Sonoran Desert Green Infrastructure Resource Library

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A Playbook for Transportation Projects in Pima County Communities

SONORAN DESERT GREEN INFRASTRUCTURE RESOURCE LIBRARY

A Playbook for Transportation Projects in Pima County Communities

This report was co-authored by Jeff Odefey (American Rivers), Mead Mier (Pima Association of Governments), and Catlow Shipek (Watershed Management Group). The authors gratefully acknowledge the contributions of Stacey Detwiler, formerly of American Rivers, whose 2015 report "*Rivers and Roads: Opportunities to Better Integrate Green Infrastructure and Transportation Projects in Atlanta, GA and Toledo, OH*" directly informed portions of this guide. The authors were also greatly assisted by input from staff at Pima Association of Governments' Transportation and Integrated Planning Departments, Pima County Departments of Housing & Urban Development and Transportation, the Pima County Regional Flood Control District and the City of Tucson's Water and Transportation Departments as well as the City Administrator's office.

The authors are responsible for any factual errors. The recommendations are those of American Rivers and any views expressed in this report are those of the authors and do not necessarily reflect the views of our funders or those who provided review.

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Historic flows restored in the Santa Cruz River.
Photo: American Rivers

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Native Tucson vegetation in a curbcut.
Photo: PAG

Introduction

Many of the requirements of street construction can be addressed cost-effectively through Green Infrastructure (GI) including managing surface drainage, providing all weather crossings, mitigating transportation's surface pollutants, meeting safety goals for all transportation modes, and ensuring final stabilization of the soils.

The Tucson region is a desert community with streets designed to convey stormwater. Like much of the West, storm sewers are separated from the sanitary sewer system. Oftentimes this creates flooding issues on bicycle and pedestrian facilities. In high water situations, rainfall can also impact the safety of a roadway facility. Localized flooding deposits unwanted sediment on the region's roads, bike lanes, and pedestrian facilities. Traditional street designs also create risks including increased heat, decreased absorption, and decreased water quality. GI offers opportunities to decrease those risks and add cost-effective approaches to protect the post-construction integrity of the roadway, mitigating stormwater pollutants from transportation sources, providing drought and heat resilient landscapes, reduced ponding and flood attenuation. Benefits also include increased access to urban green space, improved air quality, and reduced demand on grey storm sewer infrastructure and the cost of constructing expensive underground pipe systems.

Purpose of the Playbook

Transportation project leaders have increasingly used GI approaches over the last few decades. This guide was created to address common issues that inhibit the implementation of GI in the Tucson region transportation network. Many of these issues can be solved by including GI in each planning phase and through policies, funding and practices tailored to the region's urban and suburban environments, each of which have a dedicated section in this guide. Metropolitan Planning Organizations (MPOs), local governments and transportation entities are important players in creating a healthy built environment and essential to successful implementation of GI since streets are where stormwater flows. Issues and corresponding solutions in this resource guide were identified by local experts in GI and transportation engineering and planning. Top local concerns that were addressed in this document include utilities, flooding, sediment, and maintenance. This playbook is a product of American Rivers based on a general national guide filled in with local details by jurisdictions within Pima County where examples were available or with other Western examples to address any remaining gaps and models. This guide is intended to be a resource for transportation-oriented staff and to provide examples and illustrations of planning, funding, and project design approaches that may be relevant to the Pima County area. It is in no way intended to be interpreted as administering official policy, preferences, or design specifications.

Green Infrastructure Pedestrian Canopy on Scott Avenue Green Street.
Photo: American Rivers

Green Infrastructure? Green Stormwater Infrastructure? WHAT'S IN A NAME?

The terminology involved in nature-based approaches to managing stormwater can be confusing. Many practitioners use the term "green infrastructure," which has recently been incorporated into the Clean Water Act:

Section 502 of the Clean Water Act defines green infrastructure (GI) as the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to server systems or to surface waters.

However, this term has a second historical usage to refer to the parks, green spaces, preservation of large scale landscapes, and other areas that provide habitat in an urban environment. In an effort to distinguish stormwater management practices from this broader definition, many people are adopting the more specific term "green stormwater infrastructure." To add further confusion, the term "low impact development" (LID) is often used to include, among other things, the types of stormwater management approaches that utilize "green infrastructure" techniques. For the sake of consistency with local design manuals and policies, the authors of this guide will use the term "green infrastructure" throughout the document except in places where it's more appropriate to echo a usage of other terms used in policies such as stormwater harvesting, low impact development or green stormwater infrastructure.

Defining the Needs

The Tucson region has several key issues that can be addressed through urban design that includes GI along streets.

Extreme heat is the leading cause of weather-related deaths in the United States and the highest rates of impact on residents nationally are found in Arizona. Heat is amplified by hardscape, such as streets, creating heat islands. Extreme heat exacerbated by urban heat islands can lead to increased respiratory difficulties, heat exhaustion, and heat stroke. Physical, social and economic factors create a disproportionate impact on older persons, children, homeless, the poor, socially isolated, and those with mobility restrictions or health concerns. As temperatures rise in Arizona, the region will have more contiguous 100+ degree days in combination with higher nighttime temperatures. Heat-related illnesses and deaths are directly related to prolonged exposure to high temperatures in the absence of intermittent cooling down periods. Unfortunately, economically disadvantaged parts of the community are often especially impacted because under-investment in urban forestry has created denuded neighborhoods where residents commonly depend on public transportation which requires walking outdoors in the heat. Tree shade can mitigate heat and provide cooling for active modes of transportation.

The Santa Cruz currently has reaches that do not meet applicable water quality standards due to pollutants associated with transportation sources including copper and zinc. These pollutants are toxic to organisms with aquatic phases that rely on the region's ephemeral waters and rare perennial and intermittent waters. Sediment from construction is also considered a pollutant and field screening has found oil sheen in runoff. The Santa Cruz River also suffers from "impaired" status due to *E. coli* contamination from animal waste. Bioretention basins along streets can prevent accumulation of pollutants in our waterways and break down hydrocarbons and pathogens.[1]

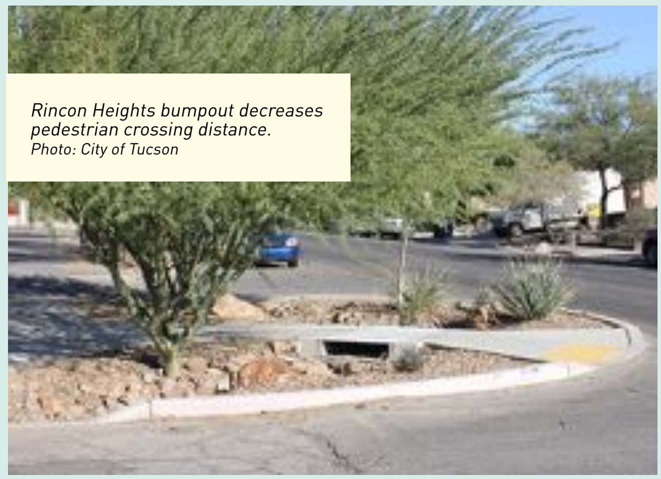
A severe local drought began in our region about 20 years ago, triggering Drought Stage 1 in local Drought Response Plans. Drought Stage 2 will occur if there are shortages on the imported Colorado River supplies. Should irrigation restrictions need to take place in Drought Stage 2, many local jurisdictions identify stormwater harvesting as a way to prepare for landscape resiliency in their Plans. It is critical

SAFER STREETS THROUGH GI

While some people may assume that trees pose risks for drivers, far less than 1% of U.S. annual vehicle crashes involve a tree on an urban street. Crash prevention efforts should address high-risk conditions, such as reducing plantings at curves, rather than generalized tree removal. The most recent research suggests that trees may improve driving safety. Drivers seeing natural roadside views show lower levels of stress and frustration compared to those viewing all-built settings. One study found a 46% decrease in crash rates across urban arterial and highway sites after landscape improvements were installed. Another study found that placing trees and planters in urban arterial roadsides reduced mid-block crashes by 5% to 20%. Several studies comparing roads with and without landscaping and trees have found a marked decrease in the number of pedestrian and bicyclist fatalities and injuries by up to 80%.*

Is GI appropriate for all street types? Yes, and different GI feature types fit each street type.

The Dallas Complete Streets Design Manual (Design Element Priorities Chart, page 85 in the document) shows an example of prioritizing trees and greenspace for almost all street types. The LA Model Design Manual for Living Streets describes which GI features work with different street typologies (Best Fit for Streetwater Tools by Street Context, Table 11.1).



