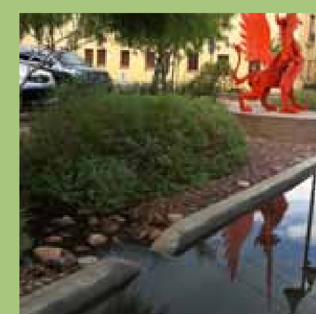
GREEN INFRASTRUCTURE

FOR DESERT COMMUNITIES



Watershed Management Group

Green Infrastructure for Desert Communities

Version 2.0

Revised January 2017

Written and edited by:

Watershed Management Group: Lisa Shipek, Catlow Shipek, Kieran Sikdar, Karilyn Roach, James MacAdam, Tory Syracuse, and James DeRoussel.

Illustrations by:

Dean Alexander, Allen Denomy, and James DeRoussel

Designed by:

Watershed Management Group & Cero Wood Graphic Design

Funding for development of this manual was provided by the Town of Oro Valley (Water Infrastructure Finance Authority Technical Assistance grant), Pima Association of Governments, United States Environmental Protection Agency, Arizona Department of Environmental Quality, Arizona State Forestry, USDA Forest Service, and donors to Watershed Management Group.

English and Spanish version are available online at https://watershedmg.org/learn/resource-library

Acknowledgements:

This manual is based on the experience, hard work, and contributions of many people and partners. In particular we would like to thank: Brad Lancaster, Christine Wilke, Cidney Jones, Dave Stewart, Ericka Gallo, Evan Canfield, Gary Wittwer, Henry Jacobson, Janice Hughes, Mayor Jonathan Rothschild, Mead Mier, and Mitch Pavao-Zuckerman. Most of all, we wish to acknowledge the dedication, hard work, and selflessness of the hundreds of Watershed Management Group volunteers who have contributed to the many green infrastructure installation workshops that form the basis for this manual.

Published by:

Watershed Management Group

1137 N Dodge Blvd
Tucson, Arizona 85716
520-396-3266
www.watershedmg.org

Clean water starts with me!


STOP
Watershed
Management
Group

Table of Contents

1. What is green infrastructure?

Green infrastructure (GI) refers to constructed features that use living, natural systems to provide environmental services, such as capturing, cleaning, and infiltrating stormwater; creating wildlife habitat; shading and cooling streets and buildings; and calming traffic.

Green infrastructure is a strategy that a growing number of communities are using to manage stormwater more sustainably, while using that water to grow vegetation that provides myriad benefits.

GI strategies for arid and semi-arid desert communities need to be different than GI strategies developed in temperate areas of North America. The Southwestern U.S. and Mexico face long periods of drought interspersed with intense rainfall that can make implementing GI challenging.

This manual provides guidelines and best practices for retrofitting neighborhood streets, open spaces, right-of-ways, and parking lots with green infrastructure.

This guide draws on Watershed Management Group's experience working with landowners, neighborhoods, and local governments to install GI in the Southwestern U.S. and Mexico. Design specifics are given only for conceptual understanding, and will always require adaptation to local site conditions and government regulations.

University of Arizona retrofitted their parking lot landscape buffer with a swale to capture runoff.

Newly planted chicanes harvest stormwater moving along the gutter. Right: This stormwater basin is constructed with repurposed urbanite in La Paz, Mexico.

2. About green infrastructure

2.1 The problem

As communities develop, natural vegetation is removed and soil is covered with asphalt, concrete, and buildings. These impervious surfaces do not allow water to infiltrate into the ground. Desert cities are no exception, where automobile-centered infrastructure has created sprawling suburban areas with wide streets and inefficient layouts that maximize impervious surfaces (also known as "hardscape"). When rainfall runs off these surfaces, it can cause a variety of problems:

- Flooding of buildings, streets, and waterways
- Increased erosion in streams and washes/arroyos
- High volume and velocity of runoff
- Delivery of pollutants like automobile oil, herbicides, and pet waste into waterways

Impervious surfaces also contribute to other issues in urban areas:

- Streets and parking lots are rarely or minimally shaded by vegetation, making temperatures hotter and neighborhoods less livable.
- Pavement and buildings retain and radiate heat, causing an "urban heat island effect," the phenomenon of developed areas becoming warmer than surrounding rural areas (which in turn causes increased energy consumption and air pollution).
- Hardscapes can also increase local drought conditions between rainfalls by preventing rainfall from infiltrating into the soil.

Grey infrastructure

Most cities have dealt with increased runoff from hardscape by building "grey infrastructure," such as concrete channels, pipes, and barren detention basins.

Pros of grey infrastructure

- Reduces local flooding by sending water out of the system as quickly as possible
- Manages enhanced urban runoff

Cons of grey infrastructure

- Exacerbates flooding downstream
- Degrades and destroys wildlife habitat and recreation areas in washes and streams
- Does not address water quality issues
- Serves only one function at high cost
- Requires maintenance indefinitely
- Increases urban heat island effect
- Prevents infiltration and creates dangerous, high-velocity runoff

Examples of grey infrastructure: Concrete channels, which have replaced natural washes, send stormwater quickly downstream.

2.2 An integrated solution

Green infrastructure

Green infrastructure offers an integrated solution to stormwater management, meaning it solves many problems and provides many benefits at the same time. GI methods utilize stormwater as a resource by dispersing it throughout a site rather than moving it off-site as quickly as possible, as grey infrastructure does.

Pros of green infrastructure [1]

- Reduces stormwater pollutants and localized flooding [2]
- Conserves water by reducing or eliminating municipal water needs for streetside landscapes and parks, where native plant landscapes are passively irrigated by stormwater instead of municipal water
- Supports riparian vegetation and wildlife, while replenishing local groundwater aquifers when utilized in shallow groundwater areas
- Enhances traffic calming and pedestrian/bike safety features
- Grows an urban forest, which in turn:
  - shades and cools neighborhood streets
  - provides wildlife habitat
  - beautifies neighborhoods
  - increases property values

Cons of green infrastructure

- May not always be able to provide largescale flood control
- Requires space to incorporate in street designs and may conflict with utilities

Implementation of GI on this corner in a Tucson neighborhood captures runoff that previously flooded the street while creating a community asset.

[1] Sikdar, K., Shipek, C., Jones, C. (2015), Solving Flooding Challenges with Green Stormwater Infrastructure. https://watershedmg.org/document/solving-flooding-challenges-green-stormwater-infrastructure-airport-wash-area

[2] Tempe Area Drainage Master Study: LID Application Review and FLOD-2D Modeling. Flood Control District of Maricopa County, 2016.

2.3 Principles of green infrastructure

Though not an exhaustive list, this section outlines a few of the most important principles that should be followed when using green infrastructure practices[3]:

(A) Protect and restore natural areas

Natural areas—like forests, grasslands, and undisturbed riparian areas—provide the functions that GI emulates. These areas offer services including air and water filtration, as well as wildlife habitat.

When a natural feature like a wetland is removed, it is costly and difficult to rebuild the original feature's complex web of ecological interactions, and thus replace the services it provides. For this reason it is always preferable to preserve and protect natural areas, not only in places that are being newly developed, but also in the pockets of nature that still exist throughout our cities and towns.

In most communities, the undeveloped areas that remain are degraded from their original state. Working with nature to restore these areas' ecological functions and services is an essential green infrastructure practice.

(B) Serve multiple functions with GI

GI marks a new way of thinking about how we meet our goals as communities. Instead of creating infrastructure that only serves one purpose (like the concrete channel in Section 2.1), the best GI practices will serve multiple functions, like calming traffic, improving pedestrian and bicycle pathways, cooling and beautifying streets, reducing and cleaning stormwater runoff, and creating wildlife habitat. For desert communities, GI is an essential way to conserve water through irrigating public landscapes with passive water harvesting. Such integrated design creates GI practices that are more cost-effective and beneficial for communities.

(C) Include the community

GI approaches require a multidisciplinary and inclusive planning and design process. Including local residents, neighborhoods, businesses, and institutions like schools and churches is essential to creating projects that are successful and supported over the long term. Through methods like volunteer workshops and tree plantings, GI construction can be a community-led process that is educational, fun, and builds community connections. Many of the sites shown in this manual were installed by volunteers in public workshops.

[3] Green Infrastructure Principles [Internet]. Washington, DC: National Association of Regional Councils; 2006; Available from http://narc.org/environment/green-infrastructure-and-landcare/green-infrastructure-principles/

3. Planning for community scale green infrastructure

Green infrastructure works great at individual sites, such as homes, parks, and businesses. Green infrastructure can be scaled-up to the neighborhood and community level to holistically address flooding, urban heat island, and community livability. At the neighborhood scale, you can use GI to create green spaces that connect people with neighborhood assets and achieve community goals, like creating safer routes to schools.

Start with the watershed

If you are planning GI improvements in a neighborhood, the first place to start is with defining the watershed—identify how water collects and flows across individual parcels, drains along the streets, and combines with drainages, arroyos, creeks, and rivers. Once you have the watershed(s) defined, map the following:

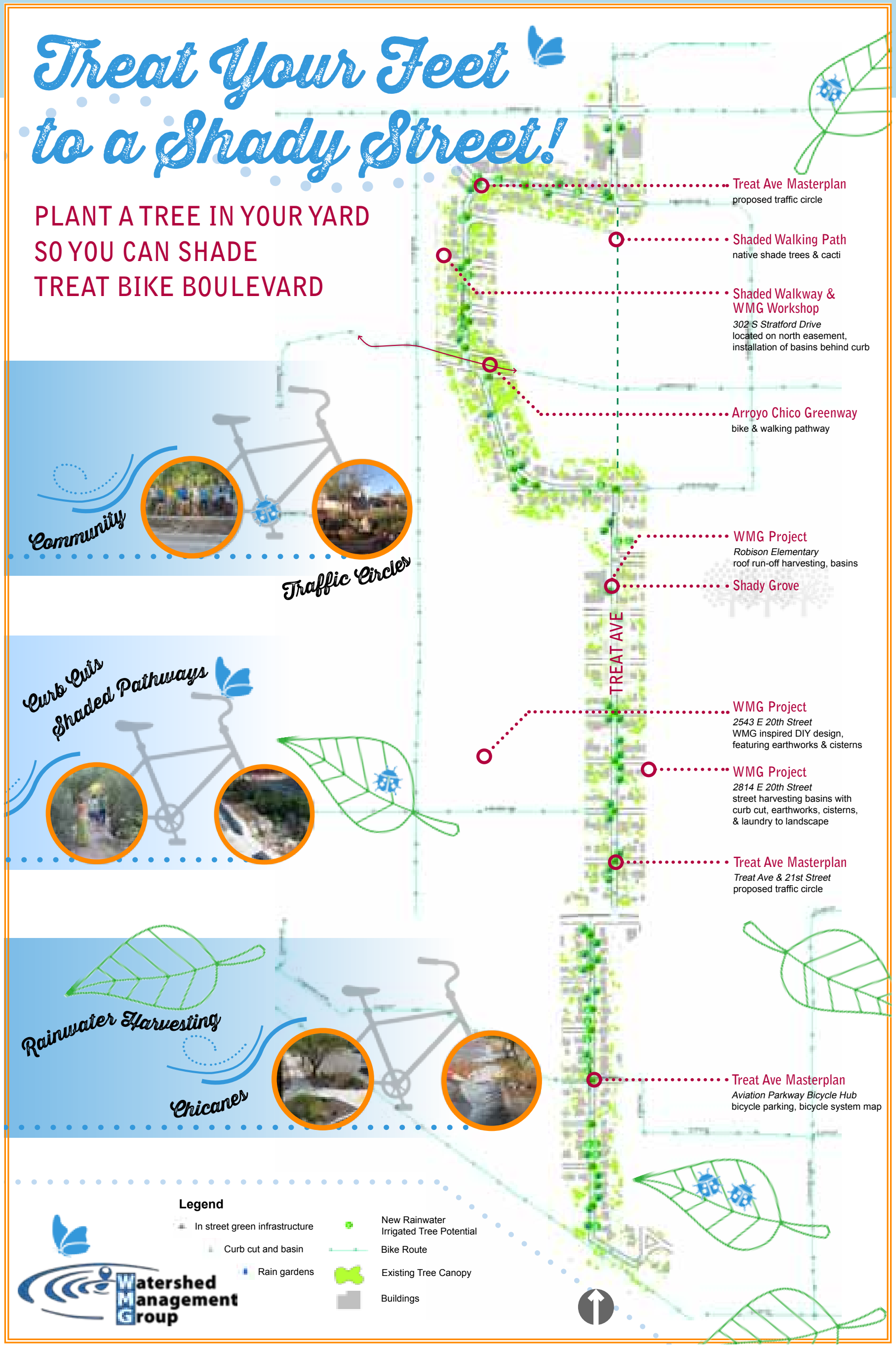
- Areas with chronic flooding, ponding, or soil erosion
- Areas ideal for groundwater recharge, like those near washes or in shallow groundwater areas
- Popular routes for pedestrians and cyclists and gathering spaces for adults and children
- Available landscape areas where GI can be installed, including:
    - wide right-of-ways (greater than 10 feet)
    - open space, relic floodplain
    - vacant lots
    - parks, churches, and schools
    - excess, unused hardscapes, and parking lots

Get creative with your GI. An overwide neighborhood intersection converted into a pocket park is complete with benches and shade trees.

Once you look at these areas on a map, you will be able to better prioritize where GI is most needed and where there are opportunities to install GI. The sweet spot is where these two areas intersect. We suggest concentrating GI to have a greater impact, instead of spreading it out across the watershed. For example, group GI features along one particular street that connects GI with nearby parks and businesses.

Vacant lots can be a blank slate for GI. Large broad basins and meandering pathways create a great place for people and wildlife habitat.

A green infrastructure traffic circle thrives with native plants, directs cyclists with signage, and calms neighborhood traffic on overwide streets.



A 2014 bike boulevard GI planning and outreach exercise helped community stakeholders identify and visualize opportunities to promote shade trees.

3.1 Finding green space opportunities

Most urban areas are in dire need of more green space, and green infrastructure provides an opportunity to create new green spaces or enhance open spaces without increasing irrigation needs in desert communities. Green infrastructure can create linear parks along streets, be incorporated into empty lots and abandoned landscapes to create pockets of new native vegetation, and enhance floodplains and arroyos. In fact, there may be more opportunities for green infrastructure in these forgotten landscape areas where there may be more space and fewer underground utilities than along streets. These GI sites can be incorporated into a larger-scale GI planning to reduce peak floods and enhance landscapes near creeks and arroyos.

Before: Palo Verde Pocket Park is a barren lot, October 2014.

One year of growth, October 2015.

After: Palo Verde Pocket Park is transformed with broad basins, meandering pathways, and a mix of native trees and shrubs, October 2016.

A newly retrofitted landscape space along a neighborhood park accepts stormwater to irrigate native plants and conserves water by reducing irrigated turf.

Identify under-utilized parcels owned by local jurisdictions where you can put stormwater to beneficial use establishing and supporting native vegetation. In Tucson, the Palo Verde Pocket Park was created in partnership with the local water utility. This parcel with a water supply well was an eyesore for the neighborhood and contributed significant runoff and sediment to the streets in heavy monsoon rains. Now basins throughout the property slow and infiltrate the flow, creating a community amenity that provides shade and wildlife habitat while significantly reducing downstream sediment and flood flows.

In existing parks, utilize opportunities to reduce irrigation needs and increase native vegetation with GI by harvesting stormwater runoff. Existing parks often have large open spaces below the grade of adjacent streets and parking lots. By directing stormwater to these areas and creating new basins to slow the flow, additional shaded areas and wildlife habitat can be created to enhance park amenities and gathering spaces. If turf is desired, large shallow basins (3 – 6" deep x 10' wide) can be utilized to achieve maximum benefit from stormwater while also maintaining equipment access. Park turf areas and underlying soils can be compacted from heavy use and large equipment. Ensure maintenance practices eliminate or minimize heavy equipment use in basin infiltration areas to reduce soil compaction and promote infiltration of water.

Washes and arroyos are important natural corridors in the urban environment. Upstream of arroyos, GI can improve conditions in washes by capturing and treating stormwater higher in the watershed. Revegetating, restoring, and enhancing wash channels and adjacent floodplains can provide significant stormwater quality and flood mitigation benefits while also enhancing riparian habitat. Review *Let the Water Do the Work* by Zeedyk and Clothier and the *Erosion Control Field Guide* by Sponholtz and Anderson for design details and site specific considerations for natural channels [4, 5].

[4] Sponholtz, C. and Anderson, A.C. 2013. Erosion Control Field Guide. Quivira Coalition.

[5] Zeedyk, B. and Clothier, V. 2014. Let the Water Do the Work: Induced Meandering, an Evolving Method for Restoring Incised Channels. 2nd Edition, Chelsea Green Publishing

3.2 Reducing flooding

According to a 2015 study conducted by Watershed Management Group, site-scale green infrastructure, when incorporated throughout a watershed, can make a significant difference in flood mitigation. To understand the potential for green infrastructure to address major flooding challenges, WMG focused on the Airport Wash area of southern Tucson[6]. This low-lying area experiences severe floods several times a year. These destructive events make the streets impassable and cause significant property damage throughout the community.

Working with Pima County Regional Flood Control District, WMG identified water-harvesting opportunities for streets, homes, businesses, schools, and churches within the Airport Wash area. Two scenarios were developed—one with 10% of private and public properties adopting green infrastructure features, and another with 25%—and both were evaluated for flood reduction and cost-benefit effectiveness.

The results were impressive. Both models showed that water harvesting can significantly reduce the flood impacts of even large rainstorms. As an example, under the 25% adoption scenario, peak flow conditions were diminished by 24% during a 100-year, three-hour rain event in a 930 acre watershed with 54% impervious cover. This sizeable effect affirms the power of simple water-harvesting features like front yard rain gardens and streetside stormwater harvesting to provide substantial benefits in watershed-scale flood mitigation.

The Flood Control District of Maricopa County has also developed a method to hydrologically model (using FLO-2D) GI across large watersheds[7]. This study also found that front yard water-harvesting GI can have a significant impact on localized flooding. Modeling of a neighborhood where 10% of residents install these features showed a 20% reduction in peak flow for a 100-year storm event. If 50% of residents retrofit their front yards with GI, this figure rises to a 62% reduction in peak flow.

[6] Sikdar, K., Shipek, C., Jones, C. (2015), Solving Flooding Challenges with Green Stormwater Infrastructure. https://watershedmg.org/document/solving-flooding-challenges-green-stormwater-infrastructure-airport-wash-area

[7] Tempe Area Drainage Master Study: LID Application Review and FLOD-2D Modeling. Flood Control District of Maricopa County, 2016.

3.3 Return on investment

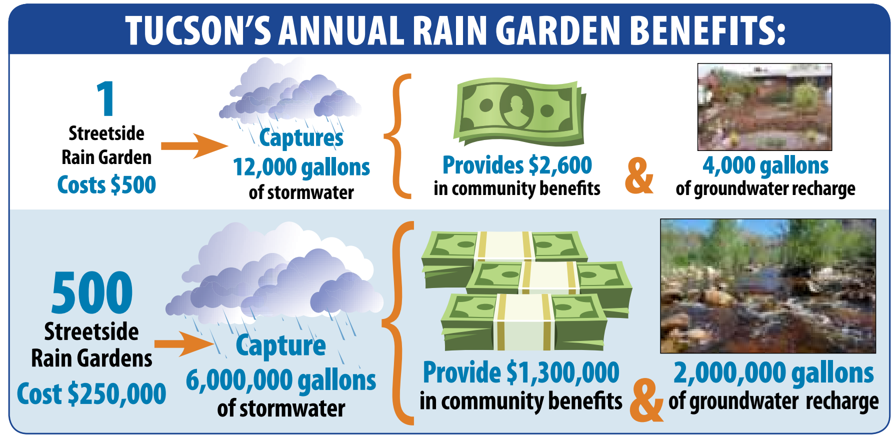
Rain gardens add economic value to community

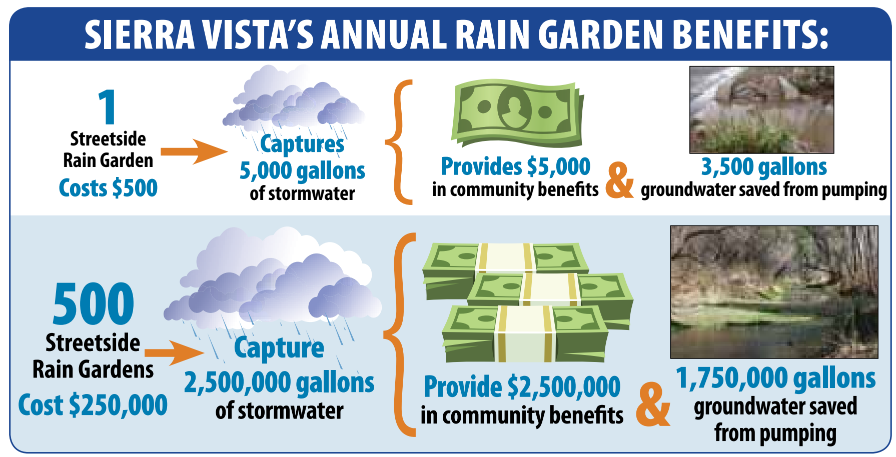
In addition to flood reduction, rain gardens provide a variety of other benefits. They create lush, shady green spaces that raise property values, lower energy costs for cooling, reduce street maintenance needs, calm traffic, and improve air quality and walkability. As thirsty sponges that soak up storm flows, rain gardens also save on irrigation costs and municipal water use, while helping filter stormwater pollution that ends up in our creeks and washes. Adding up these benefits, WMG's study found that water harvesting offers a strong return on investment, delivering $3 - $6 in community value for every dollar spent. This results in a payback period of less than eight years. For new development, the payback period is much shorter, as returns are higher with less investment.

WMG ran a cost benefit analysis for rain gardens in Tucson[8] and Sierra Vista[9] to compare the impacts these features are having in two Arizona desert communities. The impact of a rain garden depends on many factors, including soil type, climate, rainfall patterns, and plant palette. Our calculations are based on a 40 square foot rain garden with 1 to 2 native trees, organic mulch, native shrubs, and bunch grasses—totaling an average cost of $500.

Soil type plays a large role in a rain garden's performance. In Tucson, most soils can infiltrate water quickly, which supports deeper basins. This also allows for higher rates of groundwater recharge, as more water seeps through the soil to the aquifer before being used by rain garden plants. This is especially important in areas of shallow groundwater near washes and rivers as illustrated on the next page.

