Low Impact Development and Green Infrastructure Guidance Manual

March 2015

PIMA COUNTY

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Contents

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Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ac	acre
ADA	Americans with Disabilities Act
ADEQ	Arizona Department of Environmental Quality
ADOT	Arizona Department of Transportation
ASTM	American Society for Testing and Materials
AZPDES	Arizona Pollutant Discharge Elimination System
BMP	best management practice
BOD	biochemical oxygen demand
CFR	Code of Federal Regulations
cu. yd.	cubic yard
cfs	cubic feet per second
CO_2	carbon dioxide
COD	chemical oxygen demand
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
ft	foot/feet
g	gram
GI	green infrastructure
HDPE	high-density polyethylene
HIE	heat island effect
hr	hour
K_2O	potassium oxide
K_{sat}	saturated hydraulic conductivity
LID	low impact development
meq	milliequivalents
Mg	magnesium
mm	millimeter
MS4	municipal separate storm sewer system
MSDS	material safety data sheets
NCSU-BAE	North Carolina State University Department of Biological and Agricultural Engineering
NPS	nonpoint source
P_2O_5	phosphate
PICP	permeable interlocking concrete pavers
ppm	parts per million
PVC	perforated polyvinyl chloride
ROW	right-of-way
s	second
SCS	Soil Conservation Service
sq. yd.	square yard
Tc	time of concentration
yr	year

Glossary

Alternative site design: A construction and engineering practice that uses natural features of the landscape as well as engineered solutions (e.g., infiltration, and water storage) to treat, manage, and control stormwater on-site.

Basin: An earthen depression designed to collect and infiltrate stormwater.

Berm: Raised structure (generally earthen or concrete) constructed to manage stormwater runoff and control erosion.

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

Bioretention: Also known as a Rain Garden, Bio-Filter, or BMP. A low impact development (LID) practice consisting of vegetated depressions engineered to collect, store, and infiltrate runoff.

Buffer: An area that separates land from water courses or open water bodies and is designed to filter and capture pollutants from stormwater. May be vegetated.

Bufferyard/buffering: Planted walls or vegetation that screen development from adjacent neighbors or roadways in an attempt to block the view of land uses that may be considered unsightly.

Catchment: The area designated to collect stormwater runoff.

Check dam: A small dam constructed to in a channel interrupt the flow of stormwater, especially for controlling soil erosion.

Chicane: A traffic calming measure that is comprised of curb extensions or road narrowing structures.

Conservation: The practice of preserving, repairing, and protecting something; often in the context of natural landscape.

Covenants, conditions, and restrictions: A collection of rules and limitations that govern the use of property. These rules are often placed on builders, homeowners, or developers.

Curb cut: A break in the curb to allow for the passage of stormwater flow from impervious surfaces (e.g., streets) to pervious surfaces (e.g., rain garden).

Detention: The temporary storage of stormwater to control discharge rates, allow for infiltration, and improve water quality.

Distributory and shallow sheet flow: Overland flow of unconfined stormwater runoff over a broad area.

Easement/deed restriction: A legally binding restriction that governs the way in which a property can be used or built upon.

Evaporation: Vaporization of liquid in the presence of heat. In the case of surface waters, evaporation leads to the transfer of the water vapor into the air.

Evapotranspiration: The loss of water from the soil both by evaporation and by transpiration from the plants growing in the soil.

First flush: The initial stormwater runoff captured at the beginning of a rainstorm. The first flush generally contains a higher pollutant load compared to the same water volume captured at later periods of the same storm.

Flow splitter: A flow diversion structure installed to divide the flow of stormwater into two directions to capture it in stormwater control structures or sewer systems. May be installed to restrict stormwater flows in situations where a device has reached design stormwater capacity.

Flow spreader: A device installed to evenly spread flow through the width of an inlet or treatment practice.

Freeboard: The required additional height or ponding depth above base flood elevation.

Green infrastructure (GI): An adaptable term used to describe an array of products, technologies, and practices that use natural systems—or engineered systems that mimic natural processes—to enhance overall environmental quality and provide utility services including capturing, cleaning, and infiltrating stormwater; creating wildlife habitat; shading and cooling streets and buildings; and calming traffic. As a general principle, GI techniques use soils and vegetation to infiltrate, evapotranspirate, and/or recycle stormwater runoff.

Heat island effect (HIE): This phenomenon describes urban and suburban temperatures that are 2 to 10 °F (1 to 6 °C) warmer than nearby rural areas due to absorption and retention of heat by buildings and paved surfaces in the built environment. The HIE can increase energy demands, air conditioning costs, air pollution and greenhouse gas emissions, and heat-related illness and mortality. For more information, visit the U.S. Environmental Protection Agency's (EA's) Heat Island website (http://www.epa.gov/heatisland/).

Hot spots: Areas prone or susceptible to certain activities or outcomes.

Hydraulic restriction layers: A barrier (generally geomembranes, concrete, and clay) installed to restrict movement of water.

Hydrograph: A graphical, visual representation of flow rate over time.

Infiltration: A natural process through which water on the ground surface enters the soil.

Integrated pest management: A long-term control plan for pests and pest damage that focuses on reduced use of pesticides while preserving beneficial organisms.

Interception: The portion of rainfall that lands on plants and is absorbed or dissipates.

Level spreader: An outlet designed to convert concentrated runoff to sheet flow and disperse it uniformly across a slope in order to prevent erosion.

Low impact development (LID): LID is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features and minimizing effective imperviousness to create functional and appealing site drainage that treats stormwater as a resource rather than a waste product.

MS4: Municipal separate storm sewer systems, a publicly-owned conveyance or system of conveyances for stormwater.

National Pollutant Discharge Elimination System (NPDES): A regulatory program in the Federal Clean Water Act that prohibits the discharge of pollutants into surface waters of the United States without a permit. The federally delegated program in Arizona is called Arizona Pollutant Discharge Elimination System (AZPDES).

Nonpoint source: Pollution from sources that cannot be traced to a localized and stationary source (e.g., land runoff, precipitation, drainage).

Off-line practice: An LID practice where a specific design flow or volume is accepted or diverted into the constructed practice. Flows or volumes in excess of the design capacity bypass the practice.

On-line practice: An LID practice where runoff is accepted and routed through the practice. Flows or volumes in excess of the design capacity overflow to the storm drainage system.

Open space: Any open piece of land that is undeveloped (has no buildings or other built structures) and is accessible to the public.

Preservation fencing: A barrier fence established on a construction site to preserve and protect vegetation from construction equipment.

Pretreatment device: A structure incorporated into a stormwater conveyance system to remove sediment, oil, grease, and other pollutants before they enter a structural GI practice or are discharged to receiving waters.

Rain garden: See bioretention. Synonymous with bioretention, this term is typically used for general audience discussions.

RainScapes: Landscapes that, once established, rely entirely on rainwater (and greywater if available) for irrigation, while preserving tap water for indoor and drinking water needs.

Retention: An LID practice engineered to collect and store runoff.

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

Riparian/riparian area: A vegetated ecosystem along a water body through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent water body. Vegetation growing in riparian areas is called riparian vegetation.

Road diet: A reduction in traffic capacity as a result of street width reduction, intended to calm traffic.

Saturated hydraulic conductivity: Measurement of the ability of a saturated soil to transmit water through its pores.

Scupper: A structure installed along the curb of a street that is designed to carry water short distances to structural GI practices.

Secondary containment (structure): A structure used to prevent accidental releases or spills of toxic or hazardous substances to the environment. It can be an engineered means to redirect a spill away from water to a temporary diversion system.

Sediment trap: a pretreatment area at the inlet to a structural GI practice used to capture sediment, oil, grease, and other pollutants through settling.

Site fingerprinting: Development approach that places development away from environmentally sensitive areas (wetlands, steep slopes, etc.), future open spaces, areas where trees will be preserved, future restoration areas, and temporary and permanent vegetative forest buffer zones. Ground disturbance is confined to areas where structures, roads, and ROWs will exist after construction is complete.

Soil amendment: Additions to native soils to improve plant growth and water infiltration and storage.

Swale: An open drainage channel designed to detain or infiltrate stormwater runoff.

Traffic calming: The practice of slowing traffic through the use of roadway construction, vegetation, or other features.

Transpiration: A natural process in which moisture is released from plants and transferred into the atmosphere as water vapor.

Treatment train: A series of structural GI practices used in conjunction with one another to manage and treat stormwater.

Underdrain: A perforated pipe, typically 4-6 inches in diameter placed longitudinally at the invert of a bioretention facility for the purposes of achieving a desired discharge rate.

Wildlife corridor: An area of habitat that connects wildlife populations that would otherwise be separated by human-induced changes in the landscape.

Preface

This manual is intended to be technical guidance for professionals on the use of neighborhood-scale low impact development (LID) practices within Pima County, the City of Tucson, and similar areas in the desert Southwest. The sections of this manual are summarized as follows:

Introduction: The introduction explains the purpose, goals, and scope of this manual, as well as the local context and background behind the development of this manual.

GI/LID Principles: The basic concepts of LID and green infrastructure (GI) are discussed, including why using GI/LID practices is important, and how rainwater harvesting, structural practices, and LID planning practices are related to LID and GI.

Site Assessment, Planning, and Design Process: This section provides guidance on how a site should be evaluated when designing a new development, including preserving natural flow paths, identifying where to locate structural practices in the watershed based on the vegetation's water budget, and determining the design stormwater runoff volume for structural practices.

GI/LID Practices: Three sections provide detailed information and drawings for LID planning practices and structural LID practices.

- **GI/LID Planning Practices:** This section provides an overview of the different types of LID planning, or behavioral, LID practices (a.k.a., non-structural practices) that can be incorporated into a development. Emphasis is placed on the importance of the early planning stages in site design, which includes identifying natural sensitive areas and evaluating suitable locations for disturbance. The end result of this planning is an alternative site design that maintains the pre-development hydrologic conditions of a site.
- **Structural GI Practices**: This section provides guidance on the GI practices that can replace traditional stormwater infrastructure while achieving storage, infiltration, and conveyance that mimics pre-development hydrology. Maintenance is integral to the long-term function of GI practices.
- **Common LID Components**: This section describes common drainage design features and how to incorporate them into GI practices.

Appendices: The appendices contain a series of design tools for engineers and designers to appropriately size and design GI/LID practices, including the following:

- Appendix A: Analysis of Rainfall Data Collected at the University of Arizona
- Appendix B: Sizing Features to Support Vegetative Canopy
- Appendix C: Design Volume to Size GI/LID Features for Flood Control Benefits
- Appendix D: Derivation of 5 cubic feet per second/acre
- Appendix E: Simulating Offset of Water Demand from Varying Cistern Volumes
- Appendix F: AutoCASE^{TM} Beta Testing Project
- Appendix G: Plant List
- Appendix H: Drawings

Acknowledgements

This guidance manual is the product of a collaborative effort between numerous local, regional, and federal governmental organizations and interest groups. It was developed over four years and went through numerous revisions. The need for a guidance manual designed for professionals on the use of neighborhood-scale low impact development practices within Pima County, the City of Tucson, and similar areas in the desert Southwest was identified in 2011 by the Low Impact Development Working group. This ad-hoc group, comprised of agency officials from Pima County, the City of Tucson, Pima Association of Governments, as well as local development professionals, collaborated to compile local institutional knowledge of GI/LID practices.

The effort addresses the goal of the City of Tucson Pima County water study to develop a neighborhood scale water harvesting guidance document. The initial draft was prepared in partnership with Stantec Consulting under contract with the Pima County Regional Flood District. The effort to complete the manual was substantially assisted by technical assistance to Pima County from the U.S. Environmental Protection Agency (EPA). The EPA, and their consultants, Tetra Tech, were instrumental in providing their nationwide perspective and expertise on GI/LID practices and facilitated the completion of the manual. We appreciate Tamara Mittman, the EPA project manager for this technical assistance, who provided oversight in collaboration with Christopher Kloss and Jamie Piziali.

Thanks are extended to all of the many individuals who provided their talents and expertise including:

City of Tucson
Beverly Hester
Irene Ogata
Gary Wittwer

Pima Association of Governments
Mead Meir
Josh Pope
Claire Zucker

Pima County Department of Environmental Quality
Marie Light

Pima County Regional Flood Control District
Sandra Bolduc (illustrations)
Evan Canfield
Patricia Gilbert
Steve Kaplan
Akitsu Kimoto
Ann Moynihan
Lynn Orchard
Eric Shepp
Dave Stewart

Stantec
Jenny Laber
John Take
John Wise

Tetra Tech
Martina Frey
Brad Wardynski
Jason Wright

Watershed Management Group
Catlow Shipek
Kieran Sikdar

Many other individuals, not mentioned above, including members of the LID Working Group, provided insights, photos, contributions, and inspiration for this manual.

1 Introduction

1.1 Purpose

The purpose of this manual is to provide non-regulatory technical guidance for implementing neighborhood-scale water harvesting, green infrastructure (GI), and low impact development (LID) practices throughout Pima County. This manual provides supplemental guidance to the Pima County *Design Standards for Stormwater Detention and Retention* and the City of Tucson *Water Harvesting Guidance Manual*. The intended audience includes the professional community who retrofit existing developments and neighborhoods or design and build new developments and neighborhoods. In particular, the manual is intended to provide the following technical guidance:

1. Selecting appropriate GI/LID practices.
2. Implementing multi-purpose GI/LID features during site layout.
3. Implementing decentralized stormwater harvesting practices at the neighborhood scale.
4. Implementing treatment train approaches (i.e., a series of GI/LID practices) to rainwater and stormwater management.
5. Designing and constructing GI/LID practices.
6. Inspecting and maintaining procedures to ensure the GI/LID practices continue to function as designed and provide the expected benefits.

1.2 Background

As part of Phase II of the City/County Water and Wastewater Study (http://www.tucsonpimawaterstudy.com/), an evaluation of the best approach for using rainwater and stormwater as a supplemental water source concluded that capture and use of such water at the lot and neighborhood scale results in the best opportunities. The benefits of capture and use at this scale are enhanced because the percent of rainfall that can be harvested as stormwater decreases as watershed size increases as illustrated by (Figure 1). This manual was developed in part to provide local guidance on how to implement decentralized stormwater harvesting at the neighborhood scale. In 2012 the Regional Council passed the GI/LID Resolution, supporting the development of guidelines, incentives, and regional coordination to encourage this approach.

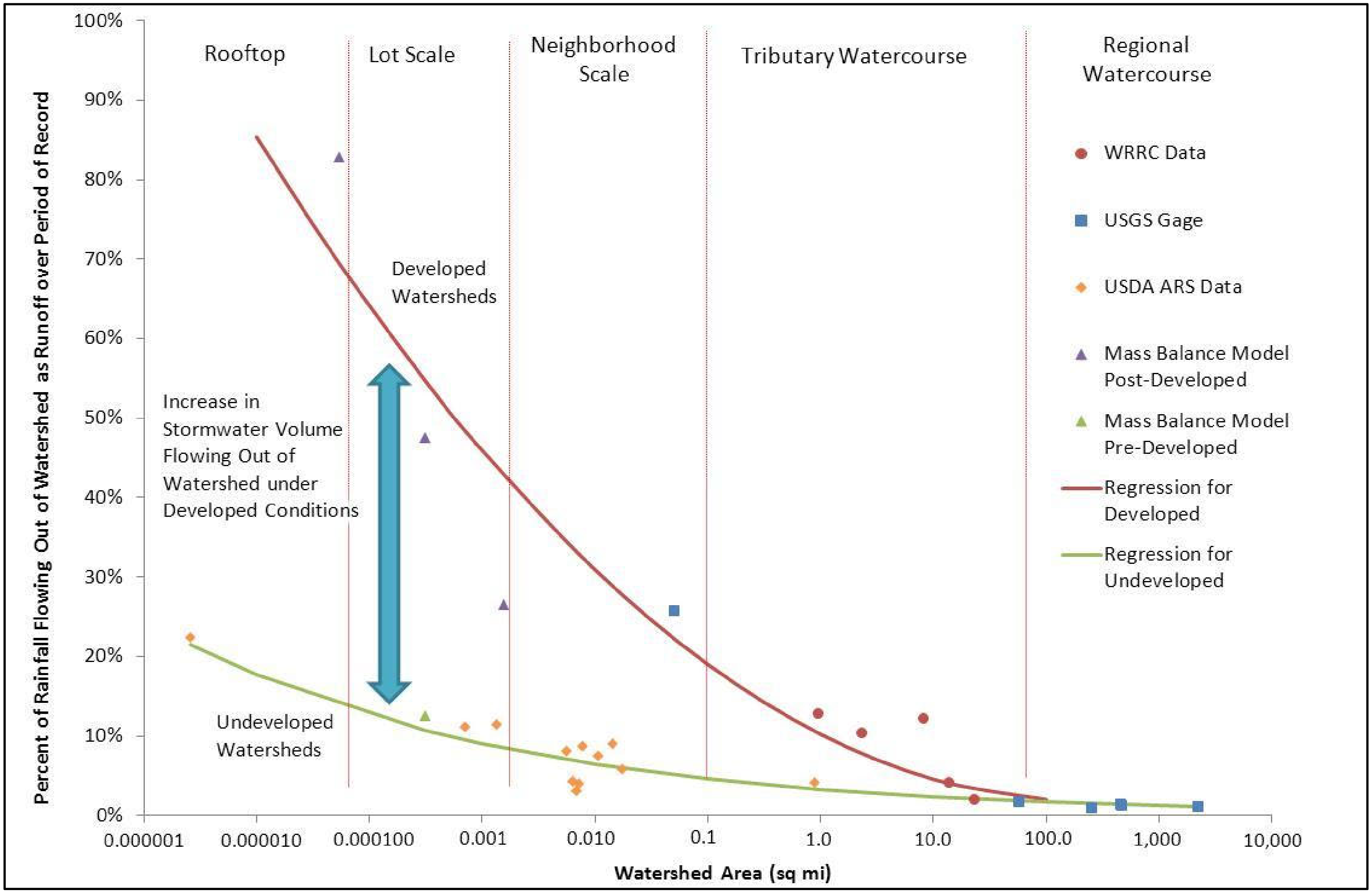


Figure 1. The percent of rainfall flowing out of watersheds as runoff over the period of record for varying scales and development conditions.

While the initial impetus for this manual came from the potable water demand reduction aspects of the City/County Water and Wastewater study, it fills a vital need in stormwater management as well (City of Tucson and Pima County 2009). In 2011, Arizona Department of Environmental Quality (ADEQ) issued individual Arizona Pollutant Discharge Elimination System (AZPDES) Municipal Separate Storm Sewer System (MS4) permits to Pima County and the City of Tucson that required them to evaluate how incorporating LID practices into their respective planning and development processes can reduce pollutants in stormwater discharges. For the purposes of this manual, LID is defined as planning methods and practices designed to reduce runoff and pollutants from the site at which they are generated using principles such as preserving and recreating natural landscape and infiltration. GI refers to structural stormwater controls that use soils and vegetation to filter, infiltrate, transpire, store, and/or recycle stormwater runoff, and can therefore reduce the use of potable water for growing trees and other vegetation. Because GI and LID are typically implemented together, the terms are often used synonymously or collectively referred to as GI/LID.

The objective of LID is to provide development techniques that allow the post-development hydrologic regime to mimic pre-development hydrology. GI/LID techniques are used to manage water and water pollutants at or near the source and thereby to prevent or reduce the impact of the development on washes, rivers, and groundwater. LID concepts can be applied to new development, redevelopment, and retrofits to existing development. Many stormwater harvesting practices are LID practices. Basic infrastructure design features of LID include reducing the use or size of pipes, curbs, gutters, and sidewalks; maintaining infiltration areas, buffer zones, and drainage courses; using infiltration swales, grading strategies, and open drainage systems; reducing impervious surfaces; and disconnecting the impervious areas that remain.

In addition to the potable water and stormwater quality benefits, GI/LID has other public health and safety benefits that are important for desert communities. By limiting the volume of excess stormwater generated, GI/LID practices are used to reduce the potential for flooding. Trees grown in water harvesting basins adjacent to pavement can improve livability by shading pavements, as well as providing evaporative cooling effects through transpiration. Therefore, selective use of GI/LID has the potential to mitigate the heat island effect (HIE). Mitigating this effect is an important benefit in Arizona where heat related illness and deaths to residents is among the highest in the nation (Centers for Disease Control and Prevention 2013). In addition to mitigating high temperatures, trees and other vegetation increase and improve habitat for wildlife, can provide sound attenuation along major streets, and have a calming effect (reduced driving speeds) on residential streets. All of these conditions enhance overall quality of life.

1.3 Scope

The scope of the document includes the following:

1. Description of GI/LID practices that can be used effectively throughout Pima County and local municipalities.
2. Specific guidance on how to use LID planning practices during site design.
3. Design guidelines for locating and sizing structural GI practices.
4. Standard plan and/or cross-section views of GI practices.
5. Standard details for GI practices.
6. Design references.

Practitioners can apply the manual's principles to assess the applicability of GI/LID and gain valuable information on field applications and design standards.

1.3.1 Project Scale

This manual is intended to cover GI/LID practices that are appropriate for neighborhood scale projects, such as the layout of commercial development and residential subdivisions. Certain practices involving site layout and planning are appropriate for new development, but other practices for the capture and use of stormwater from streets, sidewalks, rooftops, or multiple lots are appropriate for retrofits as well. In addition, some of these GI/LID practices, as well as greywater practices, can be applied at the lot scale and are encouraged as long as they comply with local regulations.

1.4 Integration with Other Efforts

The guidance and concepts presented in this manual integrate well with other efforts in Pima County and the City of Tucson, including the following:

1. **The Stormwater Detention/Retention Manual**: The Detention/Retention Manual is a regulatory document that describes which GI/LID practices have been accepted as having a quantifiable flood control benefit within Pima County. These practices can be used to reduce or offset the requirement for on-site detention. Furthermore, the manual establishes standards regarding on-site retention and describes how stormwater harvesting basins must be constructed to meet the onsite retention requirement. http://webcms.pima.gov/cms/one.aspx?portalId=169&pageId=65527
2. **Flood Control Measures:** Throughout Pima County and the City of Tucson, flood control measures must be implemented to mitigate higher runoff volumes associated with increased impervious surfaces that result from development. GI/LID mitigates the impact of development by connecting impervious surfaces to permeable surfaces and distributing stormwater for beneficial uses. The conventional approach of centralizing stormwater and treating it as a hazard, such as in detention and retention structures, misses this important opportunity that benefits the entire community. Furthermore, impervious surfaces also increase the number of runoff-producing events that are a non-life threatening nuisance, as well as peak flows that can cause flooding.

   The initial runoff in a storm event entrains contaminants and other materials. GI/LID practices can capture this first flush of runoff, which not only reduces the number of nuisance flows, but also improves stormwater quality. For this reason, Pima County Regional Flood Control District has required capture of the first ½ inch of rainfall as a means to satisfy the county and city flood retention requirements, which will apply to new development and substantial redevelopment.
3. **A GI/LID Case Study Catalog:** The Pima County Regional Flood Control District is encouraging members of the community to collect data on existing projects that use GI/LID practices. The Regional Flood Control District is compiling the case studies into a ‘catalog’ of projects that can be used to demonstrate the benefits of LID in the community. http://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Flood%20Control/Floodplain%20Management/Low%20Impact%20Development/lid-case-studies-201401.pdf
4. **City of Tucson Water Harvesting Ordinance:** The City of Tucson requires new commercial developments to obtain half of their water for landscaping using water harvesting techniques. In most cases, these are GI/LID practices. http://www.tucsonaz.gov/files/ocsd/CMS1_035088.pdf
5. **Tucson Water’s Water Harvesting Rebate:** Tucson Water periodically offers a rebates for water harvesting systems (currently up to $2,000 for half the cost of a rainwater harvesting system). http://water.tucsonaz.gov/water/rebate

6. **City of Tucson Green Streets Policy:** The City of Tucson has adopted a policy on directing stormwater runoff from roadways through GI prior to the runoff entering storm drains or natural drainage ways.

7. **Water Quality Regulations and Permits:** ADEQ stormwater quality regulations require local MS4s to follow stormwater quality regulations under the AZPDES. These regulations require local jurisdictions and engineers of new construction and redevelopment to ensure final stabilization with construction projects. Additionally, to meet the requirements of Sections 303(d) and 404 of the Clean Water Act, site-specific post-construction best management practices (BMPs) for stormwater quality may be required to address stormwater discharges for construction operators. GI/LID practices are post-construction BMP options to prevent erosion and provide vegetation cover. The designs and approaches in this GI/LID Guidance Manual can be used in concert with the Arizona Department of Transportation (ADOT) *Post Construction Best Management Practices Manual for Water Quality* (http://azdot.gov/docs/default-source/planning/post-construction-best-management-practices-%28bmp%29-manual.pdf?sfvrsn=0). The ADOT Manual was developed to provide options for ADOT's MS4 responsibilities and is referenced by other MS4s throughout the state. The manual provides information on specified ratings, appropriate applications, materials, design standards, design considerations, maintenance, and schematics for the BMPs. The GI/LID-related BMPs from ADOT's manual addressed in this manual include: roadway drainage conveyance to stormwater harvesting basins and stormwater treatment (bioretention, infiltration trenches, retention within stormwater harvesting basins, and vegetated swales).

   Municipalities can implement GI/LID during planning and design phases of land development to reduce pollutants discharged from areas where new development is taking place. Ultimately, to evaluate the effective use of GI/LID for the City of Tucson and Pima County MS4s, the benefit of the new sustainable technology will be measured in post-construction functionality of the new development. Expected positive outcomes include reduced flooding and concentrations of pollutants in stormwater. GI and LID are also measures MS4s can use to break down and sequester nonpoint source (NPS) stormwater pollutants and prevent their accumulation in downstream surface waters to meet stormwater quality standards.

   The connection between GI/LID and stormwater pollution prevention is also provided in the MS4s' required outreach for NPS pollution, including regional outreach programs conducted by Pima Association of Governments public service campaigns.

   The GI/LID manual presented here complements these other efforts. Unlike detention/retention or water harvesting requirements, this manual is non-regulatory, which means it describes what *can* be done rather than what *must* be done. However, it can be used as a supplement to the detention/retention or water harvesting requirements when considering what GI/LID practices are appropriate for a site where new development is proposed. Since what can be done is not necessarily limited to the practices included in this manual, and because this manual provides generic guidance that is not site-specific, the Case Study Catalog mentioned above can be used as a source of ideas or new approaches to design and learn from previous projects. The examples in the catalog include lessons learned that highlight what was successful and what could have been done differently.

1.5 Sources, Citations, and Additional Resources

City of Tucson and Pima County. 2009. *Water and Wastewater Infrastructure, Supply, and Planning Study*. http://www.tucsonpimawaterstudy.com/.

Centers for Disease Control and Prevention. 2013. *CDC Urges Everyone: Get Ready to Stay Cool before Temperatures Soar.* Last updated June 6, 2013. http://www.cdc.gov/media/releases/2013/p0606-extreme-heat.html.

2 GI/LID Principles

2.1 Definition of Terms

LID is a development approach that treats stormwater runoff as a beneficial resource and facilitates its use as close to the source as possible. Aspects of LID include site layouts that achieve multiple functions, including the minimization of disturbance to native vegetation and soils, and the reduction and disconnection of impervious surfaces. LID planning can reduce runoff within the site and therefore may require fewer structural and conventional engineering solutions. GI in the context of this manual generally refers to the structural components and engineering practices that are utilized to accomplish LID objectives. LID and GI practices used together (GI/LID) can be defined as systems and practices that preserve, enhance, or recreate the natural functionality of an area being developed. GI/LID practices can be implemented to improve surface water quality, mitigate flood impacts, reduce the need for irrigation, reduce energy demand by using selective shading strategies, mitigate the HIE, improve air quality, reduce greenhouse gases, improve walkability and bike-ability by shading streets and sidewalks, improve property aesthetics, provide habitat for urban wildlife, improve public health and safety, provide recreational opportunities, educate the public, and result in more livable communities. A *treatment train* is defined as a series of GI/LID practices that are utilized on LID sites to mitigate some of the adverse effects from development.

For the purposes of this manual, *rainwater* is defined as precipitation while it is falling from the sky or falling off a roof top. *Stormwater* is defined as precipitation that has landed on the ground, and will either infiltrate into the ground or flow over the surface as stormwater runoff.

Rainwater and stormwater harvesting are examples of structural GI/LID practices. The term *water harvesting* is used locally to mean stormwater harvesting (i.e., the collection of stormwater to be used near the site of collection). While the use of LID planning practices during site design will minimize the amount of new runoff from impervious surfaces, all development will produce harvestable stormwater. (Figure 2) illustrates the integrated relationship between the above concepts. Key elements of GI/LID are described in (Figure 3).

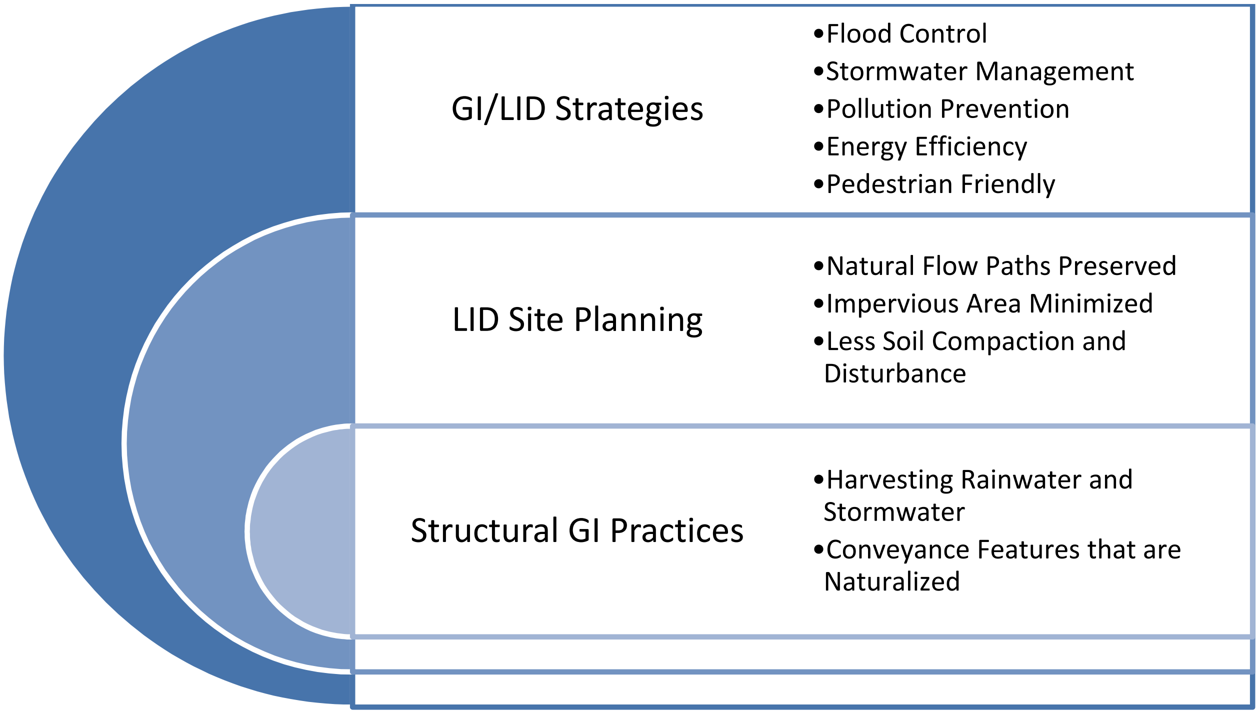
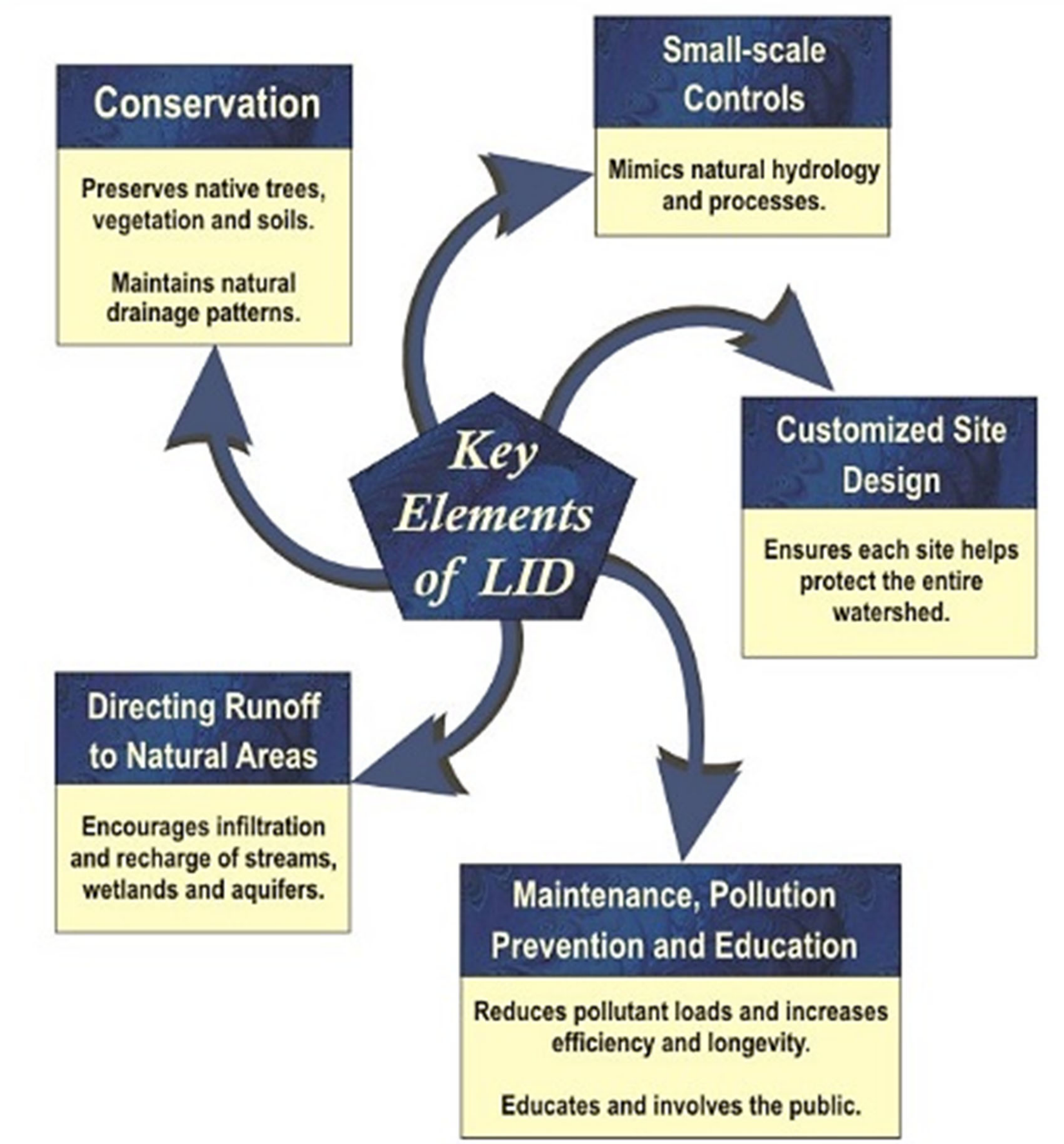


Figure 2. Relationship between GI/LID strategies, LID site planning, and structural GI practices, including key benefits.



Source: Low Impact Development Center 2014

Figure 3. Key elements of LID.

2.2 What are GI and LID?

The following descriptions and illustrations briefly describe LID planning and structural GI practices.