Rincon Heights bumpout decreases pedestrian crossing distance.
Photo: City of Tucson

**Studies can be found in Wolf, K.L. 2010. Safe Streets - A Literature Review. In: Green Cities: Good Health (www.greenhealth.washington.edu). College of the Environment, University of Washington.*

that transportation departments work in coordination with water planners to utilize stormwater as a water resource. This will prepare a more resilient streetscape.

In the semi-arid climate of Pima County, Arizona, stormwater is a valuable resource that has historically been disposed of as a nuisance and a hazard. The rain that does reach the desert floor in a summer monsoon or a fall tropical cyclone typically does so with great vigor. The altered flow regime created by traditional roadways additionally increases runoff volume and peak flows, damaging the environment and creating a risk to property downstream. These erosive flows in receiving streams will cause downcutting, clear water scours, or excessive sedimentation. As documented in studies described later in this document, GI has been found to reduce stress on traditional stormwater infrastructure, pull sediment hazards out of the travel lane, and reduce the peak of the hydrograph, which reduces the stormwater nuisances on streets and reduces the risks of flood damage to adjacent properties.

Each year, close to 4,000 Tucsonans are injured and more than 50 people lose their lives while traveling on city streets.[2] Jurisdictional leaders are committed to changing this. According to a 2019 report released by the Governors Highway Safety Association, pedestrian deaths have increased by 35 percent in the last decade. Arizona has also been ranked the second deadliest state for pedestrians per capita.[3] According to Pima Association of Governments' (PAG's) performance measures in 2020, the fatality rate for people on bikes and people walking are unfortunately trending upward per capita even as more bicycle and pedestrian facilities are built. Through the 2045 Regional Mobility and Accessibility Plan (RMAP 2045) process, over 300 miles of bicycle and pedestrian safety facilities and over 200 miles of improved roadways have been identified to address poor or fair safety ratings. Road safety can be improved when GI is incorporated on any street size and is an important part of street modernization projects including medians/islands, crossings, curb extensions, etc.[4]

The greater purpose of the guide is to:

- Increase proper utilization of GI to provide safer road conditions with reduced flood hazards and time for streets to dry
- Improve the safety and comfort of people bicycling and walking by installing traffic calming and buffer elements
- Increase transit rider comfort with enhanced shelters, shade, and greenscape at transit stops (critical to growing transit as a mode)
- Make the biking and walking environment more healthy by reducing temperature, attenuating noise, and improving air quality
- Use trees as visual friction to increase driver self-regulation and geometric features in the road can be placed to calm traffic and improve traffic safety conditions.

(Reference: NACTO Urban Street Stormwater Guide)

Definition

Green infrastructure practices reduce stress on traditional grey stormwater infrastructure and restore natural flow functions with a variety of stacked benefits for the environment and community. Also related to Low Impact Development (LID) or stormwater harvesting, examples include structures that improve infiltration, enhance or maintain vegetation, and/or capture and reuse stormwater.
GI practices emphasize the preservation and restoration of natural landscape features and connectivity. Within the transportation network, technologies may include permeable pavements, bioretention in chicanes or parking lots, curb inlets that direct stormwater, and infiltration in check-dams in rights-of-way.

Regional Interest

With more than 300 days of sunshine each year, 60 to 70 of which exceed 100-degree temperatures, shade is a critical consideration for improving the pedestrian environment. Water conservation is key to sustaining shade in the desert.

Community support and implementation of GI has grown over time and this demand has been documented in several assessments.

The PAG 2014 Regional Pedestrian Plan found, through a survey of 670 self-selected participants, that increased shade is the most common improvement desired by pedestrians (49 percent). Obstacles such as lack of shade create barriers for people who would otherwise like to walk, in addition to presenting a hazard for people who don't have other options.

In 2015, PAG used an online public engagement tool called Engage 2045 to seek public input on future transportation investment options and long-term transportation priorities for the long range transportation plan. Once again, PAG found a strong interest in GI. Of the 1,903 people who participated, 77 percent were willing to spend at least an additional $0.30 per household per month to fund GI elements of transportation projects indicating widespread interest. Forty percent even indicated a willingness to spend the maximum choice offered - $3 per household per month, which is the typical amount needed to fund a stormwater utility.

The Pima County Department of Environmental Quality conducts an annual community survey to gauge public awareness and attitudes toward air and water quality, including GI. This statistically valid survey reaches a wide spectrum of Pima County residents and business owners and in 2019 found that at least one third of the community implemented various GI practices.[5] Using the social theory of innovation to evaluate these results, it appears our community has moved from early adopters to early majority phases. During this phase, further guidance and education can aid proper implementation.

Early regional gap and barrier assessments for GI, including a 2012 Arid LID Conference in Tucson, found that funding created limitations on implementation and there were some research areas that would help leaders feel more confident in supporting GI with policy. These areas included questions about street integrity, feasibility of GI to reduce peak flows and potable water irrigation, and whether the community would support funding. Since that time, some steady funding sources have been established and guidance is now available based on modeled scenarios, local case studies, and nation-wide research. As illustrated above in the public surveys, community support also is no longer a barrier to implementation.

PART 1

Incorporating Green Infrastructure into Project Planning

Most challenges have guidance available for solutions. Encourage education of staff about these resources and practices. Use this guide's recommendations for regionally consistent practice.

Summary Of Key Planning Recommendations

Plan for GI early in process

It is critically important to consider GI measures as appropriate stormwater management strategies early in the road project design process including coordination with utilities and appropriate planning for budget. Retrofits on a built road are a more costly effort. GI should not be thought of as optional but instead an enhanced way to achieve drainage and final stabilization goals.

Utilize Context Sensitive Solutions (CSS) Planning Process

Transportation agencies in the Santa Cruz watershed should fully implement CSS planning approaches in the programmatic and project design process in order to formalize the consideration of the environmental and community impacts (and potential benefits) of a transportation project. One of the core principles of CSS is to use flexibility and creativity to preserve and enhance community and natural environments, which supports the overall goal of green infrastructure to use natural or engineered systems that mimic natural systems to capture and filter rainwater, reducing stormwater runoff to protect water quality.

Implement Green Streets Policies and Design Guides

Many local governments across the nation have established green street policies and programs to encourage the integration of forward-thinking GI stormwater management in road and street projects. City and County planners and project engineers can better integrate GI on roads and highways by updating technical manuals and design standards to support and encourage GI.

Prioritize GI in Transportation Projects through Capital Improvement Planning Processes

The Capital Improvement Planning (CIP) process can be a valuable pathway to leverage transportation-related sources of funding to achieve community GI goals. By anticipating the GI opportunities created by transportation construction, upgrades, and repairs and allocating appropriate budget resources to GI features, local governments can meet multiple goals with their infrastructure investments.

Integrate with Available Stormwater, Climate and Tree Canopy Plans

GI associated with transportation projects can be a means to accomplish the public benefit goals of other community plans and policies. Considering these plans can both leverage transportation funding to provide these benefits and potentially provide non-transportation funding for street projects. Additionally, the coordination implicit in these integration efforts can result in greater public buy-in, increased economic, engineering and construction efficiencies and more consistent provision of public benefits. The City of Tucson, Pima County and other regional municipalities have climate adaptation, urban tree canopy, stormwater management and other plans that support GI implementation on roadway projects.

Identify Priority Locations and Targets

The effectiveness of using GI to manage stormwater and provide other benefits can be optimized when individual projects are identified and implemented as part of a cohesive, prioritized approach. Using GIS-based tools like PAG's Green Infrastructure Prioritization Tool can help transportation staff recognize priority locations for GI and tailor project designs to address high-priority issues within the project's context (e.g., lack of shade, high heat island effect, etc.).

Include GI Performance Measures within Long-Range Transportation Plans (LRTP)

PAG members and staff develop and update the region's RMAP which takes a performance based approach to achieving regional transportation and related goals. By including GI related performance measures in future planning or allowing GI features to count toward safety and environmental measures, RMAP could be an effective mechanism for driving GI implementation. Similarly, the five year Transportation Improvement Program (TIP) prepared by PAG could integrate GI measures and leverage multiple sources of funding to deliver GI benefits to regional projects.

Ensure Maintenance Provisions Are Included in Project Designs and Long Term Plans

Maintenance can be 'built in' to the project design from its early stages. The maintenance implications of plant and tree selection, drainage configuration, soil compaction and other factors need to be contemplated during the design process. Similarly, maintenance plans and resources should be coordinated with the departments that conduct maintenance and developed prior to project finalization in order to ensure that maintenance crews have proper instruction and resources to achieve long-term GI performance of the investment.

Review project proposals for compliance with GI standards and policies

While public agencies, including transportation departments, have a necessary role in advancing GI, their reach generally is limited to projects on public property. There are considerably more GI opportunities on private properties, and realizing these opportunities requires the participation of property owners, managers, real estate developers and contractors. In order to meet community GI goals, agency project review and planning staff must encourage developers to design and install GI practices as part of their compliance with local codes, ordinances, and community plans. A local successful example is the City of Tucson Commercial Harvesting Ordinance review process.