Although Sierra Vista receives more rainfall than Tucson, the prevalence of high-clay soils with poor infiltration rates limits the amount of stormwater that can be harvested there. Shallower basins must be used to ensure that water does not "pond" in the landscape. Even without much groundwater recharge capacity, rain gardens in Sierra Vista provide a water conservation benefit by reducing demand for supplemental irrigation. This, in turn, reduces the need to pump more groundwater—which keeps more water flowing in the San Pedro River.





[8] Sikdar, K., Shipek, C., Jones, C. (2015), Solving Flooding Challenges with Green Stormwater Infrastructure. https://watershedmg.org/document/solving-flooding-challenges-green-stormwater-infrastructure-airport-wash-area

[9] Shipek, C., Sikdar, K., Jones, C. (2015), A Stormwater Action Plan for Sierra Vista. https://watershedmg.org/document/stormwater-action-plan-sierra-vista

3.4 Conserving and enhancing water resources

When flooding occurs, stormwater typically evaporates without providing a direct benefit to landscapes or groundwater supplies. GI practices turn this "nuisance" water into a resource to irrigate plants and infiltrate more water deep into the soil. Water is conserved through reducing the need for irrigation, and groundwater supplies are enhanced through increased recharge of the aquifer. Increasing groundwater recharge in areas of shallow groundwater near streams and rivers in especially critical. Shallow groundwater areas quickly respond to enhanced recharge, and rising groundwater levels can contribute to enhanced flow in the stream channel (see next page).

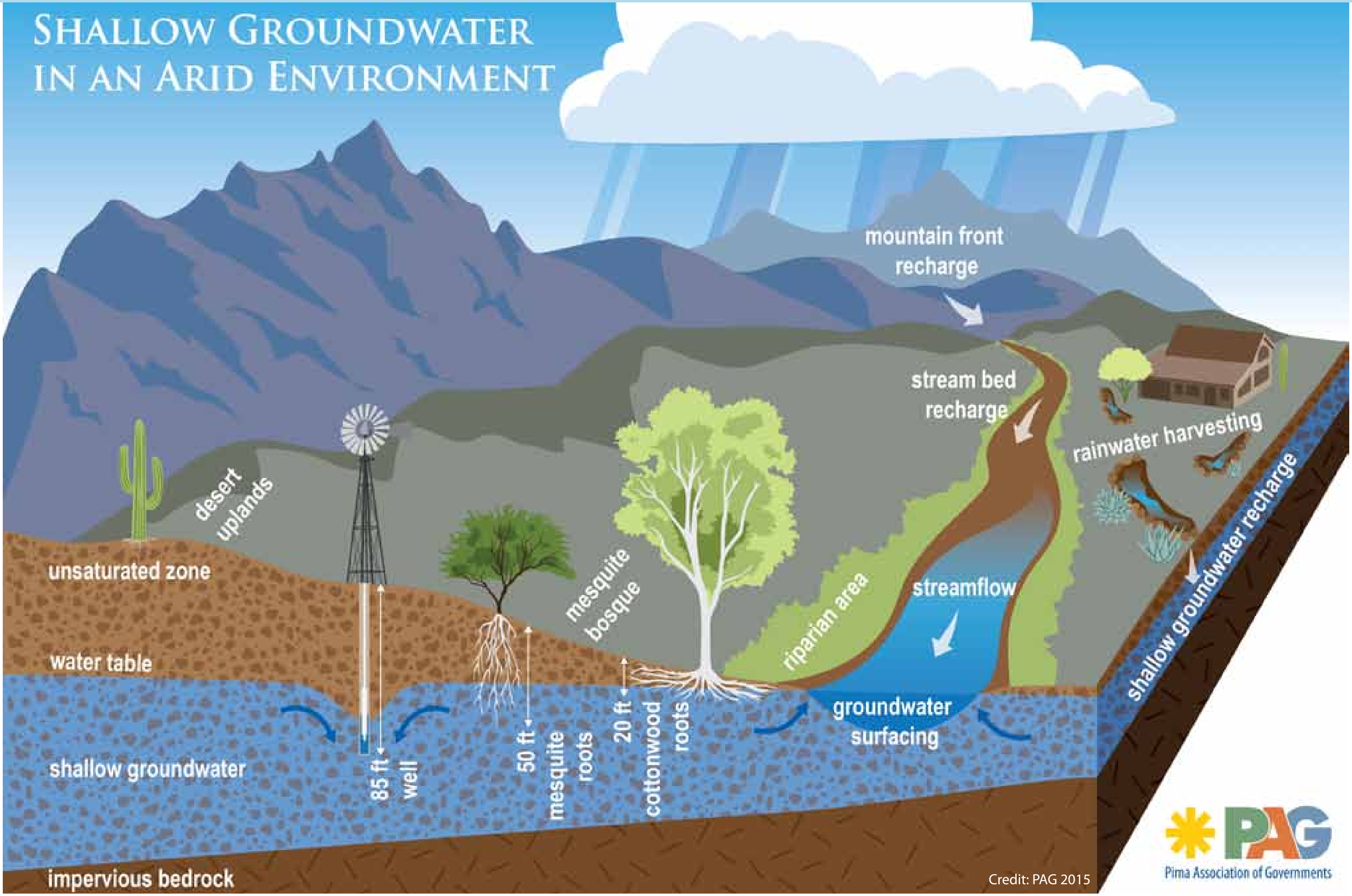
At Watershed Management Group's Living Lab and Learning Center in Tucson, Arizona, there are several stormwater basins that provide a powerful example of water conservation. The basins collect enough stormwater to provide all the irrigation needs of the native vegetation and collect additional water for potential groundwater recharge. Check out the table to the right to see one example of a stormwater basin's water budget.

A small basin accepts and infiltrates more street stormwater runoff than is needed to irrigate these native plants as highlighted in the adjacent table.

STORMWATER BASIN ANNUAL WATER BUDGET

Basin volume	Supply*		Plant Demand:		Balance:
840 GALLONS	16,800 GALLONS average total stormwater harvested annually	–	8,000 GALLONS used by native mesquites and understory plants in basin	=	8,800 GALLONS available for deep infiltration that has the potential to recharge groundwater

*See pg 27 to see how to calculate water budgets



Shallow groundwater is water found within 50 feet of the land surface—vital for supporting the native mesquite bosques, willow galleries, ash and hackberry trees, and bunch grasses associated with desert riparian habitats. Green infrastructure can help sustain these rare and important riparian areas by increasing local infiltration through sinking more stormwater into the ground. Learn more on PAG's Water Resources web page, http://www.pagregion.com/tabid/911/default.aspx

3.5 Reducing water pollutants

Non-point source pollution

Non-point source (NPS) pollution comes from dispersed sources like auto oil, pet waste, herbicides, and sediment.

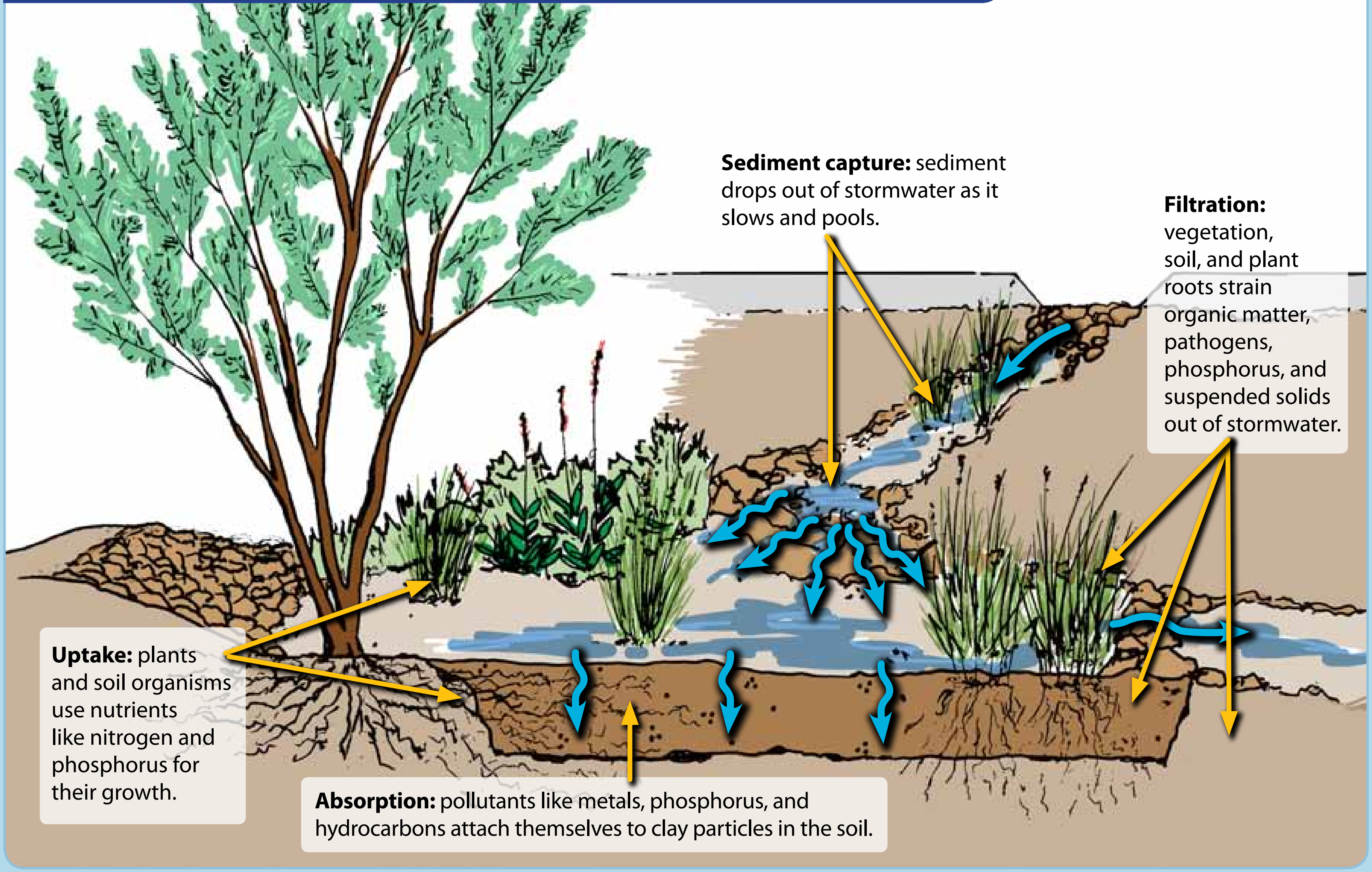
When collected and concentrated by rainfall, these pollutants can lead to serious problems for wildlife and human health alike. Other NPS pollutants common in developed areas include residue from brake pads, tires, vehicle exhaust, fertilizers, and detergents. Whatever we put on the land ends up in the water. Without changing people's behavior (like dumping trash or misusing herbicides) and the nature of the products we use (particularly automobiles, which contribute oil, heavy metals, etc. to stormwater), GI cannot solve all the problems of urban non-point source pollution.

Bioretention

GI addresses the issue of NPS through bioretention, the use of vegetation and soils to clean stormwater runoff as seen on the next page. GI can reduce pollutant accumulation in our washes and water courses, where wildlife diversity and abundance numbers are higher. Washes also have greater hydrologic connectivity to deep aquifers, thus GI can reduce the potential to pollute groundwater sources. When stormwater flows into an earthen basin lined with plants and mulch, pollutants in the water are filtered out or broken down by these processes.

Soil, mulch and plants filter pollutants from stormwater. Some potential pollutants, like hydrocarbons, are taken up by plant roots as nutrients.

RAIN GARDENS REDUCE STORMWATER POLLUTANTS



Microbial action: bacteria in the soil and plant roots break down pollutants like nitrogen and hydrocarbons, including some petroleum products[10]. Organic mulch can also increase the presence of beneficial microorganisms in soil.

[10] Environmental Protection Agency, Office of Water (US) [EPA]. (1999, September). Storm Water Technology Fact Sheet: Bioretention. Washington, DC: EPA; 1999 Sep. 8 p. Retrieved from: http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=200044BE.txt. Accessed 2016 December 1.

4. General green infrastructure practices

4.1 Vegetation

4.1.1 Function

Vegetation is an essential element of all green infrastructure practices; in other words, green infrastructure will not function without vegetation. There are many benefits of vegetation in green infrastructure[11] :

- Filters stormwater pollutants
- Reduces local temperatures by shading hardscape and providing cooling evapotranspiration, which in turn saves energy
- Extends the life of asphalt through shading
- Provides habitat for wildlife
- Builds organic matter in soil
- Increases permeability of soil through penetration of roots[12]
- Takes up atmospheric carbon dioxide and cleans the air
- Beautifies neighborhoods
- Adds value to homes
- Slows traffic along neighborhood streets
- Increases human well-being

Native plants are the best choice for use in GI practices, as they:

- Are uniquely adapted to grow in local soil and climate conditions, including low and variable precipitation in the Southwest, and generally do not require supplemental irrigation once established.
- Provide the best habitat for native wildlife.
- Help create a unique sense of place and connection with the surrounding environment.

In Tucson, for instance, South American mesquite species are sometimes chosen as landscape trees over the native velvet mesquite (prosopis velutina) for their ability to grow faster and create denser shade canopies. While these are valuable assets, South American mesquite trees have the following problems that natives do not:

- Produce shallow roots that can damage nearby hardscape
- Tend to outgrow their root systems and become vulnerable to uprooting in storms
- Produce flowers that do not attract native bees and birds as well as native plants do
- Hybridize with native mesquites in the wild

It is often difficult to find non-native plants that provide environmental services better than natives over the long term. Refer to your locally approved plant list when working in the right-of-way.

[11] Benefits of trees in urban areas [Internet]. Broomfield, CO: Colorado Tree Coalition; 2010; Available from: http://www.coloradotrees.org/benefits.htm

[12] Bartens J, Day S, Harris J, Dove J, Wynn T. Can urban tree roots improve infiltration through compacted subsoils for stormwater management? J Environ Qual 2008. 37: 2048-2057.

4.1.2 Site selection

Though each GI practice has its own vegetation guidelines, follow these guidelines for plants in all applications:

- Where possible, choose sites where adequate runoff can be collected to offset or eliminate the need for long-term irrigation of vegetation (see Section 4.1.4).
- Choose sites in which vegetation will provide maximum desired benefit, such as shading hardscape and parking areas, calming traffic, or creating community gathering spaces.
- Plan for the mature size of plants when selecting and designing GI sites. Planting too densely based on the size of young plants can create overgrown landscapes, result in stunted plants that compete for resources, and cause plants to encroach on adjacent areas (e.g. streets, sidewalks, power lines) requiring frequent pruning.

This native mesquite tree thrives in a swale that collects stormwater runoff from the street, providing shade for pedestrians.

4.1.3 Design guidelines: plant selection & placement

These two pages provide information on the environmental benefits, aesthetics, and appropriate placement of different types of plants used in GI sites. A key consideration for siting plants is where they are placed relative to standing water. During storms, water will pool in bioretention areas for periods up to several hours (see Section 4.3 for guidelines to ensure infiltration in proper time periods). The trunks and stems of many desert plants will rot when standing in water or where wet mulch lays against their trunks or stems for extended periods. Using plants, like native bunch grasses, at or near basin bottoms is critical to ensure infiltration of stormwater. Many native grasses are tolerant of standing pools of water for up to 12 – 24 hours.

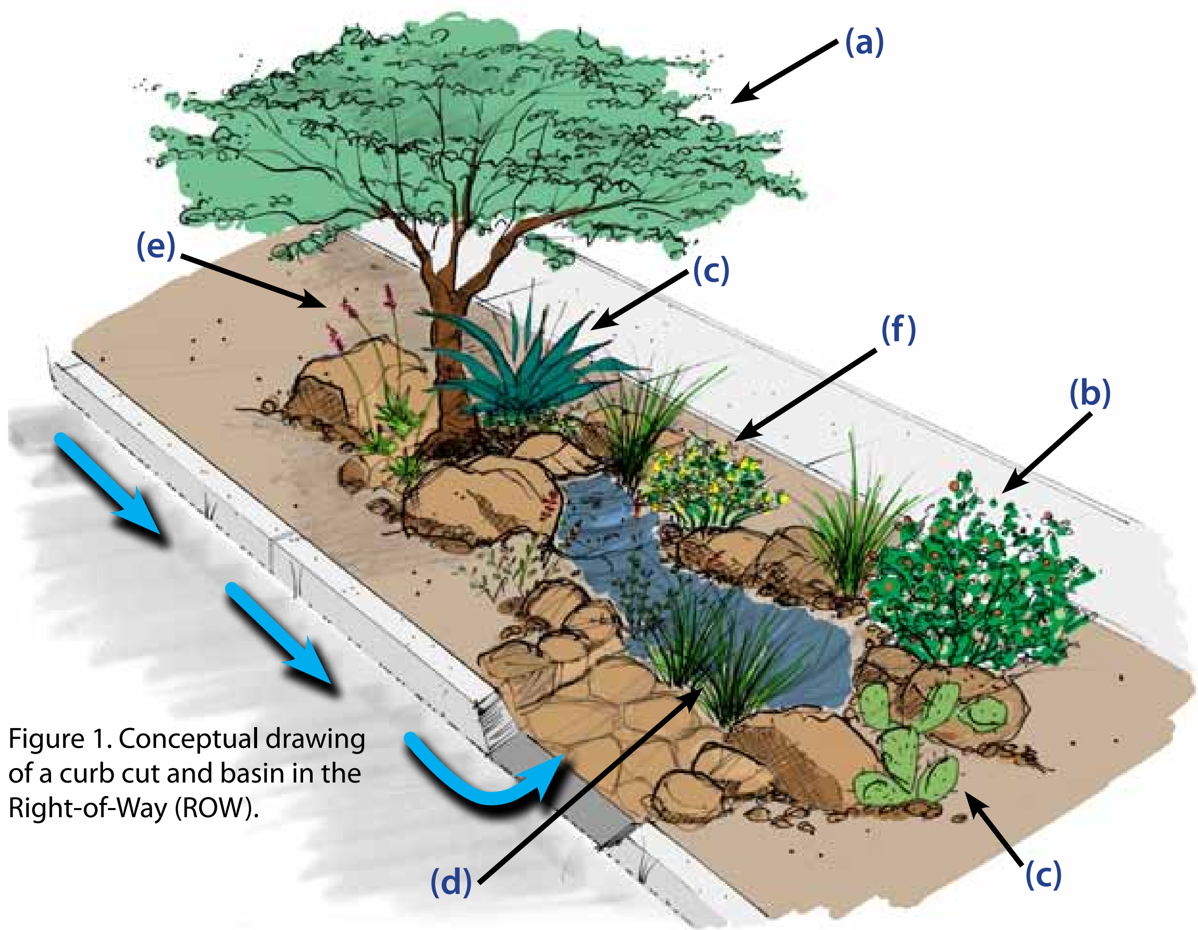


Figure 1. Conceptual drawing of a curb cut and basin in the Right-of-Way (ROW).

Trees (a)

Environmental services
See Section 4.1.1 for a comprehensive list.

Aesthetics
Trees are unmatched in their ability to create inviting, attractive landscapes.

Placement
Plant trees adjacent to bioretention areas, or on raised terraces (above level of standing water) within bioretention basins. Trees' extensive root systems allow them to reach water supplies well beyond the spread of their canopy.

Determine spacing of trees based on available water and mature canopies. For example, calculate the water demand of your tree and the amount of surface area needed to produce that amount of water. From there you can determine how many trees you can plant per basin or curb cut (see Section 4.1.4 to learn how to create a water budget).

Other considerations
Trees are not native to parts of the Chihuahuan, Great Basin, and Mojave deserts. In these areas, non-native trees, or trees native to higher elevations, may have to be used and may have higher water needs.

Shrubs (b)

Environmental services
Shrubs provide excellent habitat—flowers, fruits, seeds and cover—for native birds, insects, reptiles, and mammals.

Shrubs reduce erosion by protecting the soil surface.

Aesthetics
Shrubs create an often missing "mid-story"—an important aesthetic element in landscapes between tall trees and smaller plants.

Placement
Plant shrubs on the slope of a basin or swale or on a raised terrace just above the level of standing water, where they are low enough that their roots can easily reach moisture in the soil but not so low that they will be inundated for extended periods.

Cacti, agaves, yuccas (c)

Environmental services
Blossoms and fruits of cacti and succulents are important food sources for a variety of birds, bats, and other mammals.

These plants do little to filter stormwater or build soil, thus should not be the only type of plants used in GI sites.

Aesthetics
Cacti and succulents provide unique, sculptural landscape elements that help define a sense of place.

Taller succulents like ocotillos and Joshua trees can provide vertical elements in landscapes, while using much less water than trees.

Placement
Plant cacti and succulents above the level of inundation in bioretention basins.

Cacti and succulents use very little water, so they can be used in areas that do not receive extra runoff from hardscape.

Grasses (d)

Environmental services
Grasses provide dense networks of stems and roots that effectively filter stormwater pollutants, reduce erosion, and increase infiltration of stormwater into the soil.

Aesthetics
Native bunch grasses can provide stunning landscape elements.

Placement
Plant grasses at the bottom of bioretention areas. They typically survive both inundation and extended drought quite well and provide the best benefits in cleaning stormwater.

Other considerations
Many environments in the Southwest have primarily bunch grasses and do not have native turf-forming grasses, which are a common element of GI practices in other regions.

Wildflowers (e)

Environmental services
Flowers provide important food sources for pollinators like hummingbirds, bees, and butterflies.

Aesthetics
Wildflowers are usually the first plants to reach maturity in new GI sites and can provide welcome color during the initial establishment period for trees and shrubs.

Seeded annuals can create a rush of seasonal color in the first rainy season after planting, but will quickly turn to dry stalks when hot/dry conditions return. Plan for maintenance accordingly.

Placement
Wildflowers' tolerance of inundation varies. Seek local knowledge and experiment.

Groundcovers (f)

Environmental services
Some perennial wildflowers and shrubs can be used as groundcovers to help protect soil and hold down organic mulch.

Aesthetics
Groundcover helps to create a sense of lushness even in arid environments.

Placement
Groundcovers' tolerance of inundation varies. Seek local knowledge and experiment.

4.1.4 Water management

One of the myths about green infrastructure in the desert is that the plants will always require long-term irrigation. In many cases, the need for long-term irrigation can be eliminated or significantly reduced by 1) using native plants that are adapted to local rainfall patterns and 2) placing vegetation in areas where it will receive supplemental rainfall runoff from adjacent rooftops, streets, and parking lots.