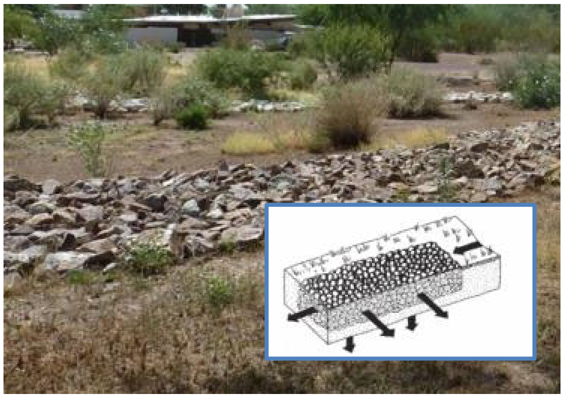
2.2.1 LID Site Planning—Avoidance and Prevention

Feature	Name	Description and Purpose
	Disconnect and Minimize Impervious Areas	Enhances infiltration, reduces runoff volumes, and allows on-site vegetation to utilize infiltrating water.
	Alternative Site Design	Considers site layouts that minimize disturbance and make use of existing resources such as stormwater flow paths and vegetation to maximize infiltration of storm flow. Directs stormwater to the site’s pervious areas, natural areas, natural flow paths, floodplain, and riparian areas. Reduces use of impervious conveyance structures (e.g., storm drains, concrete channels).
	Conserve Natural Areas and Protect Natural Flow Paths	Uses natural drainage features to reduce or eliminate the need for structural drainage systems. Sets aside sensitive areas that otherwise would be negatively impacted. Attenuates impacts of increased stormwater by capturing and infiltrating water. Provides passive recreation opportunities that can increase adjacent property values. Conforms to Sonoran Desert Conservation Plan.

	Restore Disturbed Natural Areas	Provides increased flood attenuation, increased infiltration, and storage of flood waters. Increases evapotranspiration and can help mitigate the HIE
	Minimize Disturbed Areas and Soil Compaction	Reduces overall hydrologic impacts of development.

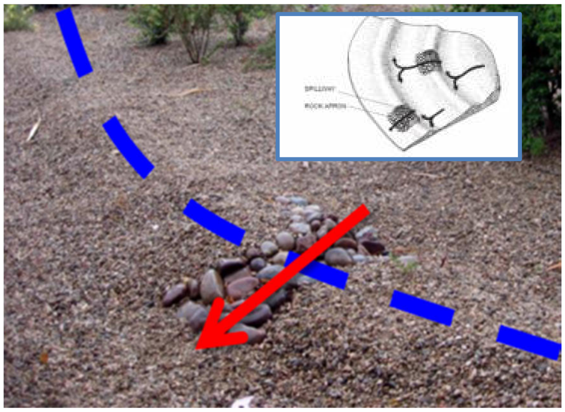
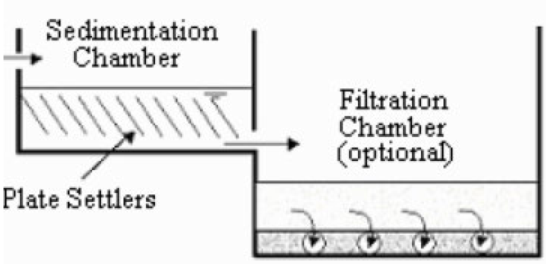
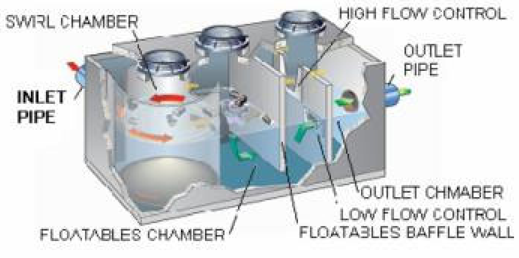
2.2.2 Structural GI/LID Practices—Mitigating Impact and Retrofitting

Feature	Name	Description and Purpose
 	Bioretention Basin	A depressed area with a constructed soil media that captures stormwater and may also contain underdrains to enhance infiltration.
	Stormwater Harvesting Basins	A depressed area that captures and infiltrates stormwater.

	Vegetated or Rock Swales	A depressed conveyance feature for transporting and infiltrating stormwater. Swales may contain check-dams or weirs to slow the flow of water and encourage infiltration.
	Infiltration Trench	An excavated trench that has been backfilled with porous material that captures and infiltrates stormwater.

	Cistern	A rigid device of metal, plastic, or other solid material that captures and stores water from an impervious surface. It can also be configured to supply irrigation to the site by a simple hose bib or a complex automatic pumping and perforated polyvinyl chloride (PVC) piping system.
	Pervious Pavement	Pavements that allow water to infiltrate, thus changing an impervious stormwater source to a stormwater sink.

2.2.3 Common Elements of Structural GI/LID Practices

Feature	Name	Description and Purpose
	Berm with Constructed Spillway	A raised soil berm that ponds and infiltrates stormwater on the upstream side.
	Curb Cuts and Inlet/Outlet Protection	Curb cuts allow stormwater to flow from streets or parking lots into a basin, swale, or other GI/LID practice. Inlet/outlet protection such as a filter strip of variable-sized rock mulch helps settle fine sediment and stabilizes underlying soil. These can be employed as a wide strip from areas of sheetflow, or at an inlet to a basin or other feature.
 	Pretreatment Devices	Often a chambered device that filters stormwater prior to introduction to a cleaner, downstream water source. These devices include sand filters, as well as many proprietary elements.

2.3 Why Use GI/LID?

2.3.1 Converting Stormwater Risk to a Resource

Urbanization creates more impervious surfaces, which increases stormwater runoff. In the semi-arid climate of Pima County, rainwater and stormwater are valuable resources that have many beneficial uses, but they have historically been disposed of as a nuisance and a hazard. The concept of LID encompasses an approach to stormwater management that preserves or mimics the natural drainage of stormwater runoff to mitigate the effects of increased impervious surfaces.

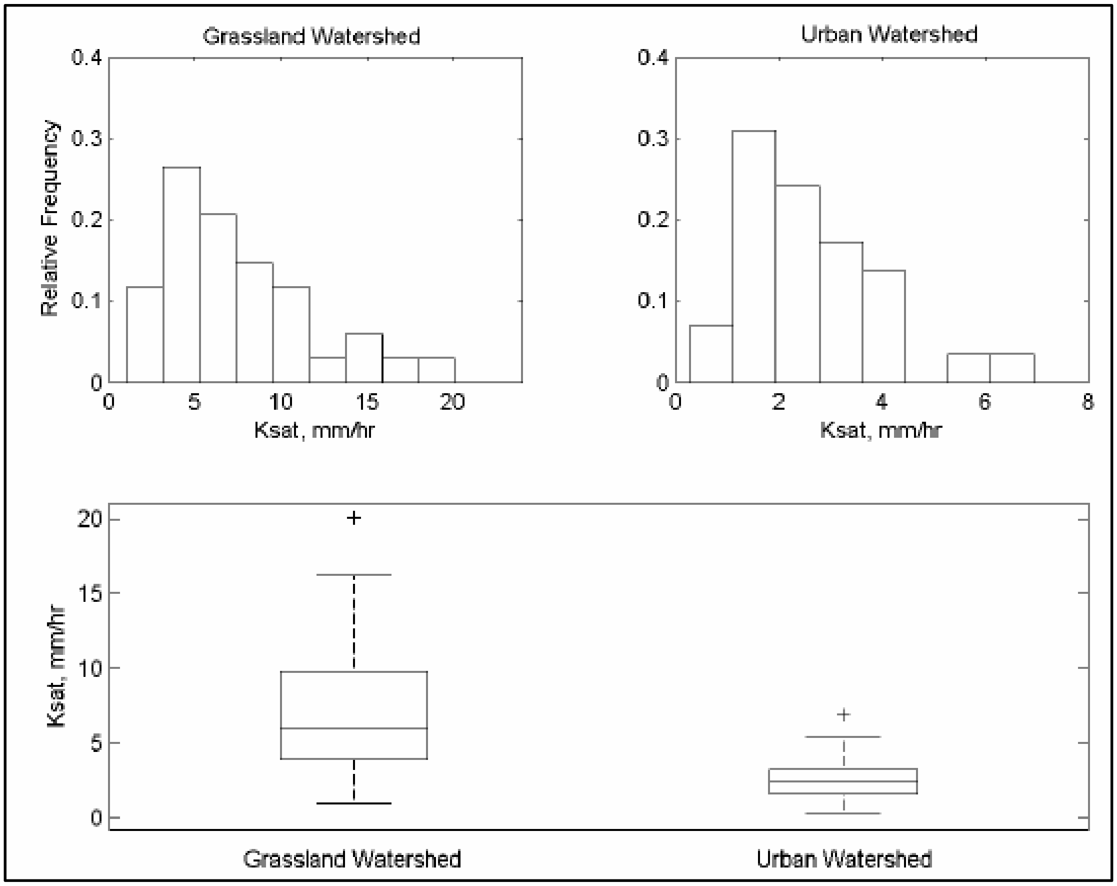
The use of LID concepts during site layout results in the preservation of natural drainage patterns and a reduction in impervious area when compared to traditional development. These, in turn, reduce the amount of runoff exiting the development, and improve runoff quality by providing greater areas for infiltration, evapotranspiration, and sediment deposition. When applied appropriately, the LID site layout concepts minimize the number of structural GI practices required to restore discharge rates and volumes and maximize the effectiveness of these structural GI practices in mitigating the effects of development on stormwater runoff.

LID is most effective for stormwater management when it is incorporated in the site layout during the initial planning phase of new development. Cost benefits are also maximized during this early stage of site design. However, LID is also applicable to redevelopment and retrofitting by implementing a comprehensive and effective set of GI/LID practices. The benefits of LID site design and implementation of GI/LID practices include:

- Flood mitigation by reduction of stormwater runoff rates and volumes.
- Improvement in stormwater quality resulting in healthy watersheds http://water.epa.gov/polwaste/nps/watershed/hwi_action.cfm.
- Facilitation of infiltration for increased soil moisture, and recharge in the few areas in Pima County with shallow groundwater, from small and large storm events (e.g., Goodrich 2004).
- Establishment or enhancement of native vegetation and habitat for wildlife.
- Reduction in potable water demand and cost for irrigation due to use of harvested stormwater.
- Reduction of the urban HIE and air pollutants due to an increase in vegetation.
- Economic value:
    - Potential cost savings in stormwater infrastructure (EcoNorthwest 2007).
    - Potential cost savings by deferring costs of drainage infrastructure and expanded water resources, including energy and infrastructure costs of importing water.
    - Increase of nearby home values in Pima County (Bark-Hodgins and Colby 2006) due to preservation of riparian habitat.
    - Increased lifespan of shaded asphalt (McPherson and Muchnick 2005).
- Transportation enhancements, such as traffic calming, reduced traffic noise, and increased pedestrian safety.

2.3.2 LID Planning Reduces Disturbed and Compacted Soils

In addition to the impact of impervious surfaces from new development, newly disturbed pervious areas also cause increased runoff due to significantly altered soil properties. LID planning practices can be used to minimize disturbed and compacted soils. A study of a new development in Sierra Vista, Arizona, found that the disturbed soils had significantly reduced saturated hydraulic conductivity (K_{sat}) (rate at which water is transmitted through the soil) compared to the adjacent undeveloped watershed when measured by a tension infiltrometer at spatially varying points (Figure 4, Kennedy 2007). The geometric mean of the K_{sat} of the undeveloped grassland watershed was 6.1 millimeters/hour and for the newly developed soils it was 2.2 millimeters/hour (Kennedy 2007), or a difference of approximately 60%. These findings are substantiated by laboratory studies demonstrating that, even in sandy soils, compaction can reduce infiltration rates by an order of magnitude (Pitt et al. 2008). LID planning practices can be implemented to reduce the development footprint and preserve areas of undisturbed soils allowing for higher rates of infiltration.



Source: Kennedy 2007

Figure 4. K_{sat} data measured by tension infiltrometer at spatially varying points within the undisturbed and developed watersheds at Sierra Vista, Arizona.

2.3.3 LID Reduces Pollutants in Stormwater

GI/LID practices reduce pollutants in stormwater by filtering solids, adsorbing dissolved constituents, and decomposing nutrients, which leads to water quality improvements. When runoff is reduced, the flow rate is slower resulting in less downstream erosion. Structures can also be incorporated into a site to filter suspended materials. A study in Davis, California, assessed the change in runoff and water quality characteristics between a control site that consisted of a grassy area covering clay loam and a bioretention basin with engineered soil. Runoff from a parking lot flowed either to the control site or to the bioretention basin, which was lined with a geotextile fabric, filled with crushed lava, and covered with compacted soil and mulch. The engineered soil absorbed 89% of the runoff and reduced the pollutants by 95% (McPherson et al. 2005).

GI/LID uses plants, soil, and inert materials such as rock riprap or curving rocky swales to improve the quality of stormwater. Stormwater can be directed through or to a structural GI practice where water quality can be improved by natural processes (Figure 5), which include the following (Chapin et al. 2002):

1. Interception: a portion of rainfall lands on plants and dissipates the impact and accumulation of the rainfall, therefore reducing runoff.
2. Infiltration: rainfall passes into soil and therefore does not become runoff.
3. Nutrient recycling: before transpiring infiltrated rainfall, plants absorb nutrients for growth and reproduction.
4. Transpiration: stormwater that infiltrates the ground is absorbed through roots, is released from the plants' leaves, and therefore reduces runoff.
5. Evaporation: stormwater is retained in crevices or swales on the land, is evaporated to the atmosphere, and therefore reduces runoff.
6. Sedimentation: stormwater is slowed by rough terrain or swales, allowing settling of clay, silt, sand, and gravel to swale bottom by gravity, thus preventing sediment transport in the runoff.
7. Filtration: as stormwater flows through rocks and plants, floating materials are physically screened out allowing clean water to pass through, preventing floatables from being transported in the runoff.
8. Energy dissipation: stormwater flow is slowed by rocky, curving swales or spillways, which reduce erosion and allow suspended material to settle to the bottom
9. Soil reactions: soil reactions are enhanced due to increased interface and exposure time with stormwater and development of a soil micro-climate, thereby cleansing the stormwater as it is absorbed into the soil. These reactions include: adsorption (adhesion of ion or molecules to oppositely charged soil particles); chelation (the process whereby organic acids combine with metallic ions making them soluble and mobile); ion exchange (exchange of ions between water and a media); and organic complexing (synthesis of organic compounds with other organic or inorganic compounds).
10. Microbial decomposition: conversion of dead organic matter into carbon dioxide (CO_2) and inorganic nutrients through leaching, fragmentation, and chemical alteration by soil, animals, bacteria, and fungi is improved.

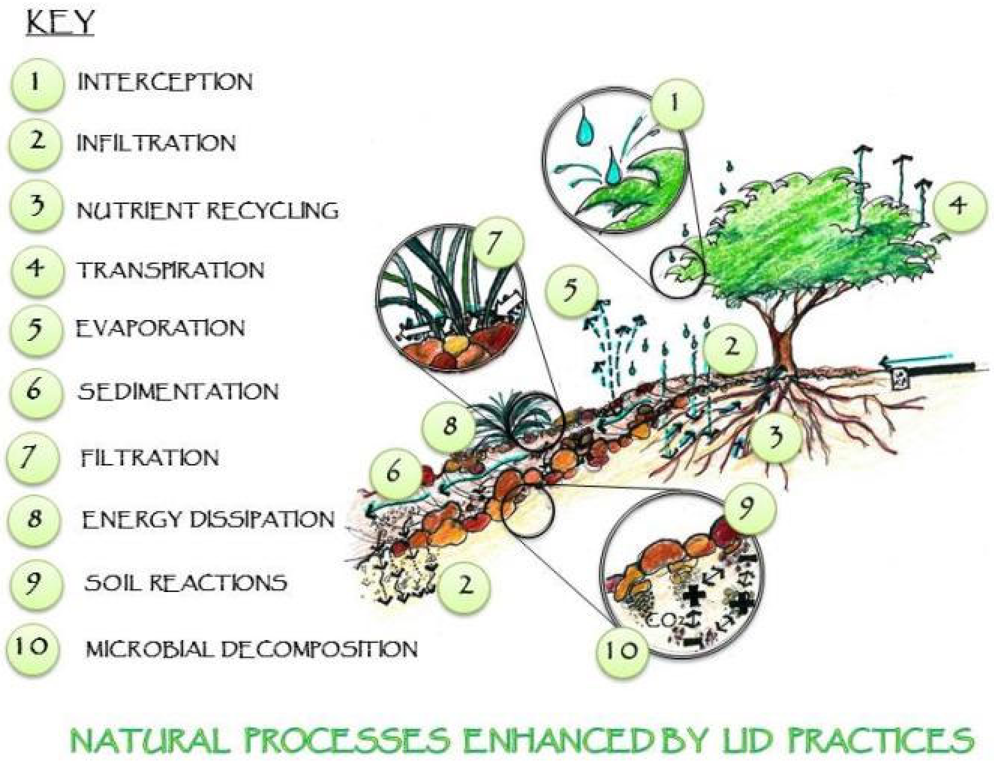


Figure 5. Natural chemical and biological transformations in LID.

Interception, transpiration, evaporation, and infiltration reduce the amount of runoff, which, in turn, slows the flow rates, reducing the potential for erosion. Nutrient cycling and soil reactions improve water quality. Sediment removal, filtration, and energy dissipation have two positive impacts by reducing runoff and improving water quality (NRDC 1999).

2.3.4 Multiple Benefits of GI/LID

Natural Irrigation

GI/LID practices promote plant viability in two primary ways:

- Stormwater is intentionally diverted directly to, or in close proximity to, planting areas.
- Stormwater is encouraged to remain longer and permeate deeper into the plant’s root zone.

These practices are beneficial to the growth and overall health of all plant materials.

Opportunities to Use Native Plant Materials

GI/LID practices further encourage sustainable design by promoting locally native vegetation or plant species with characteristics compatible to local conditions. Plants adapted to the desert are survivalists for a variety of reasons. Their leaves often are smaller and have thicker skins, reducing water loss. Their trunks and branches may have bark capable of photosynthesis. Their root systems are shallow but far-reaching, allowing fast absorption of surface rainfall after very minor storm events.

Plants native to the Pima County area require much less water than those native to regions with higher rainfall. Plants from other regions not only use more water than natives, but they may displace natives and diminish the habitat value received by our native wildlife. Native and desert-adapted plants not only will use substantially less water, but they have a better chance to become fully independent of supplemental water if properly weaned. When incorporating native plants into LID design, it is important to remember that native plants' tolerance to standing water in water harvesting basins varies from species to species. Well-drained soils are critical to promoting viability of most desert species in a variety of conditions. A list of native and desert-adapted plant materials is found in Appendix G**.**

Shade to Mitigate HIE

GI/LID practices can divert stormwater to shade-providing trees that should be located close to impervious areas with human activity such as buildings, sidewalks, and parking lots. Canopy shade reduces the temperature of walls and roofs by 20 to 40 °F. The plant evaporation reduces air temperature in open terrain by 9 °F and in suburbs without trees by 4 to 6 °F (NOAA 2014). Reducing the amount of heat absorbed by and radiating from impervious surfaces benefits residents and visitors at residential or commercial sites and encourages increased use of the area. Substantial reductions in heat absorption and radiation from buildings can result in decreased energy use and associated costs for cooling buildings (Center for Neighborhood Technology and American Rivers 2010).

Buffering and Screening

Bufferyards are typically a requirement for new development. Bufferyards consist of walls and/or vegetation that screen the new development from adjacent neighbors or roadways to block the view of land uses that may be considered unsightly. Directing stormwater to the vegetation using GI/LID practices allows the vegetation to be more self-sustaining, with more robust growth and less demand for potable water. Using stormwater for irrigation of a bufferyard reduces the cost of maintenance.

Traffic Calming

GI/LID practices can be incorporated into traffic-calming features, such as chicanes, roundabouts, and curb bumpouts, which enhance pedestrian safety by reducing vehicle speeds. Bump-outs at intersection and mid-block crosswalks slow traffic, draw attention to pedestrians, and reduce the distance pedestrians must travel to cross the road. Stormwater harvesting basins or bioretention can be incorporated inside these features for multiple benefits, including stormwater management and aesthetics.

Gardening

Although gardens are characteristically high-water users, community sustainability is also promoted by growing edible plants. Gardens are typically adjacent to homes, but a popular trend is a garden that supports an adjacent restaurant. Cistern storage can provide a longer-term sustainable water source for gardens. Although it would be difficult to have a garden fully independent of the potable water system, any reduction in potable use is a benefit to our community. The same practices that allow native plants to flourish and grow will also enhance the growth of edible plants.

Recreation and Aesthetics

GI/LID practices can provide substantial benefits to a residential subdivision. Integration of these practices into the design process increases the amount of undisturbed natural area and its proximity to proposed homes. Natural landscapes can enhance the appearance of homes and businesses. Natural landscapes already support native plants that will thrive in LID designs when stormwater is redirected for irrigation. As the landscape flourishes it will retain and further promote native wildlife and bird species. The addition of minor improvements such as pathways and benches creates a recreational amenity that neighbors can enjoy for activities such as walking, bird watching, or viewing sunsets, to name a few. Such activities increase family and social networks and create aesthetically pleasing neighborhoods.

For example, a large study of inner-city Chicago found that one-third of the residents surveyed said they would use their courtyard more if trees were planted (Kuo 2003). Residents living in high-rise apartment buildings with more greenery reported significantly more use of the area just outside their building than did residents living in buildings with less vegetation (Hastie 2003; Kuo 2003). Research has found that people in greener neighborhoods judge distances to be shorter and make more walking trips (Wolf 2008). Furthermore, *attention restorative theory* suggests that exposure to nature reduces mental fatigue. The rejuvenating effects come from a variety of natural settings, including community parks and views of nature through windows. In fact, desk workers who can see nature from their work stations experience 23 percent less time off sick than those who cannot see any nature. Desk workers who can see nature also report a greater job satisfaction (Wolf 1998).

Community Safety

In addition to the beneficial effects discussed above, GI has the potential to improve community safety through traffic calming and reduced crime rates. Where structural GI practices such as chicanes or bump-outs are proposed along roadways, the narrower road may reduce travel speeds, resulting in a calmer, quieter street. While the bump-out increases the planted area, it also narrows the vehicular travel area and pedestrians have fewer lanes to cross. The more limited a pedestrian’s exposure to active traffic, the less likely the chance of a negative encounter with a vehicle. Even if the street cannot be narrowed, enhanced vegetation creates the perception of a calmer travel corridor. Since street drainage usually occurs along the street edge, curb cuts or borings can allow the drainage to flow into a planted rocked swale and water the associated vegetation. This is an easy and ideal retrofit option for existing neighborhoods, but it can be incorporated into new development even more efficiently.

Reduced crime is another potential beneficial side effect of GI/LID. In one study, researchers examined the relationship between vegetation and crime for 98 apartment buildings in an inner city neighborhood. They found the greener a building’s surroundings are, the fewer total crimes (including violent crimes and property crimes), and that levels of nearby vegetation explained 7 to 8 percent of the variance in crimes reported (Kuo 2001a). In investigating the link between green space and its effect on aggression and violence, 145 adult women were randomly assigned to architecturally identical apartment buildings but with differing degrees of green space. The levels of aggression and violence were significantly lower among the women who had some natural areas outside their apartments than those who lived with no green space (Kuo 2001b).

Economic Values

The variety of benefits discussed above can all contribute to increased property values by improving aesthetics, drainage, and recreation opportunities within the community. Table 1 summarizes several studies of increased property values associated with natural areas and GI.

Table 1. Examples of increased property values associated with natural areas and GI.

Source	**Increase in Property Value**	**Notes**
Shultz and Schmitz (2008)	0.7% to 2.7%	Referred to effect of clustered open spaces, greenways, and similar practices in Omaha, NE
Voicu and Been (2008)	9.4%	Refers to property within 1,000 feet of a park or garden and within 5 years of park opening; effect increases over time
Ward et al. (2008)	3.5% to 5%	Estimated effect of GI on adjacent properties relative to those farther away in King County (Seattle), WA
Wachter and Wong (2006)	2%	Estimated the effect of tree plantings on property values for select neighborhoods in Philadelphia, PA
Hobden, Laughton and Morgan (2004)	6.9%	Refers to greenway adjacent to property
New Yorkers for Parks and Ernst & Young (2003)	8% to 30%	Refers to homes within a general proximity to parks
Pincetl et al. (2003)	1.5%	Refers to the effect of an 11% increase in the amount of greenery (equivalent to a one-third acre garden or park) within a radius of 200 to 500 feet from the house
Espey and Owasu-Edusei (2001)	11%	Refers to small, attractive parks with playgrounds within 600 feet of houses
Anderson and Cordell (1988)	3.5% to 4.5%	Estimated the value of trees on residential property (differences between houses with five or more front yard trees and those that have fewer) in Athens-Clarke County, GA

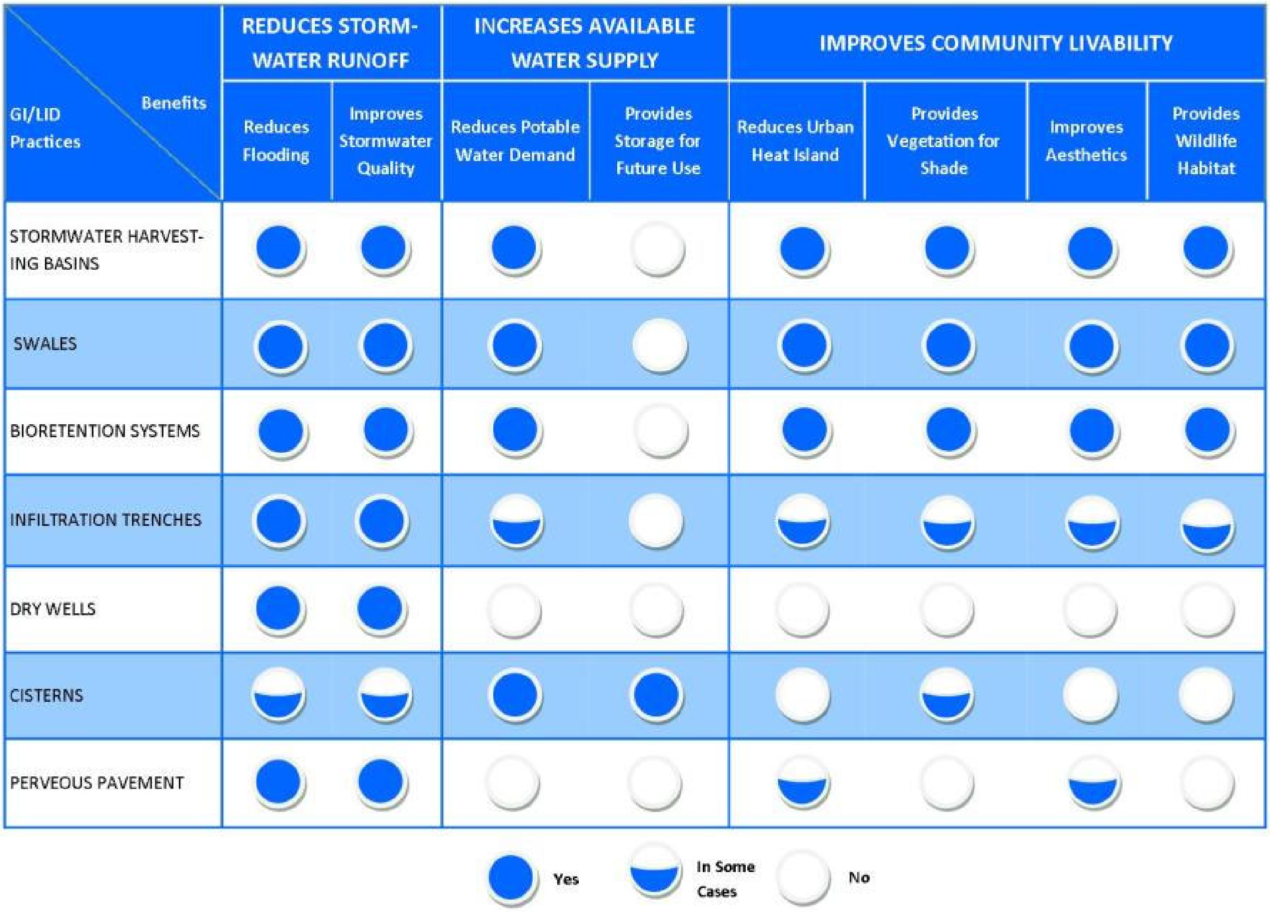
Figure 6 summarizes the multiple benefits of LID planning practices, while Figure 7 summarizes the multiple benefits derived from structural GI practices.

GI/LID Non-Structural Practices / Benefits	REDUCES STORM-WATER RUNOFF		IMPROVES COMMUNITY LIVABILITY			REGULATORY
	Reduces Flooding	Improves Stormwater Quality	Reduces Urban Heat Island	Shade for Passive Recreation	Provides Wildlife Habitat	Riparian Protection*
CONSERVE NATURAL AREAS AND PROTECT NATURAL FLOW PATHS	●	●	●	●	●	●
DISCONNECT AND MINIMIZE IMPERVIOUS AREAS	◒	●	◒	○	○	○
MINIMIZE DISTURBED AREAS AND SOIL COMPACTION	●	●	◒	◒	◒	◒
RESTORE DISTURBED NATURAL AREAS	●	●	●	●	●	●

*Ordinance No. 2010 FC5 Title 16 Chapter 16.30

● Yes ◒ In Some Cases ○ No

Figure 6. Benefits of LID planning practices.



Benefits	REDUCES STORM-WATER RUNOFF		INCREASES AVAILABLE WATER SUPPLY		IMPROVES COMMUNITY LIVABILITY			
GI/LID Practices	Reduces Flooding	Improves Stormwater Quality	Reduces Potable Water Demand	Provides Storage for Future Use	Reduces Urban Heat Island	Provides Vegetation for Shade	Improves Aesthetics	Provides Wildlife Habitat
STORMWATER HARVESTING BASINS	●	●	●	○	●	●	●	●
SWALES	●	●	●	○	●	●	●	●
BIORETENTION SYSTEMS	●	●	●	○	●	●	●	●
INFILTRATION TRENCHES	●	●	◒	○	◒	◒	◒	◒
DRY WELLS	●	●	○	○	○	○	○	○
CISTERNS	◒	◒	●	●	○	◒	○	○
PERVEOUS PAVEMENT	●	●	○	○	◒	○	◒	○

● Yes ◒ In Some Cases ○ No

Figure 7. Benefits of structural GI practices.

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3 Site Assessment, Planning, and Design Process

3.1 Site Assessment and Hydrology

An LID site design preserves existing flow paths through the site and minimizes the disturbed area. Structural GI and LID planning practices should be employed to reduce the volume of runoff and mitigate runoff from the point of generation and at each succeeding point along the flow path to create a treatment train. Ideally, LID site designs use or infiltrate stormwater close to the source of runoff. GI/LID practices can also be distributed throughout the site to the extent possible, while locating each of the practices to maximize the impervious area draining to it. These practices are preferable to concentrating stormwater in a structure and draining it away from the site as a nuisance.

The existing drainage of a site must be evaluated before site layout and LID planning practices can be applied. The analysis of existing drainage conditions should include identification and quantification of any off-site drainage and existing on-site flow paths.

New development must meet the requirements of the *Stormwater Detention/Retention Manual* (http://webcms.pima.gov/cms/one.aspx?portalId=169&pageId=65527). Discharge values can be determined using accepted models such as PC-Hydro (http://webcms.pima.gov/cms/one.aspx?portalId=169&pageId=60265) or the *Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona* (1989; Revised, 1998) for small watersheds. If structural GI practices are intended to meet the requirements of the *Stormwater Detention/Retention Manual*, it is the designer’s responsibility to determine whether the design of these practices will allow the site to meet the stormwater detention/retention requirements. The *Stormwater Detention/Retention Manual* includes tools to make this assessment. The guidance provided in this manual is non-regulatory.

3.2 Site Planning

The placement of development within regulatory floodplains, riparian habitat, and areas with concentrated flow causes a greater overall impact than development that is located in already disturbed areas and in areas where only overland flow is present. Consideration should be given to preserving these natural flow paths and any mature native vegetation. Thoughtful site layout would avoid disturbing these areas and utilize them for beneficial purposes such as to provide shading for buildings, streets, and parking lots; a natural buffer from neighboring properties; and a recreational amenity.

Once the site layout is determined, consideration of the type and location of structural GI practices is necessary. These practices should augment or enhance the natural drainages that were identified and preserved, or be located to maximize the benefits of such features, including buffering; screening; shading of buildings, streets, and parking lots; and traffic calming.

3.3 Locating Features to Provide the Multiple Benefits of GI/LID Practices

The multiple benefits of GI/LID practices as described in Section 2.3, Why Use GI/LID?, should be considered when selecting locations for the practices within the proposed site. These topics are discussed with greater detail in the next several sections to provide further guidance.

On larger commercial sites and multiple family residential sites, the strategic location of impervious surfaces and the pervious areas can optimize water usage and stormwater treatment. Maximizing placement of elevated impervious surfaces (building roof, parking, and sidewalk features) in conjunction with strategically placed vegetated surfaces (vegetated buffers, parking lot medians, and aesthetic landscapes) provides several benefits. In addition, using multiple features in a treatment train approach results in a longer path before stormwater exits the site. The more tortuous the path, the greater the infiltration to the vegetation root zone, and the less potable water required for irrigation. Greater infiltration within the vegetated areas of the site also results in less stormwater to pipe, flood, or waste after exiting the site. This philosophy can be helpful on smaller projects as well, although site constraints may be more restrictive.

3.3.1 Buffering and Screening

The use of bufferyards and vegetative screening are common methods to reduce the negative impact of new development to adjacent existing neighbors. By setting building and other improvement away from property lines and planting vegetation in between, there is some mitigation of the increased light, noise, and other perceived visual impacts that development creates, making it more acceptable to an adjacent private property owner. These concepts also apply along roadways. Bufferyards and screening are often used to enhance the aesthetics of the roadway, which further balances the visual impact of new structures or parking. These aesthetic improvements also provide a more inviting presentation to potential homeowners of residential properties or to potential patrons of commercial sites.

3.3.2 Shade to Mitigate HIE

Shade-providing trees should be considered when selecting vegetation for GI/LID practices. GI/LID practices should be located close to impervious areas such as buildings, sidewalks, and parking lots to provide shade, thus reducing the heat absorbed by and radiated from impervious surfaces.

Sites can be designed to accommodate plant water demands by using the guidance in the City of Tucson’s commercial water harvesting ordinance. For low water use trees, such as Mesquite or Palo Verde, the contributing impervious area required has been calculated to be 3.3 times greater than the canopy area. This calculation is described in Appendix B.

3.3.3 Site Design to Protect Stormwater Quality

The areas of development that have the potential to affect stormwater quality should be identified when designing an LID site. They will generally be impervious areas and may include parking lots, fueling areas, or loading zones. Water quality protection should be achieved using source control, such as the minimization of sediment erosion and other particulates from being introduced into stormwater.

The processes of bioretention, infiltration, or both can be incorporated immediately downstream of LID features to provide the largest benefit to water quality. Stormwater harvesting basins are often the most inexpensive option providing significant water quality benefits because pollutants are retained close to the source. Where protection of water quality is of utmost concern, bioretention systems, such as *rain gardens* that include engineered soils and underdrains, allow for large volumes of stormwater to be treated with lower risk of untreated stormwater bypassing the system.

3.4 Site Design to Control Erosion and Sediment Transport

LID designs should incorporate sediment control to first minimize the detachment of sediment particles (erosion) from stormwater runoff, then reduce the sediment transport capacity of runoff through the site, and finally facilitate the deposition of suspended sediment in runoff. Sediment control can be implemented in both LID planning and structural GI practices.

3.4.1 Erosion Prevention

Gradual slopes such as 3:1 or flatter should be used for earthen areas unless slopes will be riprap lined. Earthen areas that are not part of a GI practice should be covered with rock mulch, or riprap to prevent erosion and control dust. Decomposed granite or loose forms of mulch are not appropriate for this application, and decomposed granite should not be used near or within GI practices. Rock mulch should be ½-inch or greater crushed gravel and should be screened and washed to remove fines.

At the transition from impervious areas draining to pervious areas, a 1- to 2-foot-long riprap border or similar armoring should be used to prevent scouring by high velocity runoff draining from impervious surfaces. Geotextiles can also be used with riprap to further stabilize the erosion control feature.

3.4.2 Minimization of Sediment Transport Capacity

Conveyance features such as swales should have mild longitudinal slopes of 0.5% or flatter. Flow spreaders should be used at the inlet to conveyance features to dissipate energy and reduce velocity of runoff. Conveyance features should be designed with velocities not exceeding 2 feet/second. Meandering flow paths can be introduced to reduce velocity and lengthen travel times. Reducing flow velocities reduces the sediment transport capacity of the runoff which minimizes entrainment of sediment and facilitates the deposition of sediment. Check dams may also be utilized to allow for sediment deposition along conveyance features.

