trap is incorporated then it is set at least 2" below the top of rock or mulch at the basin entry point for clear passage of stormwater into the basin.

- **Routing Flow** GI bioretention basins should be designed with a single inlet/outlet to allow for use of organic mulch as a surface cover. The basins function as "backwater" basins which calm the flow and promote capture and remediation of stormwater pollutants as a "first flush" to the stormwater system.
    - If flow is routed through a landscape section along a street, then multiple inlets should be placed along the curb to ensure distribution of stormwater across the entire landscape area.

- Safety spillways or drains are included if necessary to convey excess water safely to downstream stormwater infrastructure or a channel. The drain inlets (and protective grates) will be placed at an elevation that ensures retention of water in the landscape area to at least meet performance standards. Ideally, the drains are placed as far downstream in the landscape areas as possible to maximize landscape conveyance, retention and infiltration of runoff. For example, refer to Tucson's standard detail for a Type C Catch Basin.
- For in-street features, only provide a raised curb at corners of the feature to allow stormwater to evenly flow across a flush header curb into the GI feature on the street side.
- Along streets with no curb and where a V-Ditch is created for drainage, utilize check-dams to slow flow (preventing erosion) and to infiltrate stormwater (for plant use).

- **Retention Capacity**
    - Steeper or vertical slopes allow for greater basin capacity to mitigate flooding and increase storage capacity for enhanced infiltration and soil moisture storage. Slopes steeper than 3:1 must be reinforced with appropriately sized rip-rap.
    - Basin slopes can be terraced to increase understory planting area and reduce appearance of deep drop between basin bottom and adjacent curb or sidewalk. Terrace elevation should be not higher than curb inlet elevation to retain basin volume and facilitate moisture access by plants.

- **Inlets** Curb inlets vary in style and function and preference is highly context sensitive.
    - Header curbs are the preferred inlet method for plant-able landscape areas unless behind curb bioretention basins are used. Paired with appropriate lighting and striping, continuous flush curbs ensure maximum flow and uniform distribution into landscape features without potential for blockages. Two additional benefits are a) the reduction in quantity of poured concrete necessary, as compared to raised curbs, and b) flush curbs allow for shallow flow to spread into the landscape area reducing potential for concentrated flow and resulting erosion.
    - A curb cut can refer to any standard 18"- 24" opening with beveled sides in a vertical curb. A wide opening like the cut is preferred as an inlet as it is less likely to be blocked by sediment or debris.
    - A curb core inlet refers to a 3"- 4" diameter opening at street level through a vertical curb. Although more affordable, since cores are more prone to blockage by debris, they should be used sparingly, and only in cases where a) a raised curb is required or exists, b) the beveled sides of a curb cut present safety concerns, and c) the curb is a minimum of 6" above street grade. The larger diameter is preferred when possible to prevent potential clogging of the inlet.
    - A scupper is an opening with a cover plate that allows runoff to enter a roadside bioretention basin while maintaining pedestrian access and safety. Scuppers are preferred in higher pedestrian zones and/or when water needs to be conveyed through a non-landscaped area (i.e. under a sidewalk). Scuppers are preferred over curb cores, as cores are more prone to blockages and require periodic maintenance to ensure function.

SURFACE MATERIALS SELECTION

- Landscape areas will be encouraged over hardscape surfaces wherever feasible. If runoff from adjacent collection areas cannot be directed to the landscape area, then the soil surface of the landscape area should at least be depressed to retain rainfall over the landscape surface for a 2" rainfall event.
- The design of landscape areas less than 3 feet in width will be avoided; these areas are infeasible for most plantings and are difficult to maintain.
- Utilize organic mulch (preferably coarse chippings ~3-4 in. length) as a surface cover in bioretention basins applied up to 4 in. depth. Greater depths may prevent light rains from reaching the soil. The use of organic mulch promotes healthy soils, the ability to process stormwater pollutants, cooler surface temperatures, enhanced soil moisture retention, and a reduction in germination of undesirable plants. The use of organic mulch also reduces maintenance and disposal costs since plant trimmings can be incorporated directly into surface mulch. Large coarse bark may not be appropriate in areas of stronger flows that do not have features containing the material as they may float away.

- Rip-rap is necessary in areas with higher energy conveyance, such as curb inlets, spillways, and in channels with slopes > 2%. Rip-rap can consist of angular rock mulch or salvaged concrete that is at least 4” in average diameter. Rip-rap used at the bottom of sediment traps should be laid flat to assist with periodic removal of accumulated sediment.
- Rip-rap should not be used a) for lining swales, for which the use of check dams is preferred; or b) at the bottom of infiltration basins, for which organic mulch is preferred. Rip-rap increases the difficulty of maintenance of GI features, including the ability to weed and/or remove sediment. The average size of the rip-rap should be specified based on expected flow characteristics.
- Use coarse organic mulch (preferred) or ¾” gravel for basin bottoms.
- The use of decomposed granite (DG), or “minus” material that includes fines and sediment, should never be used, since it can prevent infiltration within landscape and GI basin areas.

PLANT SELECTION AND LAYOUT PLANNING

- **Plant Water Use Considerations**
    - Avoid use of “moderate” water use plants (e.g. pomegranates and ash) to allow for reliance on stormwater as primary irrigation resource and mixing of irrigation water use zones.
    - Select low-water use, locally native plants to meet performance goals that improve survivability and reliance on stormwater for irrigation. See Appendix B for recommended tree lists.

- **Choosing Plant Varieties and Species**
    - Avoid use of fast growing hybrids (e.g. Desert Museum Palo Verde tree or Chilean mesquite species) as they often result in being weakly rooted or limbed. Research shows native trees irrigated with stormwater associated with curb-side basins grow up to 30% faster and quickly reach full size.
    - Maintain an updated tree selection list that accounts for experience with tree response to local conditions and incorporates air quality considerations (e.g. avoid high VOC trees).
    - Utilize low-profile, native, low-water use understory plants that provide an engineering (e.g. infiltration) and/or habitat function (e.g. pollinator support). For example, small to midsize native bunch grasses promote infiltration and uncompact soils without becoming overwhelming like the non-dwarf muhlenbergia species can become. Milkweed species provide critical habitat for Monarch butterfly caterpillars.
    - Native bunch grasses should be part of the plant palette for bio-retention basin and drainage bottoms. The dense fibrous root systems promote water infiltration and stability along conveyance swales by reducing potential for erosional scour of the soil surface. Only utilize native grass species as non-native grasses spread easily and adversely impact urban and natural environments. To avoid grass becoming a fire hazard use in small groupings with gaps between groupings.
    - For understory along roadways, utilize only accents and shrubs that are 3ft or under in mature height / width to reduce pruning (see suggested plant list in Appendix B).
    - Where additional space allows, consider large native shrubs, yucca, agave, and cacti in upland spaces above the bioretention areas to increase diversity of streetscapes and habitat.
    - Develop an alternate plant list that can be readily used if specified plants are not available at time of project implementation. This will help to avoid the selection of an inappropriate plant that is chosen for the project context and constraints.
    - Field check plant selection based on planting plan. Ensure if a “Dwarf” species is called out that the delivered plant is the same. Otherwise this can impact maintenance and sight visibility requirements.
    - Utilize plants that emit lower levels of VOCs for improved air quality. See resources section.

- **Plant Layout and Placement**
    - Plan layout of understory vegetation based on 100% of mature diameter and height. Overplanting increases maintenance labor.
    - Plan for appropriate placement of understory species according to microclimate requirements with clump and

gap arrangement to maximize biomass and habitat benefits.

- Select and place trees with adequate spacing from pathways (minimum 3-5 feet) and roadways (minimum 5-8 feet) to allow for minimal pruning during the first 2 years of tree planting.
- Place trees on an elevated terrace equal or slightly above ponded surface elevation height adjacent to basin or swale.
- Place plants that have a lot of litter, dropping leaves etc. away from basin inlets to avoid interior sediment from building up and preventing water from entering the basin and reducing overall maintenance

- **Site Context Constraints**
    - Select smaller stature trees if overhead utilities are present (e.g. acacia species trimmed to be multi branch).
    - Select narrow species for narrow ROWs (e.g. Whitethorn Acacia or Foothills Palo Verde)
    - Specify larger planting sizes for trees which may impact sight visibility in the first few years of growth. This will allow selective pruning to maintain sight lines.
    - For flood prone areas decrease plant roughness by selecting thin plants like grasses, that would lay down during a flow event, or a small trunked tree with foliage well above the top of curb elevation. Low lying bushes, shrubs, or other plants that increase roughness and potentially block flow should be avoided in areas with flood risk to adjacent properties.