To create a vegetated GI site that does not require long-term irrigation, create and follow a water budget for the site using one of two methods:

1. For sites where the contributing area of runoff is known (such as a portion of a parking lot discharging runoff to a bioretention basin), use local monthly or annual rainfall averages to calculate how much runoff will flow into the bioretention area over a given time period. Design a planting plan based on the estimated available water. These calculations are expertly detailed and freely available on the website of Brad Lancaster, author of Rainwater Harvesting for Drylands and Beyond[13] .

2. For bioretention features supported by street runoff such as chicanes, medians, traffic circles, or curb cut-fed basins, use the method shown in the box at right.

A velvet mesquite tree is planted on a terrace above the level of stormwater inundation at this GI site. Planting on a terrace ensures the tree's base is not inundated in water, but the roots can access the moisture.

[13] Lancaster B. Rainwater Harvesting for Drylands and Beyond Vol. 1, 2nd Edition. Tucson, AZ: Rainsource Press; 2014. 281p. (Water harvesting calculations can be found at: http://www.harvestingrainwater.com/rainwater-harvesting-inforesources/water-harvesting-calculations/)

Creating water budgets for bioretention areas in the street or right-of-way, with example for Tucson

Calculating water budgets for GI features capturing runoff from streets is an inexact process. This method assumes that, given the large amounts of runoff generated by streets, an in-street bioretention area like a chicane (see Section 6.4), or a basin capturing street runoff in the right-of-way via curb cuts (see Section 5.3), will fill to capacity with water in rainfall events of a certain size. This method is conservative in that it assumes that a bioretention area will fill only one time during all rain events (i.e. that zero infiltration is occurring). Though infiltration is actually required for a GI site to function (see next page), this conservative method is recommended to take into account such factors as climate variability. Observe local conditions to determine if this method is appropriate for your site and modify as needed.

1. Determine the water holding capacity of the bioretention area. *Example: A basin in the right-of-way with 3:1 sloping sides is designed to be 20' long and 6' wide at the full water line, with 8" of stormwater holding depth. Volume = depth x ([L1 x W1] + [L2 x W2]) / 2); Volume = .66ft x ([20 ft x 6ft] + [16ft x 2ft]) /2 = 50.2 ft3; 1 ft3 = 7.48 gallons; 50.2ft3 x 7.48 gal/ft3 =* ***375.5 gallons of stormwater capacity***

2. Determine the number of average annual rainfall events in your region. This information may be available locally or through the National Climatic Data Center (www.ncdc.noaa.gov) or Western Regional Climate Center. *Example: Tucson receives an average of* ***30 days of recorded rainfall per year.***

3. Subtract the number of events with rainfall depths less than one-tenth of an inch, as these events will generally not generate runoff[14] . *Example: about 40% of recorded annual rainfall events in Tucson are less than .1 inch =* ***20 events in an average year with more than .1 inch of rainfall***

4. Multiply the remaining total number of average rainfall events over .1 inch times the stormwater capacity of the bioretention area to calculate an estimate of available annual runoff to that feature. *Example: 20 events x 375.5 gallons =* ***7,510 gallons of available annual stormwater runoff***

Design a planting plan appropriate to the estimated annual runoff available to the site (refer to local cooperative extension offices, water departments or landscape manuals for information on local plant water requirements). *Example: this bioretention feature could support two native velvet mesquite (Prosopis velutina) trees with 20' diameter canopies (each requiring approx. 2,940 gallons annually) along with several native shrubs, grasses, wildflowers and cacti*[15] .

[14] Environmental Protection Agency, Office of Water (US) [EPA]. (2009, December). Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act. Washington, DC: EPA; 2009 Dec. 61 p. https://www.epa.gov/greeningepa/technical-guidance-implementing-stormwater-runoff-requirements-federal-projects. Accessed 2016 December 1.

[15] Lancaster, op. cit. pp. 136-141. Also available at: http://www.harvestingrainwater.com/wp-content/uploads/Appendix4PlantLists.pdf

4.1.4 Water management (continued)

- Irrigate plants for a 2- 3 year establishment period after planting; reduce irrigation as much as possible thereafter.
- After establishment period, plants may need occasional irrigation during periods of extended drought.
- Provide hand-watering for establishment instead of drip irrigation where possible. This method conserves resources, can save on costs, saves water, and ensures better plant care[16] .
- In areas where long-term drip irrigation is deemed necessary, set irrigation timers to mimic natural rainfall patterns by providing deep, infrequent irrigation (this can reduce maintenance needs by controlling plant growth).
- Irrigate at dawn or dusk to minimize evaporation rates.

Sonoran desert wildflowers pop with color in this streetside swale.

Plant Establishment Tips: Establish your native plants with this general watering guide to make sure your plants survive and grow healthy.

1st Year: Baby them now for stronger plants later.

- Water deeply right after you plant, and every 1 – 2 days for the first two weeks.
- Water two times a week during the hot season.
- Water one time a week during the cool season.

2nd Year: Start to wean your plants off additional irrigation.

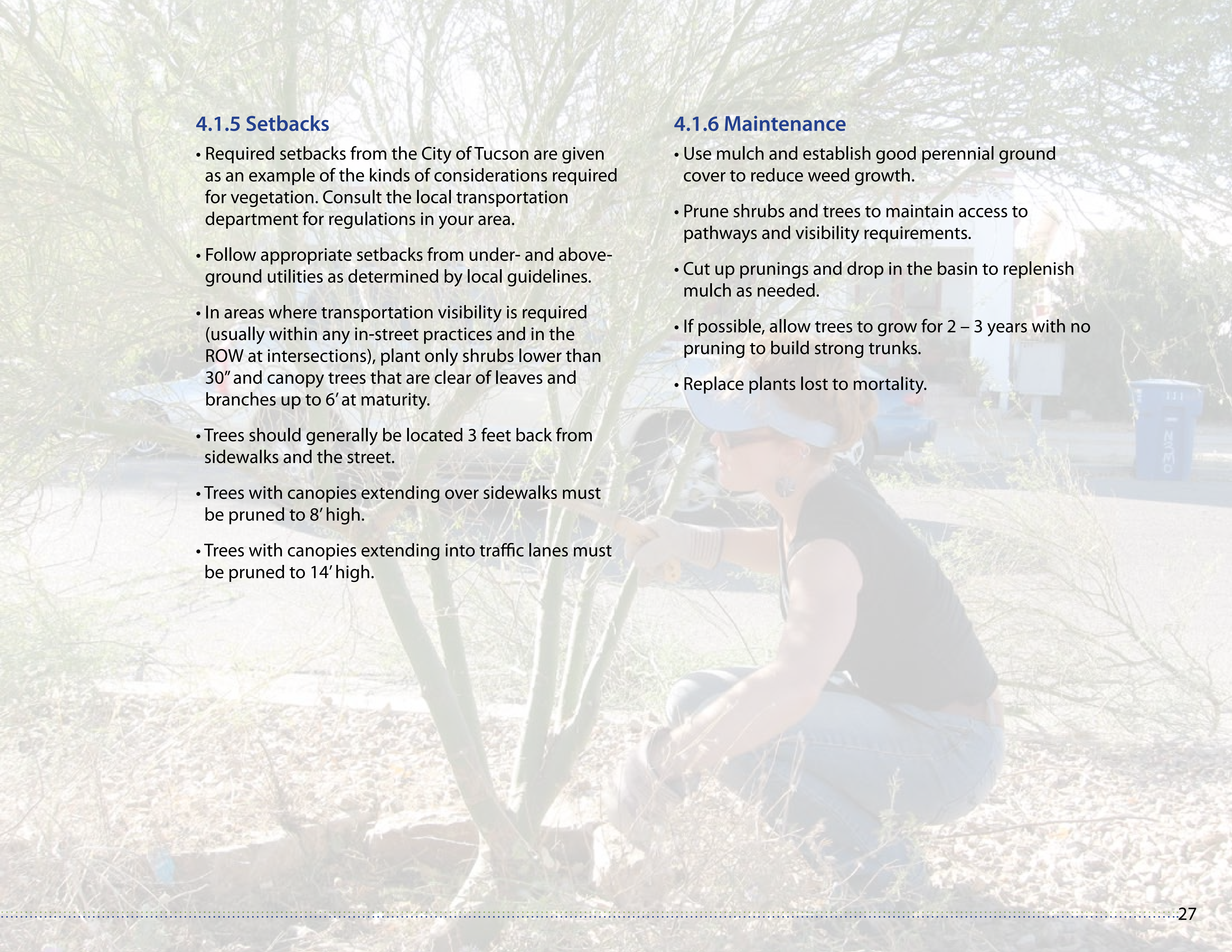
- Water one time a week during the hot season.
- Water 1 – 2 times a month during the cool season.

3rd Year and beyond

- Water during dry summer months or during times of drought.

**If you receive rainfall, then you can skip your extra watering cycle! Remember plants native to your bioregion can thrive off natural rain cycles. By harvesting rainwater and stormwater, you are actually increasing the amount of water a plant will receive in a rain event and storing extra moisture in the soil. Once plants are established this is all they should need.

[16] Wittwer, Gary. (City of Tucson Department of Transportation, Landscape Architect). Conversation with: Kieran Sikdar. 2016 May.



4.1.5 Setbacks

- Required setbacks from the City of Tucson are given as an example of the kinds of considerations required for vegetation. Consult the local transportation department for regulations in your area.
- Follow appropriate setbacks from under- and above-ground utilities as determined by local guidelines.
- In areas where transportation visibility is required (usually within any in-street practices and in the ROW at intersections), plant only shrubs lower than 30" and canopy trees that are clear of leaves and branches up to 6' at maturity.
- Trees should generally be located 3 feet back from sidewalks and the street.
- Trees with canopies extending over sidewalks must be pruned to 8' high.
- Trees with canopies extending into traffic lanes must be pruned to 14' high.

4.1.6 Maintenance

- Use mulch and establish good perennial ground cover to reduce weed growth.
- Prune shrubs and trees to maintain access to pathways and visibility requirements.
- Cut up prunings and drop in the basin to replenish mulch as needed.
- If possible, allow trees to grow for 2 – 3 years with no pruning to build strong trunks.
- Replace plants lost to mortality.

4.2 Surface mulch

Mulch refers to any substance used to cover and protect soil.

- Organic mulch is made from dry, shredded plant pieces.
- Rock mulch is made from gravel, stone, urbanite, or broken brick.

4.2.1 Function

One of the primary functions of mulch in green infrastructure is to reduce evaporation of moisture from the soil. This function is crucial in desert areas, where potential evaporation (100" in Tucson) far exceeds rainfall (12" in Tucson). See the table below for additional benefits provided by mulch.

In this just-installed chicane, 4"-8" rip-rap is used in the channel where stormwater will flow rapidly, and 1" gravel covers upslope areas.

Function, costs & benefits of organic and rock/gravel mulch

	Organic mulch	Rock/gravel
Controls weeds	yes	somewhat
Retains soil moisture	yes	somewhat
Regulates soil temperature	yes	no
Builds soil organic matter	yes	no
Reduces erosion	yes	yes
Stays in place in areas of high water flow	no	yes
Provides wildlife habitat	yes	somewhat
Leaf litter that falls must be cleaned up	no	sometimes
Renewable, low embodied-energy resource	yes	no
Promotes beneficial soil microbes	yes	no
Cost	low/free*	higher

* Tree-trimming companies will often provide chipped mulch for free.

4.2.2 Site selection & design

Based on its many beneficial characteristics, use of organic mulch is preferred when possible. The main advantage of rock mulch is that it does not move in areas of high pedestrian traffic and significant stormwater flow.

Taking these factors into account, the general rule of thumb for choosing mulch is:

- Use organic mulch in areas where water pools/eddies/is deposited, such as in a basin attached to a curb cut.
- Use rock mulch in areas where water is being transported or where flooding is a concern, such as in a swale or in-street practices.

Other considerations in using mulch include:

- A 4″ layer of organic mulch is required to effectively reduce weed growth.
- Keep mulch away from trunks of trees or shrubs to prevent rot.
- Do not use decomposed granite or unwashed gravel in or near infiltration areas; small particles can fill pore spaces in the soil and prevent infiltration of water.
- Use tightly placed larger rock (4″ – 8″ or larger) to reduce erosion in sites where serious flooding is an issue.

4.2.3 Maintenance

- Replenish organic mulch every 1 – 3 years to maintain a depth of 3″ – 4″.
- Tree and plant trimmings can be chopped and left in place to replenish the organic mulch layer.

A 4″ layer of organic mulch dramatically reduces weeds in a neighborhood park. Use organic mulch where stormwater has low velocity.

4.3 Soil health

Healthy desert soils infiltrate more water and help filter pollutants.

Understanding soil is critical to designing and building green infrastructure projects. Soil structure and ability to infiltrate water below the soil surface dictate basin size, shape, and depth. Urban desert soils are often compacted and degraded, making infiltration difficult. Often construction of green infrastructure neglects the importance of soil health and results in compacted basin bottoms filled with rock, void of vegetation, and with no means to easily manage sediment or prevent soil surface sealing. By creating the conditions for soil life and native vegetation to thrive, soils will improve naturally to ensure green infrastructure performance, and soil health will improve over time, maximizing water quality improvements and native vegetation growth.

Warning, this is bad design! This chicane was installed without plants, taking the "green" out of the infrastructure. Without plants, the soil surface may seal and cause ponding. Plant roots create spaces for water to infiltrate and are needed for the soil food web to work. Invasive plants may also take hold which will be difficult to manage. The large rip rap in the basin will make any maintenance very tedious – including removal of weeds or sediment.

4 basic steps to promote healthy soils:

1. Build organic mulch: Apply a 2 – 4" layer of organic mulch and incorporate native bunch grasses to improve infiltration (see Section 4.1.3). Let leaf litter accumulate in basin bottoms and between riprap. If needed, add compost soil amendments to enhance poorly draining soils at the time of GI installation. Leave mulched vegetation trimmings in basin bottoms to support long-term infiltration rates.

2. Reduce compaction and eliminate soil disturbances: Avoid heavy equipment in basin bottoms and break up existing compaction and/or restrictive soil layers to at least twice the ponding depth. Once installed, avoid ongoing soil disturbing activities which destroy or severely set back soil restoration (e.g. tilling, scraping, raking, spraying herbicides, pesticides, etc).

3. Create root mass: Select and mix plants with shallow, deep, and far reaching root structures. Native bunch grasses have dense and deeply penetrating roots which are helpful for improving infiltration and de-compacting soil. Native trees add organic material through root mass underground which also promotes movement of air and water through dense soil layers.

4. Encourage structural planting: Native trees provide a protective canopy which creates a beneficial micro-climate for understory plants and can send roots deep. Understory plants help to further de-compact soil through dense roots, increasing soil organic content, and prevent soil surfaces from sealing due to accumulation of fine sediments, oils, and grease.

Dealing with difficult soils

All GI sites should be designed to infiltrate their maximum stormwater capacity within 24 hours to avoid mosquito breeding. Conduct a percolation test (a simple test to assess how quickly water is absorbed into soil) to determine infiltration rates.

- In areas with clay soils, hardpan, or caliche (an impenetrable layer of calcium carbonate often found in desert soils), consider removing or boring holes, and/or improving soil with compost. A digging bar, jack hammer, or pick can be used to create drainage holes through the caliche into the underlying soil. In some cases, soil may have to be replaced with engineered soil mixes to allow adequate infiltration.

- Avoid compaction of soils during construction. Till or rip soil surface after construction to reduce compaction.

- Make your basins wider and/or add compost or loamy soil to decrease the depth of your basin.

- Soil improvements such as compost, minerals, etc. do little to enhance the growth of most drought-adapted native plants[17]. However, mixing soil with compost may be a useful tool for improving soil infiltration and moisture retention.

- In areas where the water table is high and/or infiltration is low, underdrains may need to be incorporated into bioretention features—these are not covered in this manual.

- See the Appendix for an example basin cross section that includes best practices for soil health.

[17] Cromell C, Miller J, Bradley LK. 2003. Earth–Friendly Desert Gardening. Phoenix, AZ: Arizona Master Gardener Press; 2003. 136p. (p. 71).

What is the right-of-way?

Rights-of-way (ROWs) are pieces of land reserved for transportation, utilities, and other public uses. Neighborhood streets are located within municipally-owned transportation ROWs that usually include the street itself and strips of land on either side where sidewalks, utilities, and street trees are located. For the purposes of this guide, the term rights-of-way refers only to the strip of land between the street and private properties.

Why work in the ROW?

One inch of rain falling on one block of typical city street (40′ x 300′) generates some 6,700 gallons of stormwater runoff. This runoff can become a problem for communities in the form of downstream flooding and nonpoint source pollution, or it can become a resource providing moisture for neighborhood vegetation if captured close to the source.

By using the techniques on the following pages, ROW landscape areas can be turned into rain gardens that infiltrate stormwater from neighborhood streets while growing beautiful trees and shrubs that shade streets and sidewalks[18]. ROWs are legally and logistically easier to work in than the street itself, making them good locations for volunteer-led neighborhood tree planting efforts and green infrastructure projects.

5.1 Site selection, design and workflow

Working in the ROW can be something that is undertaken by a city, a neighborhood group, or an individual homeowner. Though a single curb cut and basin in front of a home may have only a small impact on local stormwater issues, it can provide great benefit as a demonstration of green infrastructure principles and practices that others can clearly see. If a practice is installed as part of an educational workshop or neighborhood volunteer effort, the educational value is magnified as well. The ROW practices featured in the following pages were all installed via volunteer workshops led by WMG.

When working in the ROW, follow these steps:

1. *Identify owners of adjacent properties and obtain necessary permissions.* The ROW is publicly owned, but adjacent landowners are often held responsible for maintenance of landscape features and vegetation in the ROW in front of their home or business. Landowners may also be held liable for accidents that occur in the ROW. Know your municipality's policies, and get written permission from adjacent landowners.

   The best sites for working in the ROW are often those where the landowner is actively interested: they will tend to be better stewards of the site (watering, weeding, and trash pickup) than absentee landlords or disinterested neighbors.

[18] For additional details on individual practices and construction best practices see Pima County and City of Tucson's Low Impact Development and Green Infrastructure Guidance Manual, March 2015.

A Tucson neighborhood ROW captures street runoff to feed a cooling canopy of native trees and shrubs.

Volunteers install bioretention basins in the right-of-way at a workshop in Tucson led by Watershed Management Group.

5. Streetside green infrastructure practices

This 400 sq ft rain garden has the potential to harvest 4,500 gallons of stormwater each time it rains. The project was installed by WMG in partnership with the City of Mesa, in front of the Mesa Urban Gardens.

2. *Identify who will maintain the site and how it will be maintained.* This step is often overlooked, but it is crucial to the success of any GI site (see Section 8).

3. *Visit the site to assess water flows.* Visiting a site during rain events will provide invaluable information for evaluating appropriate sites for GI:

   - How much runoff flows through the site in different size storms?
   - Does stormwater flow along the gutter or in the middle of the street? If the latter, street runoff will not be available to ROW plantings.
   - Does stormwater overtop the curb in large storms? If so, plan for erosion control behind the curb.

4. *Locate utilities.* The ROW is often used as a corridor for water, gas, and other underground utility lines. Locate lines early in the process, as excavation and/or planting is restricted around them. In Tucson, for instance, mechanical excavation is not allowed within 2 – 4 feet of a buried utility line. Use a utility locating service (free in most areas) to mark lines on the site, and determine required setbacks for planting and excavation. Be creative in working around utility lines—sometimes careful hand-excavation close to lines can make a site a viable candidate for GI. When planting trees, be aware of how tree growth may interfere with overhead lines.

   Note: Many ROW GI projects are made impossible by the presence of underground utilities. Some forward-thinking cities, recognizing that the ROW is an excellent place for planting street trees, require utilities to locate in the street. "Trenchless" approaches are now available that allow utilities to maintain their lines without digging up the asphalt.

5. *Create a water budget for the site.* See Section 4.1.4.

6. *Create a design*. Use the information on individual practices (Sections 5 – 7).

7. *Submit the design for permits.* A municipal permit is often required to work in the ROW. Contact your local jurisdiction to find out about the permit process.

8. *Conduct pre-excavation if necessary.* Desert soils can be incredibly hard, particularly if they have been compacted by years of pedestrian or vehicle traffic. Using machinery for rough excavation of the site will often be necessary. Plan for where excavated soil will go. Using excavated soil locally (such as in raised pathways on-site) can reduce hauling costs.

9. *Cut curbs.* If cutting the curb is a part of the project, it should be done after rough excavation and before final installation to facilitate appropriate placement of erosion-control rockwork (see Section 5.2).

10. *Conduct final earth shaping, rockwork, planting, and mulching*. This can be a great step to involve neighborhood volunteers. The ROW features shown in this manual were primarily installed through volunteer workshops.

11. *Visit the site to assess function and maintenance needs and collect information for future sites.* Make changes as necessary. GI sites require ongoing stewardship to preserve their function.

Note: for an excellent step-by-step description of installing a ROW GI site, review Brad Lancaster's book, Rainwater Harvesting for Drylands and Beyond, Vol 2, page 198.

5.2 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. This page focuses on the curb cuts themselves; the practices in Section 5.3 – 5.5 give details on how to create the adjacent bioretention areas.

5.2.1 Function

- Curb inlets are useful for retrofitting existing neighborhoods with green infrastructure practices without major reconstruction.
- Cutting or coring curbs is significantly cheaper than working to collect stormwater via in-street practices.
- Since curb cut openings are perpendicular to the flow of stormwater on the street, they will usually collect only a portion of the water flowing along the gutter. If attenuating stormwater flows along the street is the goal, place multiple curb cuts at intervals along the street.

5.2.2 Site selection

- Crowned streets are appropriate for using curb cuts, because they are highest at the middle of the street and carry stormwater along the curb.
- Observe the site during a rainfall event to determine if and how much stormwater actually flows along the curb where a cut is planned. Even on a crowned street, one side may be higher than the other, or flows may be altered by upstream factors. Also, small divots or cracks in the pavement may direct runoff away from the curb in smaller rainfall events.
- Avoid streets with slopes greater than 5% or in areas where the curb is routinely submerged.
- A permit and/or licensed contractor may be required for curb cuts along the ROW. Check with your municipality's transportation department for permit information as well as required setbacks and location guidelines. (In the City of Tucson, for instance, curb cuts must be 5' away from driveway aprons and 20' back from intersections).
- Minimum width of the earthen area between curb and sidewalk/path must be 6' in areas with on-street parking and 5' without parking.