3.4.3 Deposition of Sediment at End of Flowpath

In addition to facilitating sediment deposition in conveyance features, the GI retention practices at the end of conveyance features should be designed to collect sediment entrained in runoff. This capture can be accomplished by designing sediment traps at the inlets of stormwater harvesting basins. Sediment traps facilitate maintenance of GI retention features and can prevent the need for major maintenance by preserving infiltration properties of GI features such as rain gardens, bioretention systems, infiltration trenches, and dry wells.

3.5 Selection of Rainfall Event for Sizing GI/LID Practices

3.5.1 Local Rainfall Characteristics and Design

The rainfall characteristics of the desert southwest are very different from many other climates. High-intensity, short-duration convective thunderstorms occur frequently during the monsoon season from July through September; dissipating cyclones may travel over the area during some years in the fall; and lower-intensity, frontal storms often occur during winter months. The rainfall seasons are often separated by prolonged periods of dry conditions with low humidity. Native plants are well adapted to these seasonal patterns (a selection of native and locally-adapted plants that may be considered is provided in Appendix G). The selection of native plants for GI is preferable, but native-adapted plants may also be sustained by rainfall instead of relying on drip irrigation.

At the University of Arizona, data from more than 4,700 rainfall events were recorded between 1895 and 2000, resulting in an average of 45 rainfall events per year. Of those, approximately 40% produce 0.1 inch or less of precipitation, and approximately 85% of all events are less than 0.5 inch (Figure 8). These rainfall events are further described in Appendix A. Because the 85% rainfall event has been identified as a good event for capture of rainfall for stormwater mitigation by the American Society of Civil Engineers (ASCE 1998), the region has chosen this 0.5-inch event as a minimum threshold for *first-flush* retention (Pima County Regional Flood Control District 2014).

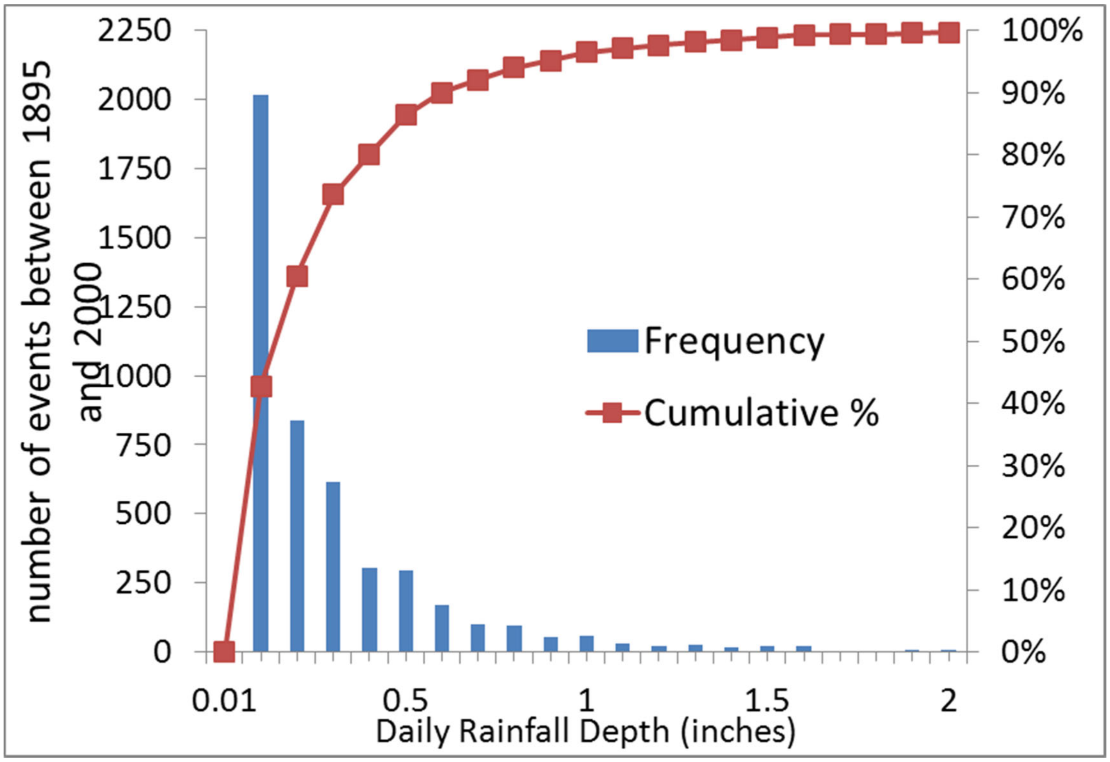

Figure 8. Distribution of rainfall events measured at the University of Arizona between 1895 and 2000.

The local rainfall characteristics provide guidance on the optimal design of GI for this area. When the frequency of the storm is considered in addition to the rainfall depth, it indicates what storms contribute most to the annual rainfall depth so that GI is designed in a cost effective manner. Figure 9 shows the average annual precipitation depth based on the 105 years of daily rainfall collected at the University of Arizona between 1895 and 2000, as well as an estimated runoff depth from an impervious surface assuming a 0.05-inch threshold.

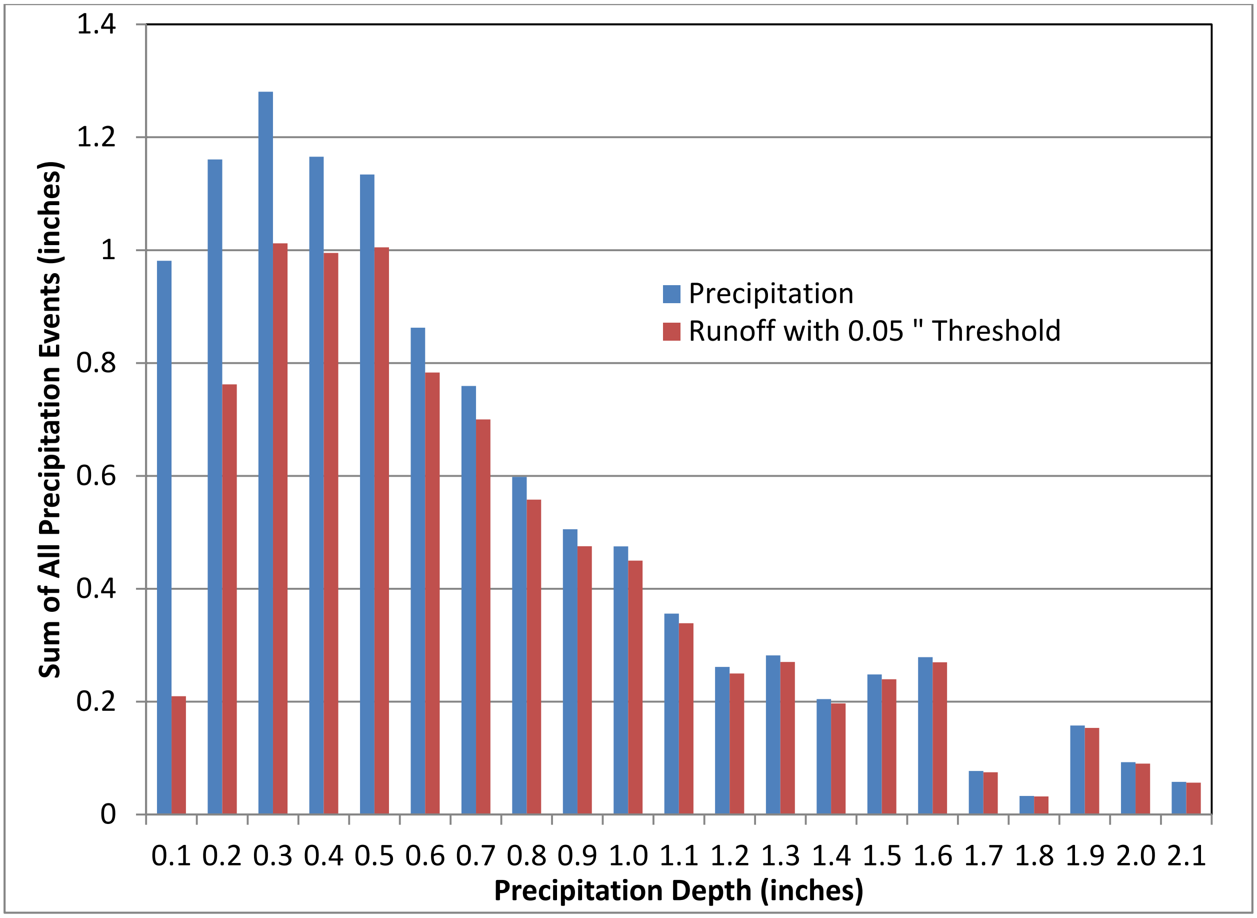

Figure 9. Average annual precipitation and runoff from an impervious surface (based on 1895–2000 daily precipitation at University of Arizona).

The figure illustrates that very small events, such as those of less than 0.1-inch, contribute very little to runoff, because most of the precipitation is required to satisfy the runoff threshold. In addition, events with depths between 0.3 and 0.5 inch are frequent enough and large enough to provide the largest single component of the average annual runoff volume. The analysis of the University of Arizona rainfall data is further described in Appendix A.

In addition, the analysis of annual peak daily rainfall from the 105 years of University of Arizona data shows that rainfall depths greater than 1.5 inches are fairly infrequent as shown in Figure 10. Since these large events cause floods, designing for these will mitigate flood events (though these may be smaller than the regulatory [i.e., 100-year] flood event). Therefore, the analysis of rainfall indicates that features should be designed to accommodate rainfall events between 0.5 and 1.5 inches. A suggested guideline for determining the design stormwater volume is to use the runoff volume from a 1.25-inch rainfall event (about 1.0 inches of runoff for an impervious watershed).The evaluation of peak rainfall volumes is described in Appendix C.

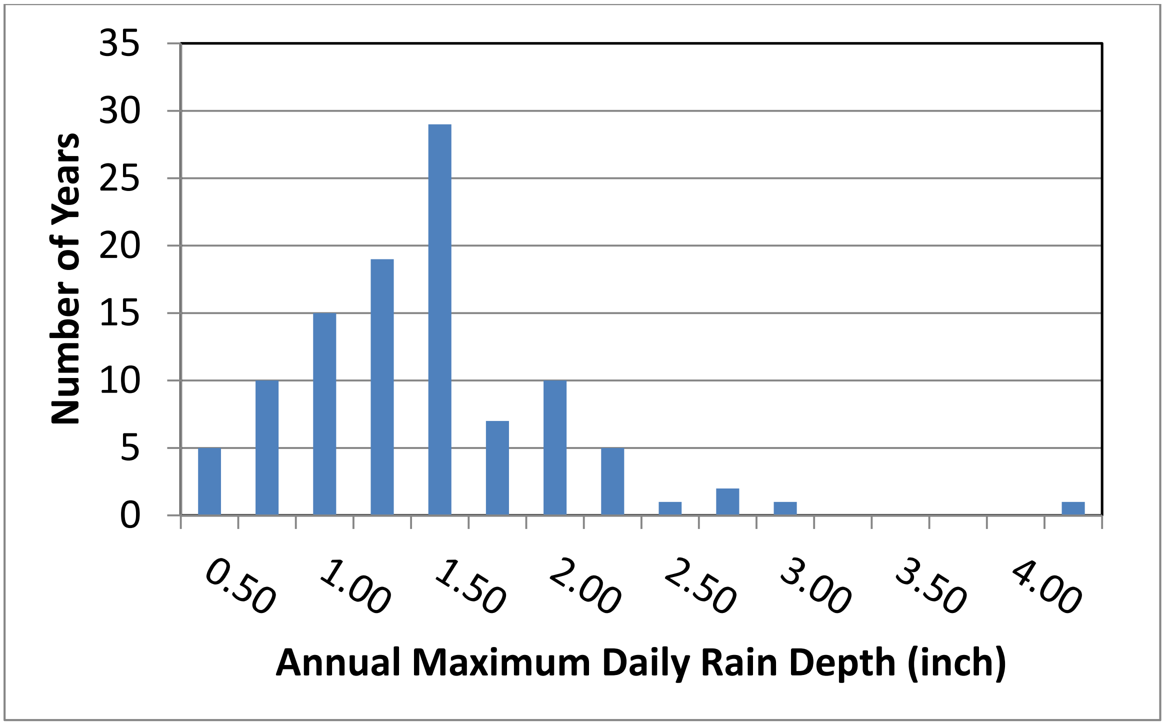

Figure 10. The annual maximum daily rainfall depths in the University of Arizona data.

In some cases GI practices may need to be sized for a regulatory requirement. In other cases, the GI practice may be the sole or primary source of water to support existing downstream riparian vegetation, whether off-site or on-site. If LID planning practices cannot be used to ensure reliable periodic flows to the riparian habitat, an adjustment in the design water harvesting volume may be necessary in order to allow more frequent flows downstream. Furthermore, when retrofits are proposed, there may be limitations on the size and location and suitable area for GI/LID practices. In these cases, the goal of the project is to maximize the water harvesting volume.

3.6 Design Flow Rates for GI/LID Conveyance Features

For design of conveyance features, a peak flow rate must be used for sizing. As a starting place, the peak one-hour rainfall for the five-year storm event is calculated to be approximately 1.5 inches in Tucson. Using this rainfall rate, the starting value of stormwater runoff flow per acre (ac) of impervious surface can be assumed to be 5 cubic feet per second. The derivation of this 5 cubic feet per second/acre value is described in Appendix D. Water harvesting has the effect of reducing the peak runoff flow rates by detaining, retaining, and infiltrating stormwater.

A more tailored estimate of the flood peak or hydrograph can be derived using site characteristics and modeling the 5-year, 1-hour flow rate using PC-Hydro in Pima County (http://webcms.pima.gov/cms/one.aspx?portalId=169&pageId=65582) and City of Tucson's *Standards Manual for Drainage Design and Floodplain Management* (City of Tucson 1989). The calculated rates can then be used with the water harvesting factors described in Section 2.2, What are GI and LID?, to estimate a reduced peak discharge rate to size conveyance features.

3.7 Sources, Citations, and Additional Resources

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4 LID Site Planning Practices

4.1 Introduction

The purpose of LID site planning practices differs from the purpose of structural GI practices. Structural practices typically address stormwater-related impacts that occur as a result of development and the construction process. They are often retrofitted to an existing condition and so are fixed or specific to one location. Although they often are an after-the-fact mitigation repair, including them in the final steps of development design is also key to the LID site planning process.

The overall goal of implementing LID site planning practices is to minimize the initial generation of excess stormwater runoff from a development site. The entire site must be evaluated with these practices in mind before site design begins. The primary goals of LID site planning practices are:

- Conserving natural areas and protect natural flow paths (Analysis)—See Section 4.2.
- Disconnecting and minimizing impervious areas (Design)—See Section 4.3.
- Minimizing disturbed areas and soil compaction (Construction)—See Section 4.4.
- Restoring disturbed natural areas (Restoration)—See Section 4.5.

The first three practices are tightly intertwined and can most effectively be addressed in the earliest stages of site design. Continued evaluation of these practices should occur for the duration of the development process. The fourth practice will be a part of design if a proposed development site was previously disturbed.

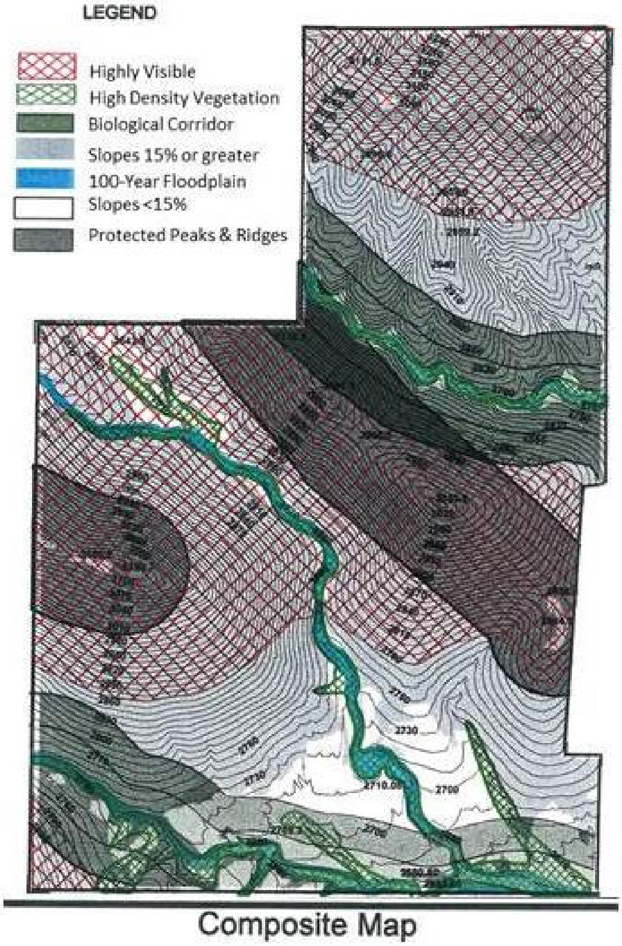


Figure 11. Sample site analysis.

4.1.1 Site Analysis

The first step of the design process is a thorough, comprehensive site analysis that should include evaluation of critical features of the natural environment. Early identification of these features results in a more efficient and effective design, and does not compromise the goals of the development. A composite map (Figure 11) of critical natural features will reveal opportunities and constraints of the site (e.g., contiguous unique natural areas, areas that require the least effort to develop). No two sites are the same, so to impose a two-dimensional paper design on a site without consideration of its unique attributes is to lose environmental as well as economic benefit. LID planning practices are tightly interwoven—a strategy that implements one principle can easily provide the benefits of another.

At a minimum, the following site attributes should be identified and delineated during the site analysis:

- Floodplains from existing floodplain maps.
- Riparian habitat and shallow groundwater from existing riparian maps, and/or ortho-photos.
- Natural flow paths, swales, and natural depressions from topographic data (e.g., PAG topographic data), and ortho-photos.
- Geotechnical and soil infiltration characteristics from resource maps, site inspections, or on-site testing.
- Steep slopes from topographic data.
- Existing native vegetation, especially threatened and endangered species from site inspections.
- Existing utilities and easements from maps and records.
- Other sensitive areas such as cultural resources, Conservation Lands Systems, viewsheds.
- Potential development areas based on above constraints and project requirements.
- Previously impacted areas.

4.1.2 Conservation Opportunities

Conservation opportunities are optimum at the rezoning or block plat stage. Not only should the subject development be evaluated, but the surrounding community may hold opportunities or constraints that can affect the site. During the planning process at the community scale, regional watershed and subwatershed studies are used to develop an understanding of the environmental context of the site.

Typically, regional watershed management objectives are relevant to an individual site. Opportunities to enhance and restore features, connectivity, and functional integrity of the broader area are identified. Soil and hydrogeological conditions that are well-suited for stormwater infiltration practices are delineated. The patterns of shallow groundwater flow and locations of discharge to receiving watercourses or floodplains within or adjacent to the limits of the site are identified.

If possible, at this point in the planning process, opportunities to integrate desirable GI/LID practices into other community design objectives can be identified. At a minimum, the general influences from the surrounding watershed conditions should be incorporated into the project area.

4.1.3 Fundamental Key Design Features

To maximize the opportunities for all LID planning practices, implementation of the following site design features should be considered:

- Avoid and conserve important hydrologic features and functions by providing a setback from natural areas and flow paths.
- Minimize the development footprint by placing functional square footage on multiple levels and/or by placing development features in less sensitive areas.
- Reduce or disconnect impervious areas such as parking lots, roof area, and access roads. Use natural flow paths or create landscaped flow paths for development stormwater flows.

These strategies should be considered concurrently as they all overlap and relate to each other. For example, preserving a natural flow path will impact the layout of the site and its structures, because that potion of the site is now designated as not to be developed. The layout of the site and its structures determines the extent of impervious area. The extent of the impervious areas can be further reduced if pavement area is reduced, alternative materials are used, landscape swales are developed, or the building footprint is reduced. The area surrounding the natural flowpath can then be expanded. In addition, drainage flows are minimized by accessing the newly created more permeable paved or landscaped areas earlier in the drainage sequence.

Site planning with LID practices in mind will reduce the cost of engineered drainage structures and direct the optimal locations of structural GI practices. Structural practices are even more efficient when included in the design phase, rather than as a retrofit option. Proper location of structural GI practices further influences how much stormwater is allowed to infiltrate.

Coordination between all design professionals, including engineers, landscape architects, architects, and hydrologists, is the basis of LID design and must be supported by the development community. Individually, each of these disciplines provides important components to a project. When their ideas are woven together, the resulting design dynamic provides a far greater benefit to the site’s developed value, to the community, and to the environment. The increasing expectation to include these benefits will prompt the continued use of LID planning practices.

4.1.4 Site-Specific Design

Once biophysical, ecological, and hydrological characteristics of the surrounding properties and subject site are known, their influence on the subject site should be assessed. For example, a subject property may have two equal areas of dense native vegetation but both cannot be set aside. Area #1 has beautiful specimen trees but is isolated from any other vegetation. Area #2 has younger vegetation, but creates a link in a vegetated corridor that provides passage for wildlife to a 50-acre park with access to a local wash that leads to a major drainage. This brief analysis of the site and the surrounding community has revealed a critical attribute of the property. Without this analysis, Area #1 may be chosen and the new development would block a critical link that had provided support to the environmental assets of the community.

With this knowledge, areas to be preserved can be clearly shown as set-asides on all construction plans. Alternatives for the development footprint can be proposed. The configuration of the major and minor road networks and development features becomes clearer. To the degree possible, roads should follow overland flow directions. Important natural flow paths and designed swales can be targeted to receive development stormwater runoff and be effectively used as conveyance systems. Flow paths double as corridors that promote wildlife survival, as well as amenity path systems and linear parks that support recreational uses. Minor adjustments can be made on paper during the design process much easier than in the field or after construction. Methods for protection, such as signage and fencing, should also be noted on the plans. See Section 4.1.7, Considerations during Construction, for more information.

In contrast, by transforming natural corridors into rigid concrete-lined channels typical of conventional development, there is a loss to the environmental systems, as well as to the surrounding community. Where possible, parks can be located at the downstream end of drainage corridors. Creative design will incorporate more drainage features, providing opportunities for further integration of LID principles.

Thoughtful placement of project elements will promote LID principles and create environmental and economic benefits. Place elements that shed the most rainfall (roofs, sidewalks, surface mechanical units) at higher elevations on the site. This placement allows the use of gravity flow to direct captured stormwater runoff to landscape areas. Create a treatment train by providing *diversions* to the runoff flowpath. Curvy vegetated or rocked swales located throughout the site create a *tortuous path* and slow the flow of stormwater. This slowing of flow allows sediment a chance to drop out and gives stormwater time to infiltrate, decreasing the water volume before it exits the site. If this stormwater runoff eventually accesses natural areas, by the time it arrives it has already achieved a healthier state.

Site designers should also consider using a smaller building footprint and explore setback reductions. By using taller multistory buildings and taking advantage of opportunities to consolidate services into the same space, a smaller building footprint can be achieved. A single story design converted to a two-story structure with the same floor space will eliminate up to 50% of the building footprint area.

As the broader design process is completed, focus can change to structural GI practices. These practices can be integrated as design elements instead of delegated solely to post-design retrofits. Structural practices include breaking up impervious surfaces and taking advantage of natural or created landscape swales with superior infiltration. Their benefits include attenuation, water harvesting, filtration, infiltration, and vegetation viability. These minor adjustments may include shifting development elements to more appropriate areas of the site, further avoiding the most sensitive areas.

Once construction commences, other means for minimizing disturbance of the natural areas may be revealed in the field. Often these modifications take little effort or cost to accomplish, yet they result in significant benefits or savings. Occasionally, the construction process impacts areas that were meant to be avoided. Restoration then becomes a possible option to bring balance back to the site. For more information, see Section 4.5, Restore Disturbed Natural Areas (Restoration).

4.1.5 Unique Opportunities

Some sites undergoing design have natural areas that were disturbed prior to the current development. Disturbed areas should be included in the original site analysis and targeted for as much of the new development footprint as possible. These sites often offer unique opportunities for restoration, whether to complete a broken link to an otherwise undisrupted wildlife corridor or riparian area on adjacent properties, or to create a path for flows that previously backed up and flooded homes. Creating a path for flows creates a bonus amenity to the project and possibly enhances community floodplain function.

The design for roadway projects is typically characterized by limited site area and lack of opportunities for right-of-way (ROW) acquisition. These projects often include a high percentage of impermeable area due to the inclusion of utilities and drainage, plus necessary accommodation for pedestrian and bicycle uses. However, opportunities still exist for LID site planning practices. Some ROWs are designated for multi-lane roadways in roadway master plans that may be outdated. Lanes can be minimized to comply with the context of the current conditions. This emphasis on a *road diet* or reduction in traffic capacity can also be applied for retrofit in some areas.

By minimizing the roadway surface, a larger natural area can be retained, and a smaller footprint of impermeable paving is constructed. Instead of traditional curb and gutter, or a concrete drainage channel in the ROW, drainage can be slowed with curvilinear rocked and vegetated swales. These swales can intermittently direct flow to nearby natural riparian areas, flow paths, or other landscaping. These practices allow sediment to drop out, water to infiltrate, and the net flow and associated debris to be reduced. Correspondingly, the need for costly stormwater inlets, channels, and culverts can be significantly reduced.

4.1.6 Benefits from Using LID Site Planning Practices

LID planning practices are so tightly interwoven that the implementation of one practice often simultaneously produces the goals of a different practice, resulting in similar benefits. This applies especially to larger sites that typically have more site features available with which to work. (See the individual practices described further in this document if a site is smaller and only benefits from individual practice are possible.)

For example, a designer directs development flows through a rock- and vegetation-lined swale to a natural area that has been preserved by a set-aside. There are several development benefits from the swale: Impermeable areas are disconnected, runoff is slowed, and the need for drainage structures is diminished; vegetation flourishes, site temperatures are lowered, and heat is mitigated; and soils in the swales improve to allow better filtration, and the net flow off-site is reduced. The development benefit from the act of setting aside the natural area is that the net increase in site temperatures is minimized. By receiving supplemental water, the vegetation in the natural area flourishes and the wildlife benefits. Infiltration generally is best in native soils, so the net flow off-site is reduced and the need for drainage structures is diminished. As the vegetation matures, the soils in the natural area further improve and infiltration is further enhanced. It is difficult to separate which principle affected the site the most. Some of the overlapping LID benefits follow:

- Improves water quality by preserving native soils and vegetation, which provide filtration, therefore reducing pollutant loads to receiving waters. Sediment is removed from overland sheet flow when the interwoven branches along the surface filter and trap sediment loads.
- Provides more rich and diverse habitat and cover for native creatures and birds by enhancing the structure, size, and volume of the vegetation. This results from the receipt of development stormwater to their root systems, and this in turn increases infiltration of rainfall.
- Enhanced vegetation volume also:
    - Improves air quality by removing pollutants from the air through the native vegetation’s natural evapotranspiration processes. This can mitigate smog formation by reducing temperatures.
    - Reduces the carbon footprint through increased sequestration of CO_2 in soils and plant biomass, therefore mitigating climate warming.
- Decreases the HIE by reducing or removing pavement and preserving or planting vegetation, which can cool and shade urban neighborhoods as well as commercial centers in the hot summer months.

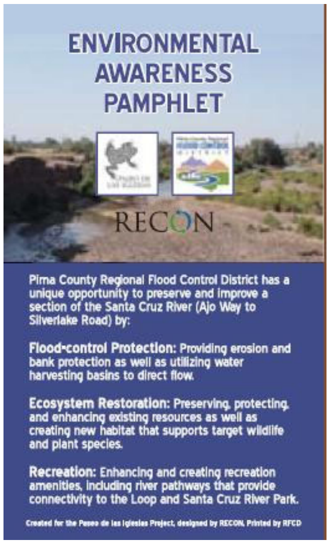
4.1.7 Considerations during Construction

During site planning, a pre-construction meeting should be conducted with local neighbors, community officials, contractors, and subcontractors. The goal of such a meeting is to establish channels of communication to everyone related to the project and instill in them an understanding of the value provided, and the care required on a project using LID planning practices. It is also critical to identify the types of activities that are not allowed in sensitive areas. All contractor employees involved in the project should attend an orientation meeting that presents every facet of the project goals. Illustrated brochures are a handy guide that could be provided. When new employees arrive, they should undergo the same training (Figure 12).

4.2 Conserve Natural Areas and Protect Natural Flow Paths (Design)

4.2.1 General Description

The first goal in the LID site planning process is the conservation of natural areas and protection of natural flow paths. This goal fulfills the objective to maintain the hydrologic response to pre-development levels. The natural state of the soils in these important areas includes the capacity for the most effective management and infiltration of stormwater flow. This includes the infiltration not only of flows that have naturally occurred in that drainage, but also post-constructed flows that can be directed to the natural areas.



ENVIRONMENTAL AWARENESS PAMPHLET

RECON

Pima County Regional Flood Control District has a unique opportunity to preserve and improve a section of the Santa Cruz River (Ajo Way to Silverlake Road) by:

Flood-control Protection: Providing erosion and bank protection as well as utilizing water harvesting basins to direct flow.

Ecosystem Restoration: Preserving, protecting, and enhancing existing resources as well as creating new habitat that supports target wildlife and plant species.

Recreation: Enhancing and creating recreation amenities, including river pathways that provide connectivity to the Loop and Santa Cruz River Park.

Created for the Paseo de las Iglesias Project, designed by RECON, Printed by RFCD

Figure 12. Pamphlet for contractor's employees.

Natural areas and flow paths often include riparian areas that have soils with some of the highest infiltration rates, and characteristically have established stands of native vegetation. They typically have a meandering character that delays the speed of flow, further increasing infiltration. Traditionally, post-construction flows quickly accumulate off hard surfaces, are transported in expensive concrete channels or culverts, and are directed through costly concrete or corrugated metal pipe to the lowest elevation of a site for retention and/or discharge. By identifying, protecting, and using the natural flow paths, and by creating new vegetated flow paths in the form of decorative landscape swales, a development can minimize stormwater impacts. This type of flow management can reduce or eliminate the need for costly flow structures, and ultimately results in minimized stormwater runoff and reduction of associated pollutants.

Benefits	CONSERVE NATURAL AREAS AND PROTECT NATURAL FLOW PATHS	
REDUCES STORMWATER RUNOFF	Reduces Flooding	●
	Improves Stormwater Quality	●
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	●
	Shade for Passive Recreation	●
	Provides Wildlife Habitat	●
REGULATORY	Riparian Protection	●

Natural riparian areas are critical to the biological, chemical, and physical integrity of floodplains. These natural areas can provide habitat, open space, improve aesthetics, and increase property values. When natural riparian areas and their associated flow paths are protected, they can function effectively for many years with low maintenance. Maintenance of flow management structures can be much more costly.

4.2.2 Applicability

Conserving natural areas and protecting natural flow paths is applicable across all types of land development projects. The most common application is in residential development, particularly a lower density single-family residential development. As density and intensity of uses increases, the ability to apply LID site planning practices decreases. Commercial and industrial developments tend to be associated with the highest density development, and thus will disturb more land. This fact makes conserving natural areas and protecting natural flow paths more challenging.

Ordinances requiring a percentage of the undeveloped site to remain as open space will be most effective in prioritizing natural areas and flow paths, along with the associated floodplains and riparian areas. Native plant protection ordinances requiring protection of vegetation often go hand in hand with protection of flow paths. The densest vegetation typically occurs nearby natural drainage and/or riparian conditions. A set-aside for vegetation serendipitously becomes a set-aside for a natural flow area.

There are unique opportunities to apply this LID site planning practice as a retrofit for existing developments or roadways and produce great benefits. Opportunities may occur due to a rezoning, a desire for property improvement, or the need for a road diet to allow bicycle lanes or other transportation improvements. Older developments and existing roadways typically have increased impervious areas resulting in the availability of more stormwater, which can be redirected for beneficial use. This excessive stormwater may also have created flood-related impacts including the conveyance of household or transportation NPS pollutants.

When a development project is a retrofit, some sites may have small or limited natural areas and natural flow paths, and the overall health of these areas may be poor. When a site has been altered or previously disturbed in this way, restoring the natural area is an appropriate LID site planning practice to apply (see Section 4.5, Restore Disturbed Natural Areas (Restoration)). Even developed sites of lower densities may offer limited, but still beneficial, retrofit potential.

4.2.3 Advantages

Natural areas and natural flow paths that are set aside and preserved also protect native soils that:

- Slow runoff flows.
- Decrease the need for costly constructed drainage systems.
- Decrease the volume of potential retention area, opening more land for development.
- Have greater infiltration and storage capacity.
- Improve water quality by providing superior filtration and microbial reactions, therefore reducing pollutant loads to receiving waters.
- More easily accept increased post-development flows, permitting infiltration of rainfall and stormwater to native vegetation root systems. This results in more rich and diverse habitat and cover for native creatures and birds by enhancing the structure, size, and volume of the existing vegetation.
- Support enhanced vegetation volumes that also:
    - Remove sediment from overland sheet flow when the interwoven branches along the surface filter and trap sediment loads.
    - Improve air quality by removing pollutants from the air through the native vegetation's natural evapotranspiration processes. This can mitigate smog formation by reducing temperatures.
    - Reduce the carbon footprint due to increased sequestration of CO_2 in soils and plant biomass, therefore mitigating climate warming.
    - Reduce the HIE by reducing pavement and preserving vegetation, which can cool and shade urban neighborhoods as well as commercial centers in the hot summer months.

4.2.4 Limitations

Despite the many advantages of conserving natural areas and protecting natural flow paths, there are several possible limitations:

- They are difficult to implement on smaller sites and sites with specific constraints.
- In some situations, regulations, and/or economics may not allow avoidance of all natural areas and protection of flow paths on a project site.
- Size of lot and/or development site may reduce ability to protect riparian buffers.

4.2.5 Key Design Features

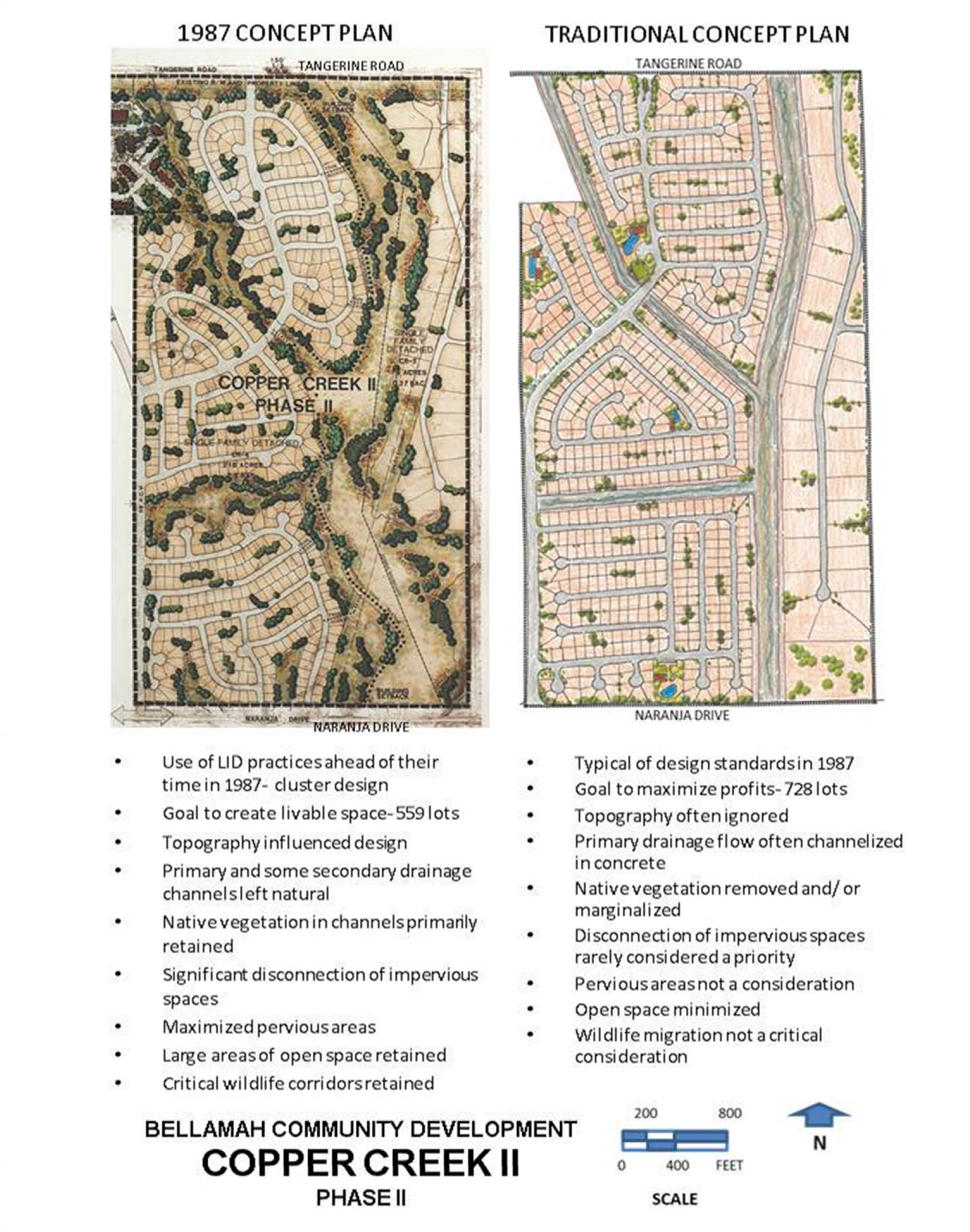
To maximize the opportunities for conserving natural areas and protecting natural flow paths, site design features can be grouped into four themes:

- Avoiding and conserving important hydrologic features and functions.
- Siting and layout of development features in less sensitive areas.
- Reducing impervious area.
- Using natural flow paths for post-development drainage systems.