Gila Monster Reading, Dunbar Springs, Tucson.
Photo: American Rivers

Planning and Project Development Recommendations for Regional and Local Transportation Agencies

Plan for Green Infrastructure early in process

It is critically important to consider GI measures as appropriate stormwater management strategies early in the road project design process. GI should not be thought of as optional landscaping to be added or altered after other design goals have been realized. While GI measures can fulfill landscaping purposes, their primary function is to manage runoff from impervious surfaces; overall project designs succeed when they embrace GI runoff reduction and management principles from the onset. At the pre-design stage, project planners should evaluate conditions in the project area for their capability to support GI and to promote delivery of community benefits. During the scoping process, GI alternatives should be evaluated for their relative abilities to satisfy runoff reduction and management requirements and relationship to other community plans and policies. Retrofits on a built road are a more costly effort.

Utilize a collaborative team of advisors to review public and private road designs early in the process. An integrated team may include members from sustainability or water departments involved in climate and drought resilience goals, MS4s, Regional Flood Control District (RFCD) and urban forestry professionals knowledgeable about landscape and canopy requirements such as Landscape architects.

Utilize Context Sensitive Solutions Planning Process

Local transportation agencies in the Santa Cruz watershed should consider requiring CSS as a planning framework for road and highway projects. This approach has been adopted by transportation agencies for decades in order to design and plan transportation projects that maintain or enhance the existing environment. Environmental stewardship practices in line with CSS can mitigate costs associated with energy consumption, material storage, environmental mitigation, and waste generation.[6] As a design and planning process, CSS requires practitioners to understand their project corridor within the environment of community goals, the street network, and land use. This process allows practitioners to link the goals and objectives of their particular communities to the physical elements of street design that will best support those goals.[7] Most importantly, the CSS approach ensures that goals and values beyond transportation infrastructure, such as environmental and public health and safety, are considered in the design of a roadway project.[8]

CSS is defined by the Federal Highway Administration (FHWA) and American Association of State Highway and Transportation Officials (AASHTO) as "a collaborative, interdisciplinary approach that involves all stakeholders in providing a transportation facility that fits its setting. It is an approach that leads to preserving and enhancing scenic, aesthetic, historic, community, and environmental resources, while improving or maintaining safety, mobility, and infrastructure conditions."[9] Both FHWA and AASHTO encourage its use in project planning and design.[10] As part of its recommendations, the FHWA suggests that planners work collaboratively to understand the landscape, community, and resources before the engineering design stage begins.[11] One of the core principles of CSS is to use flexibility, innovativeness and creativity to preserve and enhance community and natural environments.[12] This is in line with GI goals to use low-tech natural or engineered systems that mimic natural systems to capture and filter rainwater, reducing stormwater runoff to protect water quality. Tucson area streets also function to carry stormwater and GI designs are available to fit various needs from flood reduction to pedestrian enhancements depending on the traffic flow and storm flow regimes. This is an important *context* to consider for many streets in our region. Best practices with the CSS planning approach involve developing an upfront planning process that allows stakeholders including the public and environmental agencies to identify issues as well as identifying and considering existing plans relating to land use, water and sewer, and watershed management.[13]

For roadway projects in Pima County, CSS can be valuable at both the broader scale planning level and when designing specific projects. The process envisions an iterative, step-wise approach to ensure that multimodal corridor construction and reconstruction will play a relevant role in meeting a broad array of community and General Plan goals. Because of the outsized influence that street and roadway projects have on a community, transportation planners have an opportunity, and a responsibility, to factor the broad range of impacts and benefits that can result from individual projects and long-range plans. Using a CSS approach is important as a means of planning successful transportation projects, helping facilitate community dialogue, and helping build stronger communities.[14]

It would be appropriate, even preferable for City, Town, regional and County transportation departments to adopt CSS policies and practices. In advance of formal adoption, transportation planners and engineers working in the Pima County communities should take active steps to embrace CSS approaches.

These approaches include:

- Understanding the Whole Context
- Engaging Relevant Disciplines
- Engaging Affected Stakeholders
- Beginning with an Open Mind and a Blank Sheet
- Developing Consensus on Performance-based Goals[15]

Additional detail about these approaches and their application to transportation-specific planning can be found in the Federal Highway Administration Context Sensitive Solutions Primer and the Institute of Transportation Engineers (ITE), Implementing Context Sensitive Design on Multimodal Corridors: A Practitioner's Handbook. An additional, and seemingly useful resource could be a process diagram or matrix that guides practitioners through the application of CSS to a roadway project. The City of Dallas' recently adopted Complete Streets Design Manual provides an example of such a resource.[16]

There are opportunities to bring these approaches to project planning and development at different stages.

- Planning level. As regional entities, the County or cities develop capital and strategic plans, CSS approaches can be used to broaden public engagement and support for projects, plans and funding requests. At the same time, CSS approaches will ensure that complementary plans and policies are considered in development of future and reconditioned roadways. At the local level, these plans include:
    - Regional Transportation Authority and City of Tucson Process for Grant Road Improvement Plan: The City of Tucson selected the Institute of Transportation Engineer (ITE) recommended practice, Context Sensitive Solutions in Designing Major Urban Thoroughfares for Walkable Communities, for planning and preliminary design of the Grant Road Improvement Plan, which resulted in implementation of GI along the corridor.
- Project level. When reviewing or designing individual projects, CSS approaches can help ensure that project designs best address multiple community needs and provide opportunities to realize a range of community benefits. Individual projects must reflect the designs and resilience goals embedded in city and County policies and plans. To ensure success of General Plans and transportation plans, it is essential that transportation planners and plan reviewers look for opportunities to meet these plans, goals, and policies in all project opportunities. For example, even street repaving or utility work can be leveraged to include landscaping enhancements that treat stormwater.
    - City of Tucson Transit Development Handbook: includes Context Sensitive Design in the Streetcar Corridor

Implement Green Streets Policies and Design Guides

By using CSS, Tucson-area transportation planning and project design will be better able to support the implementation of the City of Tucson's emerging Complete Streets Policy as well as similar "green streets" initiatives elsewhere in Pima County.

The City's Complete Streets Policy was adopted in February 2019 and sets out design principles that "guide the development of a safe, connected, and equitable transportation network." [17] These principles are translated into action via the design specifications

GRAND RAPIDS VITAL STREETS

The City of **Grand Rapids, MI** has adopted and is moving to implement a Vital Streets Plan. The City defines "Vital Streets" as Complete Streets plus Green Infrastructure.[21] The overall goal of the Vital Streets Program is to improve the condition of the city's streets to good or fair as measured through the PASER rating system; however, Grand Rapids has recognized that improvements in street conditions come from more than just the integrity of the asphalt, they are intertwined with core community values:safety, healthy places, vibrant economy, environmental sustainability and diverse transportation options.[22] The plan prioritizes design and construction of street projects that are developed collaboratively with community stakeholders, reflect local land use and community objectives, and protect and enhance the natural environment. The accompanying Vital Streets Design Guidelines provide detailed design specifications to ensure that street projects achieve these and other goals. The guidelines incorporate appropriate GI practices.[23]

The National Association of City Transportation Officials (NACTO) has published a series of design guides that advance innovations in community street principles and designs. The Urban Street Stormwater Guide reflects a collaboration between municipal transportation, public works, and stormwater staff to create a resource that contains national best practices for sustainable stormwater management in the public right-of-way.[24] The guide couples recommendations for planning "stormwater streets" with generalized design specifications for stormwater treatment elements.

contained in the Complete Streets Design Guide.[18] The design guide incorporates green streets principles to manage drainage and streetwater generated from the street system. The key concept of green streets for Tucson is to retain, detain, infiltrate and/or filter runoff from streets and sidewalks using adjacent landscaped areas.[19] In addition to managing runoff, these landscape-based GI practices are expected to reduce ground-level ozone and provide cooling shade for streets and sidewalks.

Peer cities have adopted and implement similar policy preferences that aim to transform traditional roadway planning into collaboratively developed, multi-benefit public infrastructure. For example, in 2014 the City of Austin (Texas) adopted a "complete streets" policy which includes "green streets" as an integral component. Austin describes green streets as public rights of way (ROWs) that are context sensitive and which include landscape features, GI and sustainability measures to enhance non-motorized transportation options. The City of Austin has recognized that the street network must be adapted to function as part of the City's ecosystem as well as its public space inventory; that it must provide economic benefits through reduced maintenance and urban energy costs; and that streets and roads have a critical role in improving resilience to climate change by managing runoff in a manner that values the water supply and heat island reduction benefits of stormwater.[20]

The Pima County Subdivision Street Standards refer to the Pima County landscaping standards for landscaping requirements in the right-of-way. An update to the Subdivision Street standards may benefit from including the "first flush" concept or other GI requirements either in the right-of-way or by directing street runoff to subdivision multi-use common areas. An updated Landscape Manual would help to provide clarification to the Pima County codes and standards where modifications of roadway rights-of-way overlap with landscape, vegetation and stormwater harvesting concerns. A manual update was initiated in 2017.