5.2.3 Design and construction

Curb Cuts:

- Typically, in Tucson curb cuts are 18" – 24" wide, with 45° sloped sides. Variations based on curb type or in other communities have also been successful (see adjacent photos).
- The bottom of a curb cut should slope away from the street and slightly toward basin area.
- A rip-rap apron (sediment trap) should be built where the water flow crosses the cut curb into the ROW area. The apron will prevent soil erosion and undercutting of the road surface. Rock sized 4" – 8" can be laid in a single well-fitted course around the entrance. The top of the rock surface should be laid 1 – 2" below the level of the bottom of the curb cut to ensure positive water flow into the basin.

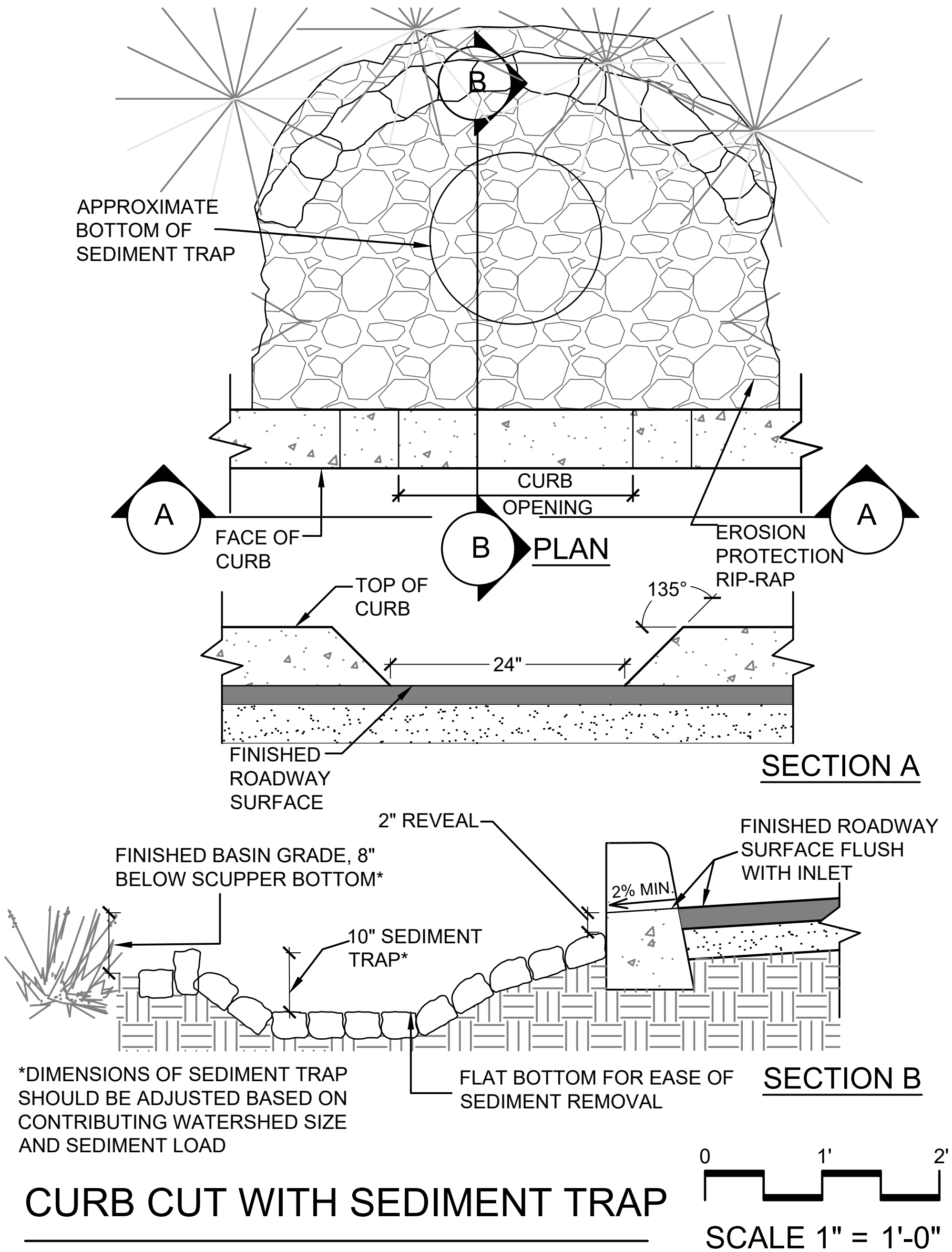


Figure 2. Example curb cut inlet detail.

Curb cuts can still work on wedge curbs.

Simple, angled curb cut enhances capture of stormwater moving along the gutter.

Curb Cores:

- Curb core inlets are typically 3" – 4" diameter with the opening at street level through a vertical curb. The larger diameter is preferred when possible to prevent clogging of the inlet. Since cores are more prone to blockage by debris, they should be used as a last resort, and only in cases where a raised curb exists, the beveled sides of a curb cut present safety concerns, and the curb is a minimum of 6" above street grade. Variations of the curb core can be used to convey water under sidewalks or pathways to basins (see adjacent photos).
- Slope of core should convey water away from the street and towards basin area.
- A rip-rap apron (sediment trap) should be built where the water flow crosses the cored curb into the ROW area. The apron will prevent soil erosion and undercutting of the road surface. Rock sized 4" – 8" can be laid in a single well-fitted course around the entrance. The top of the rock surface should be laid 1 – 2" below the level of the bottom of the curb cut to ensure positive water flow into the basin.

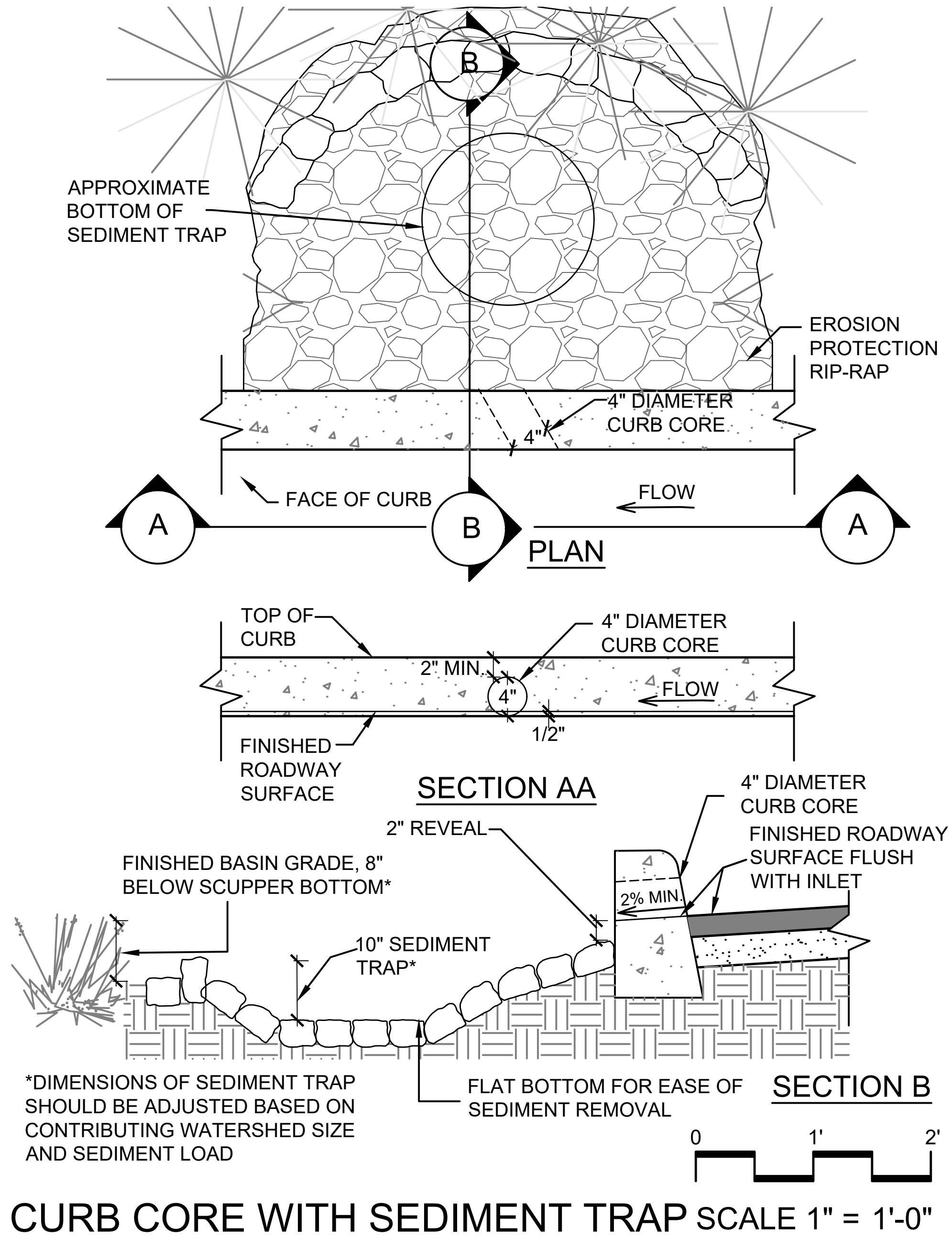


Figure 3. Example curb inlet core detail.


Drilling a 4″ core at a slight downward angle to enhance water flow into basin.


The core inlet is fitted with a plastic pipe sleeve to move water under the pathway into the basin.

Sidewalk Scuppers:

- A scupper is an opening with a cover plate that allows runoff to enter a streetside bioretention basin while maintaining pedestrian access and safety.
- Scuppers are preferred in high-use pedestrian zones and/or when water needs to be conveyed through a non-landscaped area (e.g. under a sidewalk).
- Scuppers are preferred over curb cores, as cores are more prone to blockages and require periodic maintenance to ensure function. (see adjacent photo)

5.2.4 Maintenance

- Regularly clear curb inlets of any debris that may prevent the free flow of stormwater into basins (1 – 2 times per year).
- Check rip-rap aprons for signs of erosion and repair/reinforce as needed (annually).

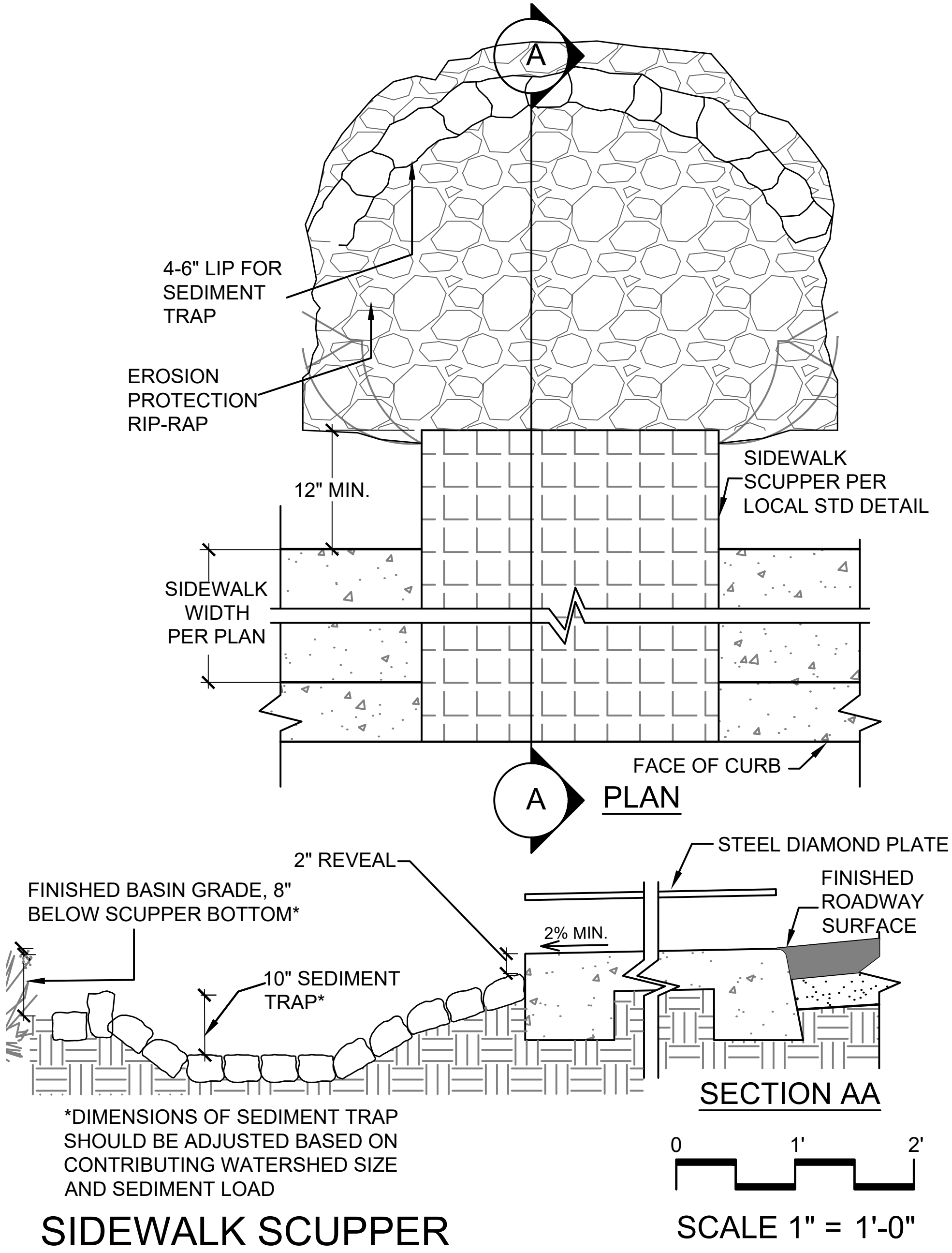


Figure 4. Example sidewalk scupper detail.

Variations of sidewalk scuppers allowing stormwater to flow under sidewalk.

5.3 Curb cut and basin

To collect and infiltrate stormwater from curb cuts into the right-of-way, bioretention basins must be excavated in the ROW to a depth below street level. If the ROW landscape width is 9′ or wider then basins with shallow slopes that are not lined with rock can be created. If the ROW landscape width is narrower, then rocks or other reinforcement materials should be used to prevent erosion along steeper sloped basin edges.

5.3.1 Function

Advantages

- This practice can be used to collect stormwater from relatively narrow or wide ROWs.
- Basins create a delineated area for mulch and planting.
- Organic mulch can be used where only a single curb cut allows water in or out and street flooding does not occur over the top of the curb.

Disadvantages

- Basins may inhibit walkability in high-use pedestrian zones.
- Basins are often constrained due to presence of underground utilities.
- Along streets with steep slopes, basins should be sized appropriately to ensure stormwater does not spill out of the lower lip of the basin. Zuni bowls can be utilized on extremely steep slopes to control the grade while reducing the velocity of water[19].

5.3.2 Site selection

- Follow site selection guidelines for curb cuts (Section 5.1) and vegetation (Section 4.1).
- Minimum width of the earthen area between curb and sidewalk/path must be 6′ in areas with on-street parking and 5′ without parking.
- Avoid streets with longitudinal slopes greater than 5%.
- Maintain setbacks from above- and below-ground utilities as required.

5.3.3 Design and construction

- Excavate bottom of basin 10″ – 12″ below the surface of the street and backfill with 2″ – 4″ of mulch. (Note: In Tucson, basins must not allow standing water deeper than 8″. Excavating deeper and backfilling with mulch allows greater stormwater capacity. The top of mulch must be 2″ below the curb cut inlet.)
- In areas where the slopes of the basin will exceed 3:1 or 33%, the edges of the basin must be lined with rock to prevent erosion.
- If pedestrian access to cross the ROW is needed, size basins no longer than 20′ in length, with 5′ level pathways between basins.
- Make level area at bottom of basin as large as possible to maximize stormwater infiltration.
- In areas with on-street parking, preserve an 18″ "step-out zone" of flat soil or gravel next to the curb (sloped 1% toward basin) to allow passengers to step in and out of vehicles.

[19] Erosion Control Field Guide, pages 6-7, Sponholtz and Anderson, Quivira Coalition.

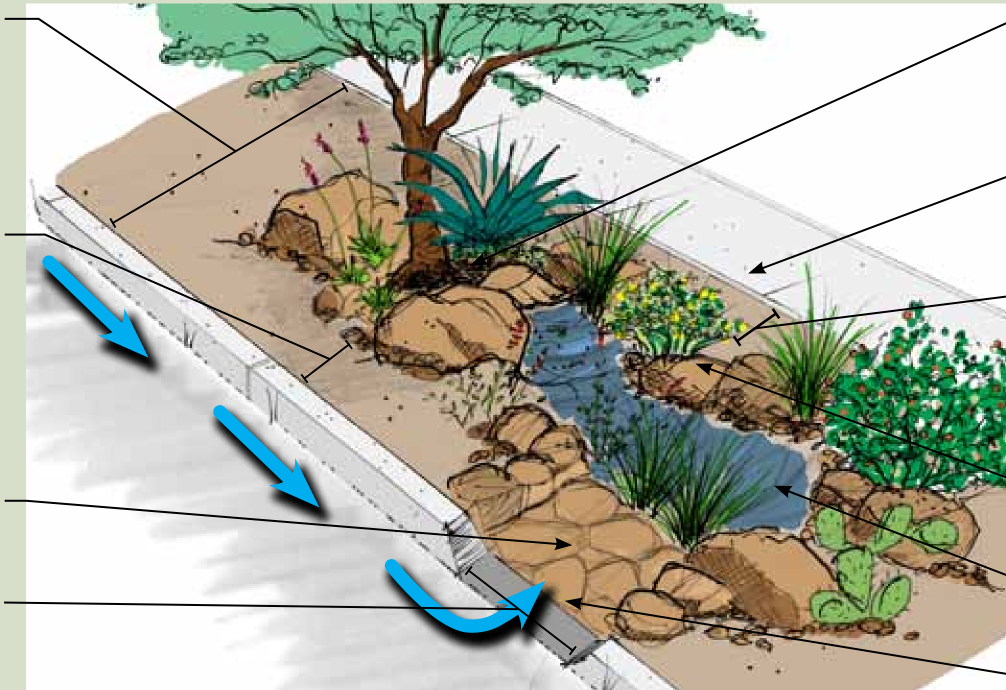


Figure 5. Conceptual drawing of a curb cut and rock-lined basin in the ROW.

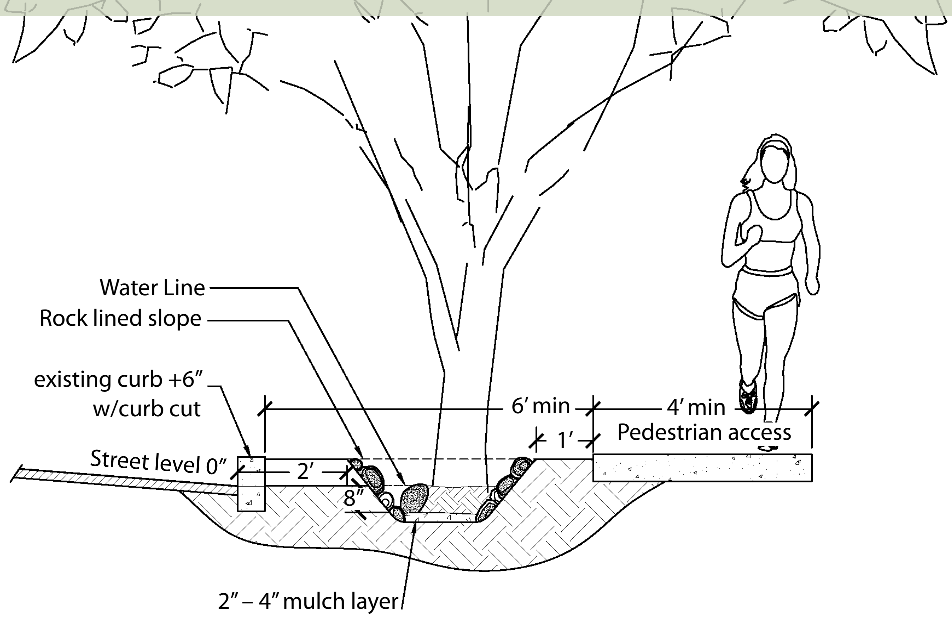


Figure 6. Section A. Typical cross-section of a basin with rock-lined edges, showing typical setbacks for a site on a residential street with on-street parking. For plan view, see Appendix.

- Preserve a 1′-wide area (sloped 1% toward basin) next to pedestrian pathways or sidewalks to ensure basin slope is not right next the pathway.
- If sidewalks are not present, preserve a minimum 4′ flat pedestrian pathway within the ROW (sloped 1% toward basin).
- The curb cut should be both the inlet and the overflow outlet of the basin. To achieve this, the bottom of the curb cut should be at least 4″ below any other point along the edge of the basin rim. This step is imperative to ensure that overflow exits back onto the street and not onto adjacent properties. The more a site is sloped, the shorter the basin must be to maintain these levels.
- Create planting terraces along the basin to support native trees and shrubs. Be sure planting shelves do not block flow of stormwater along the basin length.

To preserve visibility, do not plant trees or shrubs that will encroach into travel lanes. A tree canopy may extend over parking areas at a minimum height of 8′ – 9′ and over travel lanes at 14′ (refer to local codes).

5.3.4 Materials

- For steeply sloped basins use 8″ – 20″ rip-rap to line the perimeter.
- Use 4″ – 8″ rip-rap as an apron below curb cuts to reduce erosion. Make use of urbanite (repurposed concrete) in place of rip-rap if available.
- Use organic mulch in basin wherever possible. If street experiences severe flooding then rock mulch may be necessary.

5.3.5 Adapting the practice to your site

- In ROW areas without on-street parking, reduce "step-out zone" to a minimum of 6″.
- If utilities cross the ROW perpendicularly, use these areas as raised pathways for pedestrians to cross the ROW between basins.
- In areas where the ROW is not wide enough for this practice, consider smaller basins without curb cuts to capture runoff from adjacent sidewalk/path and properties (see Section 5.5).
- Turn an upstream driveway cut into an opportunity to harvest water flowing along the curb and gutter and direct it to the basin. This saves from having to cut a new inlet.
- A basin can be constructed along a ROW without a formed curb. Along these streets an 8′ clear setback is often required before the start of the vegetated basin. Cut a gradual slope along the street or a gentle swale laid with gravel to direct flow to the basin.
- In high pedestrian traffic areas or where minimal landscape space is available then heavy metal grates can be placed over the inlet and basin to provide a stable walking surface that irrigates the vegetation.

A minimum 9′ wide area between curb and sidewalk is needed for this practice (this allows 2′ of level bottom 3″ below street level; width can be 8′ min. if there is no on-street parking).

Trees and water-sensitive plants are placed on terraces above level of regular/extended inundation.

18″ flat step-out zone between inside of curb and top of slope allows people to step out of their cars onto a flat surface; slope 1% towards basin to collect rainfall (this zone can be reduced to 6″ at sites without adjacent parking).