4.2.6 Considerations During Design

The completed site analysis will have identified natural areas, natural flow paths, and other sensitive areas. The first step in the site design is to analyze how these areas affect the overall hydrology of the site and how they can be integrated into the proposed design. Sensitive areas include floodplains, riparian areas, steep slopes, highly permeability soils, and existing conservation areas. Some areas will be undevelopable due to their character (e.g., steep slopes); some hold critical environmental value; some improve the hydrology of the site design; and some improve the value of the overall design due to aesthetics or recreational value. Once the natural areas of greatest importance are identified, those areas can be designated for set-aside, thereby defining the remaining area suited for development.

For example, the Copper Creek subdivision, located on Tucson’s northwest side, was designed before LID principles were household terms. Figure 13 illustrates how the original 1987 Concept Plan exhibits numerous characteristics that reflect current LID site planning practices. The *Traditional Concept Plan* is a purely hypothetical design that would have maximized the number of lots available. Maximizing the lot count would have created greater profits, but this method would have also eliminated some of the site’s best attributes.



- Use of LID practices ahead of their time in 1987- cluster design
- Goal to create livable space- 559 lots
- Topography influenced design
- Primary and some secondary drainage channels left natural
- Native vegetation in channels primarily retained
- Significant disconnection of impervious spaces
- Maximized pervious areas
- Large areas of open space retained
- Critical wildlife corridors retained

- Typical of design standards in 1987
- Goal to maximize profits- 728 lots
- Topography often ignored
- Primary drainage flow often channelized in concrete
- Native vegetation removed and/ or marginalized
- Disconnection of impervious spaces rarely considered a priority
- Pervious areas not a consideration
- Open space minimized
- Wildlife migration not a critical consideration

BELLAMAH COMMUNITY DEVELOPMENT
COPPER CREEK II
PHASE II

Figure 13. Copper Creek subdivision early LID design compared to 1980s traditional engineered design.

Figure 14 is a comparison of the original undisturbed site to a 2012 aerial with the platted subdivision overlaid. The 2012 aerial clearly exhibits substantial canopy growth in drainage areas that had been left natural.


1979 UNDISTURBED SITE

2012 AERIAL
PLATTED DESIGN CLOSELY FOLLOWED 1987 CONCEPT

Figure 14. Copper Creek vegetation growth since construction.

4.2.7 Considerations during Construction

Project participants should understand why natural areas and flow paths are receiving protection. Specific riparian areas, important clusters of native vegetation, as well as individual plant specimens all must be protected from construction machinery. The protection of this vegetation results in the protection of wildlife and their crossings and corridors.

It is also critical to identify the types of activities that are not allowed in sensitive natural areas. All project participants should attend an orientation meeting. Contactors should receive an illustrated brochure as mentioned previously.

Using symbols and notations, construction documents should clearly communicate the project's special requirements such as sensitive natural areas and flow paths so the contractors can fully visualize and be aware of these important areas. Construction boundaries and set-aside areas define the edge of all construction related activities including on-site construction offices, staging areas, materials storage, stockpiles, haul routes, track out, and clean-up areas. Storage of materials may only be allowed in the designated construction and staging areas.

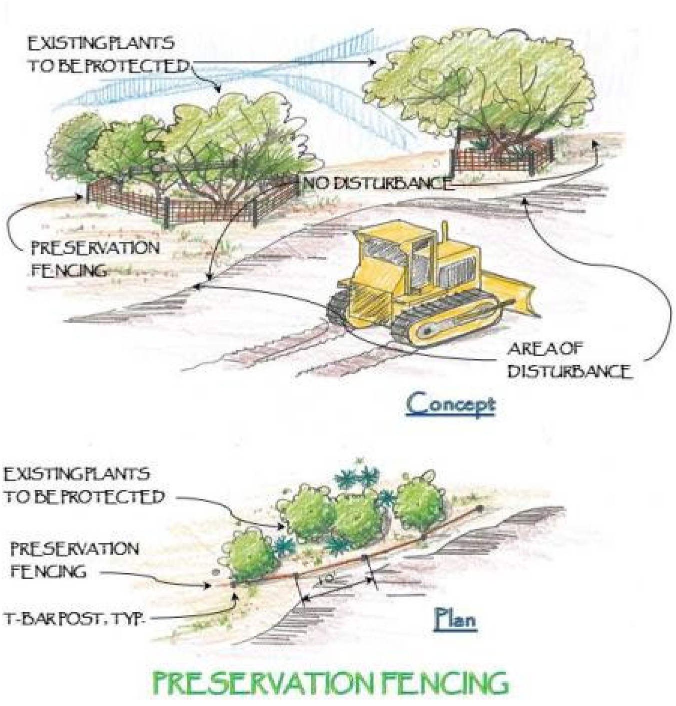


Figure 15. Fencing used to preserve and protect existing vegetation.

In general, along much of this same boundary, the plans should identify preservation fencing (Figure 15 and Figure 16). The preservation fencing is typically a highly visible material that is securely attached to posts deeply imbedded in the soil. It must be installed prior to the start of any construction activities. Properly installed, this fencing will prevent disturbance from construction equipment. Stockpiled materials should be encircled with erosion control BMPs to contain sediment runoff. The fencing should be inspected regularly to assure its function.

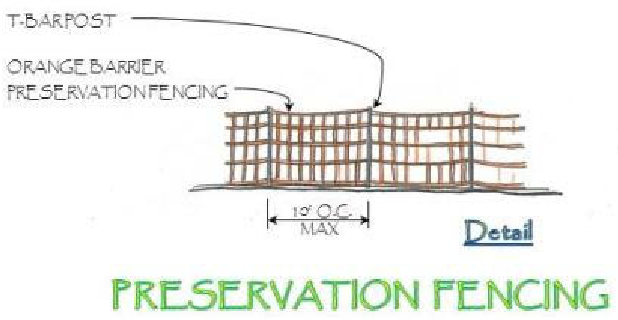


Figure 16. Detail of barrier fencing used to preserve existing vegetation.

When protecting trees, the limits of fencing should not encroach within the tree drip-line, which is the horizontal extent of the canopy branches. Trees located on the interface between construction and the sensitive natural areas or flow paths may require additional protection. Trunks may need padding or shielding to prevent or minimize damage to the bark. Construction equipment, materials, topsoil, or fill dirt cannot be located within the limit of tree drip-lines because this suffocates the root. Tree roots within the tree drip line should not be cut, but if damaged, the root ends should be smoothly cut and the exposed roots should be covered with soil or wet burlap as soon as possible.

Construction should include excavating only what is absolutely necessary to meet engineering requirements. Excavated material should not be stored in sensitive areas, but it can be used in other areas of the site to improve seeding success. Onsite monitoring should be conducted during construction to ensure sensitive natural areas are protected as planned, and post-construction monitoring should also be conducted to ensure sensitive natural areas that were impacted by construction receive restoration.

If vegetation within the natural area is damaged or removed during construction, it should be replaced with the same species. A form of irrigation will be necessary to assure survival. The greatest success results from planting native or native-adapted species (See Appendix G). To protect the soil structure, one should use hydroseed and mulch blankets immediately after site disturbance. Refer to Section 4.5, Restore Disturbed Natural Areas (Restoration), for additional information.

4.2.8 Considerations during Maintenance

The entity responsible for performing the maintenance activities must be clearly defined. Ideally, during the development process, the responsible party will be recorded in the Covenants, Conditions, and Restrictions or other binding legal document. Typically, ownership of these natural areas will be assumed by a commercial property manager, homeowner’s association, or the individual property owner. Before construction is completed, this party should meet with the development team members who can direct the proper management strategy. Specific maintenance activities will depend upon the type of vegetation present in the preserved natural areas and flow paths.

Natural areas with drainage features that are properly protected and used as part of site development should require very little maintenance. However, periodic inspections are important. Inspections should assess erosion, bank stability, sediment/debris accumulation, and vegetative conditions, including the presence of invasive species. Problems should be corrected in a timely manner.

4.2.9 Compatibility with Other GI/LID Practices

Conserving natural areas and protecting natural flow paths is compatible with the following other GI/LID practices:

- All structural GI practices.
- Disconnect and minimize impervious areas.
- Minimize disturbed areas and soil compaction.
- Restore disturbed natural areas.

4.3 Disconnect and Minimize Impervious Areas (Design)

4.3.1 General Description

Benefits	DISCONNECT AND MINIMIZE IMPERVIOUS AREAS	
REDUCES STORMWATER RUNOFF	Reduces Flooding	◒
	Improves Stormwater Quality	●
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	◒
	Shade for Passive Recreation	○
	Provides Wildlife Habitat	○
REGULATORY	Riparian Protection	○

The second goal of the LID site planning process is to disconnect and minimize impervious areas. This goal compliments the objective to preserve existing hydrology and directly affects the infiltration capacity of a site.

Traditional site development decreases infiltration by increasing the amount of impervious area, connecting impervious surfaces, and directing runoff from impervious surfaces to drainage infrastructure. Although connected impervious areas efficiently transport runoff, the negative side is these hard surfaces allow no infiltration. Flows collected from traditional site drainage systems are typically stored in retention basins until they can percolate into the substrate. This process should reduce off-site downstream damage when properly designed, but these basins often are eye-sores that trap trash and support unsightly stands of weeds. A site designed with impervious surfaces requires a much larger retention basin for stormwater storage; the larger the basin, the less available developable land. Site design including the LID practice of disconnecting and minimizing impervious surfaces greatly improves the efficiency of the site's drainage function.

4.3.1.1 Disconnect Impervious Areas

Efficient stormwater transport due to connected impervious surfaces such as roofs, roads, and driveways significantly decreases time of concentration (Tc). Simultaneously, peak runoff discharge rates and volumes quickly accumulate. As runoff from numerous impervious drainage areas converge, the combined volumes, velocities, peak runoff rates, and material, as well as chemical pollutant loads, can become hazardous. Good design disconnects impervious areas and directs runoff to pervious natural areas or flow paths, including floodplains and riparian habitat or landscaped vegetated areas. Landscape islands and medians can capture flows from parking areas, and disrupt as well as decrease the volume and velocity of the flows. Soil treatment and infiltration then occur, thereby increasing Tc, and potentially reducing pollutant loads due to filtering and infiltration. When runoff is directed to pervious areas located frequently along the stormwater flowpath within the site, the runoff carrying pollutants is treated closer to the source.

Impervious disconnection can be combined with site elements such as:

- Incorporating pervious areas into site design.
- Disconnecting downspout flows from impervious areas and directing them to discharge into pervious areas (Figure 17).
- Narrowing residential roads and considering alternative street designs (Figure 18).
- Adding alternative driveway and parking lot designs.

- Using porous materials (Figure 18).
- Reducing sidewalks or using alternative designs and materials.
- Considering clustered development and larger natural open spaces.

Figure 17. Downspout flow disconnected from impervious drive surfaces; directed to a pervious area.

Source: Seattle Public Utilities (left); Reid Park Zoo (right)

Figure 18. LID street design (left), permeable parking lot (right).

4.3.1.2 Minimize Impervious Areas

The effects of development on runoff infiltration can additionally be mitigated by reducing the amount of impervious area. This action also automatically reduces the associated runoff and pollutants. The greatest source of imperviousness in urbanized areas is the transportation network that includes roadways, sidewalks, parking, and driveways. Reduction in the building footprint is one component of minimizing impervious surfaces. When a site design achieves a reduction in impervious surfaces, stormwater runoff is decreased while infiltration and evapotranspiration opportunities are increased. Reducing impervious surfaces works best when combined with other LID planning practices.

Alternative layouts for neighborhood design will reduce the overall impervious area but can also decrease development costs (e.g., cut and fill, pavement area, drainage conveyance structures). For example, by replacing curbs and gutters with a roadside swale, the impervious surface and associated runoff volume and rate are reduced. Not only is the capital cost of curbs and gutters eliminated, but the cost of drainage structures will be as well. Meanwhile, aesthetic appeal and water quality are improved.

Individual residential lots are typically rectangular or square with direct access to the street, maximizing the impervious area. Alternative lot shapes such as flag, zero-lot-line, Zipper, or angled Zipper lots allow clustering and minimizing of developed area, reducing the impervious area and capturing additional natural area for set-aside. Shared driveways further advance these goals.

To maintain the essential hydrologic and ecological functions of a site, many different techniques for reducing the overall site imperviousness may be employed, including, but not limited to:

- Using alternative lot and street design.
- Reducing the building footprints.
- Reducing the parking area.
- Reducing setbacks and frontages.

4.3.2 Applicability

Disconnecting and minimizing impervious areas can be can be applied to any development utilizing streets, parking lots, sidewalks, and buildings. Residential, commercial (retail and office parks), and industrial sites all have opportunities to disconnect and minimize impervious areas. Most development sites have landscape bufferyard and parking lot requirements; runoff can be directed to the landscape areas.

Commercial and industrial developments have larger impervious areas that are more challenging to disconnect and minimize. Creative designers can offer unique alternative designs with improved LID values by their selection and placement of impervious materials.

Transportation projects offer unique challenges and isolated opportunities. By pairing these practices with the other LID site planning practices, as well as with structural GI practices such as swales and check dams, multiple LID objectives can be achieved. Proper placement of these elements promotes the LID objective termed as the LID treatment train.

4.3.3 Advantages

Disconnecting and minimizing impervious areas offers a number of advantages:

- Reduces runoff volume and peak rate.
- Reduces both construction and maintenance costs.
- Can be used with multiple GI/LID practices.
- Reduces development and maintenance costs.
- Enhances aesthetics and habitat.
- Improves water quality.

- Increases infiltration locally by reducing the impervious coverage of engineered conveyance systems.
- Enhances stormwater infiltration.
- Promotes soil saturation, permitting stormwater to percolate into shallow groundwater tables and, more importantly, our deeper aquifers.

4.3.4 Limitations

Any development should also consider the possible limitations to disconnecting and minimizing impervious areas:

- Local zoning standards may limit alternative roads and sidewalk design.
- Requires area for infiltration; site area may be limited.
- Porous paving systems should not be used in heavily trafficked areas.
- Porous paving systems may become clogged if not properly installed and maintained.
- Must comply with federal vehicular safety standards and local transportation standards and local ordinances.
- Development community is unfamiliar with use of LID practices and alternative site design.

4.3.5 Key Design Features

4.3.5.1 Disconnect Impervious Surfaces

- Direct flows into pervious areas.
- Combine numerous structural and planning practices to create a treatment train.
- Limit the contributing rooftop area to a maximum flow per downspout.
- Minimize use of curb and gutter systems and piped drainage systems.

4.3.5.2 Minimize Impervious Surfaces

- Evaluate traffic volumes and parking requirements.
- Consult with local fire departments and transportation departments for current regulations.
- Evaluate alternative roadway layouts.
- Minimize pavement (e.g., roads, sidewalks, driveways) widths and lengths.
- Reduce building footprints.
- Reduce yard setbacks.
- Evaluate alternative paving materials.
- Use alternative materials for patios, sidewalks, driveways.

4.3.6 Considerations during Design

Designers should evaluate the site for pervious areas that might be used to disconnect, distribute, or receive runoff, thus minimizing impervious areas. Pervious areas can be sensitive natural areas and flow paths, floodplains, riparian habitat, and required landscape areas. Disconnections to storm drain systems may be restricted based on length, slope, and soil infiltration rate of the pervious area. Minor grading of the site may be needed to promote overland flow and sediment filtering through vegetation. Directing runoff to natural low-lying areas is encouraged. Utilizing natural flow paths or drainage courses promotes the LID site planning principle of conserving natural areas and protecting natural flow paths. These concepts are illustrated in Figure 19.

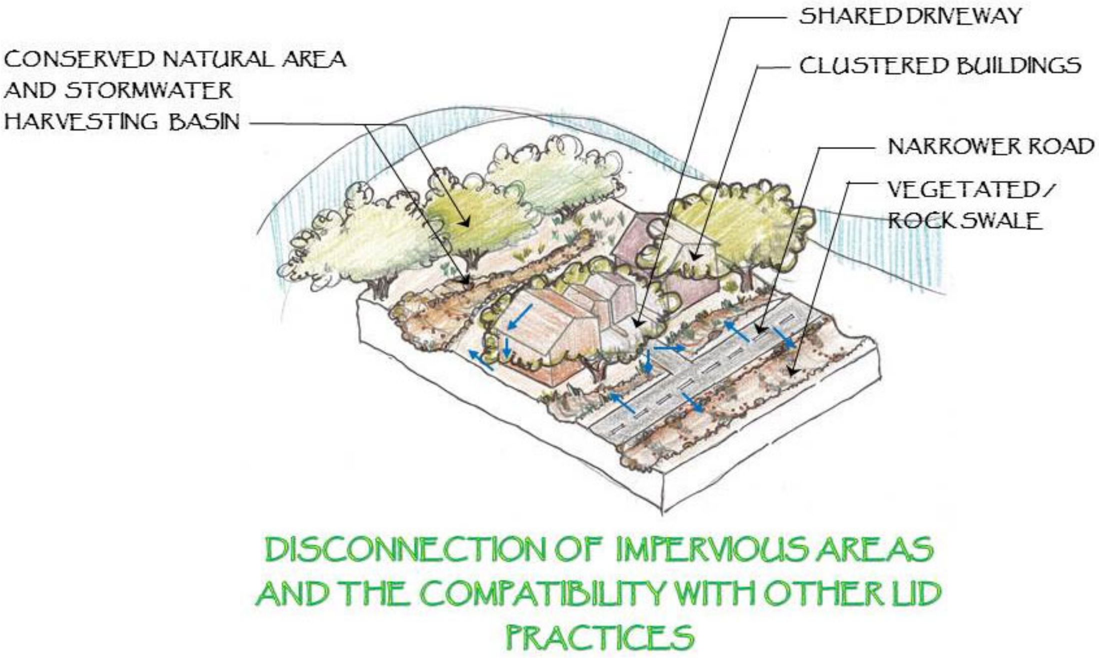


Figure 19. Use of disconnection of impervious areas with other GI/LID practices.

Paved areas can be sloped towards vegetated areas where the width of the vegetated area is dependent on the contributing area of pavement. Vegetated areas that are landscaped should be planted with native or drought-tolerant species to reduce irrigation needs. A registered geotechnical engineer should be consulted when the vegetated area is located within 15 feet of a structure so that concerns pertaining to seepage and the effect on structures can be considered and addressed.

The suitability of vegetated swales to receive runoff depends on land use, soil type, imperviousness of the contributing watershed, and dimensions and slope of the vegetated swale system. Refer to Section 5.3, Vegetated or Rock Swale, for information on how to quantify the size of a swale.

4.3.6.1 Impervious Disconnection

The infiltration area (pervious area) provided downstream of a contributing impervious area should be large enough to manage the anticipated runoff, or be one of a series of pervious areas placed to accept anticipated flows. When the contributing impervious area is discharging to a sensitive natural area or flow path, floodplain, or riparian habitat, a first stage sediment control will provide general improvement to the stormwater by providing some filtration. This vegetated area can also provide time for infiltration and should also reduce flow velocity to protect the soil structure. It is important to note that when runoff has the potential to contribute a high pollutant load, an additional level of pre-treatment should occur prior to discharge to riparian habitat and should not be directed to floodplains and natural flow paths. It is preferred that when runoff is directed to these sensitive areas, it should occur as distributary and shallow sheet flow. When swales or bioretention areas are being used as a vegetated *disconnection*, the current standards for a minimum and maximum slope can be used to ensure flow distribution.

4.3.6.2 Minimizing Impervious Surface

A site designer should consider alternatives that reduce impervious coverage within all areas of a development. Opportunities to minimize impervious surfaces can be accomplished by a reduction in the road network, parking lots, and building footprint.

A reduction in impervious surface can be achieved by reducing the road network through alternative street layouts. Clustering homes, combining driveways, and narrowing lot frontages can decrease road length by reducing the overall development area. Another approach is to lengthen street blocks and reduce cross streets. This approach necessitates the provision of pedestrian and bicycle paths mid-block through the residences to allow local neighborhood access.

Street widths are determined based on a variety of variables, such as land use, density, road type, average daily traffic, traffic speeds, street layout, lot characteristics and parking, drainage, and emergency access needs. Each variable can be evaluated to determine if it is possible to reduce the street width. The ROW should reflect the minimum required to accommodate the travel lane, parking, sidewalk/pedestrian areas, and utilities. Alternatives to the traditional paved cul-de-sac include landscaped center islands with bioretention or vegetated swales, reduction of the cul-de-sac radius, or a T-shaped hammerhead design.

Traffic calming features also offer the opportunity for stormwater reduction through the use of bioretention or vegetated swales, while also providing pedestrian safety. A network of traffic circles, chicanes, center islands, and speed humps, when combined with structural GI practices (e.g., bioretention, water harvesting basins) produce an LID treatment train.

Infiltration trenches, vegetated strips, or swales can be used to separate bike paths from roadways. Runoff from the travel surfaces can be directed to these GI practices to achieve impervious disconnection and reduction of runoff and traffic hazards.

Smaller parking lots designed with minimized standard parking space dimensions and/or one way aisles with angled parking can reduce impervious surface. Other reduction options include unpaved end-of-stall overhangs, setting aside smaller stalls for compact vehicles, and configuring or overlapping common areas like fire lanes, and loading and drop off areas. The parking footprint can be reduced by utilizing first floor indoor parking structures or underground parking.

Opportunities for shared parking should be evaluated. For example, businesses with daytime parking peaks can be paired with those with evening parking peaks, such as offices and a theatre, or land uses with weekday peak demand can be paired with weekend peak demand land uses, such as a school and church.

Driveway reductions can be accomplished by incorporating the use of alley accessed garages, front setback reductions that result in a shorter driveway, or by reducing the driveway width by allowing tandem parking (one car in front of the other).

Alternative site design can explore shared driveways that provide access to several homes; ribbon driveways, which consist of two strips of pavement with a pervious area; or some other permeable surface in between the strips and a narrowed driveway with a flared entrance for multi-car garage access.

Where possible, unnecessary sidewalks can be eliminated or reduced in width. For example often sidewalks are only necessary on one side of the street. Sidewalks that are not needed for pedestrian circulation or connectivity should be removed. Correspondingly, sidewalk width reduction can be explored when possible.

Site designers should consider using a smaller building footprint. By using taller multistory buildings and taking advantage of opportunities to consolidate services into the same space, a smaller building footprint can be achieved. A single story design converted to a two-story structure with the same floor space will eliminate 50% of the building footprint impervious area.

Site designers can look for opportunities within the site landscaping to minimize the use of impervious surface, including the use of alternative material such as canvas and screens for shade structures rather than traditional ramadas. A low retaining wall can also be used as a bench in a park or a multi-use common area, thereby combining two types of site infrastructure into one type.

In all circumstances where paving materials are used, consideration of using permeable material such as permeable pavers, porous concrete or asphalt, or gravel can be explored. Permeable materials can be considered in areas such as sidewalks, pedestrian walkways, trails, patios, and areas that have a low vehicle use, such as driveways, alleys, low use parking lots, and on-street parking.

4.3.7 Considerations during Construction

Designated pervious areas must be protected from disturbance and soil compaction during construction in order to retain their natural infiltration ability. Preservation fencing must be inspected and properly maintained. The proposed location of designed elements such as vegetated swales must also be protected from construction impacts. Often these elements are not recognized as features until the grading operations and placement of rock and vegetation; meanwhile compaction caused by machinery operation has destroyed the very soil characteristics that are supposed to provide benefits to the development.

4.3.8 Considerations during Maintenance

When disconnecting stormwater from impervious surfaces and directing it to a pervious area that is vegetated, maintenance of the vegetated area must occur to ensure continual infiltration. Sensitive natural areas or a floodplains will require inspection for erosion, rills, headcuts, or any flow obstructions, and should be restored as needed. Maintenance of riparian areas can follow the recommendations found in the *Regulated Riparian Habitat Mitigation Standards and Implementation Guidelines* (Pima County 2011).

When directing stormwater to a structural GI practice, such as bioretention or vegetated swales, the specific guidance for that feature should be followed. In general, any dead or diseased vegetation, invasive non-native species, and trash shall be removed.

When using a permeable pavement surface, the manufacturer’s maintenance specifications should be used to achieve longevity of the material. When driveways are connected to landscaped areas, maintenance and edging of the adjacent landscaping is important to allow unimpeded flow. When using a ribbon driveway, the area between the wheel tracks requires edging and maintenance, including periodic weed control. Crushed aggregate driveways may require periodic weed control and replenishment of the aggregate.

4.3.9 Compatibility with Other GI/LID Practices

Disconnecting and minimizing impervious areas can be used in combination with other GI/LID practices, including:

- Conserving natural areas and protecting flow paths.
- Minimizing disturbance and compaction.
- Alternative site design and cluster development.
- Landscape buffers and swales.
- Pervious surfaces.

4.4 Minimize Disturbed Areas and Soil Compaction (Construction)

4.4.1 General Description

4.4.1.1 Minimize Disturbed Areas

The third goal, and key component of the LID site planning principles, is to minimize disturbed areas and reduce soil compaction. Although the design process will address these issues, the area of disturbance can be reduced by decreasing the impacts during construction. Construction impacts include site clearing and grading, removal of existing vegetation, and soil disturbance often due to the need for machinery to access the entire buildable site. Minimizing the amount of disturbed areas can dramatically reduce the overall hydrologic impacts of development.

Benefits	MINIMIZE DISTURBED AREAS AND SOIL COMPACTION	
REDUCES STORMWATER RUNOFF	Reduces Flooding	●
	Improves Stormwater Quality	●
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	◒
	Shade for Passive Recreation	◒
	Provides Wildlife Habitat	◒
REGULATORY	Riparian Protection	◒

A key design factor to minimizing disturbed areas is developing a site plan to separate the disturbed areas from the natural sensitive areas. Once the site analysis is completed, project designers should work with civil and geotechnical engineers to determine the capacity of the site to support development. Some areas must be left undisturbed because they are very steep, carry large storm flows, support mature vegetation, and are unstable or require extreme measures and cost to be developed. Some areas are more appropriate for disturbance and grading; they may already be compromised or have a solid geologic foundation.

The benefit of minimizing the total disturbed areas is optimized when combined with other LID site planning principles. These may include conservation and restoration of natural sensitive areas by clustering development and connecting undisturbed areas to site storm flows to increase infiltration. Although design costs may increase slightly because more time is required to analyze and delineate these critical areas, incorporating these planning principles generally results in significant construction cost savings.

4.4.1.2 Minimize Soil Compaction

Minimizing soil compaction is the practice of protecting the existing soil quality from damage caused by development activities. Minimizing soil compaction relates directly to reducing site disturbance, site clearing, and grading and may eliminate the need for soil restoration.

Soil is a physical matrix of weathered rock particles and organic matter that supports a complex biological community. This matrix has developed over a long time period and varies throughout the county. Healthy soils, which have not been compacted, perform numerous valuable stormwater functions, including:

- Effectively cycling nutrients.
- Minimizing runoff and erosion.
- Maximizing water-holding capacity.
- Reducing storm runoff peak.
- Absorbing and filtering nutrients, sediments, and pollutants.
- Providing a healthy root environment.
- Creating habitat for microbes, plants, and animals.
- Reducing the resources needed to care for landscape plantings.

Undisturbed soil consists of pores that have water carrying and holding capacity. When soils are overly compacted, the soil storage potential and permeability is drastically reduced. The runoff response of areas with highly compacted soils closely resembles that of impervious areas, such as asphalt or concrete, during large storm events. Recent research studies indicate that compacted soils from development practices can end up as dense as concrete.

During construction, soil compaction can be deliberate in order to safely support buildings or roads, or it can be an unintentional result caused by movement of machinery to access construction areas. Compacted soils can never mimic the permeable effectiveness of untouched natural soils.

4.4.2 Applicability

Minimizing the total disturbed area of a site and soil compaction is best applied to new construction in lower density single-family developments or a clustered development that provides natural open space. This LID site practice can also be applied to larger commercial and industrial developments. Redevelopment, retrofit, or road construction have limited application, although they may be feasible depending on the site conditions.

As site area decreases and density and intensity of development increases, this LID site practice becomes more difficult to apply successfully.

4.4.3 Advantages

There are a number of advantages to minimizing soil compaction during development, including:

- Reduced runoff volume.
- Reduced peak rates.
- Water quality benefits.
- Increased infiltration capacity.
- Allows for disconnection of impervious surface.
- Provides a healthy environment for vegetation.

- Preserves drainage areas, which offers an added benefit when runoff is directed there from impervious areas.

4.4.4 Limitations

Developers should consider several possible limitations to minimizing soil compaction during development:

- Difficult to achieve on small development sites.
- Difficult to monitor and control during construction.
- New products do not have historic use data documenting applicability.

4.4.5 Key Design Features

- Identify sensitive natural areas and drainages.
- Minimize disturbance to natural areas and drainages.
- Develop site layout that reduces the construction footprint.
- Reduce disturbance through design and construction practices.
- Restrict access to those areas through fencing or signage.
- Minimize overall site disturbance and reduce limits of grading.
- Limit areas of heavy equipment.
- Avoid extensive and unnecessary clearing and stockpiling of topsoil.
- Conduct early planning and budgeting for new products to identify need for construction coordination and detailing.

4.4.6 Considerations during Design

4.4.6.1 Site Assessment to Avoid Natural Sensitive Areas

Locating the development in areas that are not as sensitive to disturbance (e.g., highly erodible soils, steep slopes) or not as vital to the hydrologic function (e.g., natural drainageway, flow paths, riparian areas, highly infiltrative soils, dense vegetation), aids in the preservation of the essential hydrology and efficiently utilizes the existing site to prevent and mitigate impacts due to stormwater runoff. Siting development away from steep slopes and on less steep terrain that is more amenable to grading and construction not only reduces the amount of disturbance but also reduces construction costs due to minimizing cut and fill procedures. Limiting the amount of clearing and grading of native vegetation also preserves the soil permeability, natural slopes, and drainages. During the site assessment, natural flow paths must be identified along with their connection to riparian areas and floodplains. Natural flow paths offer a benefit to stormwater management as the soils and habitat already function as a natural filtering/infiltrating swale.

Site assessment begins with identifying natural sensitive areas. Field reconnaissance is the primary way to access the site conditions. Once the sensitive areas are identified the information can be delineated on a site plan with topography. The areas should be marked or fenced off during construction. Existing data and maps (e.g., zoning maps, Pima County MapGuide) of natural sensitive areas can assist in identifying areas that should be left undisturbed.

4.4.6.2 Use the Natural Landscape to Reduce Limits of Clearing and Grading

To minimize development and construction impacts to soil on a site, the following design principles to the layout of newly developed and redeveloped sites can be applied:

- Site grading: Topography should be utilized to optimize the site layout and reduce the need for grading. Development envelopes should be focused in the upper elevations of a site to promote sheet flow and natural surface drainage to GI practices located at lower elevations of the site.
- Site infrastructure placement and location: When possible, the site layout should conform along natural landforms, avoid excessive grading and disturbance of vegetation and soils, and replicate the site's natural drainage patterns. Development can be located outside of designated floodplains and riparian habitats. In developed areas, grading can direct flow toward areas with high infiltration rates or to areas slated for soil improvement.
- Identify soils: Soils with high infiltration capacity can be identified with available soils maps, and the GI practices can be placed in these locations whenever possible. For previously developed areas, infiltration testing may be necessary. Development should be located on portions of the site with less permeable soils or areas where structural drains can be inserted to allow uncompacted soil volume.
- Identify erosive areas: Areas of the site where the erosive potential of the soil is high should be considered more sensitive to development and can be left undisturbed. Areas devoid of vegetation, including previously graded areas and agricultural fields, and areas of non-native vegetation where receiving waters are not present are typically suitable for development. Conversely, natural sensitive areas, natural flow paths, floodplains, and riparian areas are typically unsuitable for development.
- Identify development areas amenable to horizontal layering: In development intensive areas, identify horizontal surfaces that can accommodate water flow and capture while the paved area is supported by structural features allowing uncompacted soil below paved areas (e.g., structural soils).
- Preservation and restoration: Areas where significant native trees and shrubs are located can be identified and designated for preservation. Locations suitable for restoration and planting additional native or drought tolerant and large shrubs can also be identified. Often areas suitable for restoration are adjacent to natural sensitive areas, natural flow paths, floodplains, and riparian areas.

4.4.6.3 Develop a Soil Management Plan to Reduce Soil Compaction

Early in a project's design phase, the designer should develop a soil management plan based on soil types and existing level of disturbance, an assessment of how runoff will flow off existing and proposed impervious areas, trees and natural vegetation that can be preserved, and tests indicating soil depth and quality. The plan should clearly show the following:

- No disturbance areas: This is a designated area where soil and vegetation disturbance is not allowed. Protecting healthy, natural soils is the most effective strategy for preserving soil functions. Not only can the functions be maintained, but protected soil organisms are also available to colonize neighboring disturbed areas after construction.
- Minimal disturbance areas: These are areas that may allow some clearing, but no grading (e.g., utility lines, areas of restoration). Minimal disturbance occurs, but soil restoration may be necessary for such areas to be fully pervious after development. Minimal disturbance areas after clearing should be immediately stabilized, disked/scarified, and revegetated, and avoided in

terms of construction traffic and related activity. Minimal disturbance areas do not include construction traffic areas.

- Construction traffic areas: Construction traffic is allowed in these designated areas. Areas proposed for roads, parking lots, or building foundations are ideal areas. Soil restoration will be required if these areas are to be considered fully pervious following development.
- Topsoil stockpiling and storage areas: If these areas are needed, they should be protected and maintained. They are subject to soil restoration following development.

4.4.7 Considerations during Construction

Management of soil protection during construction activities will only be effective if it is carefully implemented, monitored, and adhered to during the entire construction process. When overlooked for a short period of time, significant damage can be done. The cost of soil remediation can be far greater than the cost of avoiding the *no disturbance areas*.

Limits of grading and disturbance can be clearly designated on the site plan, such as with a specific line type shown in the plan legend. If there are areas designated as natural sensitive areas (e.g., natural open space), riparian habitat, floodplains, and so forth, a different line type can be used and also indicated in the plan legend. It is critical that the areas are clearly delineated on the plan so the contractor is aware of the importance of not disturbing these areas with construction activities.

Limits of grading and disturbance can be physically designated at the site during construction with flagging, fencing, or other markers. Fencing is recommended for larger no disturbance areas. Flagging is recommended for smaller areas where constructing temporary fencing may be more difficult to place and could potentially harm vegetation. Delineating, flagging, and/or fencing the development envelope can help minimize unnecessary soil compaction and minimize overall disturbance. At the start of construction, no disturbance and minimal disturbance areas must be identified with signage and fenced as shown on the construction drawings.

No disturbance and minimal disturbance areas should also be protected from excessive sediment and stormwater loads while adjacent areas remain in a disturbed state.

Techniques implemented on the construction site to minimize the construction footprint should be included in the project documentation and on the construction plans. Contractors should review and comply with them while working on the jobsite. Construction site inspections should include inspection of such protocols to ensure they are maintained throughout construction.