IRRIGATION

- Installed irrigation systems should be utilized for landscape establishment periods only (1 - 5 years) and irrigation frequency should be gradually reduced after the 2nd year to meet water use performance goals.
- If an irrigation system is not installed, then a plan should be in place for supplemental irrigation) utilizing a water truck with plants carefully located to facilitate access to moisture. Typically, this is only needed ~1-4x per month during the dry, warm months, during establishment years.
- It may be preferable to use a bubbler irrigation system for directing supplemental irrigation into basin areas to facilitate simple, low cost, and easily maintained irrigation systems.
- All GI features should be designed to be reliant on only captured and infiltrated stormwater to provide the irrigation benefit. Conventional irrigation systems inhibit this healthy root development by overwatering and keeping soil moisture artificially high in the upper soil profile near to the plant. In addition, overwatering causes plants to have longer growth periods and put more energy into the above ground portion of the plant rather than investing in robust root development. This can exacerbate maintenance costs by increasing pruning frequency and making larger plants more susceptible to wind throw during storm events.

Design Checklists

GI specific checklists can provide valuable guidance throughout the process of planning and implementing roadway projects. They can be of particular value when determining whether a GI project is feasible and how to respond to site-specific challenges. Related guidebooks and design standards drawn from comparable arid-landscape communities are also available in Appendix A.

GENERAL PLANNING & DESIGN CHECKLISTS

Utilities

- ☐ Was coordination conducted with utilities during the pre-design phase to ensure collaboration?
- ☐ Are there below ground utility conflicts located in the planned GI infiltration areas? Can the utilities or the infiltration areas be relocated to accommodate the GI strategy?
- ☐ Are there above ground (e.g. overhead) utility conflicts that interfere with tree placement or require setbacks? Can the utilities, the trees, or the GI strategy be relocated to accommodate the GI strategy? Consider alternative vegetation sizes.
- ☐ For new roadway construction planning avoid placement of utility corridors or separate utility lines within landscape areas. If utility lines must cross a landscape area, they should be pre-planned for placement and bundled together to ensure maximum landscape planting and stormwater infiltration capacity.

Trees/ Significant Vegetation

- ☐ Are there existing trees that are to remain and that are constraints to locating GI strategies?
- ☐ Has tree planting been maximized within the project boundary and is there opportunity for more?
- ☐ Are trees located along walkways and integrated with GI features to support the shade trees? Is the Pedestrian/ Multi-use path Layout (PMU) layout ideal for maximizing shade from trees in relation to solar angles?

Topography

- ☐ Does the street grading facilitate potential collection of stormwater in the planned GI feature? If not, can placement of the GI feature be adjusted, or can an alternate GI strategy be selected?
- ☐ Are there steep slopes that need to be considered when designing length of GI basins or the selection of flow routing practices that can slow and retain runoff?

Soils

- ☐ Are there soil characteristics (e.g. hardpans, caliche, clay enriched layers, shrink/swell clays, collapsible soils, bedrock, etc.) that will restrict infiltration and percolation? Soil tests can be coordinated with the road construction sample cores (e.g. soil stability tests).
- ☐ Are the soil hydrological groups C or D? If so, can mechanical intervention (ripping, augering drain holes through caliche, amending with composted organics, etc.) address the soil characteristics that is causing limiting percolation?
- ☐ Optimal soil infiltration rates are at or above 0.5 inches/hour. Soil percolation tests can confirm infiltration rates. If infiltration rates are low, consider using an excavator to rip compacted soil layers, auger through calcium-carbonate accumulation zones (caliche) or amend soils with composted materials, or installing a minimum 12-inch sand layer under certain practices (e.g., bioretention, bioswale).
- ☐ Are there environmental conditions such as contaminated soil, monitoring wells, and groundwater wells that are near to the proposed strategies? If so, GI offsets may be needed. Refer to local regulatory guidance.

Flood areas

- ☐ Is this a known area of chronic or severe flooding of adjacent properties? Yes, choose flow-neutral design strategies (e.g. flush curbs and limiting understory vegetative roughness).
- ☐ Is there known nuisance flooding? Does the selected GI strategy address the localized nuisance flooding (small, short-term flooding in street)?
- ☐ Does the bioretention strategy support the retention requirements?

Pollutants

- ☐ Does the watershed location and strategy support the TMDL implementation or stormwater permitting?

Mobility

- ☐ Does vegetation placement ensure driver sight visibility or will selected plants be 3 feet in height or less or be able to be pruned to have overhead canopies providing an 8 feet clear zone from ground elevation? On driver's side, a clear zone above ground is also required.
- ☐ Does the plan include vegetation distribution and placement to promote pedestrian and bicycle safety?
- ☐ Has vegetation been included in the plan to promote traffic calming on residential and collector streets?
- ☐ Does the selected GI practice and placement of it promote pedestrian and bicycle safety (e.g. intersection bump-outs which reduce the street crossing length)?
- ☐ Does the GI practice selected support shade trees to cool pedestrian and bicycle lanes?
- ☐ Plan layout of vegetation based on 100% of mature size.

Innovation

- ☐ Is the project area conducive for experimenting with alternative GI LID strategies (e.g. permeable surfaces for sidewalks)?

Maintenance Considerations

- ☐ Has the agency/department who will perform the maintenance been invited to participate in the design process?
- ☐ Has the access of maintenance equipment been considered in the design? For example, if a separated bike lane is designed will street sweeping equipment be able to access the bike lane?
- ☐ Does the agency/department charged with maintenance have proper training for the designed features?

GI FEATURE SELECTION CHECKLISTS

Median Bioretention

- ☐ Is the street inverse crowned such that flow is routed to or along the median (e.g. via intercept drain) for collection in the bioretention area?
    - ☐ Yes, locating the GI feature in the median will facilitate collection and infiltration of stormwater.
    - ☐ No, then select an alternate strategy (see Streetside or Chicane).
- ☐ Is there sufficient area available for creating bioretention? (review requirements)
    - ☐ Yes. Great! Proceed.

- No, but the travel lanes can be narrowed to create additional space OR the use of subsurface bioretention cells could be used to support adding shade trees.

- Can the median be excavated to install the bioretention area without being in conflict with utilities, mature trees, vehicular passage or other features that cannot support excavating the median to be below existing grade?
  - Yes, proceed with planning.
  - No, intermittent conflicts are potentially present. The bioretention areas could be designed to be discontinuous along the median to avoid conflicts.
  - No, the conflicts persist for the entire median length. Consider alternate options such as meandering the travel lanes to facilitate intermittent bioretention areas; or consider intercept drains which convey stormwater to an adjacent area; or consider the potential to relocate the conflicting element if feasible.

- Is the planned bioretention area in a high flow conveyance zone?
  - Yes, select an alternate strategy or use large substrate and flow diversion strategies to locate bioretention areas off-channel.
  - No, if the slope is minimal (< 0.1%) consider designing the median to collect stormwater in contained bioretention basins to facilitate the use of organic mulch or if the slope is greater use a step fashion to facilitate a series of micro-bioretention areas along the median.

Chicane (or Bump Out), Linear Streetside Bioretention

- Is the street crowned or can flow be routed to the street gutter edge (e.g. via intercept drain) for collection in the bioretention area?
  - Yes, locating the GI feature along the roadway edge will facilitate collection and infiltration of stormwater.
  - No, then select an alternate strategy (see Median Bioretention).

- For residential street development, are the street pavement widths (curb to curb) overwide and/or allowed to be between 18 to 22 feet, with curb pullouts for passing of large vehicles? Or are travel lanes allowed to be 10 feet (or less) with curb pullouts for passing of large vehicles?
  - Yes, a linear streetside bioretention feature can decrease the hardscape footprint for additional density and integration of GI along the roadway. This can also help calm traffic on residential streets.
  - No, are there individual street parking slots that can be strategically converted into bioretention features (see chicane GI feature examples)?