Curb cut inlet lined with 4″-8″ rock to prevent erosion.

18″-24″ curb cut with 45-degree sloped sides; serves as both the inlet and outlet of basin.

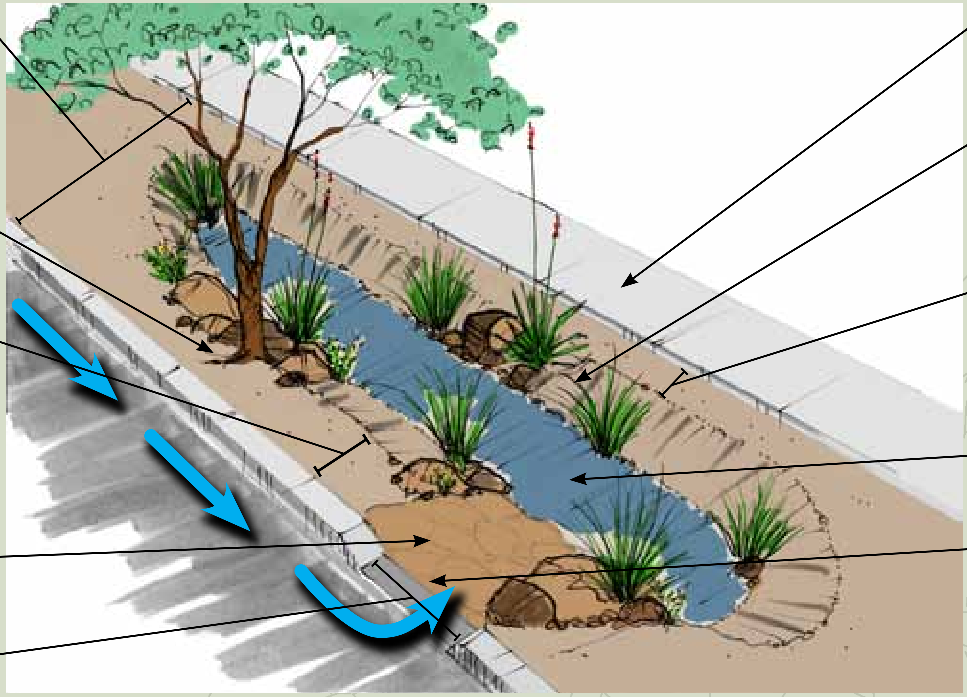


Figure 7. Conceptual drawing of a curb cut and basin with shallow slopes in the ROW.

Sidewalks/pedestrian paths slope 1% toward basin.

All slopes are made less than 33% to eliminate the need for rock reinforcement.

12″ flat safety zone between sidewalk/pedestrian pathways and rock edge; slope 1% toward the basin to collect rainfall.

Area of level bottom is maximized to increase stormwater infiltration.

2″ reveal to ensure inlet does not get clogged.

Note: this illustration shows an intentionally under-vegetated basin to show slope contours.

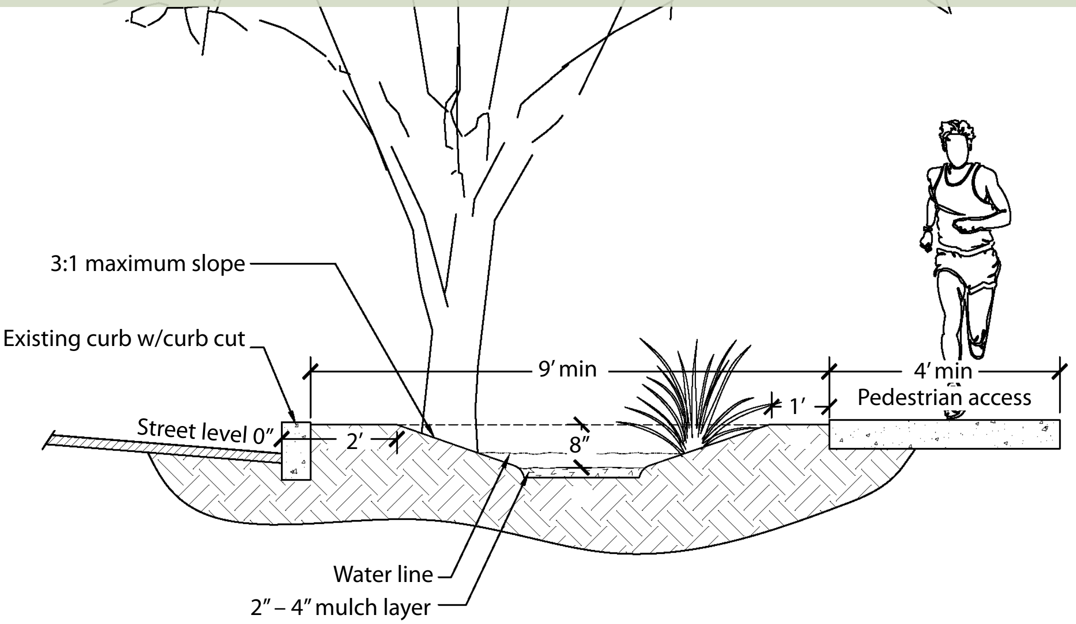


Figure 8. Section B. Typical cross-section of a basin with sloping sides, showing typical setbacks for a site on a residential street with on-street parking. For plan view, see Appendix.

5.4 Sediment traps

Sediment removal poses a considerable challenge in the maintenance of GI sites. In the arid Southwest, high proportions of bare soil are common, yielding faster rates of erosion and sedimentation. This requires that GI sites in areas of high flow be armored with rock or gravel, which in turn makes sediment removal more problematic. Sediment traps help to address this issue.

5.4.1 Function

Sediment traps capture and collect sediment at the entrance to bioretention areas, facilitating periodic sediment removal and extending the functional life of these features.

5.4.2 Site selection

- Use sediment traps in areas where high sediment loads are observed in stormwater.
- Traps can be used at the inflow of any GI feature. These diagrams show an example for use with a curb cut and rock-lined basin.

5.4.3 Design and construction

- Excavate an 8" depression, 1' from the inside of the curb cut, approximately 2' x 2'.
- Create a 4" – 6" rock lip separating this area from the rest of the basin.
- Plant native bunch grasses immediately adjacent to the rock lip on the basin side to further assist in slowing the flow and filtering stormwater pollutants.

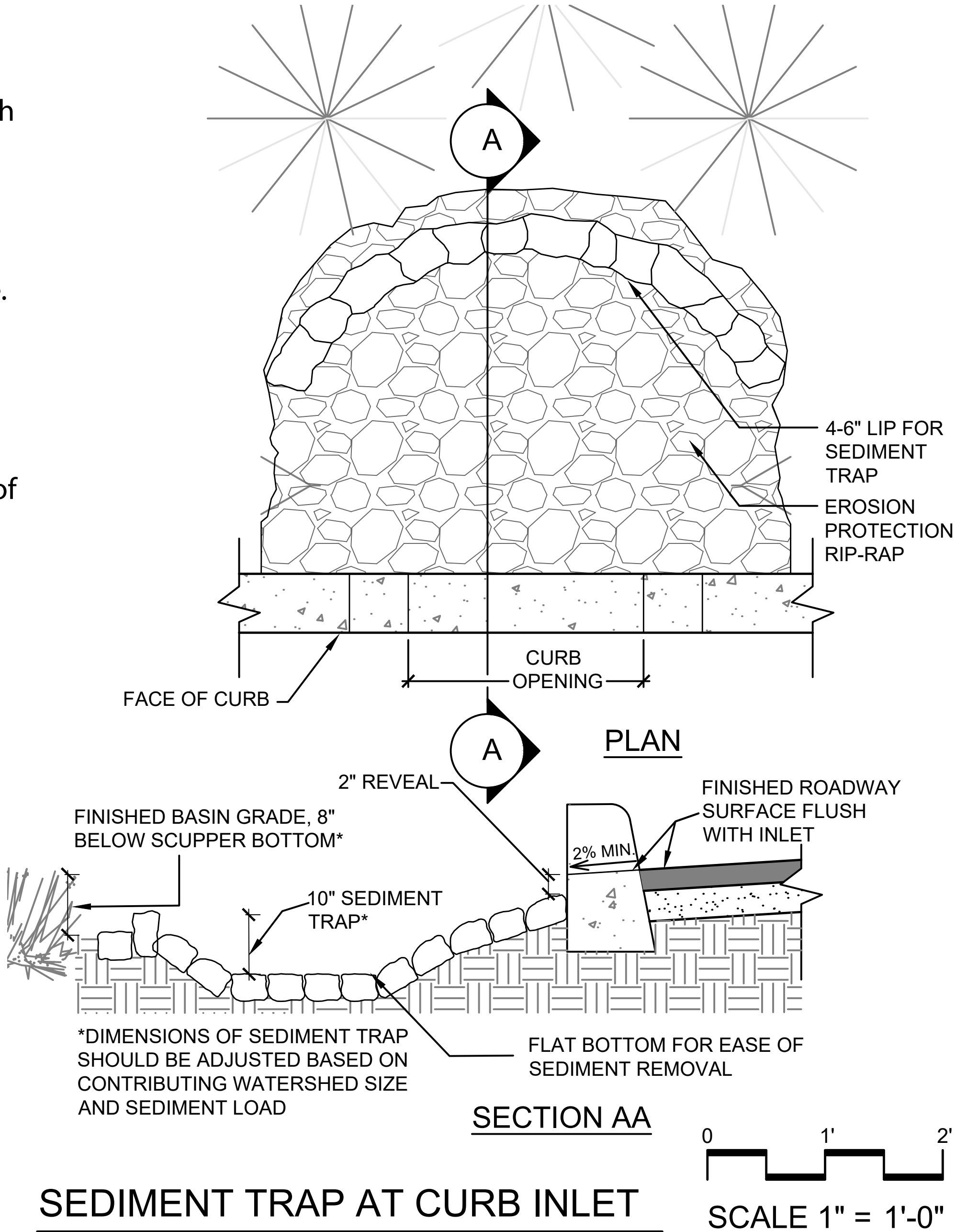


Figure 9. Example detail for a sediment trap.

5.4.4 Materials

- Line curb cut apron, bottom of sediment trap, and slope of berm with a single well-placed, well-anchored course of 4" – 8" rip-rap or urbanite (repurposed concrete).
- Tie 4" – 8" rock (above) into rip-rap edges of larger basin (see plan view for detail).

5.4.5 Adapting the practice to your site

- This concept will work for many GI applications beyond the one shown. The key concept is to create a place where water will pool momentarily to allow coarse sediments to drop out of stormwater before it spills over into the main bioretention feature.
- Always ensure that the top of the retention lip is a minimum of 4" below the bottom of the stormwater inlet (or flush curb).

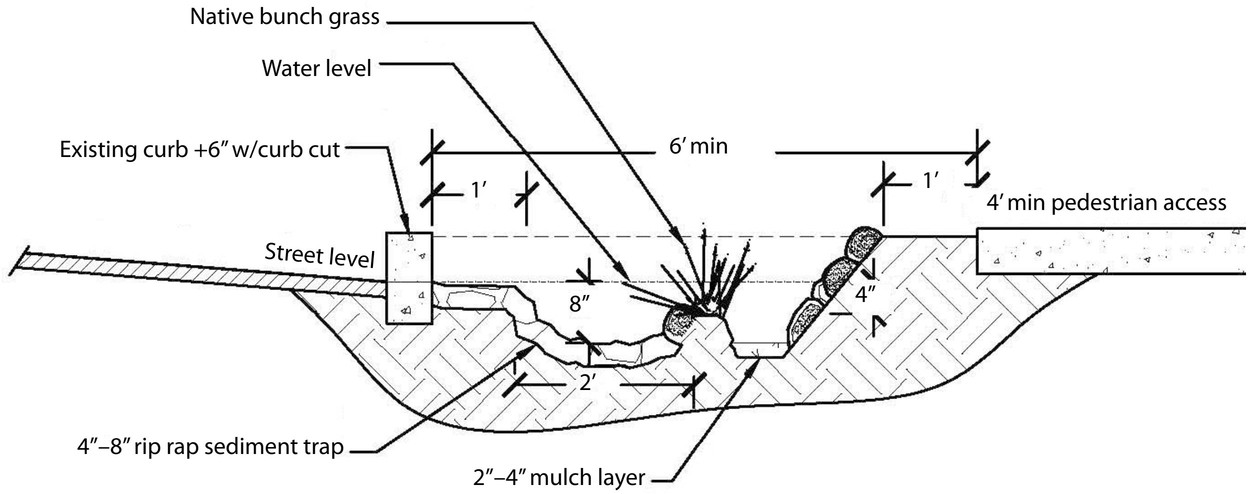


Figure 10. Section A1. Typical cross sectin of sediment trap for curb cut with rock-lined basin.

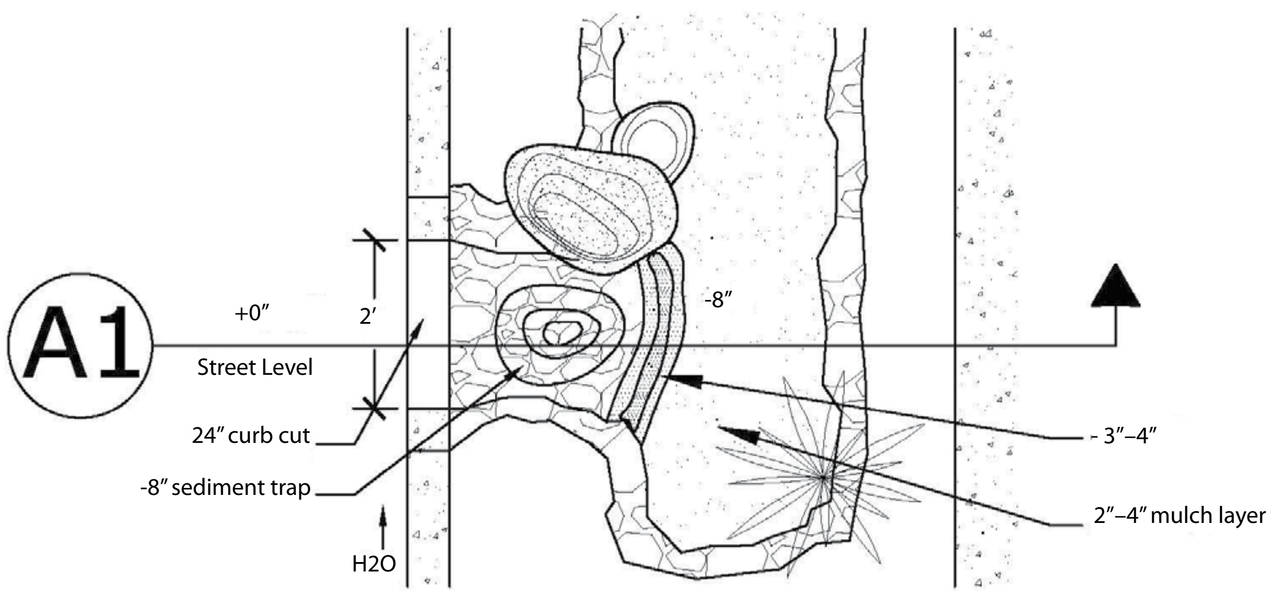


Figure 11. Plan view of sediment trap for curb cut with rock-lined basin.

5.5 Other applications

5.5.1 Swale with curb cuts

A swale is a bioretention feature with gently sloping sides that is long and linear in shape. Swales may capture and infiltrate stormwater in place (when level-bottomed), or transport water downhill to a drain or other detention feature. In the example below, a long swale was created to capture stormwater from the street via a series of curb cuts.

This design can have an identical cross-section to the shallow-sloped basins in Section 5.3.3; the difference is that the swale is one long continuous feature rather than being broken up into individual basins. This practice would not work in areas where more frequent pedestrian crossing of the ROW is required, or on steeper slopes where erosion might be caused by the through-flow of water in and out of curb cuts.

5.5.2 Basin or swale without curb cuts

In areas where the ROW is too small to create a basin with curb cuts or where stormwater does not flow along the gutter, swales and basins may still be created to capture runoff from sidewalks and adjacent properties.

- If only collecting runoff from an adjacent sidewalk (versus from a street or parking lot), this method will generally provide less passive stormwater irrigation to plants.
- Downspouts from adjacent buildings can be directed into basins in the ROW. These must be sized appropriately to capture and infiltrate the calculated rooftop runoff.
- Since no curb cut is present to serve as the overflow for bioretention features, ensure that overflow is directed to the street and not onto adjacent properties.

This long, shallow swale in the right of way has multiple curb cuts along its length.

At this site in Tucson, a 3″ deep swale was created in the ROW to collect runoff from the sidewalk and adjacent property.

This series of basins collects stormwater from the adjacent sidewalk and businesses (without curb cut).

6. In-street GI practices

The problem: Overwide streets

Too many southwestern streets are
- Too wide
- Barren of vegetation
- Hot and unfriendly to bicyclists and pedestrians, as well as adjacent homes and businesses

They generate stormwater runoff that
- Carries non-point source pollution to waterways
- Floods the street, creating traffic hazards
- Erodes soil downstream of paved areas
- Increases maintenance costs

A solution: Narrowing with green infrastructure

In-street GI features:
- Chicanes or bump outs
- Medians
- Traffic circles

These features reduce the street width, accept stormwater, and create planting areas, which
- Calm traffic
- Reduce flooding, sedimentation, and erosion
- Capture, clean, and infiltrate stormwater
- Grow vegetation that shades streets and sidewalks, cooling neighborhoods and creating more desirable places for biking and walking

6.1 Why work in the street?

The following points outline the advantages and disadvantages of using in-street green infrastructure practices versus working only in the rights-of-way with curb cuts and basins.

Advantages
- Possible in areas with limited ROW options
- Can capture more stormwater
- More effective traffic calming
- Dramatically affects streetscape and neighborhood aesthetics

Disadvantages
- More expensive
- More disruptive (can displace parking, more construction, etc.)
- May not be possible in areas where stormwater conveyance is needed

Median with curb cut

Chicane with no curb cut

Typical Southwestern street

Traffic circle with curb flush with street level

6.2 Site selection, design, and workflow

Preserving street width

To preserve access for emergency vehicles, the Uniform Fire Code requires that each lane of traffic must be at least 10′ wide, however some municipalities may require greater width. (In the City of Tucson, for instance, traffic lanes on residential streets must be 11′ wide.) An 8′ width is also required for each lane of parallel parking along the curb. For example, a street with two lanes of traffic and parallel parking on one side could be a minimum of 28′. Any width over 28′ could potentially be incorporated into a feature like a chicane, median, or street width reduction. Consider reducing on-street parking to make installing these practices possible.

Stormwater conveyance

Many southwestern streets are designed to convey stormwater. For example, in Tucson many "washes," or designated waterways, are actually streets that flow with large amounts of stormwater in powerful desert storms. Essentially the street functions as the "river bottom" and the curbs act as the "river banks." In these situations, adding a raised median or a curb extension to the street can reduce the street's stormwater capacity and increase the risk of flooding adjacent properties. GI practices designed for southwestern streets will need to take this unique challenge into account. In general, the solution is found by creating in-street GI features that have flush curbs and bioretention areas depressed below the level of the street (see following pages).

Bicycles and pedestrians

The in-street GI practices described in this manual are all designed to calm traffic. Chicanes, medians, and traffic circles all narrow the roadway forcing drivers to slow down. While they can create obstacles for bicyclists, slower overall traffic speeds mean that serious injury accidents involving bicyclists and pedestrians are less likely to happen[20]. In addition, chicanes and medians at intersections can reduce pedestrian crossing time (by reducing the distance between the curbs) and increase visibility for both drivers and pedestrians (by keeping parked cars farther away from intersections). These properties of in-street GI features make them a great option for those neighborhoods seeking to make streets safer and more livable and reduce cut-through traffic.

Workflow

Because they are on public streets, these GI features generally require a high level of government involvement in the design and installation process. Workflow of in-street projects will likely be determined by local official protocols. However, local knowledge about stormwater flows, dangerous intersections, neighborhood goals, etc. are invaluable to the planning and design process—and sadly, often overlooked. This manual is intended as a bridge to provide neighborhood residents with relevant information to contribute to planning processes and to offer officials a neighborhood perspective on green infrastructure.

[20] Bikesafe Bicycle Countermeasure Selection System [Internet]. Washington, DC: Department of Transportation, Federal Highway Administration (US). Available from: http://www.pedbikesafe.org/bikesafe/

General Design Details

- Excavate the feature to a final depth of 8 – 12″ (e.g. if laying 4″ – 8″ rock, excavate 4″ – 8″ deeper to enable at least a final depth of 8″).
- For chicanes and street reductions, where possible, extend vegetated and depressed bioretention areas into the adjacent ROW. This may be achieved by laying ROW slopes back (see plan view in Appendix) or pouring a new curb deeper into the ROW (see Figure 9 next page).
- Maximize the area of level bottom of the feature by using steep side slopes (up to 50%) armored with rock.
- Use flush header curbs 18″ deep to protect the adjacent asphalt surface.
- Create raised planting areas for trees and shrubs that do not tolerate inundation. The raised planting areas can additionally function to slow stormwater flow through the bioretention area.
- To preserve visibility, do not plant trees or shrubs that will encroach into travel lanes. A tree canopy may extend over a travel lane at a minimum height of 14′ (refer to local codes).
- Use a modified sediment trap (Section 5.4) at the flow entrance of the feature to facilitate maintenance.