Temporary storage of construction equipment and materials can be allowed only in designated areas and restricted in designated areas of no disturbance. Construction equipment storage can be located outside the no disturbance and minimal disturbance areas.

Mulch blankets can be used to protect soil from compaction during construction. The use of mulch or other types of load distributing matting materials can also be used to limit the effect of heavy equipment movement on the site.

Topsoil stockpiling and storage areas should be maintained and protected at all times. When topsoil is reapplied to disturbed areas it should be *bonded* with the subsoil. This can be done by spreading a thin layer of topsoil (2–3 inches), tilling it into the subsoil, and then applying the remaining topsoil. Topsoil should meet locally available specifications/requirements.

4.4.8 Considerations during Maintenance

Minimizing site disturbance and soil compaction will result in a reduction of required maintenance of a site in both the short- and long-term. Areas of the site left intact as natural sensitive areas do not typically require replacement of additional vegetation to retain function. Avoiding disturbance to sensitive natural areas benefits the short term developer and the long-term owner by minimizing time and the cost needed to maintain landscape areas and artificial surfaces.

Intact natural areas may require small amounts of occasional maintenance (typically invasive species control) to maintain function. In comparison, levels of maintenance required for hard surfaces and formal landscaped areas will increase over time. If invasive plant species are present in the existing vegetation, proper management of these areas will be required in order for the non-invasive vegetation to achieve its greatest hydrological potential. Native, or desert adapted, vegetation either retained or re-planted, will likely be healthier, and have a higher survival rate.

No disturbance areas on private property should have an easement, deed restriction, or other legal measure imposed to prevent future disturbance or neglect.

4.4.9 Compatibility with Other GI/LID Practices

Minimizing the total disturbed area of the site requires the consideration of multiple LID site practices, such as a cluster development and conserving and restoring natural sensitive areas. Combining these LID site practices serves to protect natural sensitive areas and the resources they produce by reducing site grading and maintenance required for long-term operation of a development. The following GI/LID practices can be used together:

- All structural LID practices.
- Protect and use natural flow paths.
- Conserve natural sensitive areas.
- Minimize and disconnect impervious areas.
- Minimize disturbed areas and soil compaction.
- Alternative site design; cluster development.

4.5 Restore Disturbed Natural Areas (Restoration)

4.5.1 General Description

Natural areas such as floodplains, riparian areas, and natural flow paths, provide flood attenuation through increased infiltration and storage of flood waters; support species diversity and provide wildlife habitat; and increase evapotranspiration while reducing the HIE. When these sensitive natural areas are disturbed or removed, the ecological benefits and function are lost. Restoring natural areas can re-establish these functions and benefits.

Benefits	RESTORE DISTURBED NATURAL AREAS	
REDUCES STORMWATER RUNOFF	Reduces Flooding	●
	Improves Stormwater Quality	●
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	●
	Shade for Passive Recreation	●
	Provides Wildlife Habitat	●
REGULATORY	Riparian Protection	●

4.5.2 Applicability

Restoring sensitive natural areas is applicable to all types of land development projects, whether a residential subdivision, an office park, or a commercial, industrial, or institutional use. As the density and intensity of a use increases, ease of application of this LID site practice decreases. When a site is undergoing a rezoning, expansion, or retro-fit, it is recommended to require restoration of disturbed natural areas, when applicable.

4.5.3 Advantages

The following are advantages of restoring disturbed natural areas:

- Reduces flooding.
- Reduces sediment transport.
- Improves water quality.
- Improves soil quality.
- Provides wildlife habitat.
- Reduces the HIE.
- Improves air quality.
- Increases stormwater infiltration and soil moisture.
- Can be used with multiple GI/LID practices.
- Reduces the number of engineered stormwater conveyance features.

4.5.4 Limitations

There are several possible limitations to restoring disturbed natural areas:

- Restored area(s) will require a commitment on behalf of the property owner/developer to maintain and monitor the restored area until plants are established.

- The practice is difficult to implement on smaller sites or those planned for higher density development.

4.5.5 Key Design Features

4.5.5.1 Habitat Restoration

Habitat restoration is the act of restoring ecosystem function to a degraded site. Restoration activities may include erosion control measures, soil improvements, native vegetation establishment, and invasive species control. These activities will increase the vegetation volume and diversity of a plant community, increasing the ecosystem's value as habitat for native birds, mammals, and insects. All of these improvements increase the beauty of a development and improve the quality of life for those who work or reside there.

4.5.5.2 Erosion Control Measures

To prevent sediment transport from the site it is important to initiate erosion control measures. The site design must be integrated with a series of rough-surfaced water harvesting swales, infiltration trenches, or other GI practices. These features will divert stormwater, allow its flow to slow, and permit it to infiltrate into the soil.

4.5.5.3 Soil Restoration

Soil is a living system comprised of invertebrates (mites and nematodes) and microbes (bacteria and fungi). The invertebrates and microbes work to break down plant and animal residues into a nutrient-rich topsoil that can be utilized by plant roots. When vegetation is removed, including plant roots that act to hold soil in place, wind and water erosion occurs, causing a decrease in soil infiltration, increased evaporation, and compaction. There are critical steps that can be taken to restore soil fertility and structure when degradation occurs, simultaneously providing numerous additional benefits. Simply by reducing the amount of soil and rainfall leaving the site allows the nutrients from the stormwater to begin infiltrating and rebuilding the soil. If the area is severely compacted, mechanically tilling the top 8 to 12 inches of soil prior to planting is recommended. Applying compost or mulch prior to tilling will restore organic matter to the soil prior to planting. This combined with planting of native vegetation provides much needed organic matter to encourage the reintroduction of soil macro- and microfauna into the system, improving the health of the soil. A healthy soil will help to bind and degrade stormwater pollutants, resulting in improved water quality.

4.5.5.4 Re-vegetation

Re-establishing native vegetation on a degraded site begins the natural cycle of ecosystem restoration, permitting nutrient exchange and improving air, water, and soil quality. To begin the process, it is important to select plant species appropriate for the site. This can be accomplished by selecting native species observed within adjacent natural areas (floodplains, riparian habitat or natural flow paths). If a reference plant community is unavailable, a resource that can be used to help with plant selection is Appendix B of the *Regulated Riparian Habitat Mitigation Standards and Implementation Guidelines* (Pima County 2011), and the extensive plant list included in this document in Appendix G. Installing plant species with tight-knit rooting structures (e.g., grasses), adjacent to swales will discourage soil transport by binding the soil and take advantage of the captured stormwater. As plants establish, large tree canopies will slow and soften the rainfall impact, and plants also use the stormwater for nourishment. Applying a native seed mix prior to the summer or winter rainy season will fill out the diversity; the greater the variety of native species, the more diverse the emerging habitat. Plants will require irrigation until established. Depending upon site conditions, a number of methods can be used to irrigate plants, including drip irrigation, bubblers, or commercially available time-release irrigation products. Whichever method is selected, root establishment can be encouraged by weaning plants from irrigation throughout the establishment period. Plant leaf litter, decomposing roots, and woody material will improve soil health by incorporating organic matter into the topsoil to facilitate nutrient cycling and provide mulch to reduce soil evaporation.

4.5.5.5 Invasive Species Removal

Disturbed areas and irrigated areas undergoing restoration provide ideal conditions for the establishment of non-native invasive plant species. It is critical to monitor and control the spread of noxious and/or invasive plants which compete with native plants for resources. There are numerous guidelines available and groups that are willing to provide instruction on how to control noxious and/or invasive plants.

4.5.6 Considerations during Design and Construction

The following practices should be considered during design and construction to prevent degradation of natural areas and help restore areas that have already been disturbed:

- Avoid and/or minimize impacts to existing native vegetation, especially those areas with the highest habitat value. Areas where soil and vegetation are not disturbed also provide the greatest permeability and least likelihood of erosion and will require no expenditure to protect. These areas also provide a natural seed source which can migrate into the restored areas.

- Avoid and/or minimize impacts to existing native vegetation that provides linkage and linear continuity to habitat adjacent to the project site.
- Avoid and/or minimize impacts to regulated riparian habitat.
- Avoid steep slopes and/or erosive soils.
- If soils are severely compromised, remove poor soils and replace with soil from areas where topsoil is clean of invasive plants or other deleterious materials.
- Use site-specific native vegetation in order to achieve optimal success with the least amount of supplemental water, once established. A survey of the existing plant community provides the most accurate source for selecting appropriate plant species.
- If site-specific information is not available, use native plant species to ensure greatest establishment success.
- As feasible, locate new structures and hardscape elements on previously disturbed areas or areas with poor quality habitat/vegetation.
- Reduce grading limits or building footprint size, as feasible.
- When applicable, reorient structures to minimize disturbance to floodplains, flow paths, and riparian habitat.
- For subdivisions, consider reducing the width and length of driveways and/or provide shared driveways when possible.
- Strategically locate driveways and parking areas outside areas with highest value.
- Direct stormwater runoff from impervious surfaces to existing vegetation and/or restored areas.
- If the stormwater runoff is expected to carry large amounts of pollutants (i.e., from a parking lot), it is recommended that a sand filter or other type of filter be installed between the impervious surface and existing vegetation and/or restored areas.
- Vegetation or sensitive natural areas that will be preserved in place (e.g., wash, river banks, and other watercourse buffers; riparian habitat; vegetation clusters; existing trees) should be clearly delineated with highly visible protective fencing to prevent incursion of equipment or the stockpiling of materials during construction. Fencing should be placed at the drip line of mature trees.
- Tree trunks at the fringes of protected areas near fencing should be sheathed during construction to prevent or minimize damage to the bark.
- If soils within the restoration area are compacted, mechanically till the top 8–12 inches prior to planting.
- Incorporate mulch into degraded soils prior to tillage.
- Refrain from placing decomposed granite within restored or natural areas. Decomposed granite contains fine particles that tend to clog soil pores, decreasing infiltration.
- If areas to be restored contain invasive species, remove or pre-treat invasives prior to plant installation and seeding.

- To assist with avoiding and/or minimizing impacts to regulated riparian habitat, Pima County Zoning Code Section 18.07 provides options for Modified Development Standards if certain criteria are met. The Code is available at: http://www.pima.gov/cob/pccode.shtml. Possible modifications include:
  - Reduction in minimum setbacks.
  - Reduction in minimum lot size.
  - Reduction in off-street parking.
  - Reduction in bufferyard plant quantities.
  - Other development standards may be proposed for review.

4.5.7 Considerations during Maintenance

The following maintenance practices should be considered to help restore areas that have already been disturbed:

- Remove non-native invasive plant species during the establishment period to encourage growth of installed plants and seed mix. Removal efforts are most effective during the active growing season, which in the Sonoran Desert occurs during the spring, monsoon, and fall. As native plants establish, they will outcompete invasives for resources, reducing the need for invasive species control over time.
- Monitor water use by vegetation during the hottest months (potentially April–June, as well as July–September if monsoon rains are brief or spotty). Use a commercially available water retention product or augment water if needed.
- Ensure proper root establishment by *weaning* plants from supplemental irrigation over time.
- If excessive herbivory is observed, protect new plantings with browser cages or a commercially available pest prevention product.
- Make periodic checks on water harvesting features to be sure they have not silted in or formed impermeable layers due to pollutants.
- Post signs with prohibitive language (e.g., *Riparian Restoration—No Trespass*) at public access points to discourage trespass into restored or natural areas.

4.5.8 Compatibility with Other GI/LID Practices

The following practices can be in combination with restoring disturbed natural areas:

- Conserve natural areas.
- Protect natural flow paths.
- Minimize disturbed areas and soil compaction.
- Utilize alternative site design such as cluster development.

4.6 Example of an Alternative Site-Layout

4.6.1 General Description

4.6.1.1 Cluster Development Example

Cluster development concentrates development to specific areas of a site, leaving portions of the development undisturbed as natural open space (Figure 20). Clustering allows development density while avoiding natural sensitive areas, such as steep slopes, floodplains, and riparian areas, without sacrificing the allowable development.

A goal of clustered development is to reduce the development site or disturbance area footprint. Strategies include smaller lot sizes, street layouts to reduce road pavement and area of imperviousness, alternative driveway and sidewalk designs. When choosing the development envelope for a site, ideally features such as riparian areas, floodplains, steep slopes, and highly erosive or permeable soils should be avoided. Clustered development can provide increased area for passive recreation, and open space landscaped areas can include LID site practices. Clustered development reduces the amount of impervious surfaces, reduces pressure on buffer areas, reduces the construction footprint, and provides more area and options for structural GI practices.

Figure 20. Drainage paths at a traditional site versus at an LID site that uses natural open space for drainage.

4.6.2 Considerations during Design

The previous LID site planning sections describe site design elements that collectively create a cluster development. Table 2 is a list of the site design elements and where each element is located in the previous sections. Additional site considerations have been added below that have not been previously described. Although they are not considered LID practices, consideration of these design elements should occur when planning for an alternative development.

Table 2. Index of site design elements for cluster development.

Site Design Element	Location in this Guidance
Site Area Classification	Section 4.2 Conserve Natural Areas and Protect Natural Flow Paths
Optimize the Site Layout	Section 4.2 Conserve Natural Areas and Protect Natural Flow Paths Section 4.3 Disconnect and Minimize Impervious Areas (Design)
Fit the Design to the Terrain	Section 4.2 Conserve Natural Areas and Protect Natural Flow Paths
Buildable/Non-Buildable Areas	Section 4.2 Conserve Natural Areas and Protect Natural Flow Paths
Alternative Lot Shapes	Section 4.3 Disconnect and Minimize Impervious Areas (Design)
Use Innovative Street Designs	Section 4.3 Disconnect and Minimize Impervious Areas (Design)
Reduce Roadway Setbacks and Lot Frontages	Section 4.3 Disconnect and Minimize Impervious Areas (Design)

4.6.2.1 Preservation of Canopy Trees

Many parcels of land offer an array of natural resources that developers can capitalize on and transform into desirable design features. Trees proved canopy that can shade homes, streets, parking areas, sidewalks, and paths, adding to the visual appeal of communities and helping to reduce HIE. Trees are a feature that homeowners value for their aesthetic and environmental benefits. As a result, developers are beginning to recognize that lots with mature trees often sell for more than comparable lots without such trees.

4.6.2.2 Solar Orientation

In an effort to maximize energy efficiency for homeowners, some developers are building resource-efficient communities by designing streets so lots are oriented to take advantage of passive solar design. Passive solar design optimally uses the sun’s energy for heating and cooling. During the design process, the goal is to maximize the number of lots that take advantage of solar benefits. Streets should be laid out on an east-west axis. The optimum position for passive solar design is to locate the house facade directly south; however, the axis can vary within 20 degrees of true south with minimal detrimental effect on solar gain.

4.7 Reduce the Discharge of Pollutants Using Source Controls

4.7.1 General Description

Stormwater drains from urban areas and picks up pollutants like microbiologic pathogens, heavy metals, trash, oil and grease, detergents, sediment, herbicides, pesticides, and nutrients such as nitrogen and phosphorus (Table 3; ADEQ 2013). These pollutants dissolve in stormwater or are carried downstream where the stormwater will either evaporate or infiltrate into the soil to irrigate plants or percolate further into the groundwater where it will comingle with aquifers used for drinking water. Controls of urban nonpoint sources of pollution, also known as source controls, decrease or prevent pollutants from entering stormwater. LID practices are source controls that remove a majority of these pollutants through natural processes, making this approach less expensive than traditional treatment methods or environmental clean-ups.

Provisions in the Clean Water Act require MS4s, such as cities, towns, and counties, to evaluate how to reduce the discharge of pollutants to the maximum extent practicable (40 CFR 122.26(a)(2)(iv)). The Stormwater Management Plans developed by the traditional large MS4s in Arizona include the evaluation of LID as a practice to achieve pollutant reduction in new construction, significant redevelopment, and retrofits of commercial and residential areas. Future Arizona MS4 permits are likely to include LID as a cost saving measure (EPA 2007) and to meet surface water quality standards for the designated uses of lakes and streams in Arizona (ADEQ 2009).

4.7.1.1 Reduce Discharge of Pollutants Using Source Controls

The amount of pollutants entering stormwater can be reduced by applying one, or a combination, of these source control practices:

- Replace chemicals that can become stormwater pollutants with non-toxic chemicals.
- Store and use chemicals indoors or in shelters.
- Contain pollutants exposed to rainfall or stormwater.
- Treat stormwater using GI and/or manufactured devices.

Source controls remove pollutants or keep them on site to ease management of the pollutants. Indoor structures and shelters, such as buildings, drive-through buildings, ramadas, and weather-resistant cabinets, keep potential stormwater pollutants out of the natural environment. Outdoor structures providing secondary containment including earthen berms, trench and sump systems, containment curbs, masonry walls, and concrete basins keep the stormwater on the property. GI includes the practices described in Section 5, Structural GI Practices, and Section 6, Common GI Components. Manufactured devices can support GI/LID designs and remove pollutants through sedimentation, precipitation, hydrodynamic separation, filtration, ion exchange, oxidation, and nitrification-denitrification.

Table 3. Pollutants in stormwater.

Pollutant	Origin	Discharge Source(s)	Location
Microbial pathogens	• Present in animal or dairy waste	Runoff from areas where waste has been deposited	Landscaped and natural areas, trails and walkways
Heavy metals	• Released in vehicle emissions • Released by tire wear • Brake pads • Leach from asphalt shingles	Motor vehicles, asphalt shingles	Driveways, roadways, highways, parking and storage lots, roofs
Trash	• Non-biodegradable plastics and coated paper products. Depending on storm intensity, a large variety of debris that would be classified as trash can be mobilized.	Human activities	Parking lots and roadways, sidewalks, parks, and recreation areas
Oils and Grease	• Leaks or spills from vehicles	Motor vehicles	Driveways, roadways, highways, parking and storage lots
Suspended solids	• Small particles of clay, silt, sand, other soil materials, small particles of vegetation, and bacteria	Soil erosion, motor vehicles, building materials	Deposited on impervious surfaces

Pollutant	Origin	Discharge Source(s)	Location
Nitrogen compounds	• Excess residential, agricultural, and commercial fertilizer use • Animal wastes • Plant decay • Atmospheric deposition	Turf grass, non-native ornamental landscapes	Highly managed landscapes in both residential and commercial developments
Phosphorus	• Excess fertilizer use • Decaying vegetation, such as lawn clippings and leaves • Animal waste	Maintained commercial and residential landscapes, golf courses	Highly managed landscapes in both residential and commercial developments
Oxygen demanding substances	• Natural origin • Biodegradable material or waste discharge	Excess organic waste products like lawn clippings and leaves	Landscaped areas
Toxic organic compounds	• Pesticides	Commercial, agricultural, and residential applications	Runoff from treated landscapes and agricultural areas
	• Polycyclic aromatic hydrocarbons	Motor vehicle fuel leakage and spillage, asphalt pavement, asphalt roof runoff	Roads and parking lots, runoff from buildings with asphalt roofing materials (shingles, membrane, other types)
	• Solvents	Industrial, commercial, and residential cleaners; degreasers and lubricants	

Source: Davis and McCuen 2005

4.7.2 Applicability

Strategies to eliminate waste materials and pollutants improve the triple bottom line by reducing purchasing costs as well as the liability for waste disposal and environmental clean-ups. Waste material can be replaced with less harmful products, such as converting from standard batteries to rechargeable batteries or replacing mineral oil with vegetable oil. A wide range of zero waste strategies and weather-resistant shelters and cabinets are readily available in stores and on the Internet. Containment structures, such as berms or concrete basins, keep polluted stormwater on the property where it can be used for landscape irrigation. Additionally, the stormwater can be treated and recycled or discharged to the sanitary sewer with an Industrial Discharge Permit, if needed. GI can remove the lower toxicity materials, whereas manufactured treatment devices are best suited for more toxic compounds or circumstances requiring quick removal of pollutants.

4.7.3 Advantages

- Reduces or removes nutrients, metals, trash, and sediment effectively.
- Reduces excess sediment transport.
- Tailored to site conditions and only the pollutants used at the site.
- Functions without moving parts or chemicals.
- Less expensive to build and maintain than large centralized structures or conventional treatment methods.

- Water kept on site or treated can be used to irrigate the landscape.
- Aesthetically attractive.
- Reduces liability of polluting a water body or having to clean up a polluted area.

4.7.4 Limitations

- GI/LID is not effective in removing organic solvents or larger volumes of toxic compounds.
- If non-toxic chemical replacements are not readily available, re-engineering a business or manufacturing process to develop new non-toxic chemicals or materials can have a high initial investment cost.
- Manufactured devices can be expensive to install and require routine maintenance to keep the system operational and also requires disposal of the treated materials.

4.7.5 Key Design Features

Identifying the key design features requires an assessment of the site, such as:

- Quantify the potential for pollutants to flow off the property during a rainfall event.
- Inventory the chemicals used outdoors and identify where they are stored, the volume stored, and the amount used outdoors.
- Assemble the material safety data sheets (MSDS) for each chemical.
- Review the MSDS to see if the product has a physical, health, or environmental hazard. Products with hazards are candidates for replacement.
- Determine how water flows over the property by using a US Geological Survey topographic map or Pima County MapGuide. Water flows downhill and at a right angle to the topographic lines. An alternate method of verifying where the water goes is by placing light, brightly colored objects for easy tracking, like rubber duckies, and observing where they travel during a rainstorm.
- Size the structures and practices as described in Section 3.5, Selection of Rainfall Event for Sizing GI/LID Practices, and Section 3.6, Design Flow Rates for GI/LID Conveyance Features.

4.7.5.1 Replace Pollutants with Non-toxic Chemicals

Replace toxic pollutants based on the identification of hazardous characteristics. If replacement products are not readily available, evaluate the business process to see if an alternative method or material can be employed.

4.7.5.2 Store and Use Potential Stormwater Pollutants Indoors or in Shelters

Structures providing shelter from the elements can be customized to the needs of the site. Large structures, such as buildings and drive-through buildings, are useful for activities occurring on a daily basis and where highly toxic compounds are used. Smaller-scale structures, such as ramadas, sheds, and weather-resistant cabinets (metal, concrete, or painted materials), may be more effective for sheltering occasional activities or where less toxic compounds are used.

4.7.5.3 Contain Pollutants Exposed to Rainfall or Stormwater

Secondary containment makes the job easier where business practices require outdoor activities combined with the use of pollutants. Common secondary containment structures that are designed to hold liquids include the following:

- Earthen berms.
- Trench and sump systems.
- Containment curbs.
- Masonry walls.
- Concrete structures.

The size of the containment should be large enough to hold the volume expected to be in use at the site and have sufficient free-board for rainfall events. Rainwater collecting in secondary containment should be monitored to verify it is evaporating or being pumped to the sanitary sewer or a treatment device prior to breeding vectors.

To facilitate cleaning spills and maintaining the area, the surface of the containment structure must be impervious to the pollutant. Maintenance will be required for earthen berms to be sure the surface is not eroding. Weed removal is necessary to reduce fire hazards and allow visual assessment of the integrity of the structure (i.e., no cracks or potential for leaks) (Wilson Environmental 2014). Spill kits with absorbent materials (kitty litter or absorbent pads), rolls of absorbent fibers, and a container to hold the spilled liquid(s) are recommended for leaks and spills.

4.7.6 Design Considerations

4.7.6.1 Replace Pollutants with Non-toxic Chemicals

Composting

Pruned and clipped material from plants can be composted (Begeman 2001). Removing dead organic material before it is swept into stormwater reduces the biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Both BOD and COD reduce the dissolved oxygen (DO) available for fish and aquatic insects. When DO has been removed from water bodies, fish kills occur resulting in strong foul odors, unsightly areas, and the need for removal of the additional dead organic matter and proper disposal.

Integrated Pest Management

Integrated pest management reduces the amount of pesticides in the environment preserving beneficial insects, including bees, and minimizing the amount of pesticides entering the hydrologic cycle. Long-term control of pests can be accomplished through a combination of the following methods:

- Cultural control (modify the environment to reduce the potential for pests).
- Biological control (use beneficial insects that are natural enemies of pests).
- Physical control (maintenance that blocks pests from plants).
- Chemical control (proper placement at the right time to disrupt the pest’s life cycle).
- Identify the pests and keep plants healthy so they do not attract pests.
- Install pest-resistant or well-adapted in the garden.
- Add netting or prune out branches with caterpillar tents to physically prevent pests from access to plants.

- To facilitate natural enemies of pests, provide favorable conditions to support beneficial insects or buy and release them in the garden (Arizona Cooperative Extension 2010).

Pesticides are used as a last resort after using the other methods. When the aforementioned integrated pest management techniques have not controlled the pests, select a pesticide that is biodegradable, is copper-free, and affects only the targeted pest. Apply pesticides when runoff is unlikely to occur or when weather conditions favor still air that minimizes drift from the treated area (Arizona Cooperative Extension 2000).

Use Non-Toxic Architectural Materials where Feasible

Architectural metals oxidize and are carried by stormwater into washes. Application of coatings has not been demonstrated to be effective in preventing migration of heavy metals, particularly for copper with a green patina layer (TDC Environmental 2006). The best method of avoiding the release of heavy metals into the environment is to apply these methods:

- Avoid the use of galvanized steel or copper for roofs, gutters, and downspouts.
- Avoid composite roofing materials that contain copper biocides.
- If using these materials, install treatment of roof runoff for copper.

4.7.6.2 Store and Use Pollutants Indoors or in Shelters

Pet Waste Stations

Pet owners can be encouraged to pick up pet waste by building structures to provide pet waste disposal baggies and a place to dispose of used bags. The structure contains a post and an upper section housing the bags and a lower section for a small garbage can (Figure 21).

Figure 21. Pet waste station with baggies and garbage can mounted on a post.

Design Trash Storage Areas to Reduce Pollution Contribution

Permanent trash storage areas can be paved with an impervious surface designed to prevent run-on from adjoining areas and screened or walled to prevent off-site transport of trash. Trash containers must have attached lids to prevent rainfall intrusion. Areas with high trash usage, such as those for fast food establishments, convenience stores, and high-density residential developments can install a roof or awning to reduce the potential for the lid to be left open.

Design Outdoor Material Storage Areas to Reduce Pollution Contribution

Materials with the potential to contaminate urban runoff can be:

- Placed in an enclosure such as a cabinet, shed, or other structure that prevents contact with rainfall or runoff and prevents spillage to the stormwater conveyance system.
- Protected by secondary containment structures such as berms, dikes, or curbs when the material storage area includes hazardous materials. The storage area can be paved and

sufficiently impervious to contain leaks and spills and be covered by a roof or awning to minimize direct precipitation within the secondary containment area.

Outdoor Processing Areas

Outdoor processing areas can cover or enclose areas that would be the most significant source of pollutants (Figure 22). Additional practices include the following:

- Sloped area draining to a dead-end sump or discharge to the sanitary sewer system.
- Treatment with oil-water separators and/or sediment traps.
- Re-engineering for non-toxic chemicals.
- Low level berm of concrete or asphalt to keep run-on out of the enclosure.

Figure 22. Shelter over outdoor activities with sources of pollutants.

4.7.6.3 Contain Pollutants Exposed to Rainfall or Stormwater

Vehicle Maintenance Bays

Maintenance bays (Figure 23) can include a repair/maintenance bay drainage system to capture all wash water, leaks, and spills. Drains can be connected to a sump for collection and disposal. Direct connection of the repair/maintenance bays to the stormwater conveyance system is prohibited.

Figure 23. Maintenance bay with covering and low level berm to prevent run-on.

Vehicle and Equipment Wash Areas

Areas for washing or steam cleaning of vehicles, equipment, and accessories can be self-contained with a raised concrete berm to preclude run-on and run-off and a trench covered with a grate (Figure 24). These areas may also be covered with a roof or overhang and equipped with a clarifier or other treatment device. These discharges may also be properly connected to a sanitary sewer.

Figure 24. Containment structure for vehicle washing set in gravel.

Fueling Areas

Fueling areas can be designed with the following elements:

- Paved with Portland cement concrete or equivalent smooth, impervious surface.
- Sloped to a trench and drain (add a raised berm to prevent clean run-on from enter drain), and designed to drain to a sump or manufactured device for treatment prior to discharge to sanitary sewer (Figure 24 and Figure 25).
- Built with a low concrete berm around fuel dispensing area to keep fuel spills within bermed area and dry cleanup methods are used, such as applying granular absorbent material, absorbent pads, and socks to soak up the fuel. This design requires the absorbent material to be swept up and disposed of properly.

Figure 25. Fuel station with sloped gutter leading to a sump.

- The overhanging roof structure or canopy can be:
    - Designed to extend 6.5 feet (2.0 meters) from the corner of each fuel dispenser, or the length at which the hose and nozzle assembly may be operated plus 1 foot (0.3 meter), whichever is greater.
    - Equal to or greater than the area within the fuel dispensing area's grade break.
    - Designed to drain the water from roof to a GI feature.

Design Loading Docks to Reduce Pollution Contribution

Loading docks areas (Figure 26) can be designed with the following considerations:

- Isolate drainage in the loading dock area through the use of paved berms and/or grade breaks to prevent the adjacent runoff from entering the loading area and to prevent liquid spills from discharging from the loading area.
- Include acceptable methods of spill containment such as a shut-off valve and containment areas.

Figure 26. Designs for loading docks and ramps.

4.7.6.4 Treat Stormwater Using GI and/or Manufactured Devices

Proprietary and Manufactured Devices

When the activities at the site require the use of toxic compounds in the outdoors and storage or containment is not practical, a pre-manufactured device can be installed. The selection of the device will depend up the pollutant needing treatment, average rainfall, the volume of polluted stormwater expected to be treated, the concentration of the pollutant, available land and budget, and regulatory requirements. A typical layout includes the following:

- Structure to collect the water.
- Pipes or channels to direct the water toward the manufactured device.
- Manufactured device to remove pollutants.
- Pollutant collection system.
- Port to allow the stormwater to flow out or be pumped out.

The treatment components will depend upon the pollutant present. Particulates, including floatables, can be removed through gravity separation or filtration. Gravity separation is a process were the heavier materials, like sediment, settle to the bottom and lighter materials, like plastic petroleum products and paper, float to the top. Some methods use a dynamic method of spinning the water to separate by gravity, and other methods slow the flow and allow time for the separation (Minton 2013). Filters are used to physically screen out particulates. The particles can be harmful, like metals or pathogens, or they can form a substrate where pollutants adsorb, such as oil and grease. Dissolved pollutants or extremely fine particulates, less than 10 microns, need to be removed by chemical processes such as nitrification and denitrification, volatilization, chemical precipitation, and ion exchange.

4.7.7 Considerations during Maintenance

GI practices require the removal of the settled, filtered, or precipitated material, as well as pruning the vegetation. The sediment will need to be properly disposed of, and prunings can be added to a compost. As these systems have ponded water, there is a potential for breeding vectors (e.g., mosquitoes), and they require maintenance.

For manufactured devices, follow the maintenance instructions. The materials will also need to be properly disposed of at a landfill licensed to take the treatment by-products.

4.7.8 Discharges Not Requiring Action

4.7.8.1 Air Conditioning Condensate

Air conditioning condensate is a source of dry-weather runoff. Copper pipes form a protective corrosion-inhibiting film of cuprous oxide when in contact with water. The film prevents exposure to copper sources (EPA 1999). This source of water is listed as a de minimis water source that can be discharged to waters of the United States (ADEQ 2010). Air conditioner condensate may safely be directed to landscaping for irrigation.

4.7.8.2 Fire Sprinkler System Discharges

The primary goal of fire sprinkler systems is fire control. The Clean Water Act addresses discharges from firefighting that are identified as significant sources of pollutants to waters of the United States. However, when a fire sprinkler system is being *maintained* and is the type that contains corrosion inhibitors, fire suppressants or antifreeze, the discharge should be directed to the sanitary sewer.

4.7.9 Compatibility with Other GI/LID Practices

Water quality improvements are inherent in all these practices and can be combined as needed to fit the function and aesthetic needs of the home or business interested in LID.

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5 Structural GI Practices

5.1 Introduction

Structural GI practices require construction to create features that store, infiltrate, or convey stormwater in order to mimic pre-development hydrology. Structural GI practices are appropriate for retrofits or redevelopment and alternative site design.

5.1.1 Selecting Structural GI Practices

Selection of appropriate structural GI practices depends on site-specific conditions and design intent. Figure 6 and Figure 7 listed the general benefits and functions of each GI/LID practice and can be used as a guide for their selection. When multiple design goals cannot be efficiently achieved with one type of structural GI practice, multiple GI practices can be combined in series to form a *treatment train*. Examples of effective treatment trains are shown in Figure 27 (presented in the order that runoff encounters the structural GI practices). Treatment trains tend to be most effective when enhanced pretreatment, conveyance, or storage components are required. Research has shown, however, that diminishing water quality performance is commonly experienced when practices with similar pollutant removal mechanisms are placed in series (Hathaway and Hunt 2010). In other words, the majority of pollutant removal is typically accomplished by the first practice in a series, while performance of the second practice is much lower (because it is less efficient to remove pollutants from runoff that is already *clean*).

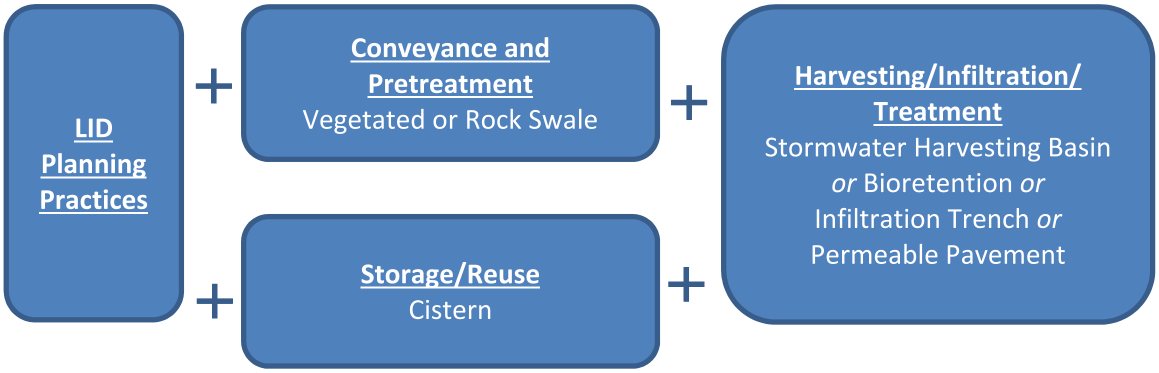
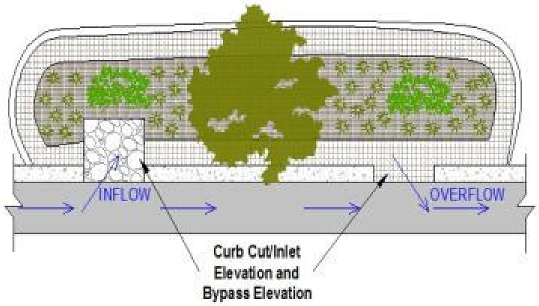
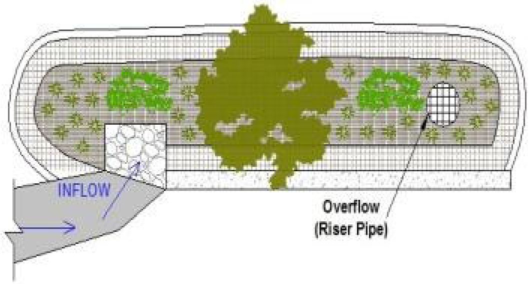


Figure 27. Example combinations of GI/LID practices with complementary design goals.

5.1.2 On-line versus Off-line Configuration

Most structural GI practices can be designed as either on-line or off-line, as described in Table 4. Design of on-line versus off-line systems is discussed for each structural GI practice presented in the following subsections.

Table 4. Comparison of off-line versus on-line configurations.