- Can the bioretention area be depressed along most of the street or are there utilities, mature trees, driveways, or other features that cannot support excavating the area to be below existing grade?
  - Yes, consider planning a linear streetside bioretention feature.
  - No, intermittent conflicts are potentially present. Consider selecting chicanes (or bump outs) and place them where there are not conflicts.
  - No, the conflicts persist for the entire roadway length. Consider alternate options such as meandering the travel lanes to facilitate intermittent bioretention areas adjacent; or consider placing the bioretention areas behind the roadway curb edge; or place intercept drains which convey stormwater to an adjacent area; or consider the potential to relocate the conflicting element if feasible.

- ☐ For linear streetside features, will the entire length of the planned bioretention area be able to receive stormwater from the adjoining street area?
    - ☐ Yes, this is preferred to ensure support of plants. Be sure to space inlets appropriately or use a flush header curb with intermittent curb bumpers.
    - ☐ No, consider how to best route water through the feature to maximize plantable area that can be supported by infiltrated stormwater.
- ☐ Additionally, for all curb-side in-street features, are bioretention areas or bioswales allowed to replace the required "planting strip" or "parkway area" between the sidewalk and curb?
    - ☐ Yes. This can reduce the cost of adding header curb and increase potential bioretention area available.
- ☐ Lastly, for all curb-side features can stormwater conveyance under the pedestrian pathway reach plantable space?
    - ☐ Yes, consider the use of a scupper under the sidewalk to ensure conveyance does not become blocked.
    - ☐ No, a scupper will not be appropriate but a plantable space exists. Consider if there is sufficient stormwater to collect off of adjoining surfaces to support vegetation. Ideally there is a 3:1 catchment to plant canopy ratio to support low water use plants in the Pima County region.

Traffic Intersections

- ☐ Is the street inverse crowned or can flow be easily routed to the intersection center area (e.g. via intercept drain) for collection?
    - ☐ Yes, then a traffic circle or round-about is appropriate to support a bioretention infiltration area.
        - ☐ Is a sewer manhole access located within the area? Yes, sewer access typically requires wide access from one side of the street to the manhole and a tree setback from the manhole. See WMG's GI Manual Appendix for a design example.[50] Consider protecting the existing manhole collar with a ring of rip-rap. Where feasible or in new construction, raise manhole above the basin overflow elevation and high water surface level, so that drainage is directed away from sewer manhole to prevent sewer overflows from flood events. Manhole covers and rims should be designed to be watertight.
    - ☐ No, the street is crowned with stormwater flowing along the roadway edges. Then select intersection bump outs as an appropriate GI feature. If there are stormwater drains near the intersection will stormwater be intercepted and pass through the bioretention area before entering the stormwater drain?
        - ☐ Yes. Great, an intersection bump-out with GI is the preferred approach.
        - ☐ No. Is it possible to shift and locate the bioretention area before the drain or add a chicane or another feature to be just before the storm drain inlet?
- ☐ Can the bioretention area be excavated without being in conflict with utilities, mature trees, or other features?
    - ☐ Yes, proceed with planning.
    - ☐ No, intermittent conflicts are potentially present. The bioretention areas could be designed to be discontinuous to avoid conflicts.
    - ☐ No, the conflicts persist for the entire area. Consider alternate design options to relocate the bioretention areas while facilitating a safe intersection; or consider intercept drains which convey stormwater to an adjacent area; or consider the potential to relocate the conflicting element if feasible.
- ☐ Is the planned bioretention area in a high flow conveyance zone?
    - ☐ Yes, select an alternate strategy or use large substrates (rocks instead of organic mulch) and flow diversion strategies to locate bioretention areas off-channel.
    - ☐ No, if the slope is minimal (< 0.1%) consider designing the feature with a raised curb on the downstream side to collect and infiltrate additional stormwater. Be careful to ensure a safe overflow route is planned.

Cul-de-sac with GI

- ☐ Is the diameter of the cul-de-sac greater than the necessary turning radius of emergency vehicles and trash collection vehicles?
  - ☐ Yes, consider using a landscaped bioretention feature similar to traffic circles or round-abouts.
  - ☐ No, if it is for a new development consider a different road layout that promotes connectivity and minimizes the need for large hardscape spaces which generate stormwater and contribute to urban heat island effects.

Adjacent Park or Open Space Bioretention

- ☐ Is there sufficient elevation difference to direct water from the street to the open space?
  - ☐ Yes, proceed with planning.
  - ☐ No. Can a portion of the adjacent open space be excavated to enable receiving and infiltrating stormwater runoff? Or, can the stormwater be conveyed to another area within the open space?
- ☐ Are pipes needed to connect the road to the open space?
  - ☐ Yes, consider use of larger diameter scuppers or culverts that will minimize the potential of blockages.
- ☐ Are landowners or the managing agency of the open space willing to be a partner for planning, implementation and maintenance?
  - ☐ Yes. Great! Be sure to discuss maintenance of the GI elements and if the partner will need additional resources or training in appropriate maintenance.
  - ☐ No. Can additional incentives be provided to facilitate a partnership?

Permeable Pavement

- ☐ Is permeable paving allowed for on-street parking and alleyways?
  - ☐ Yes. This is a great application of permeable paving to reduce downstream stormwater contributions.
  - ☐ No. Consider allowing a pilot project to utilize permeable paving.
- ☐ Is a bus stop present at the site or is bus traffic known to travel in the parking lane?
  - ☐ Yes, then permeable pavement may not be practical for that specific area due to the additional load on the feature.
- ☐ Is there the potential for excessive sediment load (e.g. adjacent landscaping)?
  - ☐ Yes, then plan for extra maintenance to periodically remove sediment or select an alternative practice that can better manage sediment loads.
- ☐ Are slopes >5% that would limit the ability to implement permeable pavement?
  - ☐ Yes, consider directing runoff to adjacent bioretention areas which are stepped appropriate for the slope.

Common GI Implementation Challenges

Design details can often be lost or not carefully adhered to during the construction process. These can lead to higher maintenance costs and/or a poorly performing GI feature. The following challenges are based on lessons learned from various Tucson-area GI projects and also an internal review of a completed City of Avondale Complete Streets with GI project. The project manager or inspector should pay close attention to the following during the construction process.

Critical Elevations

Construction observation should carefully review tolerances related to grading and critical elevations. This applies to inlets from the street to bioretention areas which are often set perpendicular to the direction of flow. The asphalt to concrete transition should facilitate diversion of runoff to be received by the inlet. A micro-rolling dip in the asphalt surface or poured concrete gutter and inlet may need to be formed to facilitate runoff diversion from the street. From the inlet to the bioretention landscape area it is critical to observe the elevation differences from the inlet structure to the receiving area. Lack of at least a 2" elevation drop from the concrete inlet to the top of the rock or mulch in the basin will invite maintenance issues to keep the inlet area clear as debris, trash, and plant material is carried with stormwater.

Often asphalt surfaces are imperfect and can be problematic in GI retrofit projects when flush header curbs are installed. It is important that consideration of even small runoff contributions which provide the irrigation value to the associated plants be allowed to freely flow across the header curb into the bioretention area. This may require addressing either the surrounding asphalt surface and/or slightly lowering the header curb to ensure even the smallest runoff events are not diverted around the GI feature and not provide an irrigation benefit or create nuisance ponding in the roadway.

This bumpout is choked with bermuda grass which impedes drainage.
Photo: Watershed Management Group

Plant Availability and Installation

Differences often arise in what plant species or variety is identified in the plan to what is actually planted during construction. This may be due to nursery availability at the time of construction or mistakes made in sourcing plant material. This is especially critical when a plant species variety with specific growth characteristics is required to address a design constraint. For example, the Central Avenue complete streets project in Avondale had called for Dwarf Deer Grass (*Muhlenbergia rigida x Nashville*) but the regular Deer Grass (*Muhlenbergia rigida*) was planted. This resulted in a sight visibility conflict along the roadway and led to a frequent need to prune the grass to maintain sight lines. And, in some areas the difference in growth size resulted in overplanting where the Deer grass covered over other adjacent plants.