Prioritize Green Infrastructure in Transportation Projects through Capital Improvement Planning Processes

At the local level, there are also opportunities to better integrate GI into transportation projects to manage polluted runoff. Specifically, the CIP process offers an importation pathway to prioritize GI for roads and highways. Funding sources for transportation construction, upgrades, and repairs are typically much larger than those for stormwater management, which typically does not have a dedicated funding source.

THE CITY OF BREMERTON, WA

The City of **Bremerton, Washington** updated its National Pollutant Discharge Elimination System (NPDES) permit in 2009 to encourage the use of GI and, as a result, also updated its Stormwater Management Plan to be in line with the new permit's requirements. This plan was integrated into the City's Comprehensive Plan which was approved by the city council, and the capital improvement plan included a specific line item for GI projects. Additionally, Bremerton included a line item in its transportation improvement program specifically for green streets.[25]

Municipalities and MPOs should consider prioritizing GI in transportation projects within the CIP process. Examples include objective numeric performance measures, standards or criteria to mimic pre-development hydrology, specific GI requirements, or limits on the amount of effective impervious area.

The local government should implement criteria to prioritize transportation projects that incorporate GI or to set aside a small percentage of capital dollars to be used for green designs. At the department level, the capital improvement plan for the relevant transportation department should include, at a minimum, requirements for coordination among the relevant water quality, water resource, flood control, permitting, and environmental departments in the planning process. The transportation department should develop and implement criteria to prioritize transportation projects in the CIP process that integrate GI elements.

The capital planning process at both the department and municipal scales represents an opportunity to better leverage transportation dollars to fund GI elements that help to cost-effectively meet permit requirements and protect water quality while providing extensive benefits to transportation safety.

Integrate Mobility Planning with Available Stormwater, Climate and Tree Canopy Plans

Much of the preceding discussion was focused on adopting best practices for incorporating GI into transportation project design development and planning review. These efforts are critically important but can succeed more fully when they also achieve the goals adopted in municipal and/or county plans and policies that also prioritize GI. Multiple departments can achieve goals collaboratively and more efficiently for overall savings and greater benefits to the jurisdiction and residents. Plans may be merged as well, such as a Green Complete Streets Plan, for increased coordination and consistent practice.

City of Tucson Green Streets Active Practice Guidelines

The City of Tucson established its Green Streets Policy in 2013. The policy requires the Tucson Department of Transportation and Mobility (TDTM) to design new and upgraded streets that convey stormwater into GI features, capturing at least the first half-inch of rainfall onsite. Additionally, the policy requires TDTM to include native vegetation so that the streets are covered by a 25% tree canopy along with sufficient understory to ensure the function of the bioretention area. Increased water consciousness among community members and leaders about the City's drinking water sources played a large role in encouraging the Green Streets Policy.

Pima County Sustainable Action Plan

Adopted in 2018, the County's Sustainable Action Plan sets forth a broad set of actions and goals for County activities intended to foster resilience to the effects of climate change. Installing GI is one of the six climate change adaptation targets identified by the plan. Specifically, the plan sets a goal of installing at least 40 GI projects in prioritized locations on County properties; implementing the County's Green Infrastructure Action Plan; and utilizing CIP funding for GI wherever possible.[26]

City of Tucson Plan Tucson

Adopted in 2013, Plan Tucson outlines broad goals and specific targets to improve livability, reduce greenhouse gas contributions and energy consumption, increase climate change resiliency, and foster economic vitality. The plan recognizes the role that GI plays in relationship to these separate goals and includes specific policies to encourage GI projects on public and private property and as part of development and redevelopment projects.[27]

City of Tucson Mayor Romero's Million Trees Initiative

Tucson Mayor Regina Romero launched the Tucson Million Trees campaign in April 2020, which aims to plant one million native, drought tolerant trees by 2030 to help mitigate the effects of climate change by reducing utility bills, improving mobility, combating the urban heat island and cooling our city. Mayor Romero is exploring priority planting locations including schools, neighborhood streets, private properties, the city's landfill, the banks of the Santa Cruz River, and urban bosques. The program is connected to the GI fund and a large portion of tree planting in Tucson will be managed by nonprofit groups, including Tucson Clean and Beautiful, which runs the Trees for Tucson urban forestry program.

Make Marana 2040 General Plan

Subject to voter approval in August 2020, the updated General Plan for the Town of Marana reflects the town's projected growth patterns and sustainability platform. Goal RS-8 is that stormwater is efficiently and sustainably managed in a way that reduces flood risks and respects water quality. Policy RS 8-3 considers establishing sustainable stormwater methods, such as GI and permeable pavements, in new development. Under the Water Resources goal is policy RS 4-3 to identify best practices for water conservation programs that can be implemented throughout the community, such as stormwater harvesting or conservation-oriented tap fees.

Aspire 2035 - Sahuarita General Plan

Policy statements encourage the adoption of GI standards that rely on natural processes for stormwater drainage, groundwater recharge and flood management.

In addition, transportation planners and project engineers should be familiar with the following plans, standards and ordinances and their respective GI-related components. These components may be relevant to either the planning and implementation of public-sector transportation projects or the review of development proposals:

Pima County Regional Flood Control District 2020 Floodplain Management Plan

includes GI (stormwater harvesting) practices among the types of appropriate actions.

Pima County Detention and Retention Requirements

The Pima County RFCD Design Standards for Stormwater Detention and Retention include a requirement for retention of the first-flush (first 0.5 inch of rainfall). To incentivize the use of LID practices, the manual allows LID practices to mitigate first-flush retention volume and provides a method to reduce the required volume of detention facilities when stormwater harvesting basins are used throughout a site. The manual standards also incentivize other LID practices when quantifiable flood control benefits can be measured.[28]

City of Tucson Commercial Rainwater Harvesting Ordinance

This ordinance requires developers of commercial properties to harvest rainwater for at least 50 percent of their landscaping needs within three years. Development standards were created with development of the ordinance including parking lot concepts.

MS4 Stormwater Management Plans

The Town of Oro Valley, Pima County, City of Tucson and the Town of Marana each have a stormwater plan and MS4 permit responsibilities

City of Tucson Drought Response Plan and Pima County Drought Response Plan

both encourage increased stormwater use at each increased drought stage.

Tucson Water 2020 Strategic Plan

summarizes policies in Plan Tucson and the Water Infrastructure Supply study regarding increasing stormwater use as part of the water portfolio.

City of Tucson Bicycle Boulevard Master Plan

includes many design and project planning elements and encourages integration with GI approaches. Uses sample evaluation of tree canopy cover to achieve shade goals.

Resolutions have been passed by the PAG Regional Council supporting Rainwater Harvesting (2008), Low Impact Development (2012), Green Infrastructure (2015), Climate Resiliency (2016), Complete Streets (2015), and Heritage of Desert Waters (2017). Resolutions highlight benefits, commend progress, affirm regional values and provide recommendations and endorsement for future direction by regional leaders.

Identify Priority Locations and Targets

PAG created the GI Prioritization Tool to help municipalities, non-profits, and neighborhood groups to select priority locations that would benefit the most from increased GI. GI resources can be distributed to areas with opportunities for enhanced stormwater management, mobility and livability. Plans can be created dynamically by the community for various related concerns and opportunities depending on criteria for a project's funding sources, goals, and requirements. Print options available on this tool aid grant applications for municipalities, non-profits and community groups. PAG's interactive web map is a publicly available tool that was first developed by PAG in 2012 and has been used to select priority locations for GI by multiple jurisdictions. The GI Prioritization Tool helps decision-makers allocate limited financial resources and support GI efforts.

The interactive map contains multiple layers to allow users to explore the relationships between environmental conditions and social demographics. Available data layers include several layers processed from PAG LiDAR data such as regional tree canopy, impervious surfaces, and stormwater flow paths. Layers were compiled by building numerous partnerships with other agencies including RFCD, UA, the Trust for Public Lands and the State Public Health Department. PAG recommends using the following priorities when assessing multi-benefit opportunities using the PAG GI Prioritization Tool.