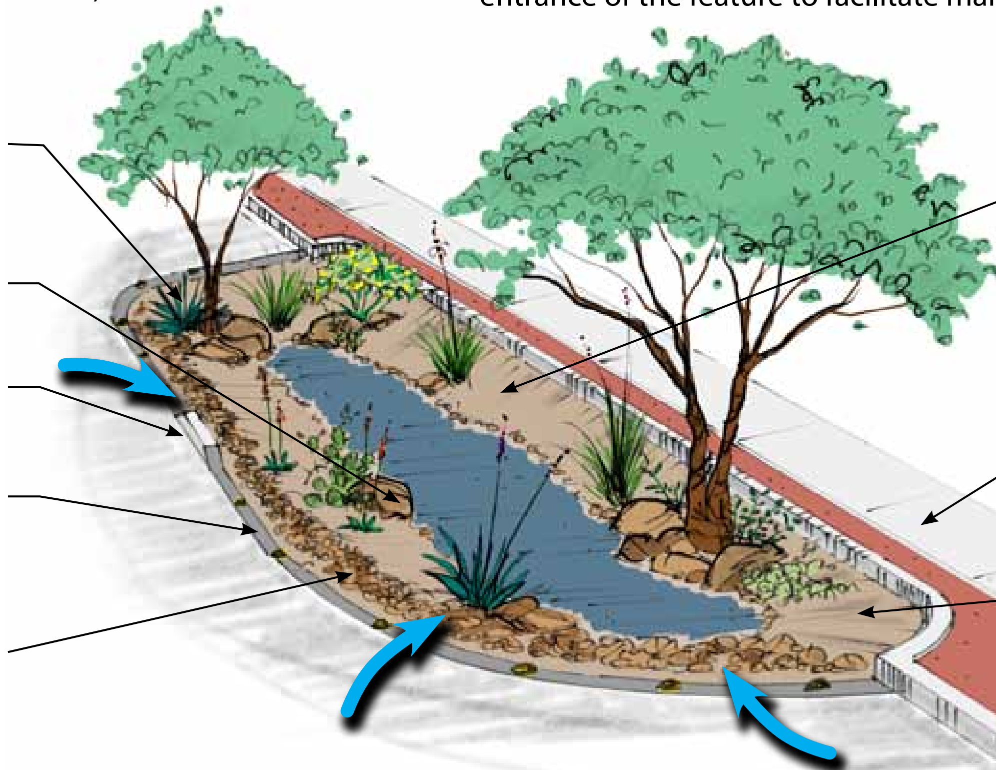


Figure 12. Conceptual drawing of a chicane with bioretention area for a neighborhood street.

6.3 Materials

- In areas of higher flow (concentrated flow with depths >1″ – 2″), line soil surface with 4″ – 8″ rock (or urbanite) to prevent scouring of soil. Areas that experience lesser flows can use coarse gravel or a mix of 1″ – 3″ rock.
- Place several larger boulders within the feature to increase visibility and prevent vehicle entry.
- Place 6″ ceramic disks along the top of header curb to discourage entry by automobiles. These may be reflective.
- Place flashing solar lights on the asphalt to warn oncoming traffic of obstruction.

6.4 Chicanes and street width reductions

For many over-wide neighborhood streets, it may be appropriate to narrow the width of the street. Narrowing of a street can occur in shorter sections using chicanes (also called "bump outs" or "curb extensions") or along the entire length of the street using street width reductions. These features are created by removing pavement and increasing the bioretention area along street edges.

Narrowing the street width significantly reduces impervious area, increases safety by calming traffic speeds, collects and infiltrates stormwater, and increases vegetation and tree canopy cover. It may also provide new space for pedestrian paths and sitting areas. Size these features as large as possible to increase stormwater mitigation and traffic calming effects. Generally, the encroachment width into the street is 8′ and the length can be from 18 – 20 feet, or the entire length of the street in the absence of driveways.

When designed with a flush curb and depressed bioretention area, these street narrowing features collect and infiltrate stormwater that flows along curbs.

Why a chicane or street width reduction?

- These features function best to collect stormwater on crowned streets, because they are highest at the middle of the street and carry stormwater along the curb.
- Chicanes can be used effectively both mid-street and on the corners at intersections. Consider incorporating chicanes with pedestrian crossings to shorten crossing distance and restrict parking near intersections.
- Most chicanes require a minimum of 8′ of available (surplus) street width. See Section 6.2 for details on preserving appropriate street width.
- Take on-street parking needs into consideration. Chicanes may displace existing on-street parking.
- On steeper sloped roads (> 2%), berms or check dams may be needed to slow stormwater flowing through the bioretention features.

The concrete curb to the left of the blue arrow is flush with the street.

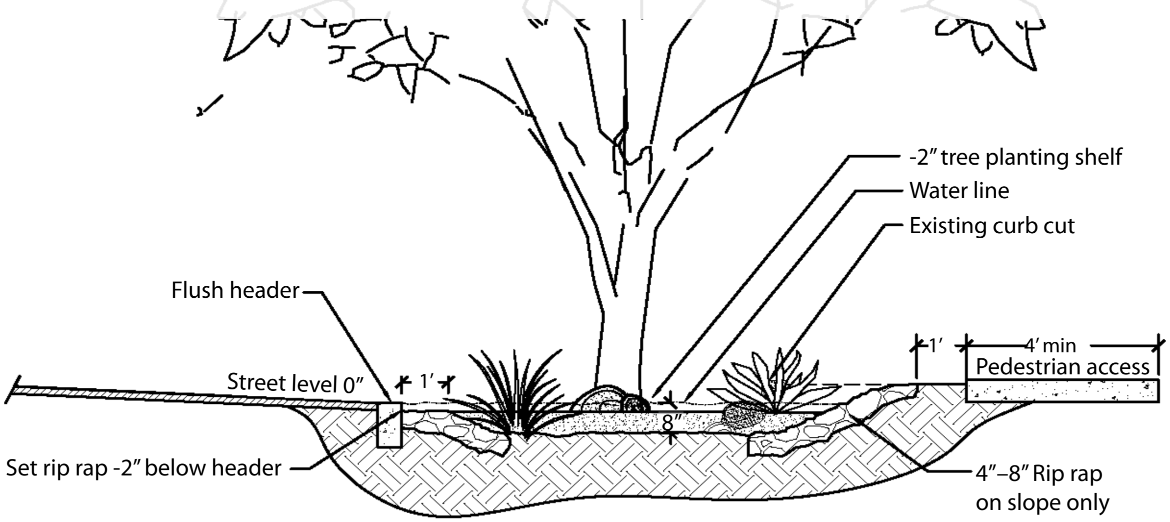


Figure 13. Section F. Typical cross-section of a chicane with flush curb and depressed bioretention area. For plan view, see Appendix.

Adapting chicanes or street width reductions to your site

- If these features are designed for concave streets (with the lowest point in the middle of the street), use a uniformly raised curb and a depressed planting area to capture and infiltrate stormwater that falls on the basin area and the adjacent ROW.

- In areas with higher sediment flows, consider using sediment traps (see Section 5.4) to improve maintenance. If you are designing a series of chicanes along a single flow path with an upstream sediment source then design the first chicane to be your primary sediment trap.

- For streets where maintaining maximum stormwater conveyance is not an issue, features with raised curbs (and a flush stormwater inlet) can also be used (see photo below). If the design can be modified to function similar to a curb cut and basin, organic mulch should be used.

- In lengthy street width reductions, parking spaces can be incorporated by cutting them in (by retaining existing asphalt) to the bioretention area at intervals along the street.

- Incorporate creative methods such as seating areas, pathways, or public art to enhance the community value and utility of larger street width reduction projects.

6.5 Medians

Medians are features that divide the street in the center. Medians slow traffic by reducing the effective street width, and can increase safety by keeping traffic lanes separate. When designed with a flush curb and depressed bioretention area, medians can collect and infiltrate stormwater that flows along the street and use that water to grow vegetation that shades the street and slows traffic. The bioretention area promotes vegetation, reduces stormwater volumes, and filters non-point source pollutants from stormwater.

Why select a median?

- Medians function best to collect stormwater on concave, or inverted crown, streets, because they are lowest in the middle and carry stormwater along the middle of the street.
- Medians can be an excellent way to slow traffic entering a neighborhood from higher-speed regional streets, and/or to prevent cars from making unsafe or unwanted turns mid-street. They can also serve as refuge islands for pedestrians and bicyclists crossing wide roads, especially when paired with crossing traffic signals.

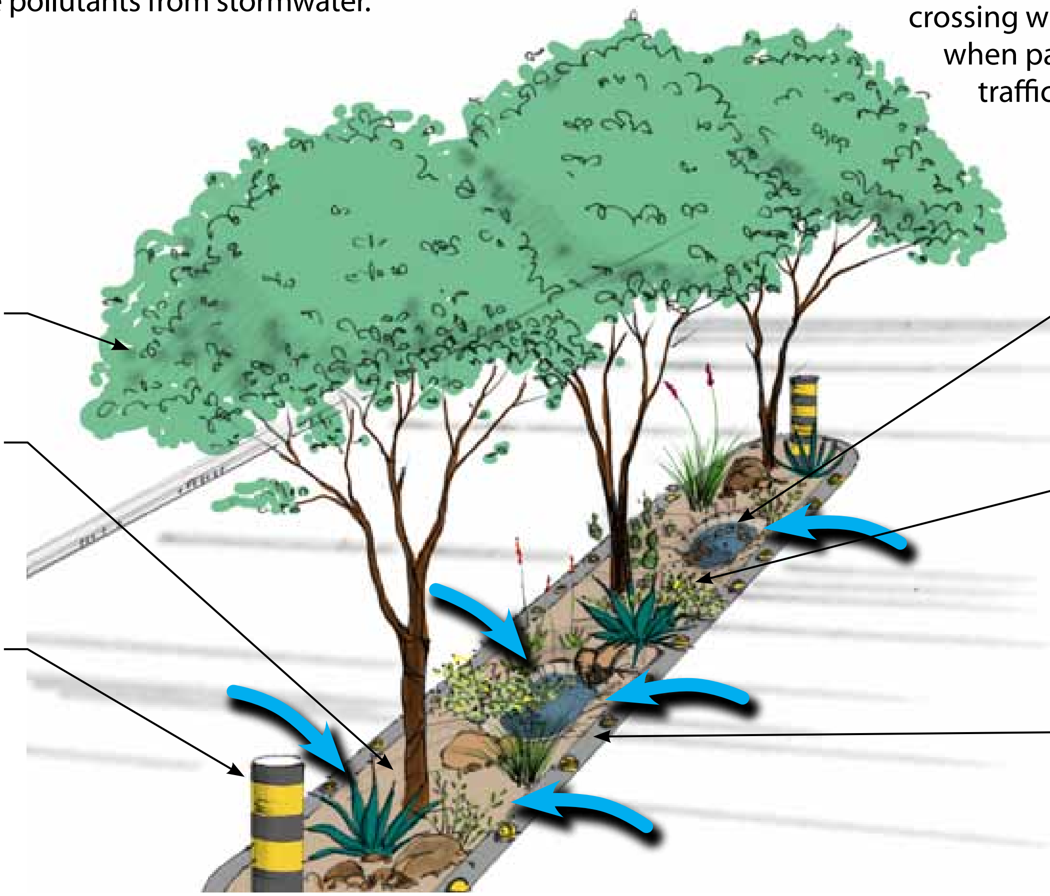


Figure 14. Conceptual drawing of a median with depressed bioretention area for a neighborhood street.

- Medians require a minimum 5′ of surplus street width. See Section 6.2 for details on preserving appropriate street width.
- Consider reducing on-street parking to make installing medians possible.
- Bioretention medians may not be appropriate for steeply sloped streets; consult local transportation departments.

Adapting medians to your site

- Place bollards (posts with reflective markings) at both ends of the median to warn oncoming traffic of obstruction.
- Consider striping pavement surface in approach to median to increase visibility of feature (see plan view in Appendix).
- If medians are designed for crowned streets (with the highest point in the middle of the street), use a uniformly raised curb and a depressed planting area, no higher than street level, to capture and infiltrate stormwater that falls on the median itself.

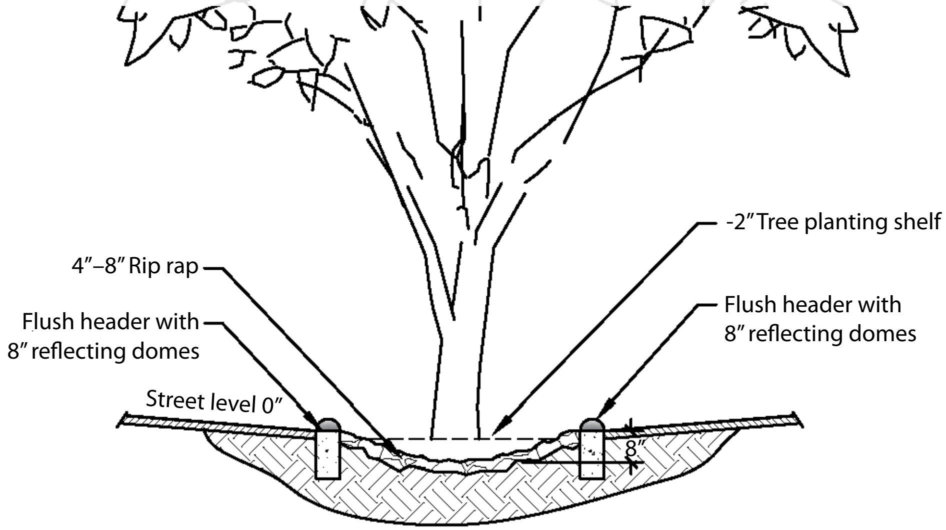


Figure 15. Section E. Typical cross-section of a median with flush curbs and depressed bioretention area. For plan view, see Appendix.

6.6 Traffic circles

Traffic circles are used in intersections to slow traffic. They are an excellent way to reduce impervious area in a neighborhood and can be designed with a flush curb and depressed bioretention area to collect and infiltrate stormwater. The bioretention area within the traffic circle will promote vegetation, reduce stormwater volumes, and filter non-point source pollutants.

Size traffic circles to be as large as possible within allowable constraints to increase stormwater mitigation and traffic calming effects. Check with your local emergency and waste hauling services about turning radius needs of larger vehicles for your intersection.

Why select a traffic circle?

- Traffic circles function best to collect stormwater at intersections where water flows through the intersection along a centerline. This usually occurs where the streets are concave (lowest in the middle).
- Traffic circles constrict the intersection and turning radius. To preserve access for emergency vehicles, codes typically require that the minimum distance from the traffic circle header to the nearest corner of the intersection be 20′ (check local municipal guidelines).

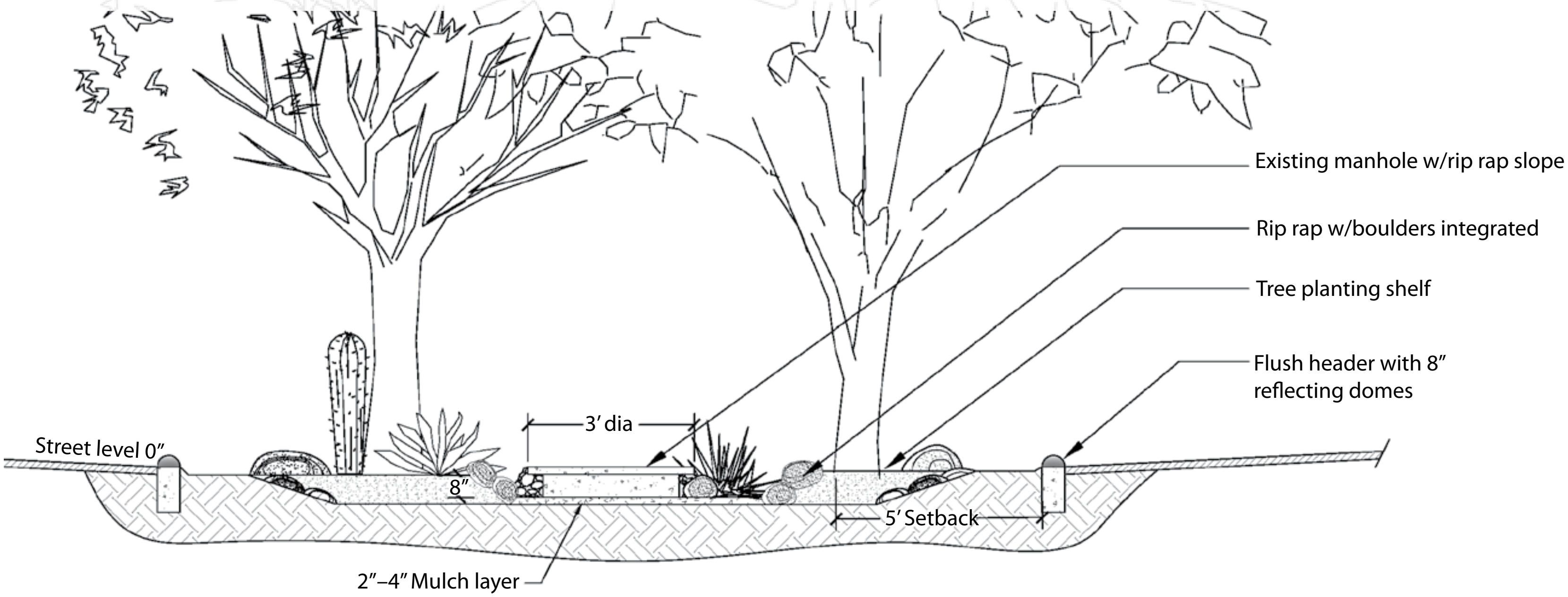


Figure 16. Section C. Typical cross-section of a traffic circle with flush curbs and depressed bioretention area. For plan view, see Appendix.

Adapting traffic circles to your site

- If traffic circles are used in crowned intersections (highest in middle), use a uniformly raised curb and a depressed planting area to capture and infiltrate stormwater that falls on the traffic circle itself (see adjacent photo).
- A traffic circle is designed to slow but not stop the flow of traffic. If you are adding a traffic circle at an intersection with stop signs you may want to check with your transportation authority about removing the stop signs and replacing with yield signs in tandem with your traffic circle.

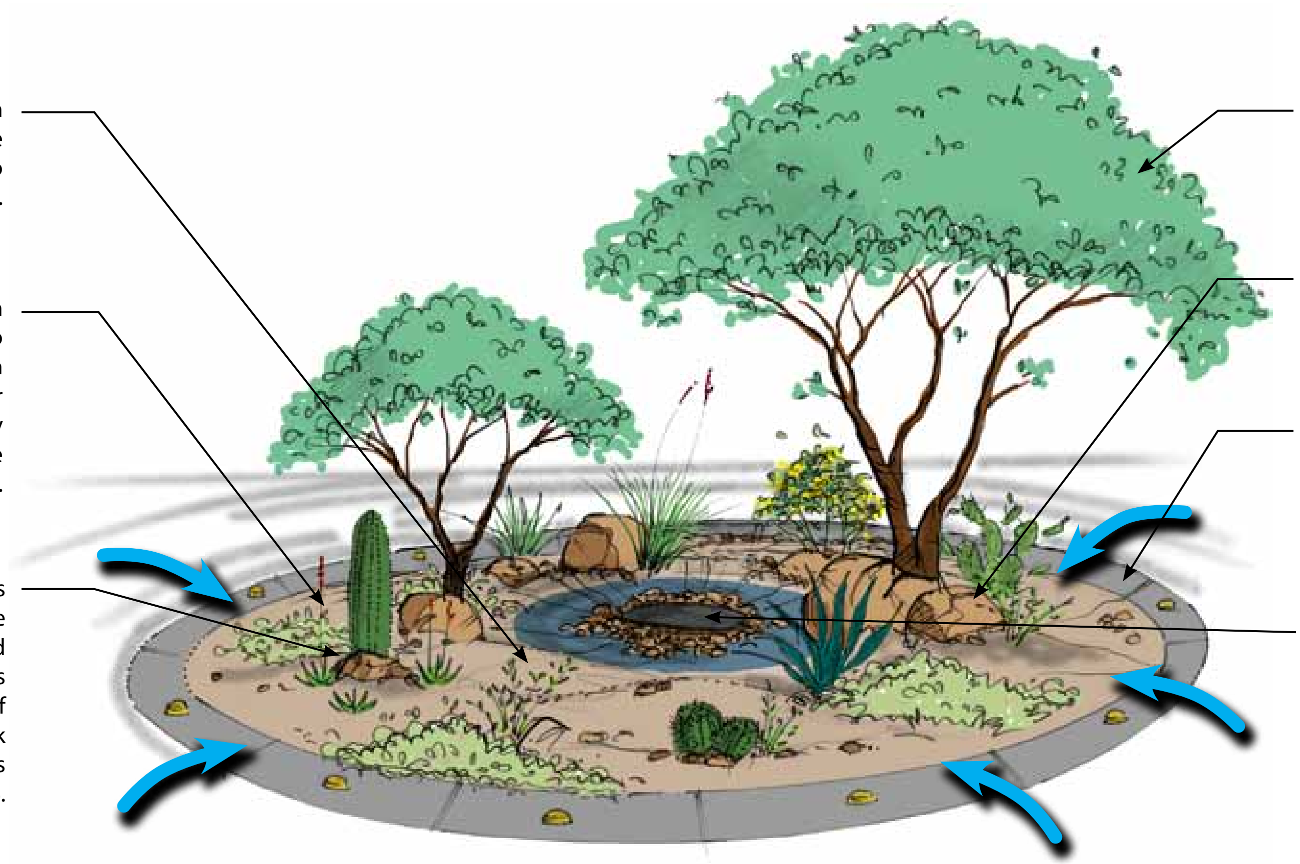


Figure 17. Conceptual drawing of a traffic circle with depressed bioretention area for a neighborhood street.

The problem: Too much asphalt

Whether at a church or a "big box" store, parking lots are a major element of many neighborhoods. Their presence, though often necessary, has several consequences for the local environment and neighborhood character.

One 8.5′ x 20′ asphalt parking space generates about 100 gallons of runoff in a 1″ storm. This runoff accumulates quickly, and in many neighborhoods, this stormwater is sent out into the street or directly into arroyos and washes. To deal with this issue, many municipalities now require parking lots to be outfitted with detention/ retention basins that capture stormwater runoff.

These "grey infrastructure" detention basins often have serious drawbacks:

- Taking up otherwise buildable land
- Creating vacant, often unusable areas without landscaping that can become an eyesore
- Failing to address water quality issues
- Requiring fencing or walls
- Serving only a single function

A Solution: Green infrastructure for parking lots

GI parking lot practices take the function of the detention basin and spread stormwater management throughout the site, creating multiple bioretention areas that collect stormwater close to its source. As GI does on neighborhood streets, these practices integrate stormwater management with landscape improvements to provide many benefits:

- Increasing the amount of buildable land, or land available for green spaces
- Creating more attractive parking landscapes that appeal to both users/customers and neighborhood residents
- Cooling local temperatures
- Cleaning and infiltrating stormwater
- Reducing landscape irrigation needs
- Reducing maintenance needs

Why work in and around parking lots?

Urban heat island

Parking lots create great expanses of asphalt or concrete that contribute significantly to warming of towns and cities. Municipalities commonly have minimum landscape requirements for parking lots that begin to mitigate this issue by shading hardscape. The City of Tucson, for instance, has stringent regulations that require one tree to be planted for every four parking spaces in new parking lots, and that at least 50% of the lot be shaded by mature tree canopy.

Neighborhood character and livability

Neighborhoods are often in favor of large parking lots as they help keep parking from businesses off of residential streets. However, large expanses of asphalt can create hot, barren areas that detract from neighborhood aesthetics.