Ensure the inspector or project manager has an understanding of plant species and expected growth form to address plant availability and species switching. Often species not even on a planting plan are planted during the project construction for one reason or another. Often species are not properly located to provide sufficient mobility access along walking or bike lanes once mature. Lastly, ensure that cacti and succulents are not planted within the ponding zone of the bioretention area and that trees are located on micro-terraces to keep them at or above the level of ponding.

It is common that trees are either planted too deep or did not have a solid soil base when planting causing the tree to settle. The increased soil moisture of bioretention areas causes a rapid consumption of the organic potting soil the plants come in which also causes the plants to settle. The planting plan should specify planting appropriately to address this and the project inspector should look to ensure this is followed.

Surface Materials Application and Sediment Concerns

Large rip-rap should not cover the surface of the bioretention area as it increases maintenance labor costs to remove weeds, litter, sediment, or replace plants. Rip-rap along slopes should not consist of more than one rock layer to allow native seed mix applications to germinate and naturalize. Rip-rap should not be placed to block inlet (maintain a 2" drop in elevation) or outlet elevations. Decomposed granite (DG) should be screened and washed so it does not contain finer particles which can clog the soil surface and prevent infiltration and never applied in or near bioretention areas.

Competing Priorities

In some contexts, it may be more important to provide a sidewalk or preserve a building than to create space in the ROW for GI. Alternative solutions could include considering alternative street widths available in complete street manuals or street tree planters with protected root areas underground.

Common Operations and Maintenance Challenges and Solutions

GI performance relies on a healthy landscape system which goes beyond just aesthetics and must promote soil and plant health to achieve desired benefits. This often requires a shift in the approach to landscape operations and maintenance (O&M) practices. The following are common challenges to making this shift and suggested solutions to facilitate shifting practices.

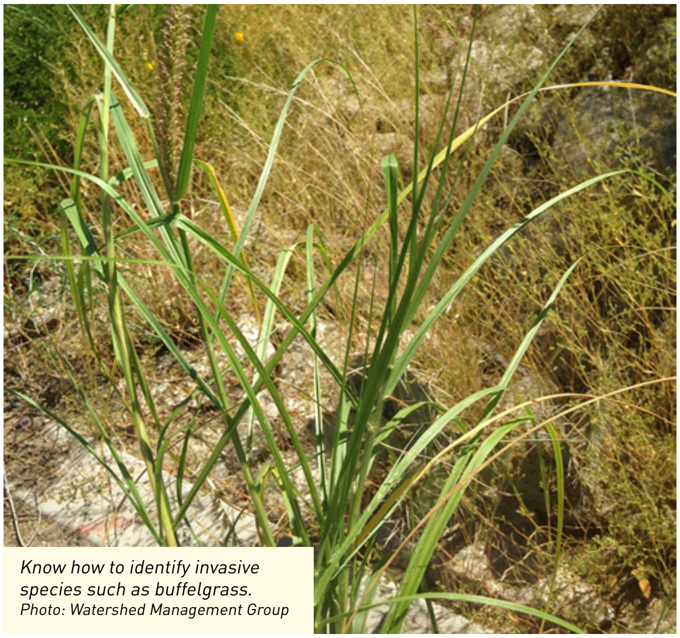
Irrigation

Irrigation ideally is used for only the three year plant establishment period as it is prone to leaks and failure to seasonally change irrigation schedules. Leaks and lack of schedule adjustments lead to over-watering of the plant material. This often results in saturated soil or even ponding conditions and/or larger growth than expected of the plants which increases pruning maintenance costs.

Tree pruning should be overseen by a trained arborist.
Photo: Watershed Management Group

Pruning

In the first three years only minimal and light pruning to maintain adjacent pathways and sight lines should be done. Too often maintenance crews are not properly trained or supervised resulting in improperly pruned trees. Improper pruning and care in the first few years is detrimental to the long-term health of the tree.



Know how to identify invasive species such as buffelgrass.
Photo: Watershed Management Group

Additionally, trees remain staked for too long resulting in poor strength and growth forms. Establishment maintenance schedules should provide clear guidance especially for the first few years following project installation.

Trash and Litter Removal

Bioretention areas are great trash and litter collectors for both wind and stormwater conveyed items. This should be viewed as a benefit as it is better and easier to remove trash and litter from along these roadway areas then it is from downstream channels. Trash and litter removal should be the focus of the weekly or bi-weekly visits by maintenance crews. This should not include removal of organic mulch or leaf litter within the bioretention areas. The organic material is vital for soil health development.

Herbicides and Pesticides

These chemicals should only be used in a sparingly spot application to deal with the most aggressive invasive species (e.g. buffelgrass). Mechanical removal is the preferred method and if done following rainfall events can be efficiently and easily accomplished for most “weedy” species. Maintenance crews should be trained on invasive species identification and also supervised to ensure desirable wildflower and naturalization of those species occurs.

Mowing and Weed Whacking

Mowing is typically not an expected maintenance activity for most GI unless it is incorporated into a park area that includes turf grass. If that is the case the design of the GI feature should consider access for mowing equipment around the feature and also the potential for turf grass (e.g. Bermuda) to heavily encroach into the GI feature.

Weed whacking of naturalized understory and/or native bunch grasses along roadway edges may be desirable for seasonal maintenance. Protection of tree species may need to be considered either with spacing or with adding root collar guards to the trees. Weed whacking is an effective treatment method for areas overtaken by Bermuda grass. The planning of planting trees or shrubs should be done carefully to minimize damage to these plants knowing that weed whacking will likely occur.

Failure to install plants diminishes GI function.
Photo: Watershed Management Group

Replacement of Plants in Bioretention Areas

The loss of understory plants within the bioretention infiltration areas should be quickly assessed on why and then plan to replace appropriately. These understory plants are critical to the function and performance of the bioretention system. Alternate species may need to be considered if the loss is due to soil moisture or other site context issues.

Periodic maintenance removes accumulated sediment in sediment trap.
Photo: Watershed Management Group

Sediment

Sediment may act as a beneficial mulch unless accumulation of fines in the basin affects retention, infiltration of stormwater quality goals. Sediment traps can be used in those cases if maintenance regimes support periodic clean out. Sediment maintenance is covered in detail in the Soil Stability Design and Design checklists. Be careful not to plant near the inlet which may inhibit stormwater flows into the basin.

A GI Maintenance Approach to Sustain Functionality of the Investment

The following information is specific to GI features and meant to supplement existing maintenance guidelines. GI systems utilize natural processes in a constructed environment to provide community services including stormwater pollutant filtration, infiltration, and bioremediation and support of shade trees. As a functional, engineered landscape appropriate maintenance is critical to improve system performance. By designing for maintenance and providing appropriate maintenance practices a GI system's performance should improve as the landscape matures. Appropriate maintenance should not be seen as "cleaning" the landscape rather it should be seen as "nurturing" the landscape.

GI requires a shift toward support of naturalized systems. As naturalized systems, irrigation and maintenance are focused on ensuring health during the critical establishment period in order to maintain ecological function and associated benefits in the long-term. These practices reinforce the potential benefits of GI features through conservation of water resources by reducing supplemental irrigation demands. Far too often maintenance degrades the performance of GI systems and provides little to no irrigation savings benefit.

The health and performance of GI is based on the health of the underlying soil. A Tucson, AZ based study of GI showed that within a few short years the native soil ecosystem attained the diversity of a mature forest soil if certain conditions were maintained.[51] These GI systems all utilized native soil without soil conditioning amendments and included native plant understory and trees, organic surface mulch (tree trimmings), and received street stormwater were much more diverse than surrounding soils that did not receive stormwater inputs or GI systems that utilized rock mulch instead of organic mulch.

An understory filled with native plants will enhance infiltration and reduces potential maintenance needs.
Photo: American Rivers

Soil health also relates to the ability to infiltrate, percolate, and store plant bio-available moisture. Organic content in a soil is critical to all of these processes. Urban soils typically are lifeless, dry, and compacted. Plants and their associated roots and leaf litter add organic content and maintain the bioretention function by helping to uncompact soil providing the support to re-establish a healthy soil ecosystem needed to sustain the function of processing stormwater pollutants and convert many of those pollutants to nutrients to support plant growth.