Location Priorities:

- Below Average (7%) tree canopy
- Proximity to shallow groundwater
- Proximity to watercourse
- Above average heat
- Heat vulnerable demographics
- Bus stops, bikeways, schools, parks
- Pedestrian activity areas

Related resources:

- PAG GI Prioritization Tool

For the City of Tucson's Green Stormwater Infrastructure Fund Proposal (2019), the City requested and utilized the diverse compilation of layers from the PAG map to assess priority locations for distribution of the funds. Prioritization of the GI projects was performed adding weights to criteria of heat vulnerable populations and low canopy as well as the City's identified priority stormwater management system areas and CIP project areas. Other example uses include City and County selection of below average canopy and above average heat for priority planting locations. In Fall 2018, the County utilized PAG's geographic assessment of those priorities to identify locations for GI on public properties in the Sustainable Action Plan for County Operations. This plan sets sustainability goals through 2025, emphasizing mitigation and adaptation measures to meet U.S. objectives for the international Paris Agreement.[29] GI prioritization examples have also been provided by PAG for the Tucson Bicycle Boulevard Plan. Landscape, transportation, and active modes plans, and guidelines would likewise benefit from GI priority location analysis and use of GI in design typologies.

PAG's 2018 Green Stormwater Infrastructure Plan includes the regional canopy cover assessments based on PAG's 2008 LiDAR datasets and recommends canopy targets based on geographic assessments. PAG found the tree cover averaged almost 8 percent in our region and approximately 3 million tree points. PAG found the region has a 4 percent lower canopy than the average for other arid Southwest urban areas. This varies widely from 1 percent to above

LONG -RANGE REGIONAL TRANSIT PLAN

Bus stop with tree shade incorporated.
Photo: PAG

RTA's Long -Range Regional Transit Plan

The RTA's Long -Range Regional Transit Plan discusses various levels of bus and streetcar stops improvement recommendations for each typology. This would be an opportunity to discuss the inclusion of GI for tree shade and other safety benefits. Planting a tree behind the bench would likely be a much more cost-effective way to provide shade than building a shade structure for all stops. Given the aforementioned risks to pedestrians on roads and the vulnerabilities of these demographics to heat related health issues, tree shade should be prioritized at the stops as well as the walksheds that users rely on to get to their stops. Appropriate contexts may be stops that are between intersections (to avoid sight visibility triangles) and that have resources for tree establishment period. If the LRRTP station typologies were translated into actual design guidelines, then GI could be incorporated at that time. While the plan is created by the RTA, the city has traditionally handled bus stop infrastructure, funding, and construction so to be implemented it would likely depend on the city adopting the idea.

District of Columbia, Sustainable DC Plan

Sustainable DC Plan calls for increasing GI in the public right-of-way (ROW) and taking actions to improve the health of the city's waterways. Under the plan, the District's Department of Transportation (DDOT) is installing GI as part of construction projects and in retrofit projects to reduce stormwater runoff. Where watershed and infrastructure improvements are prioritized, DDOT may construct green street and green alley projects that utilize GI techniques. DC's Long Range Transportation Plan includes an Environmental Inventory Map with GI features. DC's Fiscal Year 2019 - 2024 Transportation Improvement Plan, includes GI projects. In 2014, DDOT released the GI Standards which included technical drawings, specifications, design manual, plant list, and maintenance schedules. The Department has also released a GI guide, "Greening DC Streets," which summarizes GI opportunities and constraints in the District.[31]

Wasatch Front Regional Council, Regional Transportation Plan 2019-2050

This comprehensive regional plan reflects the value of integrating GI provisions throughout the planning process. The Council recognized that both green and gray infrastructure function together and that there are environmental and community benefits which arise when transportation practitioners draw from both fields to understand and respond to the complexities of the urban landscape. The plan envisions that GI will play a role in contributing to the increased resiliency of the regional transportation system by reducing or mitigating stormwater impacts.

20 percent across the region. While tree canopy provides shade benefits, understory can provide additional habitat, aesthetic and watershed health qualities. Other vegetative cover was nearly 30 percent. To reach 25 percent canopy in the urban area, the region would need a total of 7.5 million more trees. Since new hardscape, including streets, create more runoff this is sometimes referred to as "new water." Pre-development, this water would have otherwise evaporated, as very little of it naturally recharges aquifers in desert regions. "Stormwater Harvesting and Management as a Supplemental Resource Technical Paper'' from the Water and Wastewater Infrastructure, Supply and Planning Study, Phase II (Pima County and the City of Tucson, 2009) has calculated "new water" amounts that can be used as stormwater harvesting targets. That paper states that about 30,000 to 40,000 acre-feet (AF) of "new water" could be harvested from impervious surfaces in the City of Tucson in an average year. This harvestable water could theoretically support up to 4.3 million trees within the urban footprint of Pima County, depending on distribution of stormwater and vegetation types.[30] Therefore, the 25 percent canopy goal would be feasible from a stormwater availability standpoint. However, establishment periods, extreme drought, and reflective and radiant heat along streets create more stress on young trees, and so supplemental irrigation may be needed at times. Transportation projects can be a major vehicle to achieve these goals when coordinated across multiple departments.

Recommended Targets

- **Create a target of 15-25% average cover over the full urban area within 20 years (by 2040)**
- **Focus outreach and capital improvement efforts in areas with less than average tree cover**
- **Implement greater cover in areas of greater mitigation need (see priorities list above)**
- **Utilize street runoff wherever feasible to support vegetation and achieve a goal of 40,000 AF**
- **At least 90% of new trees to be irrigated primarily by stormwater**
- **Convert impervious space to green space**

Include GI Performance Measures within Long-Range Transportation Plans (LRTP)

PAG's RMAP is the region's long-range transportation plan covering a minimum of a 20-year planning period. Based on federal requirements, this plan takes a performance based approach. Performance measures were identified as targets to help the regional and operating agencies assess system wide progress relative to regional goals. This helps ensure that investments are achieving national and regional goals. Establishing similar performance based planning measures for GI, and including GI as a measurable ingredient in system wide roadway planning, could be an approach to folding GI into roadway design. Some of PAG's performance measures include System Maintenance, Safety, Multimodal Choices, System Performance, and Environmental Stewardship. Metrics toward these targets include pedestrian and bicyclist fatalities, pedestrian and cyclist facilities, air pollution and greenhouse gas emissions, and vehicle miles traveled. Performance metrics that evaluate effectiveness of the performance targets could include reduction of road closures due to water in the roadway, shade improvements (tree canopy), increased pedestrian activity, reductions in irrigation, mitigated runoff from impervious surfaces, and improved infiltration rates.

The TIP process, prepared by PAG, also utilizes the performance-based approach. Projects are reviewed for anticipated impacts to the transportation network and how they may advance the progress toward target achievement. Ideally, projects included in both the RMAP and TIP will have a positive impact in achieving the desired performance outcomes. Based on this approach, GI performance targets could be considered as part of the overall performance of the transportation network.

Related, PAG Safety Assessments gather data on incidence of trees/bushes as part of traffic incidents with injury and fatality and found that trees/bushes relate to safety in less than 1% of the incidents. Gravel and standing water are also tracked as part of the road conditions for the assessments.

Establish GI Project Performance Goals

By designing to meet performance goals for GI projects, project managers can ensure the effectiveness of the drainage benefits and of the landscape to meet its intended purposes. These are based on but may vary from Tucson's Green Streets Active Practice Guideline Performance Goals and are proposed as general minimal guidelines for use by other local jurisdictions to enhance consistency and ease of practice for practitioners and improve performance as a region.

The guiding principles for these goals include:

- Prioritize tree planting and engaging the community in areas with the greatest needs and multiple benefits.
- Use on-site non-potable water sources for irrigation before any imported water source. Invest potable water in the short term to establish trees as needed.
- Wherever possible, natural drainages should be the primary stormwater infrastructure.
- Wherever possible, canopy and natural drainages should be preserved, restored and maintained to create the primary stormwater infrastructure by protecting arroyos, creating green streets and daylighting underground systems.
- Use the conventional storm drain system as the overflow approach, not the primary system to manage stormwater. (Visible water flow systems are easier to notice and maintain.)
- Use public right-of-way stormwater installations to inspire private property installations and serve as model installations for neighborhoods. ♦ Decrease connectivity of impervious space and convert to green space. Use water harvesting to reduce runoff from hardscape from reaching the street. Emphasize harvesting efforts at the top of each watershed.

Drainage Performance Goals

1. **Routing and Conveyance.** Hardscape and landscape features will be designed to slow stormwater runoff and to encourage infiltration within the landscape. Additionally, design of all features will be mindful to:

    a. route stormwater runoff from the roadway and direct through GI features in parkways and medians before entering storm drains or natural drainage ways to provide moisture in the soil for plants and trees and provide stormwater pollution mitigation,

    b. ensure ease of maintenance, and

    c. use and integrate 'waste' materials (e.g. tree trimmings as mulch and salvaged concrete in place of mined rock for rip-rap or screened rock mulch).