	Off-line Practices	**On-line Practices**
Definition	A specific design flow or volume is accepted or diverted into the practice. Flows or volumes in excess of the design capacity bypass the practice.	All contributing runoff is accepted and routed through the practice. Flows or volumes in excess of the design capacity overflow to the storm drainage system.
Advantages	The structural GI practice is protected from erosion or excessive sediment deposition that may be experienced during high flow events. Typically require fewer structural components.	Can exhibit higher annual performance than off-line systems because all runoff has potential to be treated.
Schematic		

5.2 Stormwater Harvesting Basins

Stormwater harvesting basins (Figure 28) are shallow earthen depressions that collect stormwater runoff and infiltrate the runoff into native soils to support planted native vegetation. They are an effective and inexpensive practice for reducing stormwater runoff volume and improving water quality. Stormwater harvesting basins can be constructed to any size and designed to a variety of areas such as a residential lot, a chicane along a residential street, or landscaping at a commercial site. The recommended ponding depth for a stormwater harvesting basin is 9 inches with 3 inches of freeboard and is designed to accommodate overflow to safely drain any excess runoff to another site managing the stormwater for beneficial use.

Benefits	STORMWATER HARVESTING BASINS	
REDUCES STORMWATER RUNOFF	Reduces Flooding	●
	Improves Stormwater Quality	●
INCREASES AVAILABLE WATER SUPPLY	Reduces Potable Water Demand	●
	Provides Storage for Future Use	○
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	●
	Provides Vegetation for Shade	●
	Improves Aesthetics	●
	Provides Wildlife Habitat	●

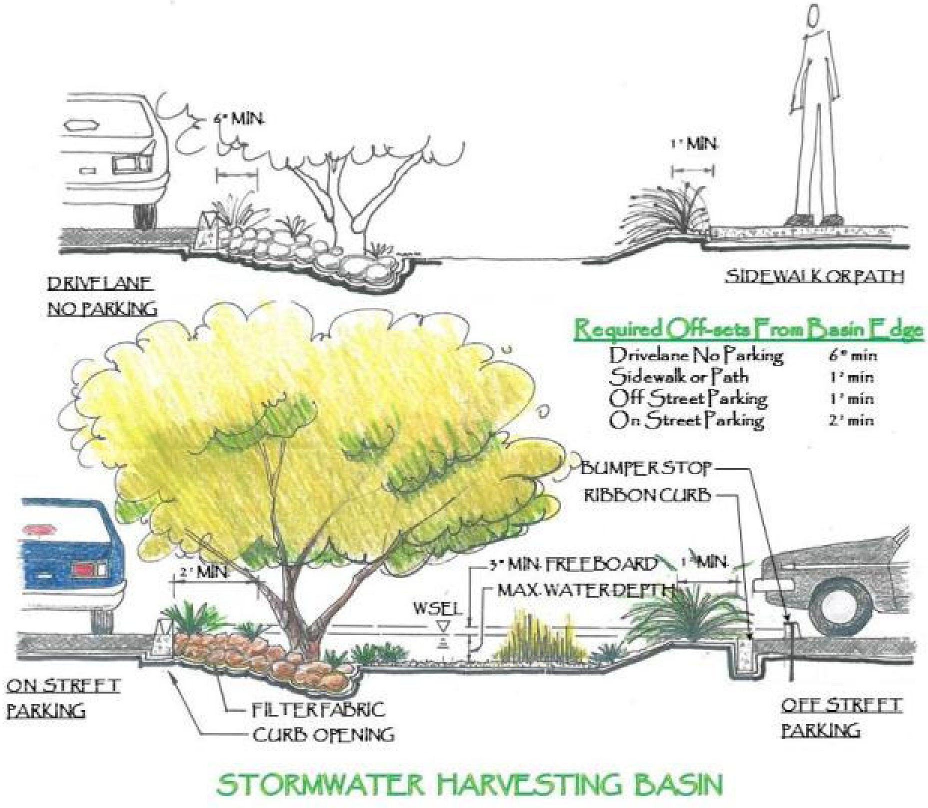


Figure 28. Stormwater harvesting basin design elements.

5.2.1 Applicable Sites

Stormwater harvesting basins (Figure 29) are appropriate within any landscaped area supporting native vegetation that will benefit from a supplemental supply of water. Stormwater harvesting basins next to impervious areas such as parking lots or rooftops or along roadways with curb openings provide cost-effective landscaped features.

Source: Grant and McCormick

Figure 29. Example stormwater harvesting basin.

5.2.2 Advantages

- Stormwater harvesting basins can retain large amounts of stormwater, reduce the amount of storm drain infrastructure required, and provide substantial cost savings (EPA 1999).
- Stormwater harvesting basins systems improve stormwater quality using physical, chemical, and biological mechanisms on the surface, in the soil and plant root, and by infiltration into subsoils.
- Stormwater harvesting basins naturally retain water for plants, thereby reducing landscape irrigation demands.
- Stormwater harvesting basins support plants that can provide multi-use benefits such as habitat, aesthetics, credit towards landscaping requirements, educational opportunities, and shade.
- Stormwater harvesting basins tend to be less expensive than bioretention because no engineered soil media and minimum structural features are required.

5.2.3 Limitations

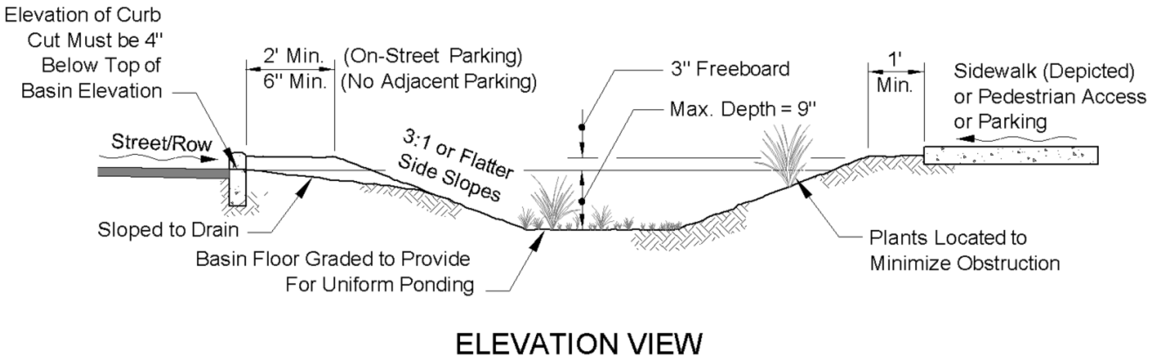
- Stormwater harvesting basins may not be applicable where infiltration is restricted by poorly-draining soils, caliche, bedrock, soil contamination, or sensitive adjacent infrastructure.
- Stormwater harvesting basins should not be used as standalone treatment practices in areas with the potential for high sediment transport. In these situations basins will quickly fill with sediment reducing their effectiveness.

5.2.4 Design Considerations

The following sections provide design considerations for the elements of a stormwater harvesting basin. For additional example details, see Appendix H.

5.2.4.1 Inlet

One or more sides of a stormwater harvesting basin may be graded to accept distributed stormwater flow along the perimeter of the basin from areas such as depressed landscaped areas within parking lots, or an inlet where flow will be concentrated before entering the basin. Sides that accept distributed flow into the basin may be earthen if the slope is no steeper than 3:1 or if the basin depth is very shallow (i.e., 4 inches or less). Slopes steeper than 3:1 should be rock-lined. Inlets where flow is concentrated, such as at a curb opening, should be rock-lined, typically with 4-inch angular rock placed in two layers on filter fabric, or have a concrete cut-off wall as illustrated in Figure 30.



Source: Pima County Regional Flood Control District 2014.

Figure 30. Roadside stormwater harvesting basin cross-section.

5.2.4.2 Sediment Trap

Figure 31. Example roadside stormwater harvesting basin.

Sediment traps or settling basins in stormwater harvesting basins should be installed when possible at inlets that receive concentrated flow. A sediment trap provides pretreatment of stormwater for incoming soil particles, oil, or other debris and facilitates removal of the materials during maintenance of the system. The sediment trap may simply be a riprapped depression at the bottom of the inlet slope that is surrounded by a compacted berm to allow for the capture of the first flush of stormwater and deposition of materials. Riprap placed in sediment traps should be laid to provide as flat of a surface as possible to aid in the removal of sediment, if necessary. Periodic inspection of the sediment trap and removal of deposited material is required to maintain the effective storage of the stormwater harvesting basin.

5.2.4.3 Designed Overflows

An overflow that safely directs stormwater to the next GI practice or to a watercourse should be designed for any stormwater harvesting basin. The most appropriate overflow for a stormwater harvesting basin is the lowest section of the berm or adjacent surface that contains the runoff that allows for ponding as designed, while providing at least the minimum freeboard relative to the other sections of a berm or adjacent surface. The overflow outlet should lead to a swale or other feature to convey overflow stormwater to another GI practice or watercourse. The inlet may also function as the overflow depression when designing an off-line basin such as a road-side basin with a curb opening.

5.2.4.4 Underdrain Systems

There are generally no underdrain systems in a stormwater harvesting basin. If site conditions restrict infiltration, the subgrade should be treated using the methods described in Section 6.10, Hydraulic Restriction Layers, or see Section 5.4, Bioretention Systems. Reducing the ponding depth and increasing the surface infiltration area may also increase infiltration.

5.2.4.5 Dewatering Duration

Stormwater harvesting basins should be designed to drain within a maximum of 48 hours or in accordance with local standards.

5.2.4.6 Soil Mix

Stormwater harvesting basins may have soil amendments or mulch added to the native soils at the top layer or basin surface; however, native soils are not replaced or mixed with engineered soils as done with a bioretention system. It is recommended that the native soils in the stormwater harvesting basin are loosened to promote infiltration and facilitate vegetative growth. Information on soil amendments and relieving soil compaction is provided in Section 6.9, Soil Amendments, and Section 6.13, Minimizing and Mitigation Soil Compaction.

5.2.4.7 Gravel Drainage Layer

There are generally no gravel drainage layers in stormwater harvesting basins. See Section 5.4, Bioretention Systems, if additional storage or infiltration capacity is needed.

5.2.4.8 Vegetation

Drought-tolerant vegetation native to the Sonoran Desert should be used. Plants that promote healthy soil biota (known as arbuscular mycorrhizal fungi) are favorable because soil microbes can improve plants’ abilities to access water and nutrients. Additionally, native vegetation that tolerates periods of inundation is appropriate for stormwater harvesting basins due to the increased amount of stormwater that will be available during the summer and winter seasons. Terraces may be designed into a basin with the inundation-tolerant vegetation planted in lower areas and other vegetation planted on higher terraces. Within any terrace or depression in the basin, vegetation will benefit by being planted on slightly elevated mounds (i.e., 2–4 inches high for shrubs, 4-6 inches high for larger trees) that will allow the roots to be saturated but the stem or trunk to remain dry during lower levels of inundation. See Section 6.14, Vegetation, for more information on plant selection.

5.2.5 Method of Sizing Stormwater Harvesting Basins

The maximum allowable ponding depth for stormwater harvesting basin should be 9 inches, with a minimum of 3 inches of freeboard from the overflow structure to the berm or the lowest adjacent finished grade surrounding the basin.

A guideline for determining the design stormwater volume is to use the runoff volume from a 1.25-inch rainfall event (about 1.0 inch of runoff for an impervious watershed) as described in Section 3.5, Selection of Rainfall Event for Sizing GI/LID Practices.

The suggested design volume may be split across several practices such as with an overflow leading from an upstream practice to a downstream practice. A design volume other than the recommended design volume may be used in sizing stormwater harvesting basins, as long as any new development meets the requirements of the Design Standards for Stormwater Detention and Retention (Pima County Regional Flood Control District 2014) and is approved by the Floodplain Administrator.

5.2.6 Considerations during Construction

- Fence off stormwater harvesting basin construction areas with construction fencing or silt fencing to prevent compaction of soils by construction equipment or traffic during construction of surrounding property.
- After excavation of existing soils, inspection should be performed to ensure that it meets design specifications. No filter fabric should be placed in stormwater harvesting basins.
- After excavation of stormwater harvesting basins, do not allow compaction by construction equipment. The soil surface of the basin should be loosened to facilitate infiltration and plant growth.

5.2.7 Considerations during Maintenance

- Inspections of the stormwater harvesting basins should be performed at least annually, and preferably after major storm events to monitor basin performance.
- Debris and sediment should be removed from sediment traps and other surfaces of the basins when significant sediment accumulation has occurred.
- Weeds and invasive plants should be removed to facilitate the growth of the planted vegetation.
- Inlet and overflow structures should be examined for damage and repaired to design specifications if necessary.
- A summary of the routine and major maintenance activities recommended for stormwater harvesting basins is shown in Table 5.

Table 5. Inspection and maintenance activities for stormwater harvesting basins.

INSPECTION AND MAINTENANCE ACTIVITIES SUMMARY	
Routine Maintenance	Remove excess sediment as needed
	Trash and debris removal
	Remove any evidence of visual contamination from floatables such as oil and grease
	Remove weeds to prevent the formation of a seed source for undesirable species
	Replace non-native vegetation with native species
	Photographs taken before and after maintenance is encouraged
	Remove sediment and debris accumulation near inlet and outlet structures
	Stabilize/repair minor erosion and scouring with gravel
Major Maintenance	Rip and re-grade bottom to mitigate ponding of water between storms or excessive erosion and scouring

Source: City of Santa Barbara 2008

5.2.8 Alternative GI Practices

- Bioretention system.
- Infiltration trench.
- Permeable pavement.
- Dry well.

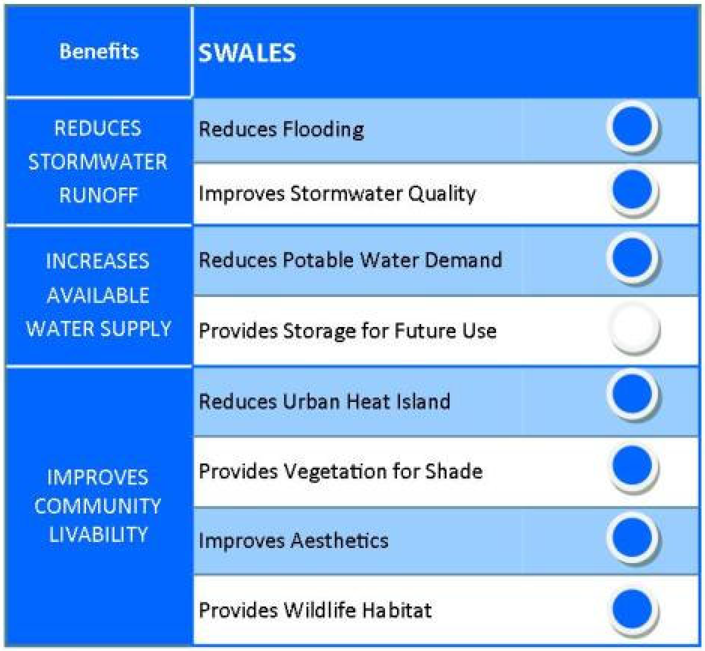
5.2.9 Compatibility with Other GI/LID Practices

Stormwater harvesting basins can be used in connection with:

- Swales.
- Overflow from cisterns.
- Soil amendments.
- Vegetation.
- Curb openings.

5.3 Vegetated or Rock Swale

Rock or vegetated swales are open, shallow channels and may have grasses or other low-lying vegetation covering the side slopes with pervious bed materials such as gravel or rock (Figure 32 and Figure 33). They are designed to slowly convey runoff flow to downstream discharge points. Vegetated swales are known to provide pollutant removal through settling and filtration in the vegetation. Swales provide the opportunity for volume reduction through infiltration and evapotranspiration, and they reduce the flow velocity in addition to conveying stormwater runoff. Where soil conditions allow, volume reduction in vegetated swales can be enhanced by adding a gravel drainage layer underneath the swale to allow additional flows to be retained and infiltrated. Where slopes are shallow and soil conditions limit or prohibit infiltration, soil ripping to break up caliche or compacted soils may be needed to minimize ponding and augment infiltration.



Benefits	SWALES	
REDUCES STORMWATER RUNOFF	Reduces Flooding	●
	Improves Stormwater Quality	●
INCREASES AVAILABLE WATER SUPPLY	Reduces Potable Water Demand	●
	Provides Storage for Future Use	○
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	●
	Provides Vegetation for Shade	●
	Improves Aesthetics	●
	Provides Wildlife Habitat	●

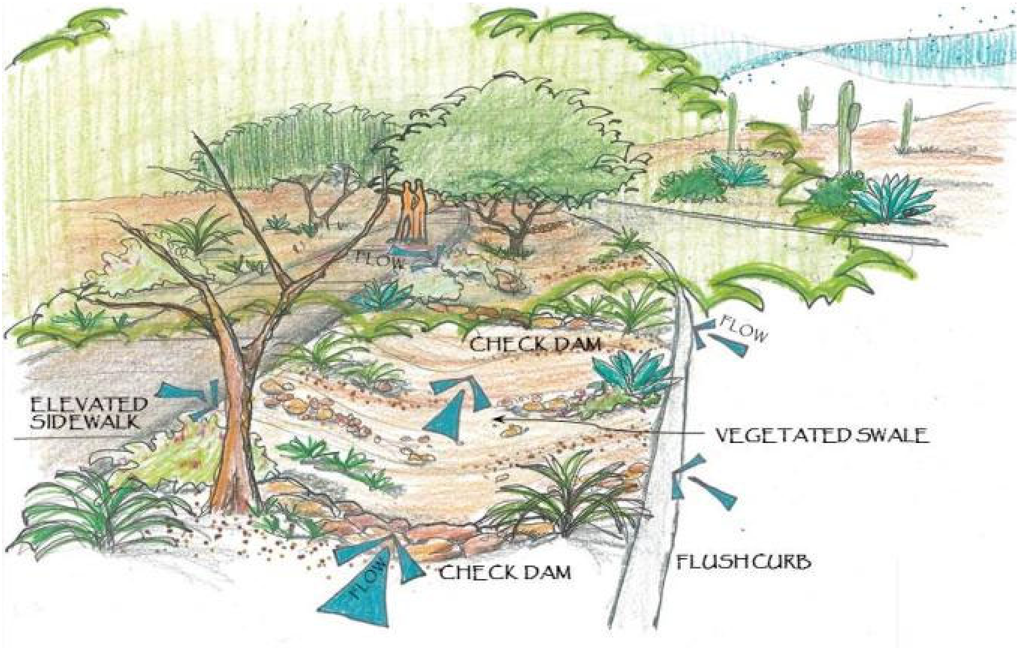


Figure 32. Elements of a vegetated swale.

Figure 33. Xeriscaped swale.

An effective swale achieves relatively uniform ponding over the bottom area and prolongs the flow path travel time (Figure 34). The rock or vegetation in the swale can vary depending on its location within a development project and is the choice of the designer, depending on the functional criteria outlined below.

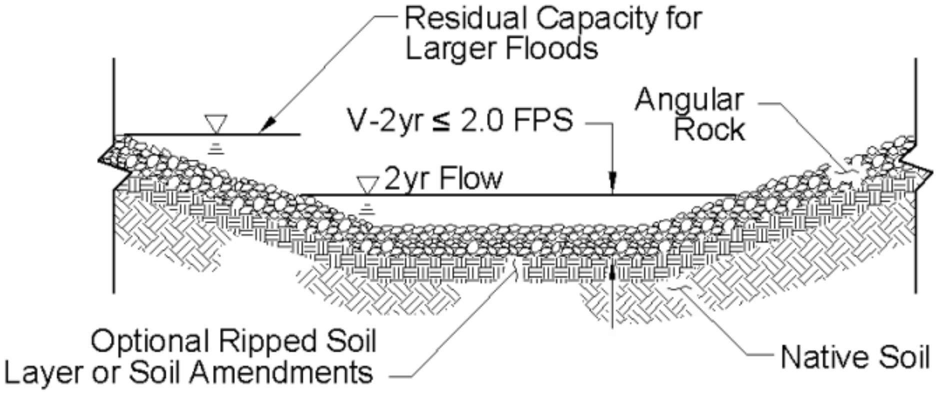


Figure 34. Cross-section of a vegetated or rock swale.

5.3.1 Applicable Sites

A swale is a conveyance feature that can be used instead of curb and gutter along streets, and as an alternative to storm drains. As appropriate, swales that are integrated within a project may use turf or other more intensive landscaping, while swales that are located on the project perimeter, within a park, or close to an open space area are encouraged to be planted with a desert plant palette using rock to reduce conveyance velocity.

A swale can be designed either on-line or off-line (see Section 5.1, Introduction, for description of these design configurations). On-line swales are used for conveying high flows, as well as providing treatment of the design flow rate, and they can replace curbs, gutters, and storm drain systems. Whenever possible, inflow should be directed towards the upstream end of the swale, but inflow can also be introduced evenly over the length of the swale. Flow velocities should be limited in on-line swales as much as possible to minimize re-entrainment of sediment and pollutants.

Off-line swales use a flow diversion structure (e.g., flow splitter) to divert flows off line to a water harvesting basin or other structural GI practice.

5.3.2 Advantages

Swales can be used as an alternative to curb and gutter drainage. By moving the drainage off the street into the swale, the street may not need to be as wide. Furthermore, swales provide infiltration and slower flows in comparison to curb and gutter, thus reducing flow rates and volumes downstream.

Because flows infiltrate within a swale, the water can be used to grow vegetation. Native and desert-adapted vegetation in particular, will thrive with deep watering during periodic seasonal rainfall.

5.3.3 Limitations

Swales transport water at a slower rate than lined channels, so they require a larger cross-section and footprint than a concrete-lined channel. In addition, on very steep slopes many check dams may be needed to maintain non-erosive flow rates.

5.3.4 Design Considerations

Below are design considerations for the elements of a vegetated or rock swale. For additional example details, see Appendix H.

5.3.4.1 Surface Cover

The surface of swales should be stabilized with rock, vegetation, or mulch to prevent erosion. Material selection depends on design flow rates, irrigation requirements, and aesthetic design preferences.

5.3.4.2 Check Dams

Obstructions installed perpendicular to the direction of flow can be used to reduce velocity and promote infiltration. Check dams can be constructed of rock, wood, or cast in place with concrete depending upon design goals. Recycled materials, such as salvaged concrete rumble, should be used when possible to reduce costs and waste, but those materials should be reinforced if high flows are predicted.

5.3.4.3 Underdrains

Underdrains are generally not required for swales if positive drainage is provided. If infiltration is the primary goal and underlying soils restrict infiltration, design the system as linear bioretention (see Section 5.4, Bioretention Systems).

5.3.5 Sizing Methodology

5.3.5.1 Swale Geometry

Side slopes of swales should be no steeper than 3:1 to reduce erosion and allow for pedestrian safety and maintenance. A 1-foot level shelf may be provided if the practice is located adjacent to sidewalks or parking areas, but it is not required. To minimize the formation of meandering flow paths and incision, bottom widths should generally be no wider than 8 feet.

5.3.5.2 Sizing Methods

The flow capacity of a swale is a function of the longitudinal slope (parallel to flow), the resistance to flow (e.g., Manning's roughness), and the cross-sectional area. The cross-section is normally approximately trapezoidal, and the area is a function of the bottom width and side slopes. Flow depth should not exceed 9 inches, and velocity in the swale should not exceed 2 feet/second, although a maximum velocity of 1 foot/second is preferred to reduce scour and transport of previously deposited fine sediment (see *Drainage and Channel Design Standards for Local Drainage for Flood Plain Management within Pima County, Arizona* for detailed maximum velocity calculation). After initial sizing, the resulting flow depth for the design flow rate is checked. If the depth restriction is exceeded, swale parameters (e.g., longitudinal slope, width) are adjusted to reduce the flow depth. Additionally, the longitudinal slope can be reduced by increasing the swale length; where space is limited, swale length can be increased by introducing meanders to the flowpath.

5.3.5.3 Energy Dissipation

The maximum flow velocity during the two-year storm event should not exceed 2.0 feet per second. This maximum water quality design flow velocity promotes settling and keeps vegetation upright.

This flow velocity can be accomplished by:

a. Increasing channel roughness using rock. Manning's n values can be estimated for larger rock using the relationship of Phillips and Ingersoll (1998):

$$n = \frac{0.0926R^{1/6}}{1.46 + 2.23\log(\frac{R}{d_{50}})}$$

where

d_{50} = Intermediate diameter of bed material (feet) that equals or exceeds that of 50 percent of the particles (i.e., median grain size).

R = Hydraulic radius at design flow depth

The equation was developed by utilizing channels with a median diameter (d50) of bed material that ranged from 0.28 to 0.36 feet.

b. Increasing channel roughness by adding roughness elements such as obstructions and vegetation. These can be estimated using methods described by Phillips and Tadayon (2006).

c. Limiting tributary areas to long swales by diverting flows throughout the length of the swale at regular intervals to water harvesting basins.

d. Splitting roadside swales near high points in the road so that flows drain in opposite directions, mimicking flow patterns on the road surface.

e. Reducing the effective slope of the swale by:

   - Installing check dams.
   - Increasing sinuosity.

A flow spreader (see Section 6.6, Flow Spreaders) should be used at the inlet so that the entrance velocity is dissipated and the flow is uniformly distributed across the whole swale. Energy dissipation controls should be constructed of sound materials such as rock, concrete, or proprietary devices that are rated to withstand the energy of the influent flows.

If check dams are used to reduce the longitudinal slope, a flow spreader should be provided at the toe of each vertical drop, with specifications described below. If flow is to be introduced through curb cuts, place pavement slightly above the elevation of the swale and vegetated areas.

5.3.6 Considerations during Construction

The following are considerations for constructing vegetated or rock swales:

- Upgradient areas need to be stabilized prior to the construction of the swale. However, if the upgradient area has not been stabilized, temporary erosion and sediment control measures should be used. Swales should be in place early in the construction schedule.

- Rough grading should be avoided in the bottom of the swale to prevent the swale from being compacted. If the soil is compacted, it should be replaced with a blend of soil and sand. It should be deep-plowed below the compaction zone. After rough grading, the swale should be fine-graded to avoid non-conformities.
- Angular rock can be placed into the swale following fine grading to provide a rough surface for slowing flows. Laying rock only one course deep and seeding with appropriate native vegetation can facilitate re-vegetation.

5.3.7 Considerations during Maintenance

The following are considerations for maintaining vegetated or rock swales:

- Inspect vegetated swales for erosion or damage to vegetation after every storm greater than 0.5 inch and at least twice annually, preferably at the end of the summer and winter rainy season. Each swale should be checked for debris and litter and areas of sediment accumulation.
- Swale inlets (curb cuts or pipes) should maintain a calm flow of water entering the swale. Remove sediment as needed at the inlet if the sediment is blocking even distribution and entry of the water, or if vegetation growth is inhibited by accumulated sediment in greater than 10% of the swale. Following sediment removal activities, replanting, and/or reseeding of vegetation may be needed for reestablishment.
- Flow spreaders should provide even dispersion of flows across the swale. Sediments and debris should be removed from the flow spreader if they are blocking flows. Splash pads should be repaired if needed to prevent erosion. Spreader level should be checked and re-leveled if necessary.
- Side slopes should be maintained to prevent erosion that introduces sediment into the swale. Slopes should be stabilized with rock and planted using appropriate erosion control measures when native soil is exposed or erosion channels are forming.
- Swales should drain within 48 hours of the end of a storm. If a gravel drainage layer is incorporated underneath the swale to promote infiltration, this layer should drain within 72 hours of the end of the storm. Till the swale if compaction or clogging occurs. The perforated underdrain pipe, if present, should be cleaned as needed.
- Vegetation should be healthy and dense enough to provide filtering while protecting underlying soils from erosion:
    - Vegetation, such as large shrubs, or trees that interfere with landscape swale operation, should be pruned.
    - Dead vegetation should be removed if they cover more than 10% of the area or when swale function is impaired. Vegetation should be replaced and established before the wet season to maintain cover density and control erosion where soils are exposed.
    - Check dams (if present) should control and distribute flow across the swale. Causes for altered water flow and/or channelization should be identified and obstructions cleared. Check dams and swale should be repaired if damaged.
    - The vegetated swale should be well maintained; trash and debris, sediment, visual contamination (e.g., oils), and noxious or nuisance weeds, should all be removed.

A summary of the routine and major maintenance activities that are recommended for swales is shown in Table 6.

Table 6. Inspection and maintenance activities for vegetated or rock swales.

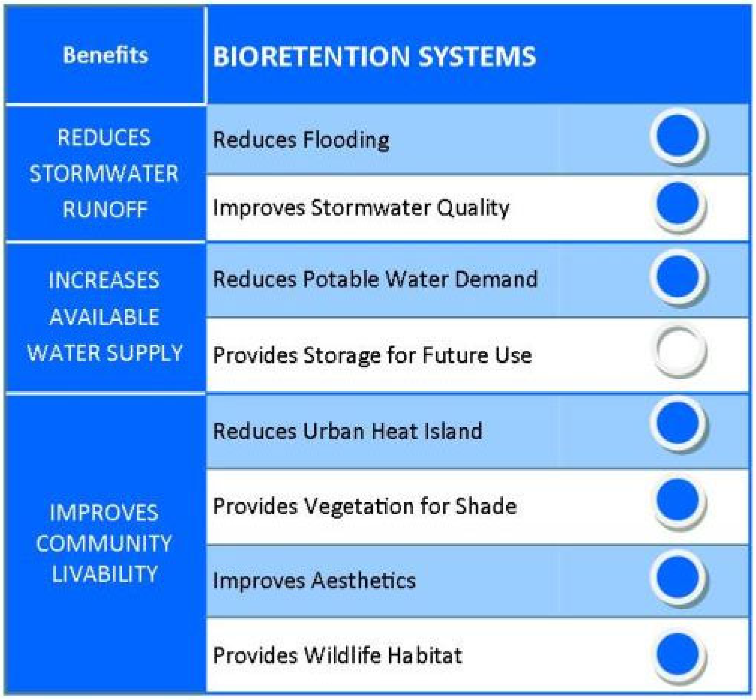
INSPECTION AND MAINTENANCE ACTIVITIES SUMMARY	
Routine Maintenance	Remove excess sediment as needed
	Remove trash and debris
	Clean underdrain (where applicable) and/or unclog outlet to eliminate standing water
	Clean and reset flow spreaders as needed to restore original function
	Remove any evidence of visual contamination from floatables such as oil and grease
	Remove weeds to prevent the formation of a seed source for undesirable species
	Replace non-native vegetation with native species
	Remove sediment and debris accumulation near inlet and outlet structures
	Stabilize/repair minor erosion and scouring with gravel
	Take photographs taken before and after maintenance
Major Maintenance	Re-grade swale bottom and reseed to mitigate ponding of water between storms or excessive erosion and scouring
	Install or replace low flow channel using pea gravel media to better convey nuisance flows

5.3.8 Compatibility with Other GI/LID Practices

Swales can be used in connection with:

- Water harvesting basins.
- Bioretention systems.
- Berms.
- Overflow from cisterns.
- Soil amendments.
- Vegetation.
- Curb openings.

5.4 Bioretention Systems



Benefits	BIORETENTION SYSTEMS	
REDUCES STORMWATER RUNOFF	Reduces Flooding	●
	Improves Stormwater Quality	●
INCREASES AVAILABLE WATER SUPPLY	Reduces Potable Water Demand	●
	Provides Storage for Future Use	○
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	●
	Provides Vegetation for Shade	●
	Improves Aesthetics	●
	Provides Wildlife Habitat	●

Bioretention is a treatment process that removes pollutants from stormwater through a combination of physical, chemical, and biological mechanisms in a vegetated soil media. One example of a bioretention system is a rain garden that is designed as a depressed area where existing soils have been excavated and replaced or mixed with improved or engineered soils to increase stormwater infiltration. Bioretention systems may either allow percolation into the subsoil or may have an underdrain that directs infiltrated stormwater to another location on the site. The planting of vegetation in a bioretention system is vital in order to facilitate long-term stormwater infiltration and to promote treatment of stormwater through biological processes in the soil media. Vegetation can also meet local planting requirements, provide aesthetic and ecosystem values, and create *visual roughness* along roadways to improve traffic calming. Hardwood mulch is appropriate for a bioretention system, but rock mulch is often substituted in arid and semi-arid environments.

Bioretention systems have a stormwater volume reduction benefit in addition to the water quality benefit, particularly when there is no underdrain, since all the runoff is retained. The effectiveness of the bioretention system will depend on the physical, chemical, and biological composition of the soil medium, depth of the soil medium, and whether a gravel drainage layer is used. The soil medium depth should typically be in the range of 16 to 36 inches, and the sub-base drainage layer is typically in the range of 6 to 24 inches of washed, coarse aggregate (although depths should be customized to suit design goals—see Section 5.4.4, Design Considerations, below). The allowable ponding depth above the soil medium surface should be in the range of 6 to 9 inches with a minimum of 3 inches of freeboard above the invert of the overflow structure (Table 7). Figure 35 shows a cross-section of a typical bioretention system with recommended depth of soil media, aggregate subbase, ponding, and freeboard.

Table 7. Recommendations for soil media, aggregate sub-base, and surface ponding depth.

Bioretention Basin Recommendations		
Recommended Depths Soil Media	**Aggregate Sub-base**	**Surface Ponding depth**
16 – 36 inches	6 – 24 inches	6 – 9 inches with 3 inches of freeboard

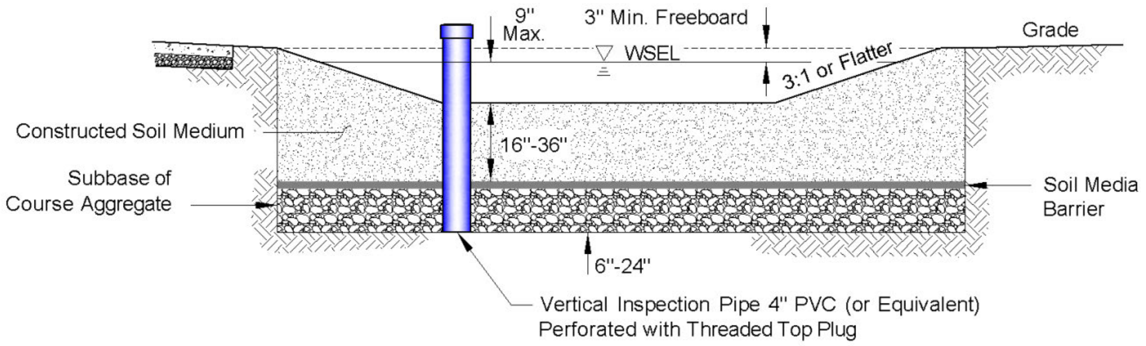


Figure 35. Cross-section of a bioretention system.

5.4.1 Applicable Sites

Bioretention systems are applicable to residential, commercial, and industrial sites and along roadways where stormwater volume reduction by infiltration or improved water quality is desired. Bioretention may be particularly well-suited for highly impervious sites where space is limited because it can provide high infiltration rates in a limited space. Caution should be used in stormwater *hot spots,* such as fueling and vehicle maintenance areas, and areas with high sediment loading to ensure that contaminated runoff is properly contained and that adequate pretreatment is provided.

Bioretention systems may be constructed in landscaped areas on commercial sites or individual lots, in neighborhood common areas, or medians in parking lots or streets (Figure 36 and Figure 37).

Figure 36. Example bioretention system.

Figure 37. Parking lot bioretention, Oxnard, CA.

5.4.2 Advantages

- Engineered soils in bioretention systems increase capacity for retaining stormwater and provide optimal soil characteristics for growing vegetation.
- Bioretention systems can retain large amounts of stormwater, reduce the amount of storm drain infrastructure required, and provide substantial cost savings (EPA 1999).
- Bioretention systems improve stormwater quality using physical, chemical, and biological mechanisms on the surface, in the soil media and plant root, and by infiltration into subsoils.
- Bioretention systems with an underdrain can continue to improve water quality after the system has reached ponding capacity by infiltrating stormwater at a faster rate than the subsoil.
- Bioretention provides multi-use benefits such as habitat, aesthetics, credit towards landscaping requirements, educational opportunities, and shade.

5.4.3 Limitations

- Bioretention systems are generally more expensive than other practices, such as stormwater harvesting basins.
- Bioretention systems allow greater infiltration of stormwater. Larger setbacks from pavement or foundations may be needed unless cutoff walls are installed to prevent the structures from water damage.

5.4.4 Design Considerations

Below are design considerations for the elements of a bioretention system. For additional example details, see Appendix H.

5.4.4.1 Inlet

Bioretention systems are well-suited to receive stormwater runoff from impervious surfaces such as parking lots, rooftops, or industrial sites. Example inlets that concentrate flow into a bioretention system include curb openings with a riprapped side slope or a concrete cut-off wall at the edge of a parking lot (Figure 38). Inflow to a bioretention system may also be distributed around the perimeter, such as a parking lot graded to a bioretention system in a curbless parking lot median. If the side slopes where inflow will occur are steeper than 3:1, then the side slopes should be rock-lined.