The establishment maintenance period of a GI system should focus on being a catalyst to develop soil health. This includes minimizing soil surface disturbances to promote fungal (e.g. mycorrhizal) colonization and development and minimize weedy (early colonizer) species ability to propagate. This includes applying woody mulch, not raking the soil surface, and addressing weedy species early in the growth season with appropriate maintenance techniques.

Weed management during the growth seasons should be built into the more frequent general cleaning and trash removal. GI as a stormwater collector functions as a great trash collector. This should be viewed as a positive as it is better to collect along streets versus in downstream water bodies and natural areas. Additionally, it can be informative of where/who are the major sources of trash and develop programs/messaging to reduce trash production. A suggested maintenance schedule for GI features is provided in Appendix C.

Education and training should be provided on weed identification and appropriate integrated pest management (IPM) options. Many weeds are actually beneficial annuals or perennials that can help naturalize a desert landscape, stabilize the soil surface, be a pollinator, and add organic content. Raking or scraping the soil surface to remove many of these annuals perpetuates a weed maintenance problem beyond the establishment phase and may provide seeding ground to more aggressive invasive species.

Lastly, as GI features utilize natural systems and thus should improve in performance as they mature it is critical that the landscape is nurtured to be productive. The health of the plants is far too often reduced within the first couple of years due to poor pruning practices. Ensure pruning of plants maintains natural form of plant or tree through selective pruning (no hedging, lion-tailing, topping, etc.). This will reduce the mortality rate of plants, ensure infiltration and soil remediation performance of the GI feature, and maximize the return on investment.

Agave planted in a curb cut.
Photo: PAG

GI MAINTENANCE CHECKLISTS

Maintenance Oversight Tips

- Provide inspection checklist to maintenance staff and/or contracted crews with clear seasonal and annual work plan. Include on the checklist a "No Action Needed" option to facilitate maintenance crew's recognition that maintenance is not always needed.
- Maintenance plans should address seasonal and annual variations as GI features become established.
- Provide emphasis and tips on how to promote soil health with maintenance practices for long-term sustainability of GI feature.
    - Maintain understory coverage of at least 25% with natural form.
    - Allow for leaf litter and prunings to be chipped and retained within the infiltration area as mulch if flow hydrology design permits organic mulch.
- Include in contract language maintenance expectations and results if not followed.

MAINTENANCE CHECKLISTS

- ☐ **Site visit and observed and noted performance:** _______________
    - ☐ Actions taken included: _____________________________
    - ☐ No action needed at this time
    - ☐ Suggested action for next visit: ________________________
- ☐ **Site Function and Stability**
    - ☐ Inspect stormwater conveyance and inlets/outlets for obstructions.
    - ☐ Check for signs of erosion and improper root growth. Stabilize areas to prevent erosion.
    - ☐ Inspect adjacent areas for sources of sediment, such as erosion of uphill areas.
- ☐ **Vegetation Management** Be careful in conducting vegetation management that may affect performance (e.g., clogging from grass clippings, leaves dropping/blowing onto the surface).
    - ☐ Irrigation schedule adjusted monthly (applicable if site is <3 years established)
    - ☐ Light pruning of trees and shrubs to maintain sight visibility and mobility. Allow for natural form. Do not 'hedge' vegetation.
    - ☐ Remove dead vegetation if not during the cold season (threat of frost).
    - ☐ Check for and remove invasive species.
- ☐ **Bioretention Areas**
    - ☐ Remove sediment from sediment traps/forebays in applicable practices (e.g., bioretention). Clean out sediment and debris at inlet structures.
    - ☐ If soils become compacted or surface sealed due to deposition of fine sediment and/or stormwater pollutants, turn or till them. Add or replace understory vegetation to help prevent compaction and surface sealing.
- ☐ **Other** Regularly maintain permeable pavement using a vacuum-assisted street sweeper and inspect it for proper drainage as well as to identify any deterioration, cracks and settling.

Next Steps

The region has many model programs and GI sites and a growing number of funding sources and guidelines. To further progress toward these goals the following summary of actions are recommended:

- Augment standards, details and specifications for local adoption as well as in an addendum to the PAG Book of Standard Specifications and Details with regionally consistent GI options.
- As updates occur, integrate GI into regional and local plans and programs as an acceptable and preferred option with prioritized locations and typologies. Utilize recommended GI targets, recognize GI as a feature the helps to meet performance measures and safety standards, and integrate into transportation funding.
- Continue innovative data driven planning. Coordinate continued regional investments in remote sensing data acquisitions for GI uses. Enhance PAG's GI Tool with statistical summary features, opportunity analysis, and multi-benefit queries to support programs for GI implementation.
- Support regional coordination and recommendations, update manuals to fill in gaps and modernize approaches, and collaborate on cohesive and consistent guidance such as a green streets feature decision matrix based on street typology.

Part 3 Endnotes

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[51.] Pavao-Zuckerman, M.A., & Sookhdeo, C. (2017). Nematode community response to green infrastructure design in a semi-arid city. Journal of Environmental Quality (46), 687-694.

St Marys Road
Photo: gmvargas.com

APPENDIX

Appendix A:
GI Design and Maintenance Guides for Transportation Projects in Arid and Semi-arid Communities: An Annotated Bibliography

Appendix B:
Trees and Plants Suitable for Pima County GI Projects

Appendix C :
GI Maintenance Schedule

Appendix D :
Registry of Embedded Links

Avondale Road GI
Photo: Watershed Management Group

Appendix A:

GI Design and Maintenance Guides for Transportation Projects in Arid and Semi-arid Communities: An Annotated Bibliography

The annotations below include descriptions of key unique aspects of each document and why it is recommended as a resource. This appendix also describes resources that address gaps in our region's standards and specifications identified by the Low Impact Development Working Group's (LIDWG). (LIDWG is composed of GI related professionals from around the Tucson metro area including consultants, jurisdictional staff, academics and others.) The following gaps were identified related to transportation and are called out if available in the guides below: roundabout with sanitary sewer manhole, cul-de-sac with landscaping, traffic calming and speed management with landscaping.

GI Design Guides

Arizona State University/Sustainable Cities Network, et al,,

Greater Phoenix Green Infrastructure & LID Handbook: Low Impact Development for Alternative Stormwater Management

GI practice details and specifications developed by City of Scottsdale, City of Phoenix, Sustainable Cities Network @ Arizona State University and Maricopa Flood Control.

City of Avondale (AZ)

City of Avondale: Green Stormwater Infrastructure Supplement for Avondale's Street Tree Master Plan

The city of Avondale conducted a design and maintenance performance review in collaboration with Watershed Management Group of their Central Ave road diet complete streets project which integrated green stormwater infrastructure features. The outcome of this process led to the creation of a GI Supplement to Avondale's Street Tree Master Plan. The supplement provides updated standard road typology details which integrate GI, establishes design performance goals, and suggests best practices for design, construction, and maintenance of the GI features.

Bernalillo County (NM)

"Bernalillo County Green Stormwater Infrastructure: Low Impact Design Strategies for Desert Communities"

This guide focuses on providing technical design information for GI practices that are appropriate for implementation in arid landscapes.

City of Dallas (TX)

Complete Streets Design Manual

One of the valuable elements in this Manual is the Design Element Priorities Chart on page 85 which shows an example of prioritizing trees and greenspace for almost all street types.

City of Los Angeles (CA)

Rainwater Harvesting Program, Green Streets and Green Alleys Design Guidelines Standards,
1st Edition, 2009.

One of the valuable elements in these guidelines is the information on green alleys. The Green Streets BMP summary matrix provides an overview of each BMP including a description, context for best application, cost, effectiveness, and challenges.

City of Los Angeles (CA)

Model Design Manual for Living Streets

This model was made so that local jurisdictions could customize the Manual and adopt it, or parts of it, for their own. Downloads are available in Word or InDesign versions to edit.
One of the valuable elements in the Manual is a table which explains GI features work with different street typologies (Best Fit for Streetwater Tools by Street Context, Table 11.1).

City of Mesa (AZ)

"Low Impact Development Toolkit"

This toolkit describes and provides technical information for a wide range of GI practices that are appropriate for Arizona urban landscapes, including for roadway and transit projects.