7.1 Site selection, design and workflow

Retrofitting vs. new construction

Cities like Tucson are doing much through codes and ordinances to improve new parking lots through proactive stormwater, landscape, and/or green infrastructure requirements like those mentioned above. Several excellent references provide information on incorporating GI practices into new parking lot construction[21].

However, most of the hundreds of square miles of existing southwestern parking lots do not incorporate these best practices. At these sites, GI practices can become part of resurfacing, reconstruction, and revitalization projects. This section provides examples of ways to retrofit existing parking lots with GI approaches to improve neighborhood environments.

7.2 Replace asphalt with bioretention

Existing parking lots often have inefficient layouts with wasted space. Even in those that do not, a few parking spaces can often be converted to bioretention areas. Replacing asphalt with bioretention has the double effect of reducing impervious area while creating spaces to collect and infiltrate runoff.

This parking lot retrofit was designed to reduce flooding. Tucson Association of Realtors also installed a large cistern to provide landscape irrigation.

Follow these best practices:

- To protect the asphalt surface, reinforce cut asphalt edges with flush concrete header, 6″ wide x 12″ – 18″ deep.
- In areas where there is a risk of motorists driving into bioretention areas, use concrete curb stops at the pavement margin or landscape boulders within the basin to prevent vehicle entry, or use a raised curb with curb cuts to allow stormwater flow while deterring vehicles.
- Plan for where overflow will exit bioretention features and, where possible, route to the next downstream basin.

[21] Phillips AE, editor. City of Tucson Water Harvesting Guidance Manual. Tucson, AZ: City of Tucson; 2005. 35p.

7.3 Create bioretention in ROW/ landscape buffer areas

Where space allows, bioretention basins or swales can be incorporated into existing landscape areas within or adjacent to parking lots. Methods will vary widely depending on the type and amount of space available:

- Use curb cuts, flush curbs, and/or natural spillover points to collect stormwater in bioretention features.
- Speed bumps can be used as a retrofit tool to direct stormwater from existing parking lots.
- Infiltration chambers can be used under parking lots or adjacent landscape areas to create additional water collection capacity while maintaining pedestrian access.

First-hand observation is essential when designing retrofit features. It is cheaper than surveying and will help you notice small topographical details that can dramatically affect stormwater flow. For example, at the site shown in the photo progression at right, observing the site in a storm revealed a small bump in the pavement that sends runoff from both an alley and parking lot into an earthen ROW area.

This progression of photos shows a ROW that collects runoff from a UA parking lot (far right of photos).

December 2008: Runoff from the lot and adjacent alley wash over bare dirt and the sidewalk into the street.

April 2009: newly-dug basins capture storm runoff to feed young plants.

August 2010: Native grasses, shrubs and trees thrive just 18 months after installation.

At this Tucson City Council Ward office, asphalt was removed from an unused portion of the parking lot. Runoff from the lot (foreground) and the adjacent building fills the unfinished basins in a summer storm.

One year later, stormwater-fed native vegetation has grown to shade the parking lot and entrance. Note that basin slopes are lined with rock to reduce erosion.

At this University of Arizona parking lot, an unused space happened to coincide with the lot's natural low point. The asphalt was removed and a biorention basin installed. Note concrete header and curb stops. The basin's interior was terraced and shaped to distribute stormwater evenly. Overflow exits the back left corner and flows to the street.

Before: At this University of Arizona (UA) parking lot, small curb cuts allowed stormwater to flow past existing trees onto the pedestrian area in the ROW, and then on to the street.

After: A long, thin swale was installed and additional trees and shrubs planted to capture and use runoff from the lot.

7.4 Alternative parking lot materials: pervious pavement

Pervious pavement allows for percolation of stormwater through subsurface aggregate and offers an alternative to conventional concrete and asphalt paving. It is particularly useful when space is limited and stormwater goals cannot be met in available landscape areas. There are many different types of pervious pavement[22] :

- Stabilized aggregate: a mixture of compacted stone aggregate and a binder
- Porous asphalt: standard asphalt pavement in which the fines have been screened and removed, creating void spaces that make it highly permeable to water
- Porous concrete: single size, screened aggregate consists of a special mix design with void spaces that make it highly permeable
- Structural grid systems: consist of plastic, concrete, or metal interlocking units that allow water to infiltrate through large openings filled with aggregate stone or topsoil and turf grass
- Permeable pavers: pre-cast concrete pavers designed to be set on a compacted base and highly permeable setting bed with joints filled with sand or fine gravel

The use of pervious pavement is encouraged for sites such as parking lots, driveways, pedestrian plazas, and rights-of-way. Pervious pavement must be designed to support the maximum anticipated traffic load but should not be used in high-traffic areas. Stormwater that drains through the pervious surface is infiltrated into underlying soils and excess runoff should be directed to landscape areas. Pair pervious pavement with basins and swales to increase infiltration capacity and make the most of infiltrated water to grow native trees and shrubs.

The complexity of pervious pavement design will highly depend on soils. If the soil has poor percolation, engineered soils and drainage pipes may be required. Regular maintenance is essential to maintain runoff infiltration capacity. Specialized equipment is required to remove accumulated materials that clog porous surfaces with vacuuming or pressure washing.

Participants in a professional green infrastructure training learn how to install a permeable parking surface. A recycled plastic base retains a gravel surface that promotes infiltration.

[22] Low Impact Development Toolkit. City of Mesa. April 2015.

8. Appropriate care of GI features

Green infrastructure needs regular care to function properly and enhance delivery of environmental services over time. Appropriate care of GI features will also ensure the maximum return on investment. Maintenance tasks usually include:

- Watering new plants during establishment period
- Identifying and removing noxious or invasive weeds
- Clearing inlets of debris and vegetation
- Pruning trees and shrubs for safety, visibility, plant health, and aesthetics
- Removing sediment and trash
- Replacing dead plants
- Adding organic mulch
- Repairing erosion
- Repairing human-caused damage

Without adequate planning for maintenance from the outset of a project, GI features may lose their capacity to function properly and become perceived as eyesores or hazards by the community. Maintenance responsibility, necessary funding, and plans for enforcement of maintenance requirements must be accounted for at the beginning of project planning.

8.1 Green infrastructure care fact sheet

Monthly:

- Remove invasive plants and weeds, particularly buffel grass and bermuda grass which, left unchecked, can render green infrastructure ineffective.

- Clean up any trash that may have blown or floated into your basins.

Hand tools are the best way to remove weeds. You can be selective about what weeds you pull, and there is no noise or chemical pollution!

Mulch may float when basins fill with water. Plants and rock features can help keep mulch in place, but if your mulch is consistently washed away in rain storms, use larger rocks as mulch.

Bermuda grass, *Cynodon dactylon* (Note: Tricky to remove. You will need to be diligent to remove Bermuda grass manually. Dig out full root system—up to 1.5 ft deep.)

Buffle grass, *Cenchrus ciliaris* (Note: This plant is a fire hazard. Make sure you carefully identify buffel grass. Don't make the mistake of removing native bunch grasses, which look similar to buffel grass, and are often used in rain gardens. Learn more at buffelgrass.org.)

Seasonal (before and during rainy seasons):

- Observe basin during rain events to evaluate function and make necessary adjustments.
- Inspect inlets and outlets for blockage.
- Remove sediment from basin inlets and sediment traps.
- Inspect berms, basin slopes, and spillways for signs of erosion. Reinforce or armor earthworks as necessary to mitigate erosion.
- Add plant trimmings and other yard waste to basin bottoms to replenish mulch with on-site materials. Exception: undesirable weeds that have set seed should be disposed of off-site!
- Check basins and swales after rainfall for excessive ponding. Incorporate organic mulch, deep-rooted plantings, or deep infiltration trenches if needed.
- Prune trees and plants to ensure plants do not obstruct pathways or required traffic visibility at intersections.

If you hire a landscape crew for routine maintenance, they can reduce their number of visits and tasks. Here's what you can tell them:

- No raking, please!
- Keep pruning to a minimum—only prune trees and shrubs if they interfere with human pathways.
- Weed less by using more organic mulch.
- Don't spray chemical herbicides—hand pull weeds when they pop up during rainfall seasons.

8.2 Design for maintenance

To facilitate long-term care, take the following into consideration when designing GI practices:

- **Remove perennial weeds during site preparation.** For instance, throughout Arizona, Bermuda grass is a persistent, deep-rooted non-native turf grass that aggressively invades disturbed soil. If established within a landscape, it is virtually impossible to remove without disturbing other plant roots or affecting desirable plants through overspray of herbicides. If the grass is removed through deep excavation during the preparation phase of a project, later maintenance needs can be significantly reduced.

- **Use native, drought-adapted plants and climate-appropriate watering schedules.** Desert plants are adapted to prolonged periods of drought interspersed with intermittent rainfall. If constant irrigation is applied, plants can grow too quickly, developing weak growth and requiring constant pruning. If a regionally-appropriate schedule of deep, infrequent watering is maintained (see Section 4.1.4), many plants will require less pruning through the year. Trees will develop deeper root systems that will help them withstand high winds.

- **Prune native trees and shrubs to natural growth forms.** Prune only to promote the health of the tree, keep branches clear of walkways, and shape the canopy for better shade. Wait at least one year, and up to two years, before you prune trees after planting. Trees become stressed when they are transplanted, and they need ample time to adjust to the new soil, moisture, and light conditions. By not pruning, you allow the tree to develop a more natural shape and strengthen as it grows. Plants will be healthier and stronger if they are allowed to keep their natural shape. When laying out the plants in your feature, plan for the mature size of shrubs and trees. This will ensure plants don’t need to be constantly pruned to prevent crowding.

Plan your landscape to let the water flow through your yard and soak into the soil.

Let your plants grow and prune minimally. You’ll be pleased with the results—healthier plants, unique shapes, and better wildlife habitat.

Desert plants have characteristic shapes and growth forms that are part of what make our regions unique. Most arid-adapted trees, for instance, naturally grow multiple trunks. When pruned into "lollipop" trees of a single stem and high canopy they require much more pruning, and are more likely to blow over in the wind. Shrubs pruned into fine sculptures obviously require more maintenance.

- **Use organic mulch wherever possible.** Since it can be easily removed and replaced, organic mulch better facilitates sediment removal than gravel or rock mulch. Leaf drop and chipped tree trimmings can be used to replenish mulch instead of being constantly picked up and hauled away (which is often required for gravel surfaces).

- **Use sediment traps (see Section 5.4).** If sediment traps are not used at GI sites armored with rock or gravel, sediment removal will be labor-intensive. This may be achieved by total removal of rock and sediment, and subsequent grading and replacement of rock.

9. References

1. Sikdar, K., Shipek, C., Jones, C. (2015), Solving Flooding Challenges with Green Stormwater Infrastructure. https://watershedmg.org/document/solving-flooding-challenges-green-stormwater-infrastructure-airport-wash-area
2. Tempe Area Drainage Master Study: LID Application Review and FLOD-2D Modeling. Flood Control District of Maricopa County, 2016.
3. Green Infrastructure Principles [Internet]. Washington, DC: National Association of Regional Councils; 2006; Available from http://narc.org/environment/green-infrastructure-and-landcare/green-infrastructure-principles/
4. Sponholtz, C. and Anderson, A.C. 2013. Erosion Control Field Guide. Quivira Coalition.
5. Zeedyk, B. and Clothier, V. 2014. Let the Water Do the Work: Induced Meandering, an Evolving Method for Restoring Incised Channels. 2nd Edition, Chelsea Green Publishing
6. Sikdar, K., Shipek, C., Jones, C. (2015), Solving Flooding Challenges with Green Stormwater Infrastructure. https://watershedmg.org/document/solving-flooding-challenges-green-stormwater-infrastructure-airport-wash-area
7. Tempe Area Drainage Master Study: LID Application Review and FLOD-2D Modeling. Flood Control District of Maricopa County, 2016.
8. Sikdar, K., Shipek, C., Jones, C. (2015), Solving Flooding Challenges with Green Stormwater Infrastructure. https://watershedmg.org/document/solving-flooding-challenges-green-stormwater-infrastructure-airport-wash-area
9. Shipek, C., Sikdar, K., Jones, C. (2015), A Stormwater Action Plan for Sierra Vista. https://watershedmg.org/document/stormwater-action-plan-sierra-vista
10. Environmental Protection Agency, Office of Water (US) [EPA]. (1999, September). Storm Water Technology Fact Sheet: Bioretention. Washington, DC: EPA; 1999 Sep. 8 p. Retrieved from: http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=200044BE.txt. Accessed 2016 December 1.
11. Benefits of trees in urban areas [Internet]. Broomfield, CO: Colorado Tree Coalition; 2010; Available from: http://www.coloradotrees.org/benefits.htm
12. Bartens J, Day S, Harris J, Dove J, Wynn T. Can urban tree roots improve infiltration through compacted subsoils for stormwater management? J Environ Qual 2008. 37: 2048-2057.
13. Lancaster B. Rainwater Harvesting for Drylands and Beyond Vol. 1, 2nd Edition. Tucson, AZ: Rainsource Press; 2014. 281p. (Water harvesting calculations can be found at: http://www.harvestingrainwater.com/rainwater-harvesting-inforesources/water-harvesting-calculations/)
14. Environmental Protection Agency, Office of Water (US) [EPA]. (2009, December). Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act. Washington, DC: EPA; 2009 Dec. 61 p. https://www.epa.gov/greeningepa/technical-guidance-implementing-stormwater-runoff-requirements-federal-projects. Accessed 2016 December 1.
15. Lancaster, op. cit. pp. 136-141. Also available at: http://www.harvestingrainwater.com/wp-content/uploads/Appendix4PlantLists.pdf
16. Wittwer, Gary. (City of Tucson Department of Transportation, Landscape Architect). Conversation with: Kieran Sikdar. 2016 May.
17. Cromell C, Miller J, Bradley LK. 2003. Earth–Friendly Desert Gardening. Phoenix, AZ: Arizona Master Gardener Press; 2003. 136p. (p. 71).
18. Pima County and City of Tucson's Low Impact Development and Green Infrastructure Guidance Manual, March 2015.
19. Erosion Control Field Guide, pages 6-7, Sponholtz and Anderson, Quivira Coalition.
20. Bikesafe Bicycle Countermeasure Selection System [Internet]. Washington, DC: Department of Transportation, Federal Highway Administration (US). Available from: http://www.pedbikesafe.org/bikesafe/
21. Phillips AE, editor. City of Tucson Water Harvesting Guidance Manual. Tucson, AZ: City of Tucson; 2005. 35p.
22. Low Impact Development Toolkit. City of Mesa. April 2015.

10. Glossary

Note: These definitions were developed for the purposes of this manual, and are not necessarily intended to be generalized for other uses.

apron: a reinforced area at the inlet to a bioretention feature to prevent erosion from stormwater; usually made of set-in rock

basin: an earthen depression designed to collect and infiltrate stormwater

bioretention: the use of vegetation and soils to clean stormwater runoff

green infrastructure: constructed features that use natural processes to provide environmental services such as capturing, cleaning, and infiltrating stormwater; creating wildlife habitat; shading and cooling streets and buildings; and calming traffic

hardscape/impervious area: surface that does not allow water to infiltrate into the ground (e.g. asphalt, concrete)

infiltration/percolation: absorption of water into the soil

native plants: a plant that is indigenous or naturalized to a region over a given period of time

non-point source pollution: pollution often carried by/in stormwater that comes from dispersed sources—auto oil, pet waste, herbicides, and sediment

rights-of-way (ROW): the area along a street between the curb and property lines

runoff/stormwater: rainfall that has hit the ground and begun to run off

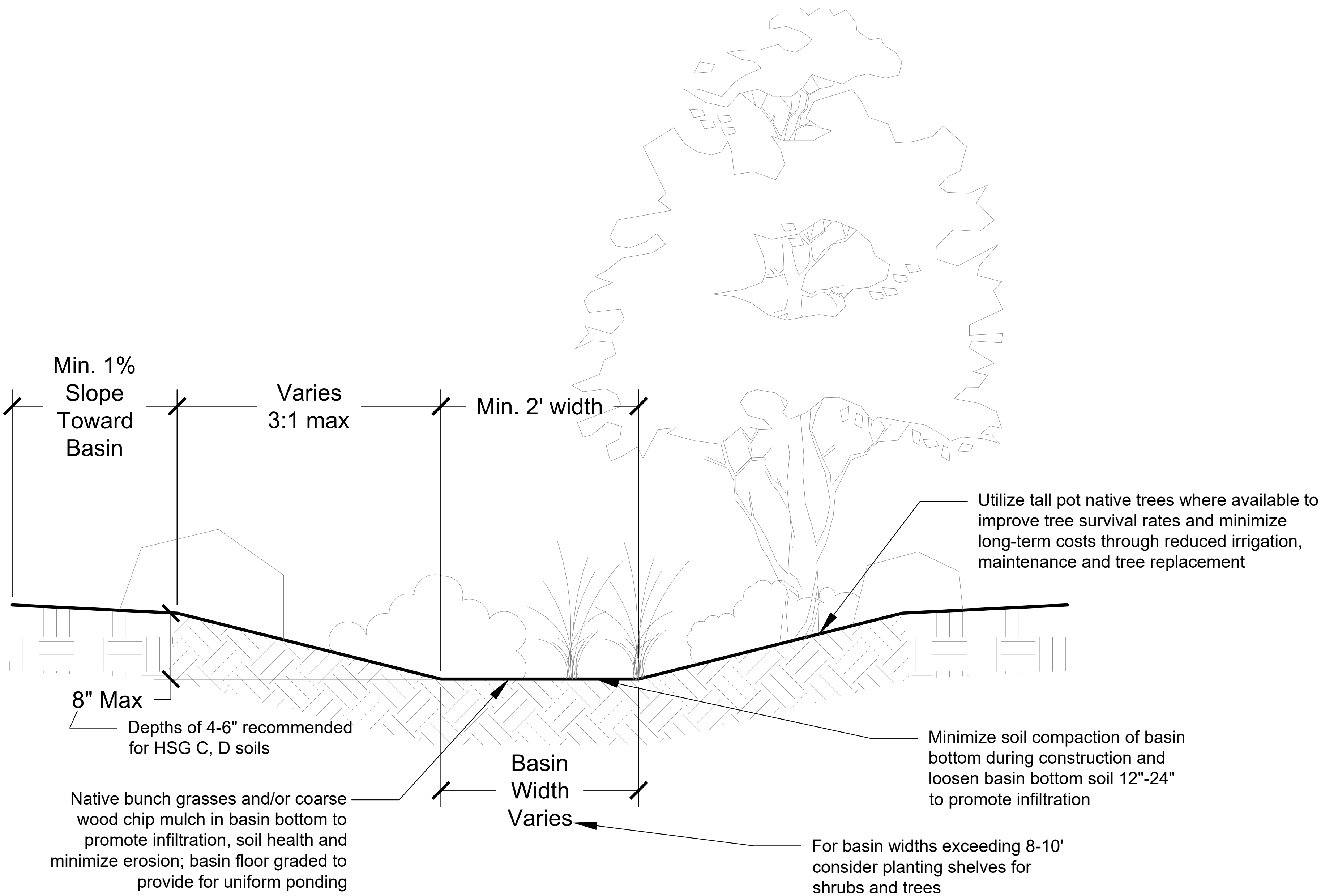
swale: an elongated, shallow depression designed to infiltrate and transport stormwater

urban heat island effect: the phenomenon of urban areas being warmer than surrounding rural/undeveloped areas due to the higher proportion of heat-trapping surfaces

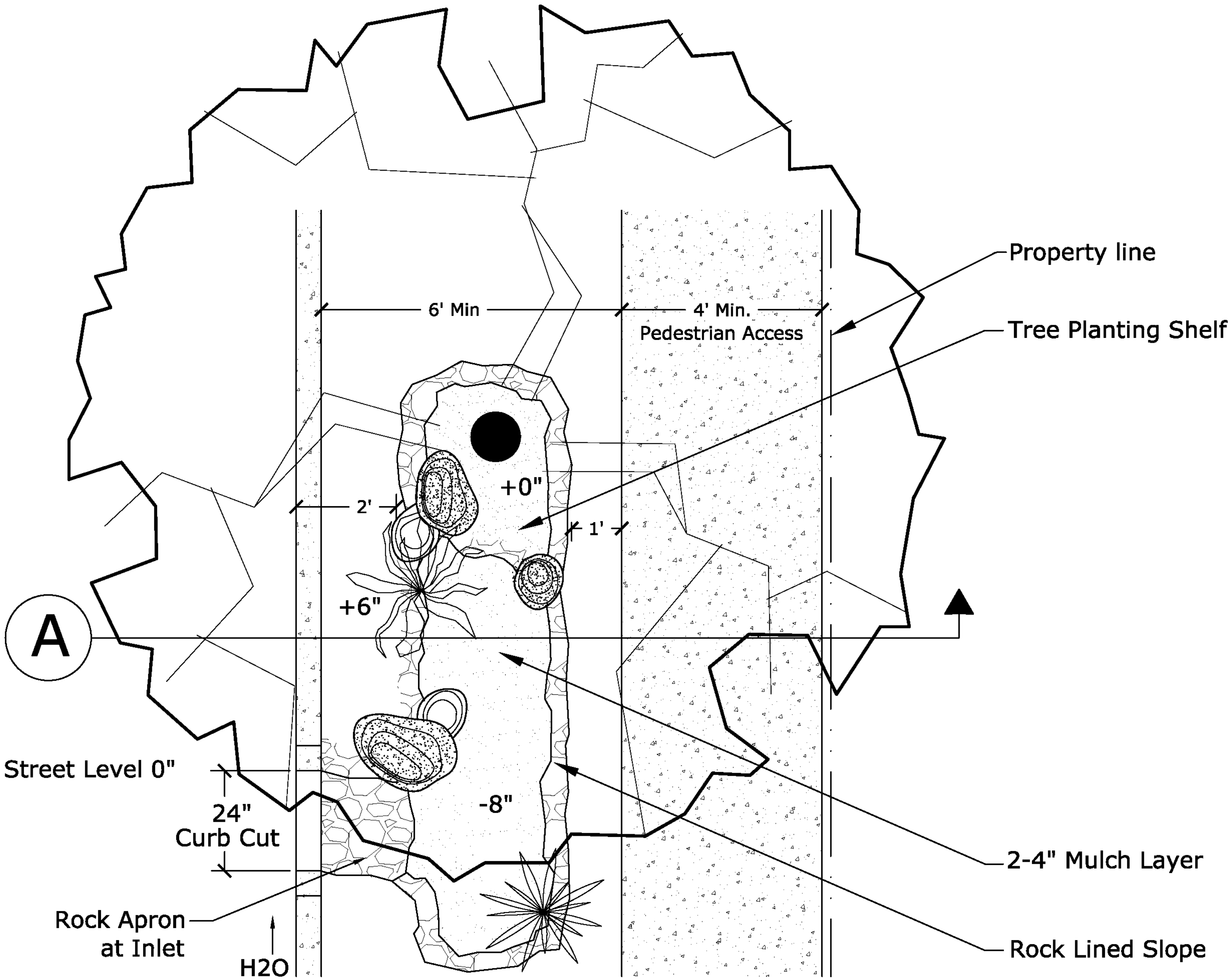
traffic calming: the practice of slowing traffic through residential areas using roadway constrictions, vegetation, or other features