5.4.4.2 Sediment Trap

Sediment traps or settling basins are an essential feature of bioretention systems and are required at inlets that will receive concentrated flow. A sediment trap provides pretreatment of stormwater for incoming soil particles, oil, or other debris and facilitates removal of the materials during maintenance of the system. The sediment trap may simply be a rip-rapped depression at the bottom of the inlet slope that is surrounded by a compacted berm to allow for the capture of the first flush of stormwater and deposition of materials. The sediment trap prolongs the effective life of the bioretention system by preventing clogging and maintaining the infiltration rate of the soil medium. Periodic inspection of the sediment trap and removal of deposited material is required to maintain the capacity of the sediment trap and the effectiveness of the bioretention system.

5.4.4.3 Designed Overflows

An overflow which safely directs stormwater to the next GI practice or watercourse must be designed for any bioretention system. Some examples of designed overflows appropriate for a bioretention system are:

- An outlet to a swale at an elevation allowing for the minimum required freeboard and the maximum ponding depth for the system, or
- A storm drain in the bioretention system that discharges to another location with the invert at an elevation at the allowable ponding depth above the soil surface and below the system inlet (particularly appropriate for box planters), or
- The inlet may also function as the overflow when designing an off-line bioretention system such as a curb opening for a bioretention system in a median (see Section 5.1.2, On-line versus Off-line Configuration, for a description of off-line versus on-line systems).

5.4.4.4 Underdrain Systems

Designing a bioretention system without an underdrain provides greater stormwater retention. However, if conditions onsite inhibit or altogether restrict infiltration, an underdrain will allow the system to slowly dewater while still providing treatment. Note that substantial incidental infiltration can still occur in unlined systems with underdrains, but underdrains should be omitted when practicable to maximize plant-available water, stormwater volume reduction, and pollutant load reduction. Infiltration and plant-available water can also be enhanced by upturning the underdrain outlet to create a sump, also known as an internal water storage layer (Figure 38). This design configuration ensures greater retention while still allowing for drainage of excess runoff volume.

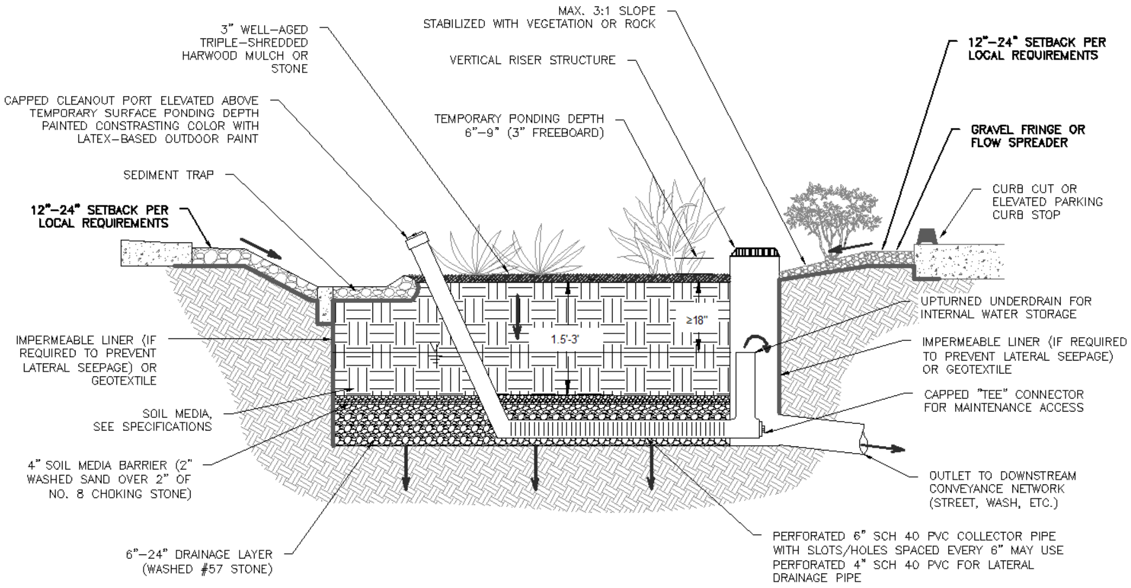


Figure 38. Example bioretention system detail.

When underdrains are used, they should be a minimum of 6-inches in diameter so that they can be cleaned without damage to the pipe and should be PVC pipe conforming to American Society for Testing and Materials (ASTM) D 3034 or corrugated high-density polyethylene (HDPE) pipe conforming to American Association of State Highway and Transportation Officials (AASHTO) 252M (City of Santa Barbara 2008). Perforations in the underdrain can be slotted or round. Although slotted underdrains can be expensive or difficult to source, the added value is a consideration because they do provide greater intake capacity and clog resistant drainage, and they reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.

The underdrain should be placed parallel to the bioretention bottom and backfilled and bedded with 6 inches of drain rock. Drain rock should form an envelope of at least 1 foot around the sides and top of the underdrain and should be comprised of washed ASTM No. 57 stone or a similar alternative that has been washed to remove all fines. See Section 5.4.4.7, Gravel Drainage Layer and Soil Media Barrier*,* for more details.

5.4.4.5 Cleanout Risers and Inspection Wells

Cleanout risers with diameters equal to the underdrain pipe should be placed at the terminal ends of the underdrain and intermediately along the length of the system (a maximum spacing of 50 feet is recommended). Terminal cleanouts can be incorporated into the flow spreader and outlet structure to minimize maintenance obstacles, and intermediate cleanout risers may also be placed in the check dams or grade control structures. The cleanout risers should be capped with a lockable screw cap. Cleanouts should extend above the temporary ponding elevation to prevent accidental damage and to prevent short circuiting of stormwater in the event that the cap is damaged or lost. PVC exposed to direct sunlight should be painted with a latex-based outdoor paint to reduce photodegradation.

Cleanout risers can also serve as observation wells. If perforations are provide in the riser, ensure that perforations terminate at least 1.5 feet below the media surface to prevent stormwater from bypassing treatment in the media.

5.4.4.6 Soil Medium Mix

The soil medium of the bioretention system should be a minimum of 16 inches and a maximum of 48 inches, depending on vegetation selection, hydrologic design, and pollutants of concern. Table 8 provides media depth recommendations to target categories of pollutants. Note that for systems without underdrains, media depth is primarily selected for vegetation and hydrologic design, rather than for pollutant removal, because additional pollutant removal is achieved via infiltration into underlying soils.

Table 8. Recommended depth of bioretention media to target pollutants of concern.

Pollutant of Concern	Removal Zone	Recommended Depth
Sediment	Surface, top 2 to 8 inches	1.5 feet
Total nitrogen	At depth in saturated layer (>2 feet)	3 feet
Total phosphorus	Top 1 to 2 feet	2 feet
Pathogens	Top 1 to 2 feet	2 feet
Metals	Top 1 to 2 feet	2 feet
Oil and grease	Surface	2 feet
Temperature	At depth	4 feet

The medium should be a mixture of sand, topsoil, and organic matter as described in Table 9. Organic matter should be well-decomposed, stable, weed-free, and can be derived from waste materials including yard debris and wood waste, but **not including manure or biosolids.**

Table 9. Recommended bioretention soil media composition.

Bioretention Soil Medium Specification	
Component	**Properties**
Sand	Conforms to ASTM C33 Fine Aggregate
Organic material	Compost or shredded hardwood mulch
Topsoil	
○ Sand (2.0–0.050 mm)	75%–85% weight
○ Silt (0.050–0.002 mm)	0%–10% by weight
○ Clay (less than 0.002 mm)	0%–5% by weight [1]
○ Organic matter	1.5%–5% by weight
○ pH	5.5–7.5 (NOTE: pH can be corrected with soil amendments if outside acceptable range)
○ Magnesium (Mg)	Minimum 32 parts per million (ppm) (NOTE: magnesium sulfate can be added to increase Mg)
○ Phosphorus (Phosphate–P_20_5)	Not to exceed 15 ppm
○ Potassium (Potassium oxide–K_20)	Minimum 78 ppm (NOTE: potash can be added to increase K)
○ Soluble salts	Not to exceed 500 ppm
○ Cation exchange capacity	≥5 milliequivalents (meq)/100 gram (g) of dry soil

Adapted from Low Impact Development Center 2010.

5.4.4.7 Gravel Drainage Layer and Soil Media Barrier

A washed gravel drainage layer should be placed below the soil medium to increase the infiltration capacity of the bioretention system and provide temporary water storage for plants. The depth of the gravel drainage layer should be in the range of 6 inches to 24 inches. Research recommends a gravel depth of 24 inches to provide water storage for deep-rooting desert plants, regardless of whether an underdrain is specified. Low density aggregate such as expanded slate or expanded shale can be substituted for washed gravel in systems without underdrains to allow greater root penetration. All gravel or aggregate should be thoroughly washed and free of fines prior to arriving onsite to prevent clogging of the subsoil interface.

The soil medium should be separated from the gravel drainage layer by a soil media barrier to prevent migration of the soil medium into the voids of the gravel while maintaining proper drainage. The soil media barrier should consist of approximately 2 inches of washed sand over approximately 2 inches of ASTM No. 8 stone (also known as *choking stone*). Filter fabric is sometimes used to separate soil medium from the gravel drainage layer, but filter fabric is generally not recommended because it is prone to clogging over time, may prevent percolation into the subsoil, and may prevent plant roots from reaching water available at depth.

5.4.4.8 Vegetation

Drought-tolerant vegetation native to southern Arizona should be used. Additionally, native vegetation that tolerates inundation is appropriate for bioretention systems due to the increased amount of stormwater that will be available during the summer and winter seasons. Terraces may be designed into a bioretention system with plants tolerant of inundation in lower areas and non-inundation-tolerant plants on higher terraces. Within any terrace or depression in the bioretention system, vegetation will benefit by being planted on mounds (i.e., 2-4 inches high for shrubs, 4-6 inches high for larger trees) that will allow the roots to be saturated but the stem or trunk to remain dry during lower levels of inundation.

5.4.5 Method of Sizing Bioretention

The maximum allowable ponding depth for a bioretention system should be 9 inches, with a minimum of 3 inches of freeboard from an overflow structure to the berm or the lowest adjacent finished grade surrounding the system. The bioretention system should be designed to drain within 48 hours.

As described in Section 3.5, Selection of Rainfall Event for Sizing GI/LID Practices, a guideline for the design stormwater volume is to use the runoff volume calculated from a 1.25 inch rainfall event based on the drainage area to the GI practice. This runoff volume can be determined by the Soil Conservation Service (SCS) Curve Number equation using the PC-Hydro Curve Number values. For a highly impervious drainage area, this volume can be approximated as the runoff volume from 1 inch of runoff depth multiplied by the drainage area.

The suggested design volume may be split across several practices with an overflow leading from an upstream practice to a downstream practice. A design volume that is different may be used in designing a bioretention system, as long as any new development meets the requirements of the *Design Standards for Stormwater Detention and Retention* (Pima County Regional Flood Control District 2014) and is approved by the Floodplain Administrator.

The bioretention system should be sized using the design stormwater volume (V_{design}, Section 3.5, Selection of Rainfall Event for Sizing GI/LID Practices) with the limiting infiltration rate, k (inches/hour); depth of soil medium, d (feet); the porosity of the soil medium, n;, the allowable ponding depth, p (feet); and whether the bioretention system has an underdrain.

For bioretention systems without an underdrain, the limiting infiltration rate should be taken as the subsoil layer. If infiltration is to be considered in the size of the bioretention system, the infiltration rate of the subsoil must be measured. The effective infiltration rate of the bioretention system can be expected to be significantly lower than small-scale measured infiltration rate and reduction factors should be applied to the measured infiltration rate for a conservative design. The duration of the infiltration rate is taken as the storm duration (assumed to be 3 hours), because the runoff volume is only available for capture until soon after the storm has ended and subsequent infiltration will not reduce the required area to contain the design volume.

The minimum required area for the bioretention system with an underdrain can be found as:

$$A = \frac{V_{design}}{(d_s \cdot n_s) + (d_g \cdot n_g) + p + d_{in}}$$

Where,

V_{design} = Design stormwater volume (cubic feet)
K = Effective infiltration rate (inches/hour)
d_s = Depth of the soil medium (feet)
n_s = Porosity of the soil medium (dimensionless)
d_g = Depth of the gravel layer (feet)

n_g = Porosity of the gravel layer (dimensionless)

p = Allowable ponding depth (feet)

d_{in} = Depth of infiltration (feet) calculated as

$$d_{in} = k\left(\frac{p + d_g + d_s}{d_g + d_s}\right) \cdot 3hrs \cdot (1ft/12in)$$

k = Effective infiltration rate of the subsoil (inches/hour)

3 hours = Assumed storm duration and approximate time of runoff.

The effective infiltration rate can be assumed to be zero if the infiltration rate of the subsoil is not available.

If an underdrain is used with the bioretention system, the infiltration rate of the soil medium should be taken as the limiting infiltration rate. A laboratory soil test should be performed on the soil medium with the soil compacted to field conditions. Reduction factors will need to be applied to the measured infiltration rate for it to be sufficiently conservative and used as the effective infiltration rate. The area of the bioretention system can be found using the same equation as the system without an underdrain.

5.4.6 Considerations during Construction

The following should be considered when constructing bioretention systems:

- Bioretention system construction areas should be fenced off with construction fence or silt fence to prevent compaction of soils by construction equipment during construction of surrounding property.
- After excavation of existing soils, inspection should be performed to ensure that the bioretention system meets design specifications. No filter fabric should be placed at the bottom of the bioretention system or on top of the gravel drainage layer. If an underdrain pipe is used, it should be surrounded by washed gravel.
- Gravel must be washed and free of fines before being placed in the bioretention system.
- Once gravel drainage layer and soil medium have been placed, no compaction should occur to the soil medium from construction equipment.

5.4.7 Considerations during Maintenance

- Inspections of the bioretention system should be performed at least annually, and preferably after major storm events.
- Debris and sediment should be removed from sediment traps and other surfaces of the bioretention system when significant accumulation has occurred.
- Weeds and invasive plants should be removed to facilitate the growth of the planted vegetation.
- Inlet and outlet structures should be examined for damage and repaired to design specifications if necessary.

5.4.8 Alternative GI Practices

- Stormwater harvesting basin.
- Infiltration trench.
- Dry well.

5.4.9 Compatibility with Other GI/LID Practices

Bioretention systems can be used in connection with:

- Swales.
- Overflow from cisterns.
- LID site planning practices (e.g., downspout disconnection).
- Vegetation.
- Curb openings.

A summary of the routine and major maintenance activities recommended for bioretention systems is shown in Table 10.

Table 10. Inspection and maintenance activities for bioretention systems.

INSPECTION AND MAINTENANCE ACTIVITIES SUMMARY	
Routine Maintenance	Repair small eroded areas and ruts by filing with gravel. Overseed bare areas to establish vegetation
	Remove trash and debris and rake surface soils to mitigate ponding.
	Remove accumulated fine sediments, dead leaves, and trash to restore surface permeability.
	Remove any evidence of visual contamination from floatables such as oil and grease.
	Eradicate weeds and prune back excess plant growth that interferes with facility operation. Remove non-native vegetation and replace with native species.
	Remove sediment and debris accumulation near inlet and outlet structures to alleviate clogging.
	Clean and reset flow spreaders (if present) as needed to restore original function.
	Mow routinely to maintain ideal grass height and to suppress weeds.
	Periodically observe function under wet weather conditions.
Major Maintenance	Repair structural damage to flow control structures including inlets, outlets, and overflow structures.
	Clean out under-drain if present, to alleviate ponding. Replace media if ponding or loss of infiltrative capacity persist and re-vegetate.
	Re-grade and re-vegetate to repair damage from severe erosion/scour channelization and to restore sheet flow.
	Photographs taken before and after major maintenance are encouraged.

Source: City of Santa Barbara 2008

5.5 Infiltration Trenches

An infiltration trench (Figure 39) is a channel-like subsurface excavation that has been filled with gravel to provide large pore spaces for stormwater to infiltrate. An infiltration trench may have the purpose of retaining stormwater for infiltration into the subsurface, or it may have a longitudinal slope designed to convey stormwater to another location similar to a swale. An infiltration trench may have a perforated pipe underdrain system similar to a bioretention system. Infiltration trenches can be effective in reducing stormwater volume and improving water quality by capturing sediment loads. It is recommended that some pretreatment of the stormwater is provided upstream (e.g., filter strips) in order to prevent clogging of infiltration trenches by sediment over time.

Benefits	INFILTRATION TRENCHES	
REDUCES STORMWATER RUNOFF	Reduces Flooding	●
	Improves Stormwater Quality	●
INCREASES AVAILABLE WATER SUPPLY	Reduces Potable Water Demand	◒
	Provides Storage for Future Use	○
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	◒
	Provides Vegetation for Shade	◒
	Improves Aesthetics	◒
	Provides Wildlife Habitat	◒

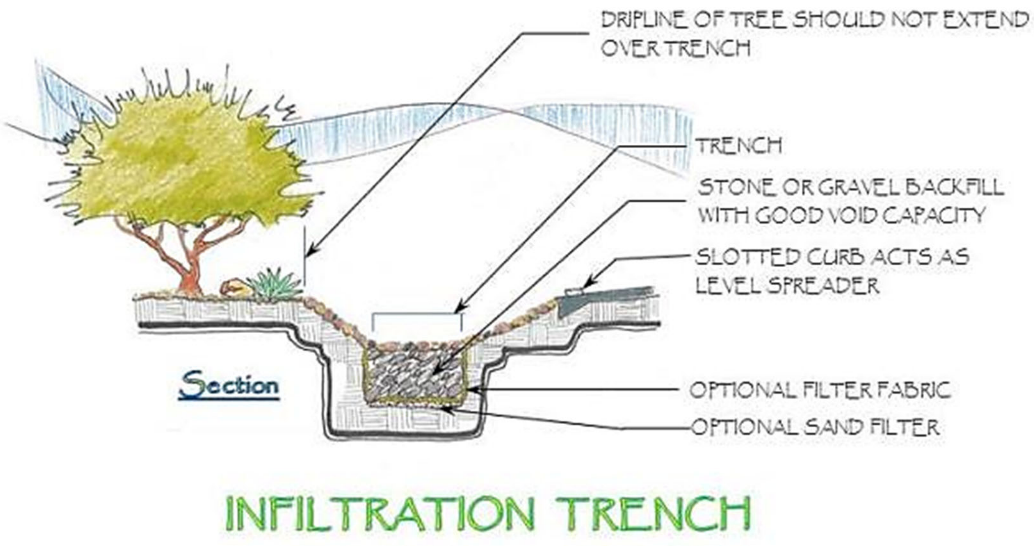


Figure 39. Example infiltration trench design with xeriscape filter strip.

5.5.1 Applicable Sites

Infiltration trenches (Figure 40) are applicable to most commercial, industrial, and high-density residential sites. They are generally not as effective for single-family residential sites because they are generally higher in cost than simple stormwater harvesting basins and not as effective in growing vegetation. However, due to the additional storage capacity in the porous gravel material, infiltration trenches may be an appropriate choice for sites with high impervious area and limited space for implementation of GI practices.

Source: Laura Mielcarek

Figure 40. Infiltration trench.

A geotechnical investigation should be performed for the site before an infiltration practice such as an infiltration trench is installed. Infiltration trenches require a minimum infiltration rate of 0.5 inches/hour (City of Santa Barbara 2008), and a site should be selected with a permeable subgrade that will allow this infiltration rate. For infiltration trenches, an underdrain system may be used if the infiltration rate is too low. The depth to bedrock is recommended to be at least 4 feet from the bottom of the infiltration trench (State of Michigan 2008). The geotechnical report should address the slope stability on sites with a slope greater than 7% (City of Santa Barbara 2008). Pretreatment also needs to be used for sites that are *hot spots* or areas with high traffic or potentially hazardous materials (gas stations and some industrial operations). Infiltration trenches may be appropriate for larger drainage areas than dry wells, which are generally recommended for drainage areas of less than one acre.

5.5.2 Advantages

- Infiltration trenches may increase storage capacity for retention or conveyance due to the gravel drainage layer, which may be up to 4 feet deeper than the surface of a swale.
- Can be an effective use of space for maximizing storage of stormwater.
- Can reduce ponding concerns, if located within a stormwater harvesting basin.

5.5.3 Limitations

Vegetation may not be grown on the infiltration trench, unlike a stormwater harvesting basin or bioretention system.

5.5.4 Design Considerations

Below are design considerations for the elements of an infiltration trench. For additional example details, see Appendix H.

Infiltration trenches may have a maximum depth of 4 feet deep and a minimum width of 1 foot.

5.5.4.1 Inlet

The top of an infiltration trench should have the gravel drainage layer exposed at the surface with the surrounding area graded to it, similar to a stormwater harvesting basin. Pretreatment of stormwater for sediment is recommended to maintain the storage capacity of the gravel drainage layer in the infiltration trench, and the surrounding area should be graded towards the infiltration trench with a slope of 3:1 or flatter. Some appropriate types of pretreatment in the surrounding area are xeriscaped filter strips or sediment traps. Decomposed granite should not be used in the areas surrounding the infiltration trench, because it decomposes into clay and will clog the infiltration bed over time.

5.5.4.2 Designed Overflows

An overflow should be designed for any infiltration practice that is *on-line* or an area graded to flow through it. An infiltration trench can have an overflow swale or an underdrain system discharging to another location, but surface overflow tends to be more advantageous because it eliminates the need to trench and backfill pipes. The bottom of the infiltration trench should be relatively flat, but it may have a longitudinal slope of up to 3% to facilitate drainage at an overflow (City of Santa Barbara 2008).

5.5.4.3 Gravel Drainage Layer

The stone aggregate in infiltration trenches should be uniformly graded, clean-washed, and contain 40% void capacity such as 1.5- to 3-inch gravel or AASHTO No. 3 aggregate (State of Michigan 2008).

5.5.4.4 Underdrain Systems, Clean-out Risers, and Observation Wells

An underdrain system may be used with infiltration trenches, if necessary, to facilitate drainage in soils with poor permeability. A perforated PVC pipe that is a minimum of 6 inches in diameter may be placed in a layer of washed gravel with the outlet at an acceptable point of discharge. Clean-out risers should be installed at the terminal ends, and at least every 50 feet along the underdrain length. If no underdrain is specified, it is recommended that a perforated pipe (4–6 inches in diameter) with a removable cap be used as an observation well to identify the water surface level in the infiltration trench. For more information see Section 5.4, Bioretention Systems, for underdrain and clean-out design details.

5.5.4.5 Vegetation

The planting of vegetation next to the infiltration trench or dry well is encouraged so that the roots of the vegetation may utilize the infiltrated stormwater, as long as the location of the vegetation does not inhibit regular maintenance of the infiltration trench or dry well. No vegetation is planted within the infiltration trench. See Section 6.14, Vegetation, for additional information.

5.5.5 Sizing Methodology

The infiltration rate of the subsoil should be measured in order to size infiltration practices without an underdrain. The effective infiltration rate of the system should be expected to be substantially lower than a small-scale test of the infiltration rate. The duration of the infiltration rate is taken as the storm duration (assumed to be 3 hours), because the runoff volume is only available for capture until soon after the storm has ended and subsequent infiltration does not increase the capacity to contain the design volume.

The required area for an infiltration practice based on the design volume can be found as:

$$A = \frac{V_{design}}{(d_g \cdot n_g) + p + d_{in}}$$

Where,

V_{design} = Design stormwater volume (cubic feet)

d_g = Depth of the rock, stone or gravel layer (feet)

n_g = Porosity of the rock, stone, or gravel layer (dimensionless)

p = Allowable ponding depth (feet)

d_{in} = Depth of infiltration calculated as

$$d_{in} = k\left(\frac{p + d_g}{d_g}\right) \cdot 3hrs \cdot (1ft/12in)$$

k = Effective infiltration rate of the subsoil (inches/hour)

3 hours = Assumed storm duration and approximate time of runoff

5.5.6 Considerations during Construction

- Construct the infiltration practice after construction of the surrounding site if possible, and avoid sediment deposition in the infiltration bed by preventing inflow during construction.
- Prevent heavy equipment from traveling over the site of the infiltration bed by fencing it off during construction of the surrounding site.
- Do not compact the underlying soils once the infiltration trench or dry well has been excavated.
- The infiltration trench or dry well may be lined with geotextile fabric before placement of the gravel to prevent fine soil particles from filling the voids in the coarse aggregate.
- The coarse aggregate should be covered with filter fabric during construction to prevent loose sediment from entering the system, and the filter fabric should be removed following construction.

5.5.7 Considerations during Maintenance

- Infiltration trenches and other infiltration practices should be inspected at least annually and preferably after large storm events.
- Debris or excess sediment that has accumulated at the surface of the system should be removed.
- If infiltration rates have decreased substantially, major maintenance may be performed by removing, cleaning, and replacing the top gravel layer or removing the gravel and replacing any clogged filter fabric.

- See Section 5.2, Stormwater Harvesting Basins and Section 5.4, Bioretention Systems, for recommended maintenance activities and frequencies.

5.5.8 Alternative GI Practices

The following are other practices that can be used in lieu of infiltration trenches:

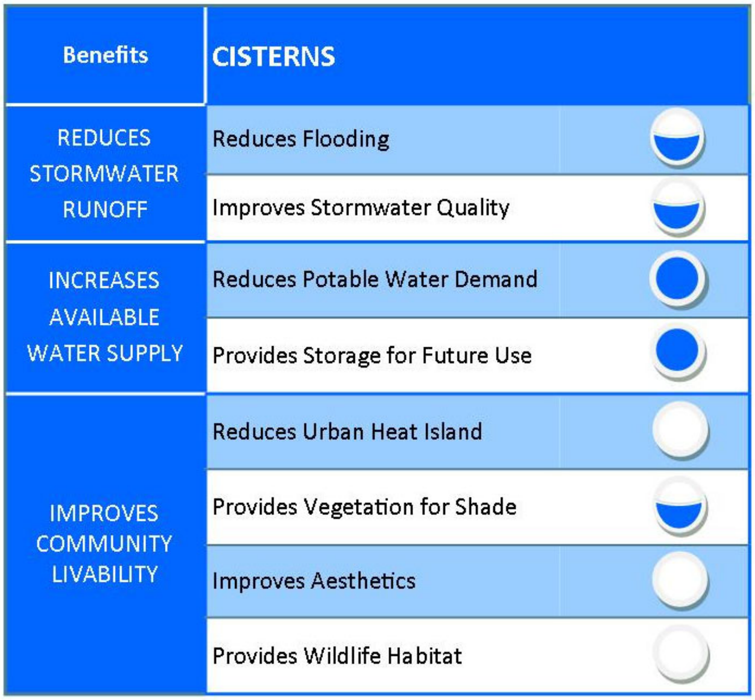
- Stormwater harvesting basins.
- Bioretention systems.
- Permeable pavements.
- Dry well.

5.5.9 Compatibility with Other GI/LID Practices

Infiltration trenches can be used in connection with:

- Swales.
- Overflow from cisterns.
- LID planning BMPs (e.g., disconnected downspouts).
- Soil amendments.
- Vegetation.
- Curb openings.

5.6 Cisterns



Benefits	CISTERNS	
REDUCES STORMWATER RUNOFF	Reduces Flooding	◒
	Improves Stormwater Quality	◒
INCREASES AVAILABLE WATER SUPPLY	Reduces Potable Water Demand	●
	Provides Storage for Future Use	●
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	○
	Provides Vegetation for Shade	◒
	Improves Aesthetics	○
	Provides Wildlife Habitat	○

Harvesting rainwater from rooftops in cisterns provides a high quality renewable source of water that reduces demand for potable water. Storing rainwater in cisterns and rain barrels (Figure 41) provides a source of water for many non-potable uses including irrigation during dry months when no rainfall may occur, or indoor uses such as flushing toilets. Cisterns may be corrugated metal, plastic, or concrete, and hold several thousands of gallons, while rain barrels are generally plastic and may hold fifty to a hundred gallons.

It is recommended that cisterns are placed above ground to use the head to supply water when low pressure is adequate, such as for many irrigation applications. If cisterns are placed below ground or the water will be distributed indoors, a pump will be necessary to supply water. Unused septic tanks are typically suitable for underground cisterns. The use of a pump, or any indoor use of cistern water that will be connected to the municipal supply will require backflow prevention. Cistern volumes cannot be counted to mitigate the flood control requirement in the *Design Standards* *for Stormwater Detention and Retention* due to the variation in water level and stormwater retention volume available in cisterns at any given time (Pima County Regional Flood Control District 2014).

5.6.1 Design Considerations

Below are design considerations for cisterns. For additional example details, see Appendix H.

- Cisterns should be sized based on the draining roof area and a design rainfall depth. It is recommended that a cistern should have a minimum volume of 1.2 inches of runoff multiplied by the draining roof area. See Section 3.5, Selection of Rainfall Event for Sizing GI/LID Practices, for details.
- It is recommended that cisterns are placed above ground to use the head provided by the cistern water level to supply water. If cisterns are placed below ground, a pump is necessary to supply water.
- Any openings to the cistern must be screened to prevent mosquitos from breeding. A screened rainhead is sufficient for the inlet. It is recommended that the outflow pipe be screened or have a lid/flap that only opens when outletting water to prevent insects from entering.
- Cisterns must be opaque and have a lid that does not allow sunlight into the tank to prevent the growth of algae.
- All cisterns should have a lid or an access hatch (manway) that allows for access to perform routine maintenance. Access manways should be labeled as confined spaces and locked accordingly.
- The location of all underground utilities must be identified when an underground tank will be used.
- A pump will be necessary for any water use applications requiring high pressure.
- Backflow preventers are required if rainwater supply will be pressurized and if any of the pipes will be connected to the municipal water supply.

Figure 41. Example cistern.

5.6.1.1 Inlet and Pretreatment

Cisterns should have a rainhead or screen to prevent debris from entering the inlet pipe, and a cistern should have a first flush pipe to capture sediment before it enters the tank. Table 11 shows multiple pretreatment options for various roof areas. The size of the first flush pipe is typically 4 to 6 inches in diameter, with varied lengths to adjust the captured volume. Once the diverter is full, water flows to the cistern. A relief valve is required to drain the diverter between events to provide capacity for the next rainfall event.

Table 11. Inlet and pretreatment options.

Parameter	Specification	Example
Installation location	At the gutter	
	End of the downspout	
Contributing area size filter type	<1,500 square feet = flow through filter	
	1,500–3,000 square feet = bypass capable filter	
	>3,000 square feet = bypass capable filter	
Self-cleaning screen	45 degrees or greater as measured from horizontal (Nel 1996)	See image above

5.6.1.2 Low Flow Outlet (Optional)

Many cisterns are manually operated and are dewatered between storm events to satisfy irrigation needs. If passive management is desired, the outlet of the cistern should be designed to release the volume of captured runoff at a rate below the design storm inflow rate. The outlet should be directed to a vegetated area or an infiltration-based GI practice (e.g., stormwater harvesting basin).

The elevation of the low-flow outlet depends on the demand for alternative water use. Table 12 outlines the two alternatives for low-flow outlet placement. Note that although cisterns can provide valuable water quality and hydrologic benefits by slowly releasing the design storm volume, the *Design Standards for Stormwater Detention and Retention* does not currently allow cisterns as an option to satisfy water quality and flood control requirements (Pima County Regional Flood Control District 2014).

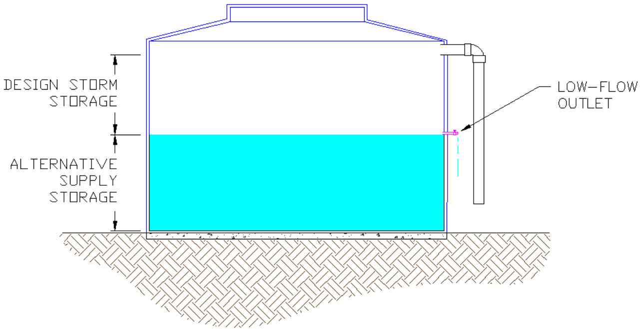
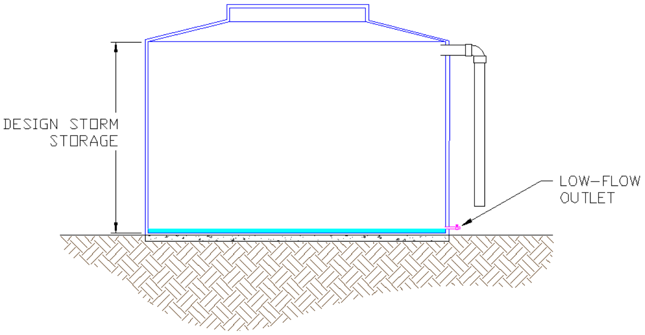
5.6.1.3 Designed Overflows

Cisterns must have an overflow pipe to divert excess stormwater to another location, preferably a vegetated area or another GI/LID feature, when the cistern reaches capacity. It is recommended that metal cisterns have the overflow pipe placed up through the location of where the concrete pad will be poured. The overflow should be sized appropriately to handle peak inflow.

5.6.1.4 Vegetation

Harvested rainwater is appropriate for many uses including the irrigation of vegetable gardens, fruit trees, or native vegetation. See Section 6.14, Vegetation, for additional details.

Table 12. Cistern water demand outlet configurations.

Alternative Water Demand	Typical Uses	Outlet Location	Example Profile
High	Supplements potable or graywater supply. Uses can include irrigation, toilet flushing, and car washing.	Above the volume to be stored for reuse. Volume above outlet slowly dewaters to maintain capacity for next storm event.	
Low to none	Cistern acts solely as a stormwater management device.	Bottom of the cistern. Creates a dewatering device and allows for maximum storage capacity of future rain events.	

5.6.2 Safety and Signage

Although not required in Pima County, signage is recommended to label cistern water as non-potable. Cautionary signage should be provided in English and Spanish anywhere rainwater is reused for irrigation, toilet flushing, or other non-potable purposes. Locking mechanisms on fixtures may be specified to prevent accidental ingestion in certain locations, such as schools and public parks.

5.6.3 Sizing Methodology

Cisterns should be sized based on the roof area draining to the cistern, and the benefit in additional rainwater captured relative to the additional cost in constructing a larger volume cistern. The volume of water supplied by the cistern is most sensitive to the draining roof area, and the cistern should be located to maximize the area draining to it. If the roof area for the cistern is too small, it will not fill very often. If the roof area is too large for the cistern, the rainwater will not be captured and instead will spill over.

The expected volume of the cistern can be determined with the following equation:

$$V_C = Z \cdot A \cdot \left(\frac{7.48\, gal}{1\, ft^3} \right)$$

Where:

V_c = Cistern design volume (gallons), which should be rounded to the nearest tank volume

Z = Cistern volume / roof area (cubic feet/square feet) (recommended value is 0.20 feet)

A =Roof area draining to the cistern (square feet)

Our analysis shows that Z = 0.2 feet (1,500 gal of storage per 1,000 square feet of roof) provides a storage volume that is optimal if the expectation is to capture enough water to grow a desert tree during the March to June dry period. This value was determined by simulating rainfall and water use for the 105 years of daily rainfall observed at the University of Arizona from 1895 to 2000, and the expected plant water requirements for each day of the year as described in Appendix E.

While Z = 0.2 feet is considered optimal, smaller cistern volumes also provide significant offset of annual water use and should be used when cistern volume is constrained by cost or space. Based on Tucson, AZ, rainfall and expected plant water demand, a cistern with a volume as little as 375 gallons per 1,000 square feet of draining roof area (Z = 0.05 feet) can provide from 2,600 to 3,300 gallons of offset in annual potable water demand per 1,000 square feet of roof if used efficiently (Appendix E).

When the goal is to maximize water supply, the storage per area of roof (i.e., Z) can be increased. However, a cistern design volume larger than Z = 0.40 feet (3,000 gal storage per 1,000 square feet) is likely to be limited by rainfall and unlikely to provide additional benefit for the increased volume and cost, so we consider 3,000 gal of storage to 1,000 square feet of roof to be the highest feasible ratio of storage to roof size.