NACTO Urban Street Stormwater Guide

"A flooded street is not a complete street. During storm events, people walking, bicycling, and using transit are the first users to encounter barriers and lose access to the street, and are the last to regain it. Green street design tools for the right-of-way are a critical component of complete street design, ensuring the street remains usable and safe for all people during storm events, regardless of mode. Use this guide to take into consideration both the impacts of stormwater on multi-modal travel and the potential for green street investments to transform the public realm and create economic, social, and environmental benefits for all street users."

Pima Assn of Governments, *Inventory of GI/ LID Policies, Guidance, Education, Funds and Efforts in the Region* (updated 2017)

Over 70 policies, programs and other efforts were documented and showed that municipal support of GI/LID has increased steadily since 1985.

Pima Assn of Governments, City of Tucson, Pima County RFCD, Stantec, and Impact Infrastructure, *Return on Investment Study for GI*

A multi-partner, collaborative study conducted in 2013 and 2014 found that investing in GI or LID approaches for infrastructure projects will lead to cost-savings that benefit the community, municipalities and the private sector. As part of best tests for this study, two local projects were tested to evaluate the impact of a "green streets" policy and local commercial stormwater harvesting ordinance. The analysis of the return on investment covered the full life cycle of the projects. The study also evaluated specific local design standards. Results of the study were used to enhance the recommended design strategies in the Pima County LID Guidance Manual.

Pima County
Case Studies: Low Impact Development/ Green Infrastructure

This inventory, created by PC RFCD with the LID Working Group, features a section on local transportation projects and summaries include costs, lessons learned, before and after photos.

Pima County Subdivision Street Standards

This document guides planners and engineers in the preparation of subdivision plats and commercial/industrial site plans. This manual incorporates complete streets sustainable and low impact development which supports accessible, livable and attractive communities. The manual states that where practical, landscaped medians or median islands may be depressed to provide for stormwater harvesting and refers to the Design Standards for Stormwater Detention and Retention manual for further information.

Pima County Standard Operating Procedures: Landscape Additions in the Public Road Right-of-Way

This procedure outlines landscape additions that fulfill goals including increasing shade and vegetative cover, providing stabilization and erosion control, and taking advantage of excess roadway stormwater runoff by creating water harvesting areas. These procedures provide guidance on vegetation in clear zones and Native Place Preservation Ordinance mitigations.

San Mateo County (CA)
"Green Infrastructure Design Guide"

A comprehensive design guide targeted to assist public agencies, developers, design professionals and construction firms in their efforts to design, build and maintain GI in San Mateo County, California. Of particular relevance, the guide is intended to support the planning and development of integrated complete streets and green streets for water quality and public safety benefit.

City of Santa Fe (NM)
"Incorporating Green Infrastructure into Roadway Projects in Santa Fe"

Prepared with technical assistance from the US EPA, this document provides detailed guidance about incorporating GI into the definitional, development and design of roadway projects. It also discusses design and maintenance considerations and provides examples of GI incorporation into site locations with characteristics typical of Southwestern cities.

City of Tucson (AZ)

City of Tucson Complete Streets Design Guide

The City of Tucson has recently completed an initial draft of the new Street Design Guide. The Guide provides design guidance to city staff and project teams on how to design and construct transportation projects in a way that forwards the intent of the City's Complete Streets Policy. 2020.

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

This manual includes a site assessment guide and information on practices. Table 7 can be used to select a structural GI practice that provides the benefits needed for a site. Design details are available in Appendix H, and Appendix F is a GI AutoCASE/BCE ROI Study summary.

City of Tucson Water Harvesting Guidance Manual. 2006

Techniques, designs and codes for compliance with the City's commercial water harvesting ordinance.

US Environmental Protection Agency, *Managing Wet Weather with Green Infrastructure: Municipal Handbook - Green Streets,* 2008.

Some of the unique features in this handbook include examples of stormwater pollutants on roads and their impacts, a survey of alternative street width usages across the county, example green street policy language, elements of a successful program.

Zeedyk, Bill, *Water Harvesting from Low-Standard Rural Roads,* 2006

Describes treatments to improve rural roadways and their impact on habitat, waterways, and erosion.

GI Maintenance Related Guides

Tucson Clean And Beautiful - Trees for Tucson: *Planting and Maintenance Webpage*

Includes, location, planting, watering/stormwater harvesting, and pruning tips and illustrations and printouts

University of Arizona Extension office: *Smartscape Program*

Offers training classes including stormwater harvesting and maintenance.

Watershed Management Group: *Field Guide for Rain Garden Care*

A Guide for backyard, neighborhood, and commercial gardens. Includes helpful information such as when to prune, tree life spans, good "weeds" versus invasives, and photos of common mistakes.

Watershed Management Group: *Green Infrastructure Manual for Desert Communities*

This manual provides information for neighborhood residents, municipal professionals, grassroots advocates and others who seek to implement GI strategies in their communities. It is tailored to work with the unique climate conditions of the southwestern US. The guide includes detailed, step-by-step approaches for designing, constructing, and maintaining GI practices that can be used to retrofit existing neighborhoods. Includes conceptual drawings, cross sections and details for sediment traps, parking lots, and in-street practices with GI for speed management (medians, chicanes, street width reduction, and traffic circles with manholes).

Shading pathways reduces heat stress and enhances walkability.
Photo: Watershed Management Group

Appendix B:

Trees and Plants Suitable for Pima County GI Projects

The following example plant recommendations are based on lists from the following resources:

- Watershed Management Group, *Green Infrastructure Manual for Desert Communities*
- Brad Lancaster, *Rainwater Harvesting for Drylands and Beyond Volume 1, 2nd Edition*, and
- The City of Avondale, *Street Tree Master Plan Green Infrastructure Supplement*.

Additional varieties are identified on several local lists. Native plants are well adjusted to local bimodal rain seasons and frost levels.

Recommended Native Trees

Larger native, low water use, trees recommended for roadway projects:

- ***Chilopsis linearis*** **(Desert willow)** - drought tolerant, easy to establish with minimal irrigation; 20-35 feet in height and diameter, provides moderate shade, open and spreading crown; low root damage potential
- ***Celtis reticulata*** **(Canyon/Netleaf Hackberry)** - drought tolerant, easy to establish with minimal irrigation; single to multi-trunk, upright 30-40 feet in height with near equal spread, provides moderate shade; low root damage potential
- ***Olneya tesota*** **(Desert ironwood)** - drought tolerant, easy to establish with minimal irrigation; 25-30ft in height and diameter, moderate growth - can be more rapid when paired with GI basins, provides heavy shade, single to multi-trunk, typically slow growing but can be more rapid when paired with GI basins; low root damage potential
- ***Parkinsonia florida*** **(Blue Palo Verde)** - drought tolerant, easy to establish with minimal irrigation; 25-30 feet in height and diameter, fast growth, provides heavy shade; low root damage potential
- ***Prosopis velutina*** **(Velvet Mesquite)** - drought tolerant, easy to establish with minimal irrigation; 25-30ft in height and diameter, fast growth, provides heavy shade, single to multi-trunk; be sure not to use hybrid varieties as they result in weak structure and prone to fall; low root damage potential

Space constraints in relation to vehicular traffic need to be considered. Shorter native, low water use, trees recommended for height constrained areas*:

- ***Acacia constricta*** **(Whitethorn Acacia)** - drought tolerant, easy to establish with minimal irrigation; 10-15 feet in height and diameter, provides light shade; low root damage potential
- ***Acacia greggii*** **(Catclaw acacia)** - drought tolerant, easy to establish with minimal irrigation; 15-20 feet in height and diameter, multi-trunk, provides light shade; low root damage potential
- ***Fraxinus greggii*** **(Littleleaf Ash)** - drought tolerant, easy to establish with minimal irrigation; 10-15 feet in height and 6-10 feet in diameter, provides moderate shade, form of a dense screen shrub or shaped early into multi-trunk tree, moderate growth; low root damage potential
- ***Lysiloma watsonii*** **(Featherbush)** - drought tolerant, easy to establish with minimal irrigation; 15-20 feet in height and diameter, slow to moderate growth, provides light shade, form of a small tree or large shrub; multi-trunk, produces root suckers when pruned; low root damage potential
- ***Parkinsonia microphylla*** **(Foothills Palo Verde)** - drought tolerant, easy to establish with minimal irrigation; 20-25 feet in height and diameter, slow to moderate growth, provides light shade, multi-trunk; low root damage potential