2. **Runoff Collection.** Landscape areas along streets are designed to:

    a. retain at least the first 0.5 inch of rainfall falling on the roadway and public right-of-way (not including run-on from other streets and properties) dependent on right-of-way width, to mimic pre-development conditions and capture first flush, and

    b. accept a maximum final pooling depth of eight inches of stormwater for public safety.

80' row GSI integration - typical street design with shared use path.
Graphic: Watershed Management Group

3. **Infiltration.** Infiltration of retained stormwater runoff is a critical function of GI. Several items will be considered when designing the feature to ensure infiltration within 24 hours to prevent mosquitos and promote soil health.

    a. Compaction of landscape areas will be avoided. A 12"-18" depth for tilling or ripping will be performed in all plant-able and infiltration areas which have been compacted.

    b. On-site soil percolation tests will be used to evaluate the ability of the soil to transmit water through the soil profile. If a restrictive soil layer is present (e.g. caliche, or clay accumulation) then it is recommended to auger or rip through the restrictive layer to allow water percolation to underlying soil layers. Coarse, well drained soils often underlie caliche and clay lenses.

    c. Soil amendments and structural soils may be used if necessary, to ensure sufficient infiltration of stormwater runoff. Use of amended soils may be impractical at a larger scale due to high construction cost.

Landscape Performance Goals

1. **Irrigation.** The planting plan is based on a water budget where plants associated with GI elements can be fully supported by collected stormwater in seasons receiving 80% of average rainfall for drought resilience. Where feasible, plan for plants that require no irrigation after establishment. First and foremost, plant to capture rain that falls on the project site.

2. **Plant composition.** Plant composition must include a minimum of 75% native, low water use plants so that water demands match seasonal availability. The 25% non-native may be needed for space constraints. All plants shall be in a low water use, low water use/ drought tolerant category to reduce overall demand.

3. **Vegetation coverage.** GI is a living engineered system that requires plants as a functional element to achieve desired primary and co-benefits. The following guidelines will ensure a functional feature that safely infiltrates stormwater while providing for myriad co-benefits. When using goals to create policies, ensure they are simple to calculate and understand in order to aid compliance and review.

    a. Create a goal setting process based on street typologies that help to meet larger community canopy goals. Streets are major opportunities for increasing overall canopy coverage due to access to street runoff. Example goal: Canopy of shade trees, when mature, covers a minimum of 25% of the rights-of-way without creating sight visibility, pedestrian or utility conflicts.

    b. Coverage of understory vegetation, based on mature diameter, is a minimum of 25% of the Stormwater Infiltration Area.

Stormwater Infiltration Area is defined as the maximum pooling extent within a landscape area. This will ensure that sufficient root mass is present to facilitate infiltration and increase of soil organic content critical for long-term soil health.

c. Coverage of understory vegetation for other permeable landscapes should resemble natural plant community densities to facilitate water savings by not requiring long-term irrigation once plants are established.

4. **Other.** As part of final landscape stabilization, 100% of disturbed and/or barren areas to be covered with native revegetation mix and equal replacement of trees, shrubs, herbaceous plants and succulents. To save expense and prevent excess heat, stabilization with hydroseed is preferred over gravel and rock and use of large rip-rap is recommended only for slope stabilization. Provide enough space to allow the tree to grow to maturity.

Ensure Maintenance Foresight is Included in Project Designs and Long Term Plans

In transportation projects, the original funding often covers only the establishment period for vegetation for a limited number of years due to restrictions on use of some funding types on maintenance. For example, RTA projects excluded maintenance due to state laws until there was a recent legislative change. A supplemental plan for ongoing maintenance resources is key to long term success of the investment. Locally, maintenance of GI along streets in subdivisions and neighborhoods relies on agreements by adjacent private homeowners and often assisted by stewards such as through Tucson Clean and Beautiful. In the City of Tucson, businesses are also responsible for maintaining the adjacent ROW and buffer yards and the City assists with maintenance when critical for safety. ROW maintenance is the County responsibility in the unincorporated County. Sites that are maintained by municipalities could improve results by setting standards for GI training for employees and qualifications for contractors. Challenges with community pushback for a tidier look could be addressed through outreach.

Design is also key to success of the project over the long term. GI sites can be designed for cost-effective maintenance from the onset. Further information on design, installation, and operations and maintenance (O&M) best practices can be found in Part 3 along with associated guidance checklists.

Additionally, it is critical to preserve future GI retrofit opportunities especially behind the street curb. This may include a review check before issuing permits for utility installations, upgrades, or other ROW infrastructure work which could limit or hinder the ability to design and install GI.

Review project proposals for compliance with GI standards and policies

Project review and permitting staff in development services have an important role in ensuring and encouraging private developers to implement GI to manage roadway and parking lot runoff and should coordinate with transportation departments and others. Existing standards and policies incentivize or require GI/rainwater harvesting for many private development projects. Staff can help leverage these projects for the benefit of the community by ensuring that development projects routinely and consistently comply with these policies/standards. It is worth noting that multiple policies may apply to a project depending on the jurisdiction. For example, a commercial development in the City of Tucson could claim that their grading addressed both the first flush requirement and the commercial water harvesting requirement.

Leadership at municipal and County levels have provided staff with a foundation of support by implementing GI policies and standards. Development services, transportation departments and their civic and community partners can assist with compliance by undertaking targeted outreach and education efforts. The resources, example design guides, and checklists provided in this document can be valuable tools in departmental efforts to resolve barriers, challenges and uncertainties about the feasibility and benefits of GI. Through consistent application of existing standards and policies, the private development community can become valuable champions of GI.

Part 1 Endnotes

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Pima Cty Water Reclamation Campus
Photo: gmvargas.com

PART 2

Funding Green Infrastructure as Part of Transportation Projects

Assuring adequate funding for GI in transportation projects has unique challenges and opportunities. Opportunities may arise for using transportation-specific funding sources to provide GI benefits that other municipal funding sources cannot. Alternatively, transportation projects may provide an opportunity to leverage non-transportation oriented funding in order to optimize public investment in GI benefits. In general, and regardless of source, funding goes further when used for multi-benefit purposes and using an integrated approach.

Bonding and Debt Financing Green Infrastructure

The funds used for transportation projects can complete the GI aspects, or additional funds can be sought to enhance and retrofit GI features. In addition to the funds that may flow to GI from private development projects and from municipal/county Capital Improvement Projects, below are some transportation funding sources that allow and encourage GI uses.

Transportation agencies and local governments may opt to fund roadway and other transit projects through debt financing, particularly by issuing municipal bonds.[32] Debt financing should be thought of as an important option for creating sufficient capital for investments in up-to-date transportation networks, particularly because they create sufficient one-time resources for investments in major projects or multiple projects included in a CIP. In addition, financing spreads the debt burden across time, which allows the project(s) to be paid for by the people who benefit across the lifetime of the constructed infrastructure. Debt financing requires a dedicated, sustainable source of revenue for repayment of the bond principal plus interest. Often a tax or rate increase will provide that source of income. Arizona law requires that voters approve general obligation, highway user revenue and utility revenue bonds which creates both an obligation for transportation agencies to obtain voter approval and an opportunity to engage the public in a way that is consistent with a CSS approach.

There are at least three approaches to funding GI through bond financing. First, transportation related bond issuances may be an option for future city or Pima County roadway projects. As the bond package is designed and drafted it is important to include the capital costs of any associated GI components of the bond funded projects and to specifically allocate bond revenues to GI features. A second approach would be to include transit corridor GI projects as eligible features within a non-transportation bond, such as a park, flood control, or even school bonds. GI practices are appropriate for managing runoff from constructed features of many capital improvements. Finally,

Mural by El Ojito Historic Spring, Tucson. Photo: American Rivers

Tucson-area cities and towns or Pima County may consider a bond issuance that is specifically intended to fund GI projects, either as a "stand alone" effort or perhaps as part of a broader investment package intended to fund climate resiliency projects.[33]

There can be challenges associated with incurring bond debt to finance GI projects. These projects are, by their nature, distributed across many locations in contrast to more traditional, centralized assets. They may even be constructed on private property with the intention of providing a public benefit. Recent changes to accounting rules have reduced some of the obstacles, making it easier for public agencies to treat distributed infrastructure projects (even conservation programs) as assets. These changes, although arcane for most transportation planners, make it easier to contemplate bond financing for GI.[34]

Tucson Parks and Connections Bond:
Proposition 407, approved by Tucson voters in 2018, provided $225 million in general obligation bond funds to support investments in city parks, park amenities and connections projects (pedestrian pathways, bicycle pathways, pedestrian, and bicycle safety). While there are significant opportunities to incorporate GI features into parks and playgrounds, the corridor connections projects also create opportunities for integrating GI into transportation-related infrastructure.