11. Appendix

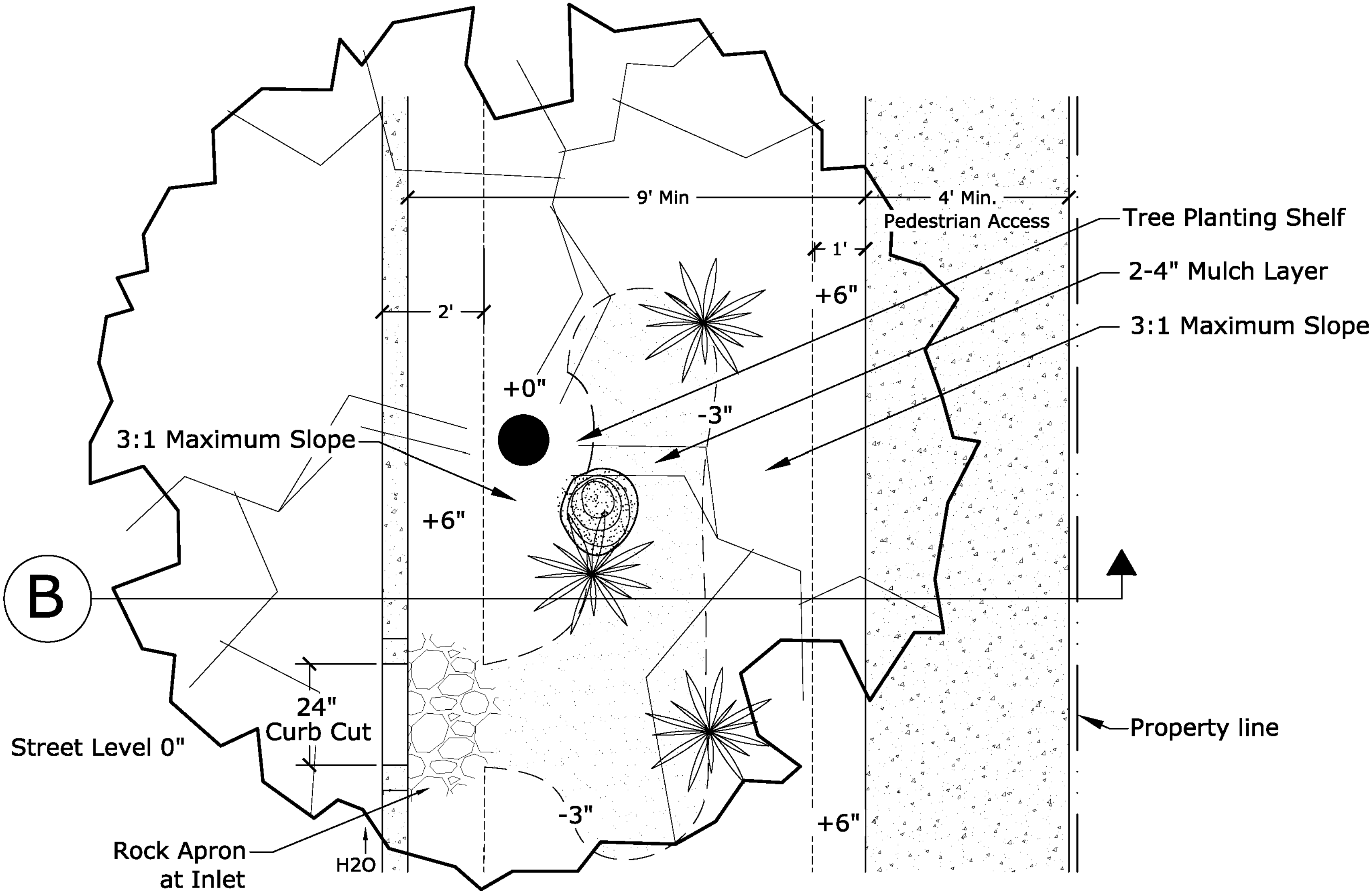
11. Appendix: rainwater harvesting basin/swale



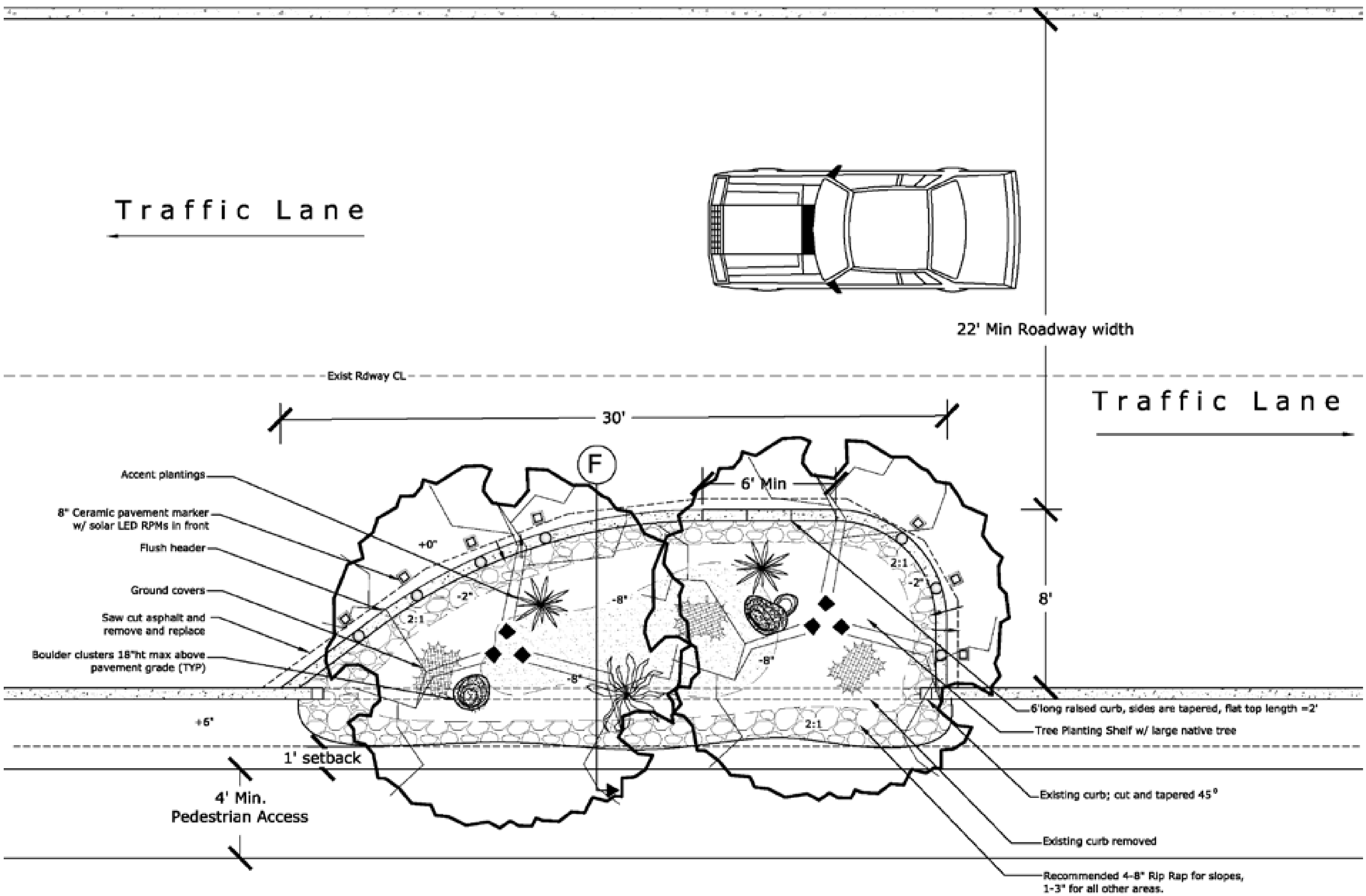
11. Appendix: curb cut & basin, rock-lined, plan view



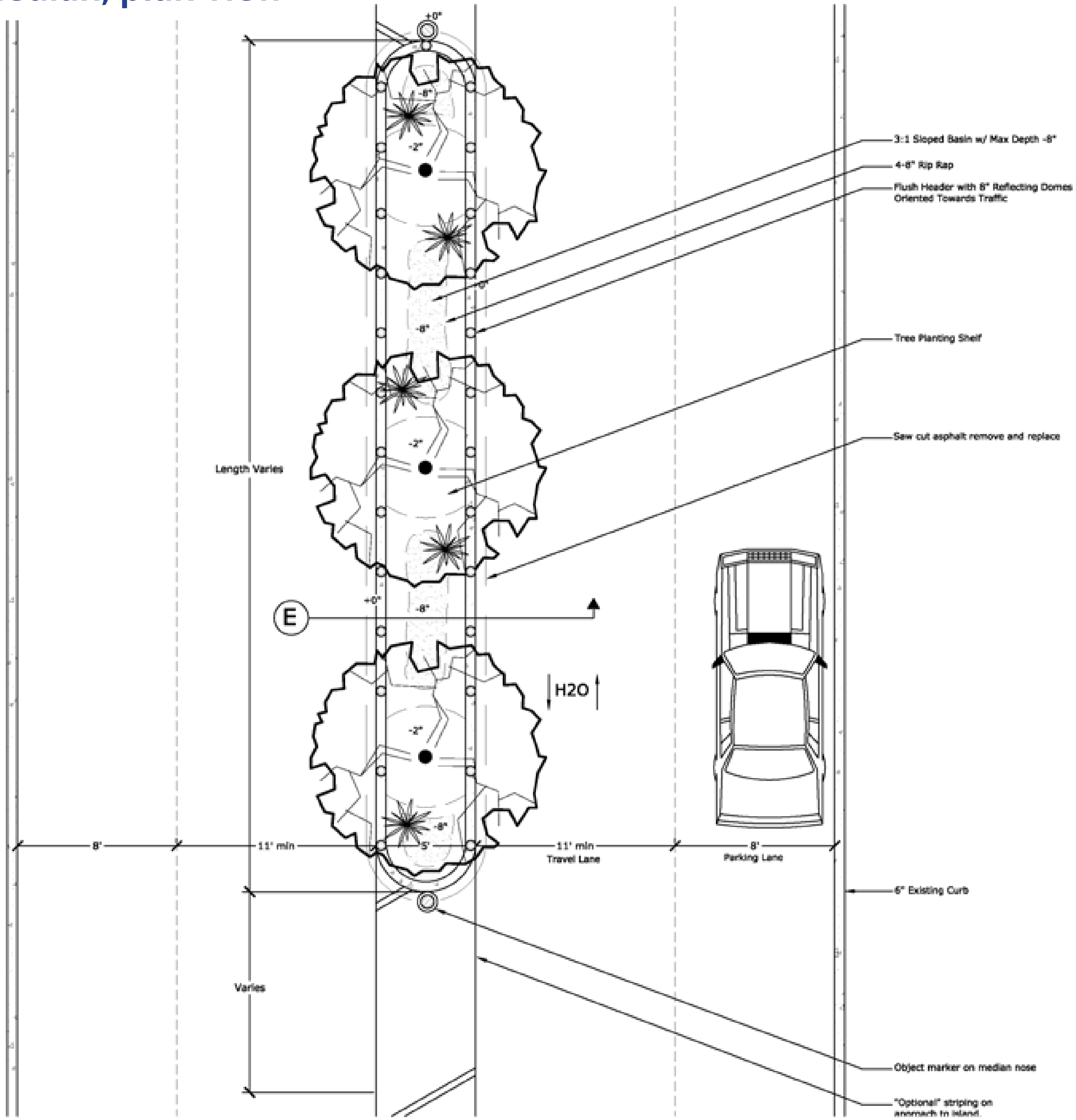
11. Appendix: curb cut & basin, shallow slope, plan view



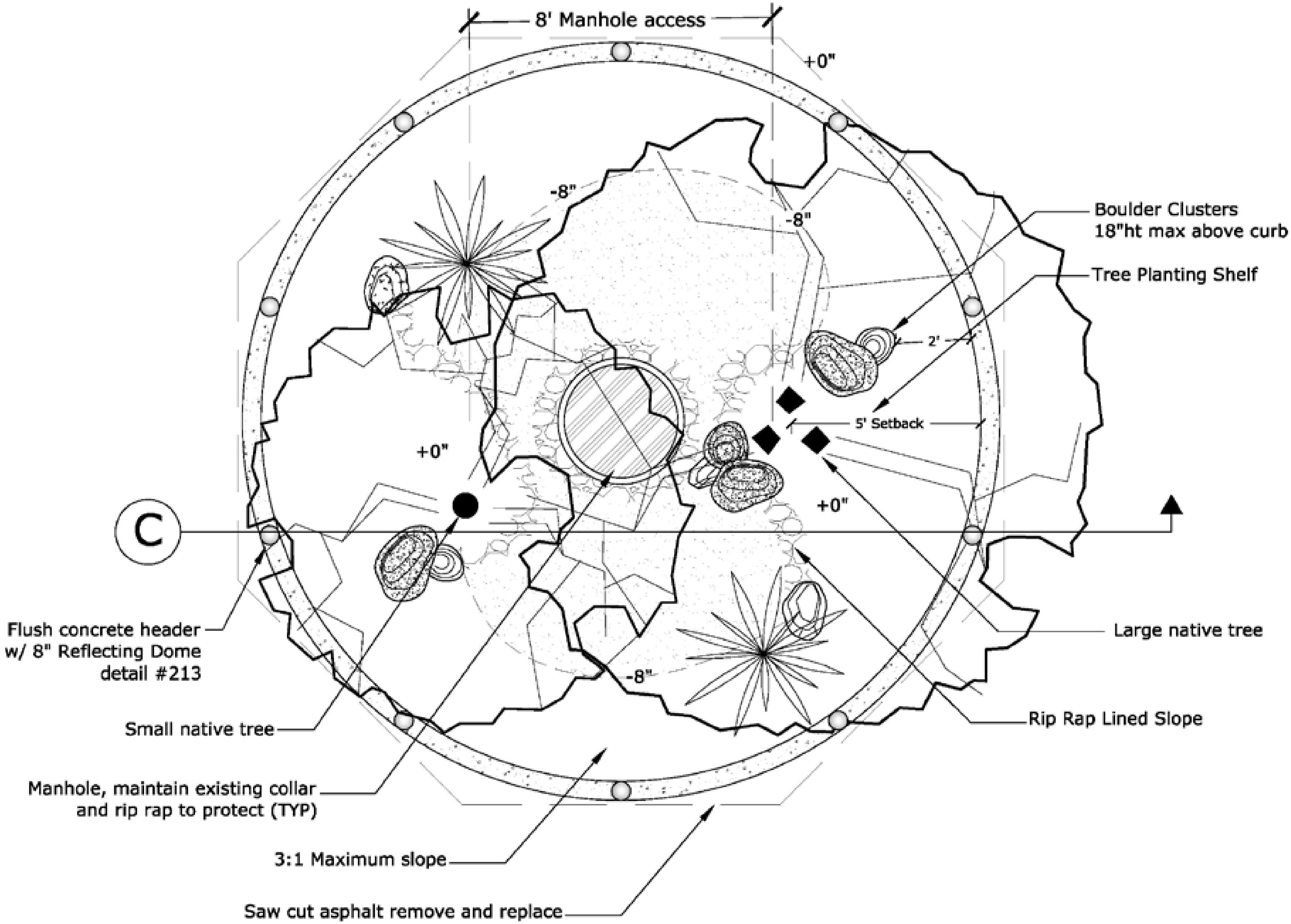
11. Appendix: chicane, plan view



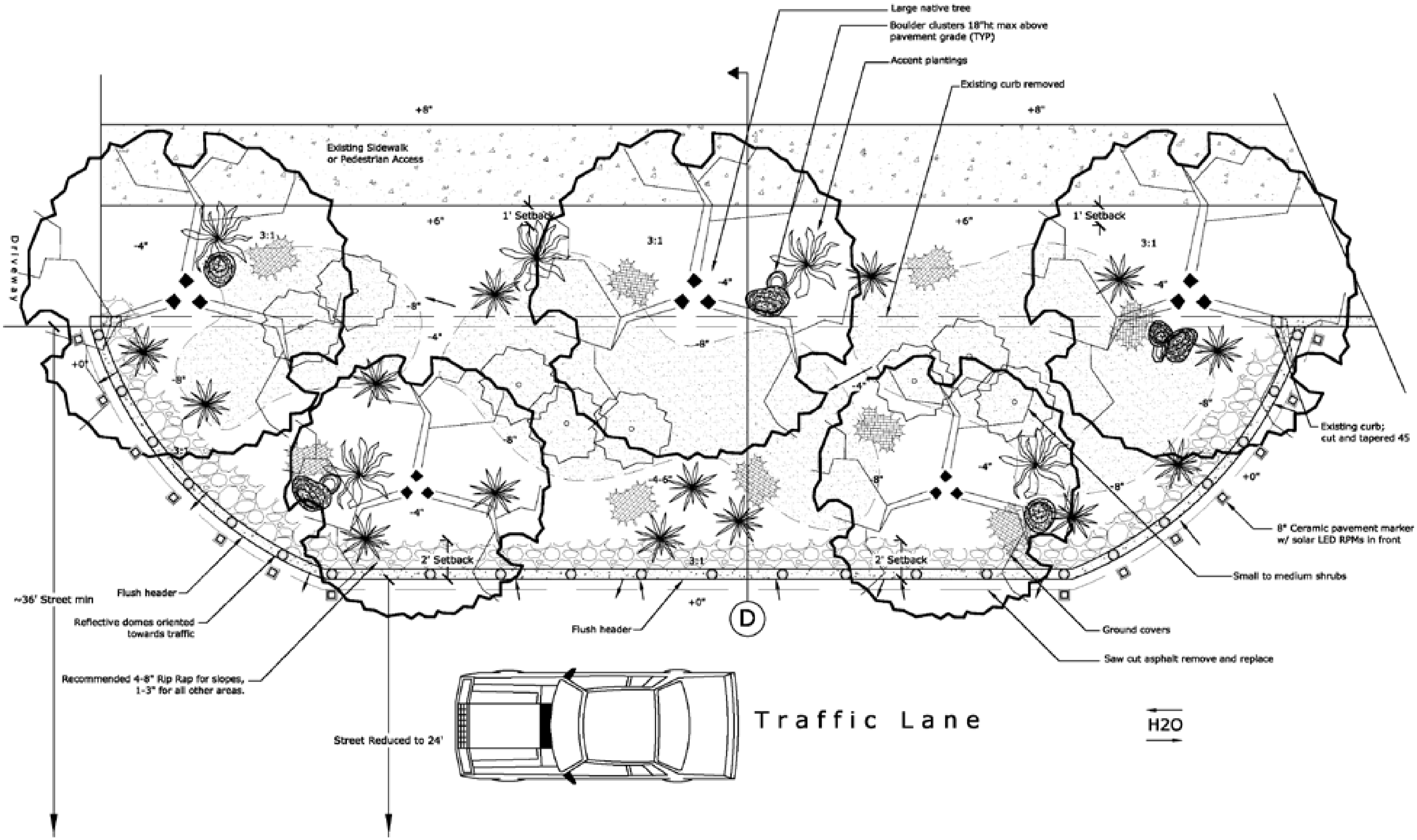
11. Appendix: median, plan view



11. Appendix: traffic circle, plan view



11. Appendix: street width reduction, plan view



12. About Watershed Management Group

Watershed Management Group (WMG) is a 501(c)3 non-profit organization whose mission is to develop and implement community-based solutions to ensure the long-term prosperity of people and health of the environment. We provide people with the knowledge, skills, and resources for sustainable livelihoods. WMG's programs include:

Green Living Co-op

WMG's popular Co-op helps people transform their yards with rainwater and greywater harvesting, native and edible gardens, soil building, and passive solar. Projects are installed through fun, barn-raising workshops led by experienced WMG project managers.

Green Infrastructure and Watershed Planning

We provide consulting, design, demonstration site, and capacity building services to both public and private partners in the Southwestern U.S. and Mexico.

Living Lab and Learning Center

The Living Lab and Learning Center is a community educational hub for regenerative desert living in the heart of Tucson. Visitors of all ages are invited to explore sustainability practices in action through our interactive exhibits, classes, and events. The center features water harvesting, native habitat, food forests, composting toilets, passive solar, monitoring systems, and is a campus entirely supported by rainwater.

Schoolyard Water Education

WMG provides customized programs for K-12 Students, focusing on water conservation and wildlife habitat through water harvesting and native gardening activities on school campuses.

Advocacy and Public Policy

WMG staff provide leadership on advisory boards, coalitions, and stakeholder groups to develop policy that restores our rivers and promotes green infrastructure in our cities. WMG is a founding member and fiscal sponsor of the Community Water Coalition, a group that provides leadership and guidance toward water policy that sustains healthy ecosystems and quality of life in Southern Arizona.

50 Year Program: Restoring Tucson's Free Flowing Rivers

WMG is leading a long-term initiative to restore Tucson's heritage of year-round, flowing rivers through community education, on-the-ground restoration, and policy actions. The first campaign in this program is to restore regular flow to Sabino and Tanque Verde Creeks.

Consultation and Design Services:

WMG staff provide clients with expert advice on water conservation and water harvesting, edible landscapes, landscape restoration, and green infrastructure features. Staff create conceptual landscape plans for clients including a written report with recommendations of active and passive water harvesting features and a water budget summary with rain and greywater supply and plant water use calculations.

Green Workforce Development:

WMG conducts job training for a variety of professionals and youth in water harvesting, green infrastructure, stream restoration, eco-sanitation, and more.

International Programs:

WMG works with partners in Mexico to offer training and create demonstration projects in watershed restoration, green infrastructure, and eco-sanitation.

For more information visit: www.watershedmg.org

Watershed Management Group

1137 N Dodge Blvd
Tucson, AZ 85716
520-396-3266
www.watershedmg.org

Watershed
Management
Group

1137 N Dodge Blvd. • Tucson, AZ 85716 • 520-396-3266 • www.watershedmg.org