**These short trees may have shrub-like growth so Sight Visibility Triangle requirements are imperative*

Common trees and large shrubs to avoid and associated reasons*:

- **Eucalyptus species** - non-native, become invasive in downstream riparian areas, does not contribute to Sonoran Desert sense of place
- ***Nerium oleander* (Oleander)** - non-native, toxic, does not contribute to Sonoran Desert sense of place; consider Arizona Rosewood or Hopseed Bush as native alternatives
- **Palm species** - higher VOC emitting, poor shade providers
- ***Parkinsonia x 'Desert Museum'* (Desert Museum Palo Verde)** - this hybrid is fast growing and when paired with GI features develops weekly limbed and easily wind-thrown trees.
- ***Prosopis chilensis*** and other non-native or hybrid Mesquite species - non-native mesquites and hybrids tend to be fast growing which results in a weak rooting and limb structure; increased susceptibility to wind-throw; GI integration tends to accelerate tree growth in these species resulting in frequent roadway problems.
- ***Quercus virginiana* (Southern Live Oak)** - Live oaks do not perform as well without regular supplemental irrigation. Oaks are also higher VOC emitting trees.
- ***Pistacia x 'Red Push'* (Red Push Pistache),** susceptible to prolonged hot dry periods, non-native, does not contribute to Sonoran Desert sense of place
- ***Ulmus parvifolia* (Chinese Elm),** susceptible to prolonged hot dry periods, non-native, does not contribute to Sonoran Desert sense of place; ability to reseed heavily; moderate potential for root damage
- ***Vachellia farnesiana* (Sweet Acacia)** - freeze, drought stress, and pest prone

**In areas with space constraints, sometimes a non-native low water use tree may be still be a good option*

Recommended Native Understory

Larger native, low water use, shrubs recommended for roadway projects:**

- ***Celtis Pallida* (Desert Hackberry)** - 8-10 feet, slow to moderate growth, dense vegetation drought tolerant, easy to establish with minimal irrigation;
- ***Dodonaea viscosa* (Hopseed Bush)** - 4-12 feet in height, moderate growth, dense screen, drought tolerant, easy to establish with minimal irrigation;
- ***Justicia californica* (Chuparosa)** - 3-4 feet in height, moderate to fast growth, drought tolerant, easy to establish with minimal irrigation;
- ***Lycium fremontii* (Wolfberry)** - 3-6 feet in height, moderate to fast growth, drought tolerant, easy to establish with minimal irrigation;
- ***Rhus microphylla* (Littleaf desert sumac)** - 8-15 feet in height, moderate growth, large shrub or pruned to be small, multi-trunked tree, drought tolerant, easy to establish with minimal irrigation;
- ***Simmondsia chinensis* (Jojoba)** - 5-7 feet, slow to moderate growth, dense screen, drought tolerant, easy to establish with minimal irrigation
- ***Atriplex canescens* (4-wing saltbush)** - 4-5 feet, moderaete growth, dense screen, drought tolerant, easy to establish with minimal irrigation.

***With large dense shrubs, Sight Visibility Triangle requirements are imperative.*

A curb inlet allows stormwater into a bioretention basin along a complete street in downtown Tucson.
Photo: American Rivers

Smaller native, low water use, understory plants that grow 3ft or less to maintain site visibility and provide bioremediation function and facilitate infiltration and percolation:

Native Grass (swales, basin bottoms or sides) - can tolerate temporary inundation

- *Bouteloua curtipendula* (Sideoats Grama)
- *Digitaria californica* (Arizona cottontop)
- *Muhlenbergia emersleyi* (Bull grass)
- *Purpura aristada* (Purple three-awn)
- *Pappophorum vaginatum* (Pima pappusgrass)

Understory (upland areas and basin slopes)

- *Artemisia ludoviciana* (Western Mugwort)
- *Asclepias linaria* (Pineleaf Milkweed) - monarch butterfly host
- *Asclepias subulata* (Desert Milkweed) - monarch butterfly host
- *Baileya multiradiata* (Desert Marigold) - naturalizes easily
- *Calliandra eriophylla* (Pink Fairy Duster)
- *Chrysactinia mexicana* (Damianita)
- *Dalea greggii* (Trailing Indigo Bush)
- *Encelia farinosa* (Brittlebush) - naturalizes easily
- *Ericameria laricifolia Aguirre*™ (Turpentine Bush)
- *Penstemon parryi* (Parry Penstemon) - naturalizes easily
- *Senna covesii* (Desert Senna) - naturalizes easily
- *Sphaeralcea ambigua* (Globe Mallow) - naturalizes easily
- *Thymophylla pentachaeta* (Golden dyssodia) - naturalizes easily

Understory (basin terraces or sides)

- *Eriogonum fasciculatum v. poliofolium* (Flattop Buckwheat)

Additional Plant Resources

- If possible, avoid the "high VOC-emitting" trees to help reduce emissions that form ground-level ozone air pollution. These trees and allergen trees are covered in the "*Urban Tree Selection List*" created by Maricopa County Air Quality Department after researching information from the Desert Botanical Garden and many other organizations.
- Outside of or above the raingardens (where less stormwater is gathered with less depth) cacti, yucca and agave, ocotillo are valuable desert plants. Recommended cacti and succulent plants are included in this *Pima County Riparian Mitigation Area List*. Even desert adapted plants benefit from stormwater capture to survive such as in microbasins, terraces, and small checkdams
- *Eastern Pima County Native Plant Tool*: Identify the native plants that are best for your site's climate and soils on this interactive map.
- *Pima County Plant List*: Excel list of all native and "naturalized" or invasive exotic plants found in Pima County.
- *ADWR Plant List*

Appendix C:
GI Maintenance Schedule

Recommended Maintenance Items for Green Infrastructure Features		
Maintenance Item	**Suggested Frequency**	**Recommendation**
Cleaning/Litter Removal	Bi-weekly to Monthly	Focus on trash removal and manual spot removal of problematic weeds (no spray or raking options). Frequency should be greater during wetter months as litter accumulates in flow and basin areas with stormwater flows.
Invasives and Weed Control	Seasonal	Schedule weed whacking and/or mowing (grassland areas) of adjacent roadsides after nesting and pollinator seasons. If invasive species control is required schedule interventions before target species produces seed.
Mulch (organic) replenishment	Every 2-5 years	Inspect for need to replenish organic mulch if not sufficiently replenished during plant pruning and chipping process. Typically, plant leaf litter and pruning chippings are sufficient to maintain organic mulch cover.
Pre-Emergence	Semi-annual	Shift to an Integrative Pest Management (Organic First) system to eliminate/minimize need for herbicide applications.
Post-Emergent	Semi-annual	Shift to an Integrative Pest Management system to eliminate/minimize need for herbicide applications.
Shrub/Groundcover Maintenance	Quarterly	No topiary pruning or hedging; replace groundcover or re-seed as needed to maintain minimum 25% coverage.
Tree Maintenance	Annually	Years 1-3: Conduct semi-annually before and after growing season, light pruning to maintain site visibility and clearance, overseen by certified arborist Years 4+: Annual pruning, overseen by certified arborist; avoid summer pruning
Irrigation Inspection & Maintenance	Monthly	Years 1-2: Regular irrigation schedule Years 3-5: Reduce/eliminate irrigation during winter months (Nov – Feb) Years 5+: Reduce/eliminate irrigation unless abnormally dry & hot or to maintain aesthetics in May and June. Supplemental watering once per month during warm, dry season may be desired to maintain plant aesthetics
GI Performance Inspection & Maintenance	Semi-annual / Periodic	Sediment: accumulation of sediment in the sediment trap or basin bottom should be removed only if it reduces the ability to meet performance objectives of the GI feature from either a water quality or retention volume perspective. Often sediment acts as a mulch as long as vegetative cover is present to reduce evaporative water loss and infiltration rates are not impacted. Ponding: check for ponded water 1-3 days following rain events. If ponding persists then take appropriate action to A) decompact underlying soil, B) integrate organic mulch or compost, and C) re-establish native plants (i.e. native grasses) to facilitate infiltration. Mosquito larvae develop into an adult in 3-7 days.