Paying for green infrastructure with transportation funding

There may be many instances in which implementing GI is an appropriate practice for achieving transportation objectives and is eligible for funding through traditional transportation-related and funding sources.

Better Utilizing Investments to Leverage Development (BUILD) Transportation Discretionary Grants

The BUILD Grant program was launched in 2018 as a federal transportation infrastructure investment program. Formerly known as TIGER Grants, BUILD grants are intended to fund large infrastructure projects and can be used for planning initiatives. BUILD Grants include a designated allocation for rural projects in an effort to equitably distribute the funding between rural and urban areas. Although BUILD Grants are highly competitive, the criteria for developing a successful project include environmental protection, innovation, and quality of life improvements. GI design elements could factor into a successful BUILD grant application.

FAST Act Transportation Alternatives/Surface Transportation Block Grant Program (STBG)

MPOs, such as PAG, are required to consider several planning factors in the development of transportation plans and programs. The metropolitan planning process includes the following planning factors that could be applied to GI-based projects or projects which include GI:

- improving transportation system resiliency and reliability [23 U.S.C. 134(h)(1)(I)]
- reducing (or mitigating) the stormwater impacts of surface transportation [23 U.S.C. 134(h)(1)(I)]
- enhancing travel and tourism [23 U.S.C. 134(h)(1)(J)]
- reducing the vulnerability of existing transportation infrastructure to natural disasters [23 U.S.C. 134(i)(2)(G)]

The Transportation Alternatives (TA) set-aside funds from the STBG program encompass a variety of smaller-scale transportation projects, community improvements and environmental mitigation related to stormwater, and habitat connectivity. Tribal governments, local governments, transit agencies, school districts, and nonprofit organizations responsible for local transportation safety programs are eligible to apply for this competitive grant program. PAG uses its TIP for applications, and all projects included in the TIP must be drawn from the RMAP, described further in the performance measures section above. The TIP is a five-year schedule and budget of anticipated transportation improvements within eastern Pima County. The TIP is typically updated biennially through a multi-step process in association with PAG's member jurisdictions and other implementing agencies. The goal of the process is to develop a TIP that makes optimum use of available federal, state and local funds and resources to serve the region's multi-modal transportation needs. The RTA Board set policy that any funds available through the TIP process be prioritized to the delivery of RTA named projects and promises made to the voters.

FHWA Congestion Mitigation and Air Quality Improvement Program (CMAQ)

The CMAQ program provides a funding source to state and local governments for transportation projects and programs to help meet the requirements of the Clean Air Act. Funding is available to reduce congestion and improve air quality for areas that do not meet the National Ambient Air Quality Standards for ozone, carbon monoxide, or particulate matter (nonattainment areas), as well as former nonattainment areas that are now in compliance (maintenance areas). States with no nonattainment or maintenance areas may use their CMAQ funds for any CMAQ- or STBG-eligible project. Under the FAST Act, a State with PM2.5 (fine particulate matter) nonattainment or maintenance areas must use a portion of its funds to address PM2.5 emissions in such areas. Pima County is not in nonattainment for PM2.5.

List of eligible CMAQ projects: https://www.fhwa.dot.gov/environMent/air_quality/cmaq/reference/cmaq_essentials/

EPA link regarding CMAQ regarding pedestrian and bicycle projects that have GI elements incorporated: https://www.epa.gov/green-infrastructure/green-infrastructure-funding-opportunities

In Pima County, the Tucson Air Planning Area (TAPA) is under a second 10-year Carbon Monoxide (CO) Limited Maintenance Plan which concludes at the end of 2020. The region is designated attainment status for the ozone National Ambient Air Quality Standard (NAAQS). In Pima County, there are two designated PM10 nonattainment areas in Rillito and Ajo.

The Pima County region is not currently a recipient of CMAQ funds as outlined in statewide transportation funding distribution. Any receipt of CMAQ funds would impact other fund sources available to the region and the region would likely lose proportionate funding from other less restrictive funds like STBG which have greater flexibility and simpler reporting requirements. These funds may be attractive if a reliable funding source for focused air mitigation is needed but may not be an appropriate tool for the Tucson region.

Local Tax Revenue and Capital Improvement Projects

Local tax revenues are used for local funding priorities. The CIP budget is typically planned over a five-year period because it is funding construction projects rather than day-to-day operating costs. The CIP budget includes all the costs necessary for major construction projects such as land acquisition, project design, project management, and construction costs. The CIP is funded primarily through taxes, fees, grants, and bonds. Tax revenues can fluctuate with the economy and local spending so it is important to balance urban design, mobility and safety needs with a balance of other regional and federal funds. Many examples of CIP projects with GI can be found in the City of Tucson since they follow the Green Streets Active Practice Guidelines.

Special Revenue funds consist of revenue sources that are dedicated to a specific purpose. This includes state and local taxes as well as grants and certain fees. Special revenue tax funds, such as Rio Nuevo tax increment financing fund, have been used for GI projects. One such project is the Scott Avenue retrofit in downtown Tucson.

Regional Transportation Authority

The Regional Transportation Authority (RTA) is an independent taxing district within Pima County overseen by the PAG Regional Council members. The RTA delivers multimodal transportation projects that improve our region's mobility, safety and environment through a half-cent excise tax. Pima County voters approved the 20-year RTA plan in 2006.

The current RTA program is set to expire in 2026, which is prompting an "RTA Next" process. In 2020, the RTA is in the process of developing the plan for "RTA Next." Currently, as a general value engineering rule, landscape costs on RTA projects must be under 4% of the project budget. The challenge is when landscape is also performing functions for drainage management or when sufficient funds are not available for this end of a project. The current RTA has a category of funding for wildlife corridors, which in the environmental planning field are considered large scale GI projects. Voters in the future may be interested in small scale GI installation and maintenance in developed transportation corridors either as a category of funding or as a part of the enhanced drainage and safety performance for each roadway project. In Maricopa County, the half-cent sales tax for transportation approved through Proposition 400 is the comparable effort approved by Maricopa County voters in 2004. This could serve as an example of other areas the Pima County RTA could fund. The MAG Prop 400 funding goes in part toward regional and state highways and encompasses landscape maintenance and outreach.

Accessing Non-Transportation Loan and Grant Programs

604(b) Funds

The Arizona Department of Environmental Quality (ADEQ) distributes the 604(b) Water Quality Management Program with a focus on water quality management planning (not projects on-the-ground). Up to $60,000 is available annually and is currently given on a rotational basis to each of the Designated Planning Agencies (DPA) under section 208 of the Clean Water Act, across the state. The DPAs may work or pass the funds to other partners such as cities, Universities and non-profits. Allowable categories have included LID, flood control, stormwater infiltration, streambank stabilization, education/outreach, and addressing pet waste. Priority has been given to plans that address Impaired Waters. In Pima County, PAG is the DPA and the Santa Cruz River's impairment for *E. coli* contributed by stormwater can be addressed through GI planning. Past uses of these funds have included updating GI standards and specifications in the Maricopa region. This document may help prepare similar local efforts.

Urban Forestry Grants

The Urban and Community Forestry Challenge Cost-Share Grant Program is run through the National Urban and Community Forestry Advisory Council (NUCFAC) established in the 1990 Farm Bill under the U.S. Forest Service.[35] NUCFAC assists the Secretary of the U.S. Department of Agriculture in the grant application and development process. The purpose of the grant program is to fund urban and community forestry projects that have a national or regional impact.[36] While this program is not designed to fully fund capital projects or demonstration projects, it could be an important source of funding for capacity building and planning to set policies that incentivize GI for transportation. For example, the Fiscal Year 2020 funding cycle invites applications for projects that integrate urban and community forestry into all scales of planning (including transportation) or for efforts to promote health and resilience of urban and community forests. Previous funding rounds have focused on projects that will address significant barriers to GI, focusing on the role of trees and urban forests.

Palo Verde pocket park.
Photo: Watershed Management Group

The Urban Forestry Grants create opportunities for transportation agencies to work collaboratively with civic organizations and local governments to implement a green street policy, integrate GI upfront in planning processes, or address specific barriers to including GI in transportation projects.