Irrigation Guide for Green Infrastructure Features with Low-Water Use, Native Plants.

Year	Months					
	Jan - Feb	Mar- April	May-June	July-Aug	Sept-Oct	Nov-Dec
1	Follow general establishment schedule based on soil type, season, and canopy size.					
2	None	deep soak 2x/ month				1x/month
3	1-2x/month	deep soak 1x/month		deep soak 1x month if no rain		none
4	none	deep soak 1x/month if no rain within 1 month				none
5	none unless replacement planting is needed					

Appendix D:

Registry of Embedded Links

Accessible as of June 2020

- **Page 14**
  Federal Highway Administration Context Sensitive Solutions Primer:
  https://www.tucsonaz.gov/files/projects/CSSPrimer.pdf

- **Page 14**
  Regional Transportation Authority and City of Tucson Process for Grant Road Improvement Plan: http://www.grantroad.info/pdf/dcr/grant-road-dcr-chapter-02.pdf

- **Page 14**
  City of Tucson Transit Development Handbook:
  https://www.tucsonaz.gov/files/pdsd/transit_oriented_development_handbook.pdf

- **Page 16**
  City of Tucson Green Streets Active Practice Guidelines:
  https://www.tucsonaz.gov/files/transportation/Green_Streets_APG_Signed_by_Director.pdf

- **Page 16**
  Pima County Sustainable Action Plan: https://webcms.pima.gov/cms/one.aspx?portalId=169&pageId=52026#

- **Page 16**
  City of Tucson Plan Tucson: https://www.tucsonaz.gov/pdsd/plan-tucson

- **Page 17**
  City of Tucson Mayor Romero's Million Trees Initiative: https://www.tucsonaz.gov/newsnet/mayor-romero-launches-tucsonmilliontrees

- **Page 17**
  Make Marana 2040 General Plan: https://www.maranaaz.gov/make-marana-2040

- **Page 17**
  Aspire 2035 - Sahuarita General Plan: https://sahuaritaaz.gov/DocumentCenter/View/1169/Aspire-2035-Sahuaritas-General-Plan-Amended-2019?bidId=

- **Page 17**
  Pima County Regional Flood Control District 2020 Floodplain Management Plan: https://webcms.pima.gov/cms/One.aspx?pageId=450475

- **Page 17**
  Pima County Detention and Retention Requirements:
  https://webcms.pima.gov/cms/One.aspx?pageId=65527

- **Page 17**
  City of Tucson Commercial Rainwater Harvesting Ordinance: https://www.tucsonaz.gov/files/pdsd/projects/cms1_033871.pdf

- **Page 17**
  Town of Oro Valley MS4 Stormwater Management Plan:
  https://beta.orovalleyaz.gov/files/assets/public/documents/public-works/stormwater-utility/manuals-guides-reports/2019-stormwater-management-program.pdf

- **Page 17**
  Town of Marana MS4 Stormwater Management Plan:
  https://www.maranaaz.gov/s/2018-SWMP.pdf

- **Page 17**
  Pima County MS4 Stormwater Management Plan:
  https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Environmental%20Quality/Water/Stormwater/2015_SWMP_Report.pdf

- **Page 17**
  City of Tucson MS4 Stormwater Management Plan: https://www.tucsonaz.gov/files/transportation/SWMP_2014.pdf

- **Page 17**
  City of Tucson Drought Response Plan:
  https://www.tucsonaz.gov/files/water/docs/drought_plan_update_spring_2012.pdf

- **Page 17**
  Pima County Drought Response Plan: https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Drought%20Management/Drought_Ordinance.pdf

- **Page 17**
  Tucson Water 2020 Strategic Plan: https://www.tucsonaz.gov/files/water/docs/2020_Strategic_Plan.pdf

- **Page 18**
  City of Tucson Bicycle Boulevard Master Plan: https://www.tucsonaz.gov/projects/bicycle-boulevards

- **Page 20**
  Wasatch Front Regional Council,
  Regional Transportation Plan 2019-2050: https://wfrc.org/vision-plans/regional-transportation-plan/2019-2050-regional-transportation-plan/

- **Page 25**
  Pedestrian Traffic Fatalities by State: 2018 Preliminary Data: https://www.ghsa.org/sites/default/files/2019-02/FINAL_Pedestrians19.pdf

- **Page 25**
  Evaluation of the 2018-2019 Pima County Clean Air Program Campaign and Clean Water Program Campaign Survey: https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Environmental%20Quality/Reports_and_Publications/Pima%20DEQ%202018-2019%20report%20-%20final.pdf

- **Pages 42**
  City of Tucson / Pima County Low Impact Development and Green Infrastructure Guidance Manual: https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Flood%20Control/Floodplain%20Management/Low%20Impact%20Development/li-gi-manual-20150311.pdf

- **Page 75**
  City of Avondale, AZ, City of Avondale: GI Supplement for Avondale's Street Tree Master Plan: https://watershedmg.org/document/GI-supplement-avondale-street-tree-master-plan

- **Page 75**
  Metro Phoenix, AZ, Greater Phoenix Green Infrastructure & LID Handbook: Low Impact Development for Alternative Stormwater Management: https://sustainability.asu.edu/sustainable-cities/resources/lid-handbook/

- **Page 75**
  Santa Fe, NM, "Incorporating Green Infrastructure into Roadway Projects in Santa Fe: https://www.santafenm.gov/media/archive_center/9910_SantaFeR4.pdf

- **Page 75**
  Bernalillo County, NM, "Bernalillo County Green Stormwater Infrastructure: Low Impact Design Strategies for Desert Communities: https://www.bernco.gov/uploads/FileLinks/590808d5c7dd4e0cbfaf3009cf1affb9/Green_Infrastructure_and_Low_Impact_Design_Guide_1.pdf

- **Page 75**
  City of Mesa, AZ: "Low Impact Development Toolkit: https://www.mapc.org/resource-library/low-impact-development-toolkit/

- **Page 75**
  San Mateo County, CA: "Green Infrastructure Design Guide: https://www.flowstobay.org/gidesignguide

- **Page 75**
  NACTO Urban Street Stormwater Guide: https://nacto.org/publication/urban-street-stormwater-guide/streets-are-ecosystems/complete-streets-green-streets/

- **Page 75**
  Pima County: Case Studies: Low Impact Development/Green Infrastructure: https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Flood%20Control/Floodplain%20Management/Low%20Impact%20Development/lid-case-studies.pdf

- **Page 75**
  Model Design Manual for Living Streets: http://www.modelstreetdesignmanual.com/

- **Page 76**
  PAG Regional Council resolutions: https://www.pagregion.com/Default.aspx?tabid=1273

- **Page 76**
  PAG GI Prioritization Tool: http://gismaps.pagnet.org/PAG-GIMap

- **Page 76**
  Watershed Management Group Green Infrastructure for Desert Communities: https://watershedmg.org/document/green-infrastructure-manual-for-desert-communities

- **Page 76**
  PAG Inventory of GI/LID Policies, Guidance, Education, Funds and Efforts in the Region (updated 2017): https://www.pagregion.com/Default.aspx?tabid=189

- **Page 76**
  Return on Investment Study for GI (PAG, City of Tucson, Pima County RFCD, Stantec, and Impact Infrastructure): https://www.pagregion.com/Default.aspx?tabid=189

- **Page 76**
  Pima County Subdivision Street Standards: https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Development%20Services/Building/2016%20SDSS.pdf

- **Page 77**
  City of Tucson Complete Streets Design Guide: https://www.tucsonaz.gov/tdot/complete-streets-tucson

- **Page 77**
  City of Tucson Complete Streets Tucson webpage: https://www.tucsonaz.gov/tdot/complete-streets-tucson

Tucson streets at night.
Photo: Frankie Lopez on Unsplash

Sonoran Desert Green Infrastructure Resource Library

A Playbook for Transportation Projects in Pima County Communities

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