Community Development Block Grants

The U.S. Department of Housing and Urban Development (HUD) Community Development Block Grants (CDBG) program provides annual grants through a formula to local governments and states. The CDBG program is designed to assist in community redevelopment, providing funding to expand economic activity, improve community services, and revitalize neighborhoods. Eligible activities include the construction of water infrastructure and streets.[37] States and local governments could look to the CBDG program as a potential source of funding to add GI elements into a street reconstruction project, for example.[38]

Rincon Heights Pocket Park Art.
Photo: Watershed Management Group

EPA Section 319 Funding

Authorized by Section 319 of the Clean Water Act, this program provides funding to projects that address nonpoint source pollution reduction projects.[39] These funds are distributed by the U.S. EPA to state and tribal agencies which then administer them. In Arizona, the ADEQ Water Quality Division manages the state's 319 Program. ADEQ awards Water Quality Improvement Grants to local governments, watershed partnerships, and other entities to fund projects that will quantifiably reduce nonpoint source pollution. The grant program is one element of the Department's 5-year Nonpoint Source Management Plan. At times ADEQ has targeted these funds toward waters with impairments. Since the Santa Cruz River has an impairment for *E. coli* contributions in stormwater, GI is a valid solution for treatment.

EPA/NFWF Five Star and Urban Waters Small Grants Program

This program, an evolution of an earlier EPA Urban Waters Small Grants Program, is co-sponsored by EPA and the National Fish and Wildlife Federation (NFWF). The program supports projects that develop community stewardship of natural resources and address water quality issues.[40] Urban tree canopy restoration and stormwater management are among the activities funded through the program.

FEMA Pre-disaster Mitigation Grant Program

This FEMA program is designed to assist local communities with implementing a natural hazard mitigation program in order to reduce overall risk from future disasters. This program awards planning and project grants and provides opportunities for raising public awareness about reducing future losses before disaster strikes. To be eligible, projects must be consistent with the goals and objectives identified in a current FEMA-approved Hazard Mitigation Plan.[41] GI is an eligible mitigation method.

FEMA Flood Mitigation Assistance Grant Program

FEMA's Flood Hazard Mitigation Assistance program provides funding support to communities for projects that reduce the risks associated with flood and drought conditions. Aquifer storage and recovery, floodplain and stream restoration, flood diversion and storage, and GI methods are eligible for funding.[42]

A rainy day on Scott Avenue.
Photo: PAG

Clean Water State Revolving Fund

Like the Section 319 funding, the Clean Water State Revolving Fund (CWSRF) provides federal funds to state-administered programs which, in turn, distribute money to qualifying cities, towns, special districts and tribes. These awards are typically loans, with very favorable repayment provisions and occasional interest or principal forgiveness options. In Arizona, the CWSRF is managed by the Arizona Water Infrastructure Finance Authority (WIFA).[43] Stormwater management projects, including GI, are eligible for funding. Financing GI through the CWSRF allows transportation agencies to access project funds with no application or closing fees, 30 year repayment periods, and other advantages. WIFA also provides funding for technical assistance, enabling local governments to develop, fund and implement capital improvement projects.

The City of Flagstaff, in conjunction with Tucson-based Watershed Management Group, recently used WIFA technical assistance to develop a GI-focused Watershed Action Plan. The City of Peoria recently closed a 20-year, $6.2 million dollar loan to fund several stormwater management projects. The low, 1.6% interest rate and $1 million of forgivable principal enable the City to undertake drainage and flood reduction projects affordably.[44]

Local utility fees

Two jurisdictions within Pima County have adopted specific fees, levied against water customers or property owners, that provide sustainable revenue for GI projects. Coordination with these municipalities may create opportunities to align funding for specific projects.

Tucson Water Green Stormwater Infrastructure Fund

The Green Stormwater Infrastructure (GSI) Fund adopted in 2020, creates a reliable and dedicated funding source for planning, implementing, education, and maintaining GI projects city-wide. The fund will be resourced by a fee, assessed on Tucson Water customers within the City of Tucson, generating approximately $3 to $5 million per year. The majority of this sustainable revenue stream will be allocated to installation of GI projects; however, a portion will be directed to maintenance of existing projects and administration of the City's stormwater program.

Oro Valley Stormwater Utility

Established as an enterprise fund in the stormwater code, the stormwater utility "provides for the planning, design, construction, operation, and maintenance of stormwater facilities that safely drain and control the quantity and quality of storm run-off" in accord with the Town's stormwater management plan. Projects include ROW improvements.

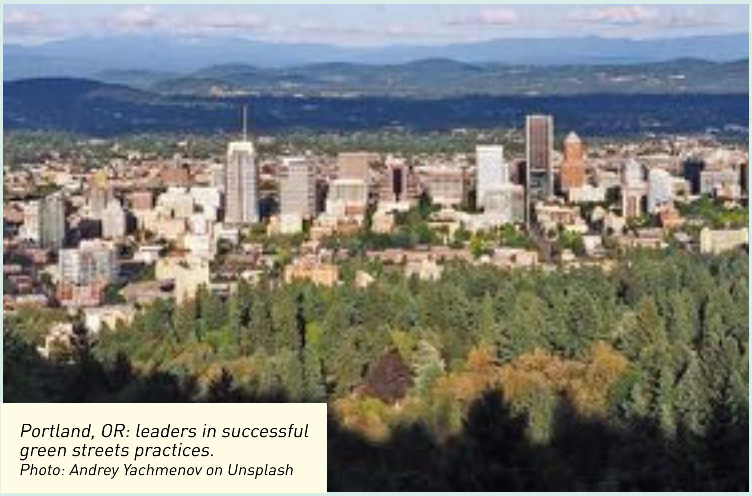
Policies that Support or Ensure Projects

Offsets/ In Lieu

In lieu fees or offsets provide flexible pathways for property developers to comply with local stormwater codes. When soil conditions or other factors limit or preclude on-site management of requisite volumes of stormwater and vegetation, these provisions allow developers the option to construct equivalent stormwater management and vegetation at an alternative location or to pay local government a fee intended to fund publicly constructed stormwater and vegetation practices. The benefit of these options is in the reduction in the number of projects granted waivers or exemptions from stormwater and vegetation management requirements. An example In-Lieu Compensation program could require that the ROW user(s) shall be responsible for covering 100% of the replacement cost for plant material removed during a project if there is no adequate space on site or nearby for replacement landscape and no space for stormwater harvesting. For retrofit sites, where the shade cover goals cannot be met, nearby sites may be used or commensurate payment into a GI fund.

CITY OF PORTLAND, OR

Any funded redevelopment or enhancement project that doesn't incorporate green street facilities as required in the Stormwater Management Manual but that requires a street opening permit or occurs in the ROW shall pay into a "% for Green" Street fund. The amount shall be 1% of the construction cost for the project. Exceptions apply such as emergency maintenance, repair of driveways, pedestrian path replacement, tree planting, and utility pole installation.



Portland, OR: leaders in successful green streets practices.
Photo: Andrey Yachmenov on Unsplash

Part 2 Endnotes

32. For information on Pima County bond issuances and related projects, see https://webcms.pima.gov/cms/one.aspx?portalId=169&pageId=7386.

33. Pima County. (2017, July 11). Climate Resolution. https://webcms.pima.gov/cms/One.aspx?pageId=356418

34. See Earth Economics, Go Green: Muni Bond Financing for Distributed Water Solutions, available at https://tapin.waternow.org/wp-content/uploads/sites/2/2019/02/GASB_Go-Green.pdf.

35. See National Forest Resiliency Innovation Challenge Cost Share Grant Program Online Grant Portal at https://grants.urbanandcommunityforests.org/

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37. U.S. Department of Housing and Urban Development. Community Development Block Grant Entitlement Communities Grants. http://portal.hud.gov/hudportal/HUD?src=/program_offices/comm_planning/communitydevelopment/programs/entitlement

38. Information available at https://www.hudexchange.info/programs/cdbg/,

39. "Nonpoint source" runoff or pollution is another term for stormwater.

40. National Fish and Wildlife Foundation. (2020). Five Star and Urban Waters Restoration Grant Program.https://www.nfwf.org/programs/five-star-and-urban-waters-restoration-grant-program

41. Federal Emergency Management Act. (2019, December 23). Pre-Disaster Mitigation Grant Program.https://www.fema.gov/pre-disaster-mitigation-grant-program

42. Federal Emergency Management Act. (2020, February 20). Flood Mitigation Assistance Grant Program. https://www.fema.gov/flood-mitigation-assistance-grant-program and Federal Emergency Management Act. (2018, February). Mitigating Flood and Drought Conditions Under Hazard Mitigation Assistance. https://www.fema.gov/media-library/assets/documents/110202

43. https://www.azwifa.gov/loan-programs/?cw

44. https://www.azwifa.gov/loan-programs/?cw

45. City of Tucson. (August 2016). Floodplain Management Plan. TSMS Phase V.

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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48. Watershed Management Group. (2015). Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area. https://watershedmg.org/document/solving-flooding-challenges-green-stormwater-infrastructure-airport-wash-area

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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/

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

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

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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

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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

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

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

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

Tucson streets at night.
Photo: Frankie Lopez on Unsplash

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