The spreadsheet used to simulate the 105 years of rainfall and plant water demand can be obtained from the Pima County Regional Flood Control District. In addition, long-term, continuous simulation models such as the Rainwater Harvester Design Model (NCSU-BAE 2008) can be useful to optimize cistern capacity for both water demand and stormwater management based on local rainfall data. Designing cisterns using long-term, local data helps guide selection of the most cost effective cistern size and configuration.

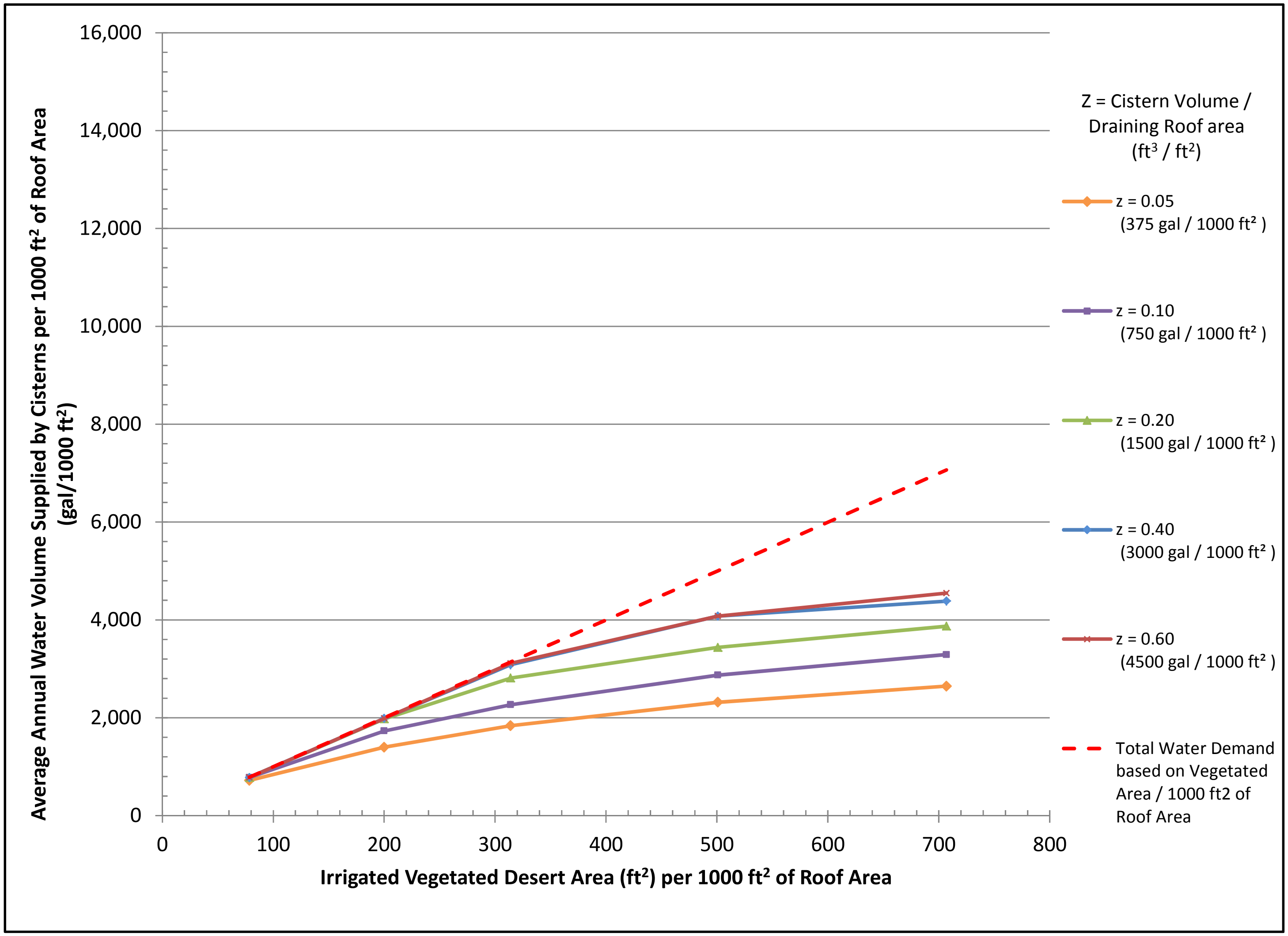


Figure 42. Offset in annual irrigation water demand by vegetated desert area relative to draining roof area.

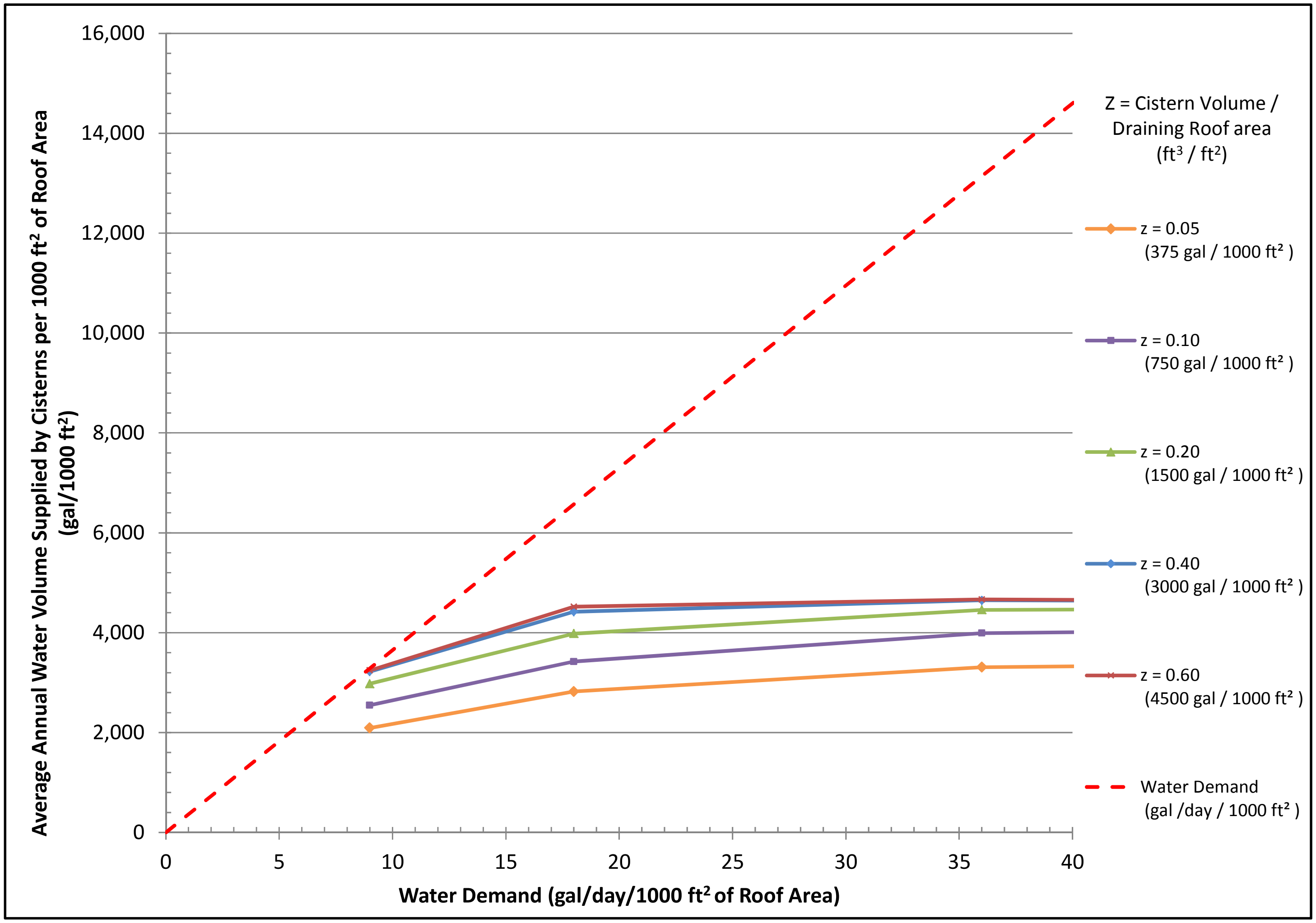


Figure 43. The average annual offset in constant daily water demand, such as indoor use that can be supplied by cisterns at varying levels of water use.

5.6.4 Considerations during Construction

The following should be considered when constructing or installing cisterns:

- A level pad of compacted ASTM No. 57 stone, or comparable aggregate, is typically sufficient to support cisterns under 5,000 gallons. Cisterns larger than 5,000 gallons should be set in a poured 6-inch concrete pad.
- In general, overflow, water supply, and drain pipes are in place before the concrete pad is poured. However, the timing of the placement of the piping also depends on the kind of cistern being installed.
- The inside of metal and concrete cisterns must be coated with a non-toxic water sealant.

5.6.5 Considerations during Maintenance

- The cistern first flush device should be emptied within 2 days following rainfall events.
- The rainhead or inlet must be inspected periodically and any debris must be removed.

INSPECTION AND MAINTENANCE ACTIVITIES SUMMARY	
Routine Maintenance	Inspect gutters during rainstorms to determine if they are overflowing. Clear gutters of debris, if necessary.
	Clean or replace clogged inlet filters.
	Clean or replace clogged first flush filter to prevent constant flow to the cistern.
	Unclog outlet if cistern does not drain within 48 hours.
Major Maintenance	Repair any damage to cistern structure.

5.6.6 Alternate GI Practices

The following practices can be used in lieu of cisterns:

- Stormwater harvesting basins.
- Bioretention basins.
- Infiltration trenches.
- Dry wells.

5.6.7 Compatibility with Other GI/LID Practices

Cisterns can be installed in series with:

- Stormwater harvesting basins.
- Swales.
- Bioretention systems.

- Infiltration trenches.
- Permeable pavements.
- LID planning BMPs (e.g., disconnected downspouts, soil amendments).

5.7 Permeable Pavements

5.7.1 Introduction

Permeable pavements can be used to infiltrate or store water, thus making a typical source of water into a sink. Because the systems include both the actual paving surface and a permeable material that can hold water, they can be designed to reduce runoff peak and volume as a GI practice. Depending on site conditions, water could be collected in drains below the pavements for use or allowed to infiltrate. Because these are pavements, they must be designed to account for the structural needs of the application. As such, geotechnical assessments will be required.

Benefits	PERVIOUS PAVEMENT	
REDUCES STORMWATER RUNOFF	Reduces Flooding	●
	Improves Stormwater Quality	●
INCREASES AVAILABLE WATER SUPPLY	Reduces Potable Water Demand	○
	Provides Storage for Future Use	○
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	◒
	Provides Vegetation for Shade	○
	Improves Aesthetics	◒
	Provides Wildlife Habitat	○

5.7.2 Applicable Sites

Permeable pavements are useful for vehicular use areas, such as parking lots, as well as sidewalks and other pedestrian use areas. To date, most permeable pavements are not suitable for higher velocity loads such as occur on roadways.

Permeable pavements support high infiltration rates so that ponding will not occur even at the highest rainfall intensities. However, materials that can clog interstitial pores, such as oil and grease or fine sediment, can render the pervious pavements ineffective.

Sequence of construction should be considered when developing an area with permeable pavements. Upstream watersheds should be stabilized before constructing the permeable pavement, so that sediment-laden flows do not impact the pavement. Erosive flows from steep slopes with sparse vegetation should be mitigated.

Both the source of the inflow water and the downstream fate of the water must be considered. Obviously, the contaminant load of the water and the potential for contaminating groundwater affect this evaluation.

Because permeable pavements can allow water to infiltrate, designs must consider the potential for moisture to affect building foundations. As such, mitigation, such as setbacks, may be needed for permeable pavements that impervious pavements would not require. A geotechnical analysis may further define an adequate solution.

5.7.3 Design Considerations

The components of a permeable pavement differ depending on what the design purpose is for the pavement. However, in general, the components include a permeable paving surface and a reservoir material, such as crushed rock (e.g., ASTM No 57 or 67 and No 2 coarse aggregate). Whether liners, geotextiles, underdrains, or other pervious materials are required depends on the actual design.

Below are design considerations for the elements of permeable pavements. For additional example details, see Appendix H.

5.7.3.1 Surface Course/Pavement Type

Some of the different kinds of permeable pavements and associated reservoir materials are as follows:

Porous Gravel

Porous gravel is well-suited for industrial applications that do not pose a risk to groundwater (per Urban Drainage and Flood Control District). Note that gravel should be washed and free of fines; decomposed granite should not be used in porous gravel lots. An example porous gravel installation and typical detail are provided in Figure 44. Porous gravel is suitable for:

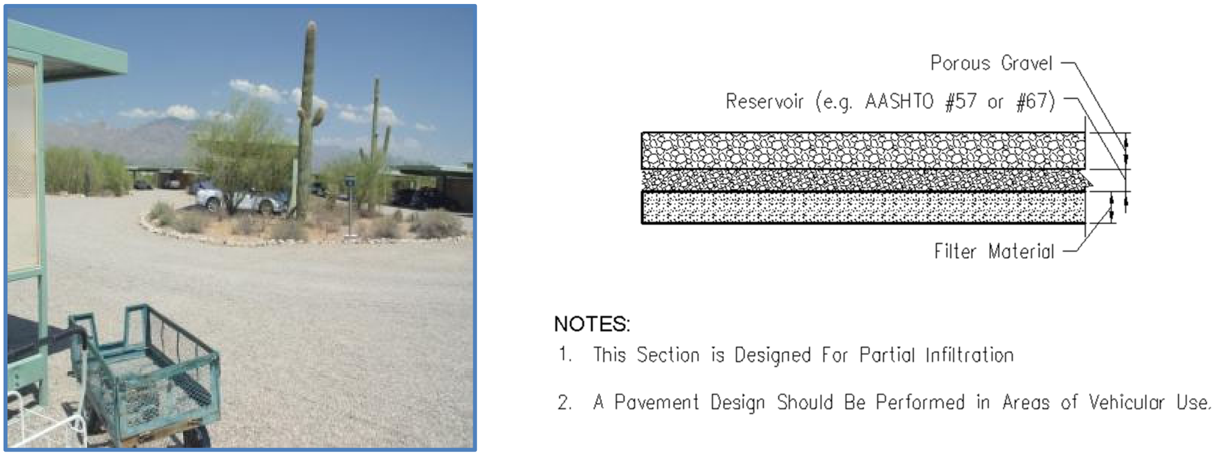
- Parking lots.
- Driveways.
- Storage yards.
- Maintenance roads.

Benefits

- Low cost

Limitations

- Not Americans with Disabilities Act (ADA) compliant, which limits applications and may require a stable paved surface for at least some of the area.
- Ruts easily without stabilization. A proprietary interlocking cellular paving product, can be used to further stabilize the gravel.
- Preventative maintenance to sustain subsoil infiltration capacity is typically not possible; restorative maintenance or replacement is required.



NOTES:
1. This Section is Designed For Partial Infiltration
2. A Pavement Design Should Be Performed in Areas of Vehicular Use.

Source: Urban Drainage and Flood Control District

Figure 44. Example porous gravel installation (left). Typical permeable pavement detail (right).

Permeable Interlocking Concrete Pavers

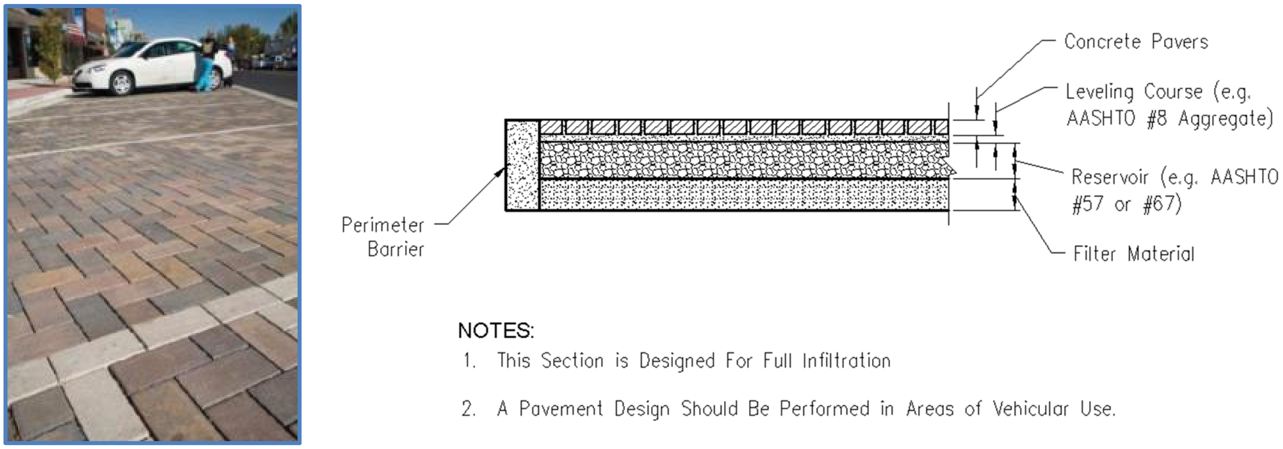
Permeable interlocking concrete pavers (PICP) uses pavers that interlock in such a way that 5% to 15% of the surface remains open to allow water to pass. The pavers themselves are not pervious. Pavers should be laid per manufacturer guidance, but a herringbone pattern is typically the best structural design for rectangular PICP (see Figure 45). PICP is a flexible pavement system, which means a structural analysis must be performed to ensure that the underlying aggregate layer provides sufficient structural support for the anticipated vehicular loads. An example PICP installation and typical detail are provided in Figure 45.

Benefits

- Can be removed and replaced for maintenance of underlying utilities.
- Maintain infiltration rates well.
- Longer life than traditional pavement.
- Can be reused.
- Can be used in a decorative way.
- PICP meets ADA requirements for accessible paths.

Limitations

- Costs can be greater than concrete or asphalt.



NOTES:
1. This Section is Designed For Full Infiltration
2. A Pavement Design Should Be Performed in Areas of Vehicular Use.

Source: Urban Drainage and Flood Control District

Figure 45. Example PICP installation (left). Typical PICP detail (right).

Pervious Concrete

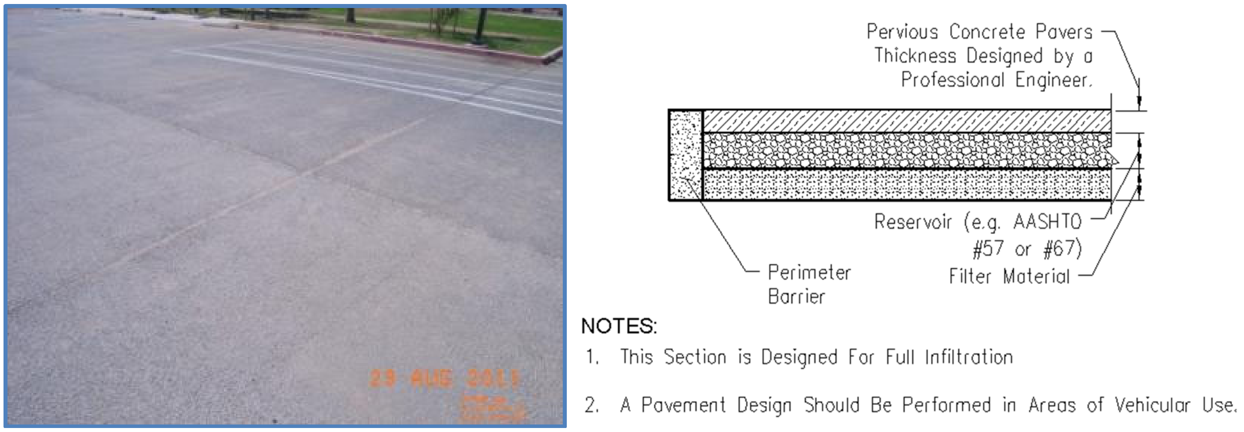
Because it is designed without the fines used in most concrete aggregate, pervious concrete is a surface that allows water to infiltrate, resulting in a gap-graded mixture with high connected pore space. Pervious concrete is a rigid pavement system, which means that structural analysis should ensure that the thickness of the slab can support the anticipated vehicular loading. An example pervious concrete installation and typical detail are provided in Figure 46.

Benefits

- Pervious concrete provides a means for paving large areas in a fairly rapid time.
- Meets ADA requirements for accessible paths.

Limitations

- Costs can be greater than traditional concrete or asphalt.
- Requires specialized design and construction capabilities.



NOTES:

1. This Section is Designed For Full Infiltration
2. A Pavement Design Should Be Performed in Areas of Vehicular Use.

Source: Urban Drainage and Flood Control District

Figure 46. Example pervious concrete installation (left). Typical pervious concrete detail (right).

5.7.3.2 Structural and Reservoir Base Layer

For flexible pavements, like PICP, a stone structural base layer must be provided to support the surface course. Refer to local pavement designs standards for structural sizing requirements. For rigid pavements, like pervious concrete, a structural base layer is not required, but a stone reservoir base layer should be provided as a bedding course and to capture and retain stormwater.

Aggregate that forms the base layer should be uniformly graded to have connected pore space, such as ASTM No. 57 stone, and should be washed free of all fines. The base layer should generally have a minimum thickness of 4 inches. If the total thickness of the reservoir layer exceeds 4 inches, a subbase layer of washed ASTM No. 2 stone is recommended below the 4-inch-thick No. 57 stone base layer. Exceptions apply to pedestrian applications, where a 6-inch base layer of No. 57 stone is generally acceptable.

Stone base and subbase layers should be sufficiently compacted to provide structural support and to prevent differential settling. Level and method of compaction will vary depending on the chosen pavement type. Contractors should take care not to compact the soil subgrade in order to maximize infiltration (see Section 6.13, Minimizing and Mitigation Soil Compaction).

Base and subbase layer designs should always conform to local design standards and should address site-specific conditions.

5.7.3.3 Underdrain Systems

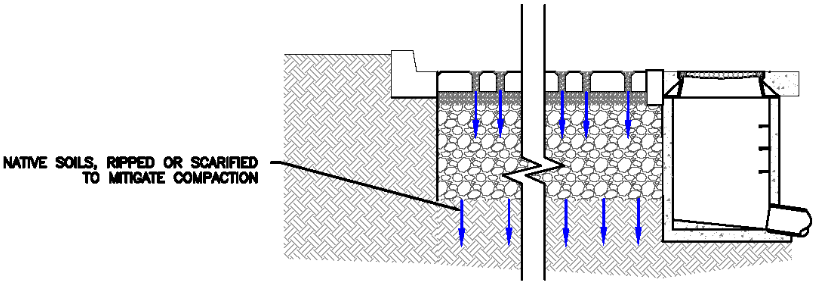
While an argument can be made for the suitability of permeable pavements in many different conditions, there are three primary designs for pervious pavements as follows:

1. Full infiltration design: Full infiltration systems (Figure 47, Configuration 1) are designed to infiltrate the full design volume (recommended to be 0.5 to 1.5 inch rainfall event as described in Section 3.5, Selection of Rainfall Event for Sizing GI/LID Practices). Full infiltration designs are effective for groundwater recharge when water quality is acceptable. However, few places in Pima County have good hydrologic connections to the regional aquifer, and the high potential evapotranspiration rates tends to pull soil moisture upward, so that in many cases the water infiltrated will be unlikely to be recharged. Full infiltration

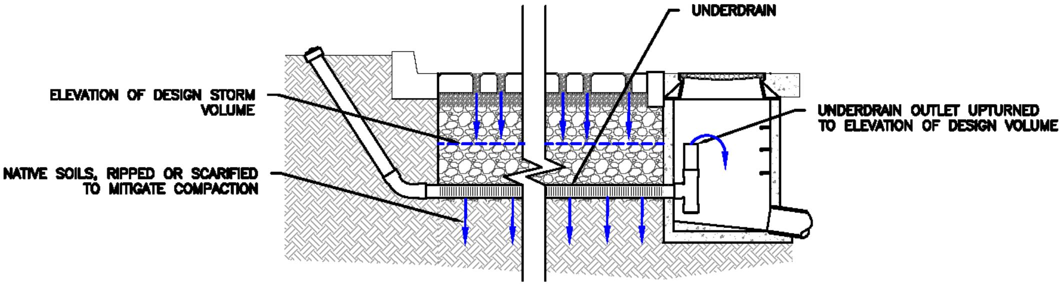
designs may be effective in areas near ephemeral streams or where the local aquifer is shallow.

2. Partial infiltration design: In partial infiltration designs, an underdrain system is used, but a liner is not; the underdrain outlet can be upturned to create a sump (also known as internal water storage) to enhance infiltration and treatment (Figure 47, Configuration 2), or can be placed at the subgrade to allow for complete drainage (Figure 47, Configuration 3). Partial infiltration systems may be suitable when the native soils are not very pervious or caliche is pervasive.
3. No infiltration design: In no-infiltration design (Figure 47, Configuration 4), a liner and underdrain system are used to collect water draining through the pavement and underlying pervious media. No infiltration designs are needed to prevent movement of contaminants into groundwater or to limit moisture migration that might compromise foundations or hydrate expanding clays.

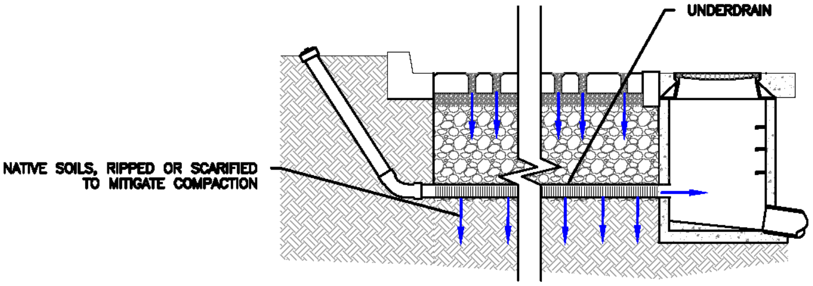
For details regarding underdrain design, see Section 5.4, Bioretention Systems. Capped cleanout ports should be installed to allow for cleaning and inspecting the underdrain pipe. For systems without underdrains, perforated inspection wells should be installed to allow for monitoring. The cleanouts and/or wells can be housed in utility boxes within the pavement surface or can be routed to and accessed in adjacent areas like parking lot islands and parkways. Underdrain slope should be at least 0.5 feet/100-feet of pipe for 6 inch pipe, and 1 foot/100-feet for 4 inch pipe (1/8 inch/1-foot), which will assure a flow velocity of 2 feet per second. It is often more efficient to install an underdrain in a trench of washed ASTM No. 57 stone dug into the subgrade instead of mounding an envelope of stone around the pipe.



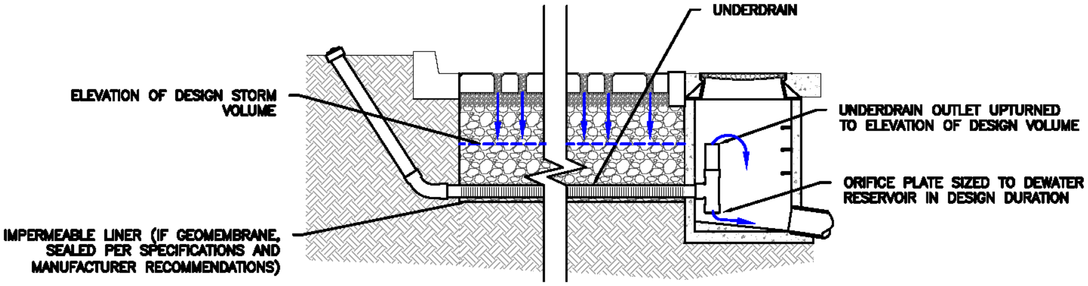
CONFIGURATION 1: INFILTRATION, NO UNDERDRAIN



CONFIGURATION 2: INFILTRATION, W/ UPTURNED UNDERDRAIN



CONFIGURATION 3: INFILTRATION, W/UNDERDRAIN AT SUBGRADE



CONFIGURATION 4: NON-INFILTRATING, W/UNDERDRAIN AT SUBGRADE

NOT TO SCALE

Figure 47. Various configurations for infiltrating and non-infiltrating permeable pavement.

5.7.3.4 Concrete Transition Strip

A concrete transition strip is necessary for all types of permeable pavement. The strip provides an edge restraint, or header, to maintain the structure of flexible pavements, delineates the permeable surface from adjacent impermeable surfaces, and can function as a hydraulic restriction layer if installed monolithically to the subgrade. Examples of concrete transition strips are shown in Figure 48.

Figure 48. Concrete transition strip examples.

5.7.3.5 Slopes

Permeable pavement designs can generally accommodate slopes up to 15%. In such cases, the subgrade should be bermed or stepped to minimize later flow velocity along the subgrade and to ensure capture of the required design volume within the reservoir layer. A detailed structural analysis should be performed for sites with substantial slopes.

5.7.3.6 Signage

Signage is recommended to identify permeable pavements and to forbid activities that could adversely affect performance. Signage should prohibit activities such as stockpiling soil and other materials that could clog the permeable surface course and educate the public on the importance of GI/LID for stormwater management. Identifying permeable pavement as such will also reduce the likelihood that permeable systems will be unknowingly replaced/repaved with <u>im</u>permeable pavements.

5.7.4 Sizing Methodology

Permeable pavements should be sized for both structural and hydrologic design criteria, considering the unique components of the selected type of permeable pavement. The pavement should be designed to withstand the expected routine and incidental traffic loading with the appropriate factors of safety. Even if a permeable pavement is intended primarily for pedestrian use, it may be subject to emergency vehicle traffic and should be designed accordingly. Refer to local pavement design standards for structural design requirements and methodology.

For hydrologic design, the pavement should be designed with a reservoir layer that holds the design volume of the pavement and the upstream contributing area. As described in Section 3.5, Selection of Rainfall Event for Sizing GI/LID Practices, this should be at least 0.5 inch rainfall event, however, in many cases, the 1.5 inch rainfall event can be accommodated with pervious pavements.

For the simplest case where no infiltration is assumed, the volume should include a 20% safety factor, so that:

$$V_{design} = V_{runoff} + 0.2V_{runoff}$$

Where V is in cubic feet. The area and depth of the permeable pavement can then be sized as follows:

$$d_{\min} = \frac{V_{design}}{A\eta}$$

Or

$$V_{design} = d_{\min} A\eta$$

Where:

d_{min} = The minimum thickness of the reservoir layer (feet)

V_{design} = Design volume (cubic feet)

A = Area of pervious pavement (square feet)

η = Porosity of the gravel layer (unitless)

AASHTO #57 or #67 aggregates can be assumed to have a reservoir porosity of 0.4. For Porous Gravel (AASHTO #3), the porosity can be assumed to be 0.3.

For pervious concrete, the volume of the pores in the concrete can also be considered in the calculation of the reservoir volume, with the porosity of the pavement specified by the design engineer.

5.7.5 Considerations during Construction

The same principles involved in constructing bioretention apply to permeable pavements, in addition to design-specific considerations. Construction sequencing, equipment, materials, and expertise will vary depending upon the chosen permeable pavement design, so it is often advantageous to consult industry representatives to ensure proper installation. Ensuring that the contractor is industry-certified to install the chosen product, and that they are aware of the design intent, will reduce the risk of failures due to miscommunication.

5.7.6 Considerations during Maintenance

Maintenance should be considered during the design phase, because even under the best scenario vacuuming or other maintenance will be required to keep the pavement pervious.

Permeable pavement mainly requires vacuuming or regenerative air sweeping and management of adjacent areas to limit sediment contamination and prevent clogging by fine sediment particles; therefore, little special training is needed for maintenance crews. The following maintenance concerns and maintenance activities can be considered and provided:

- Trash tends to accumulate in paved areas, particularly in parking lots and along roadways. The need for litter removal can be determined through periodic inspection.
- Regularly (e.g., monthly for a few months after initial installation, then quarterly) inspect pavement for pools of standing water after rain events, which could indicate surface clogging.
- Actively (3–4 times per year, or more frequently depending on site conditions) sweep the pavement with a regenerative air or vacuum sweeper to reduce the risk of clogging by frequently removing fine sediments before they can clog the pavement and subsurface layers. Regenerative air sweeping may be more efficient for preventative maintenance of PICP because it minimizes removal of interstitial aggregate; for restorative maintenance of PICP and preventative/restorative maintenance of pervious concrete, vacuum sweepers can be used.
- Inspect for vegetation growth on pavement and remove when present.
- Inspect for missing sand/gravel in spaces between pavers and replace as needed.
- Activities that lead to ruts or depressions on the surface can be prevented or the integrity of the pavement can be restored by patching or repaving. Examples of such activities are vehicle tracks and utility maintenance.
- Spot clogging of porous concrete may be remedied by drilling 0.5 inch holes every few feet in the concrete.
- Interlocking pavers that are damaged can be replaced.
- Maintain landscaped areas; reseed bare areas.

5.7.7 Alternate GI Practices

- Stormwater harvesting basins.
- Bioretention basins.
- Infiltration trenches.
- Dry wells.

5.7.8 Compatibility with Other GI/LID Practices

- Stormwater harvesting basins.
- Bioretention basins.
- Xeriscaped swales.

5.8 Dry Wells

Benefits	DRY WELLS	
REDUCES STORMWATER RUNOFF	Reduces Flooding	●
	Improves Stormwater Quality	●
INCREASES AVAILABLE WATER SUPPLY	Reduces Potable Water Demand	○
	Provides Storage for Future Use	○
IMPROVES COMMUNITY LIVABILITY	Reduces Urban Heat Island	○
	Provides Vegetation for Shade	○
	Improves Aesthetics	○
	Provides Wildlife Habitat	○

A dry well is an excavation filled with gravel similar to an infiltration trench, however the excavation tends to be deeper and may only be a few feet in diameter. In Pima County, the water table is typically deep, so stormwater entering a dry well may remain in the unsaturated zone where it is typically too deep for many plants to access. As such, dry wells are typically a last resort.

Dry wells can only receive stormwater without pollutants and must be registered with ADEQ. If there is potential for pollutants, the owner may also be required to obtain an aquifer protection permit from ADEQ.

Some dry well designs use a catch basin as pretreatment that settles sediments and contaminants out of stormwater before overflowing to a subsurface gravel dry well. Dry wells can be effective in reducing stormwater volume and improving water quality by capturing sediment loads. It is recommended that some pretreatment of the stormwater is provided upstream (e.g., filter strips) in order to prevent clogging of the dry well by sediment over time.

5.8.1 Applicable Sites

Dry wells can be used at multi-family residential and commercial sites. Dry wells are not appropriate for sites that are hot spots or areas with potentially hazardous materials (gas stations and some industrial operations) without substantial pretreatment of stormwater and therefore may be limited in use for industrial sites or along roadways. A geotechnical investigation should be performed for the site before an infiltration practice such as a dry well is installed. The design disposal rate for a dry well, after application of a de-rating factor, should not be less than 0.1 cubic feet per second per well nor more than 0.5 cubic feet per second (Pima County Regional Flood Control District 2014). A percolation test must be performed to determine the infiltration rate at the proposed site. The depth to an impermeable layer or to the water table should be a minimum of 10 feet from the base of the injection screen. In addition, a dry well must be located a minimum distance of 100 feet from any water supply well or dry well (Pima County Regional Flood Control District 2014). On sites with a slope greater than 7%, the geotechnical report should address the slope stability (City of Santa Barbara 2008).

5.8.2 Advantages

Dry wells can be used to remove large volumes of water with a fairly small surface footprint. Therefore they can be effective at mitigating flood waters and stormwater. If groundwater is shallow, a dry well may be an effective way to recharge the aquifer with stormwater—this has been an effective strategy in Chandler, AZ. (Geosystems Analysis 2004).

5.8.3 Limitations

The primary limitation for dry wells is that they do not lend themselves to on-site use of stormwater. In most cases, stormwater harvesting basins, bioretention, and infiltration will provide a viable alternative for on-site use of stormwater, while also providing stormwater and flood control benefits.

5.8.4 Design Considerations

Below are design considerations for the elements of a dry well. For additional example details, see Appendix H.

The dry well depth will be determined by site constraints. The washed coarse stone aggregate used for the gravel drainfill should be uniformly graded and about 40% void capacity (i.e., AASHTO No. 3) (State of Michigan 2008).

Dry wells may meet the U.S. Environmental Protection Agency's (EPA's) definition of a Class V drainage well because they are deeper than the widest surface dimension. Class V drainage wells are regulated by the EPA (see http://water.epa.gov/type/groundwater/uic/class5/types_stormwater.cfm). The ADEQ also maintains requirements for dry wells (see http://www.azdeq.gov/environ/water/permits/drywell.html).

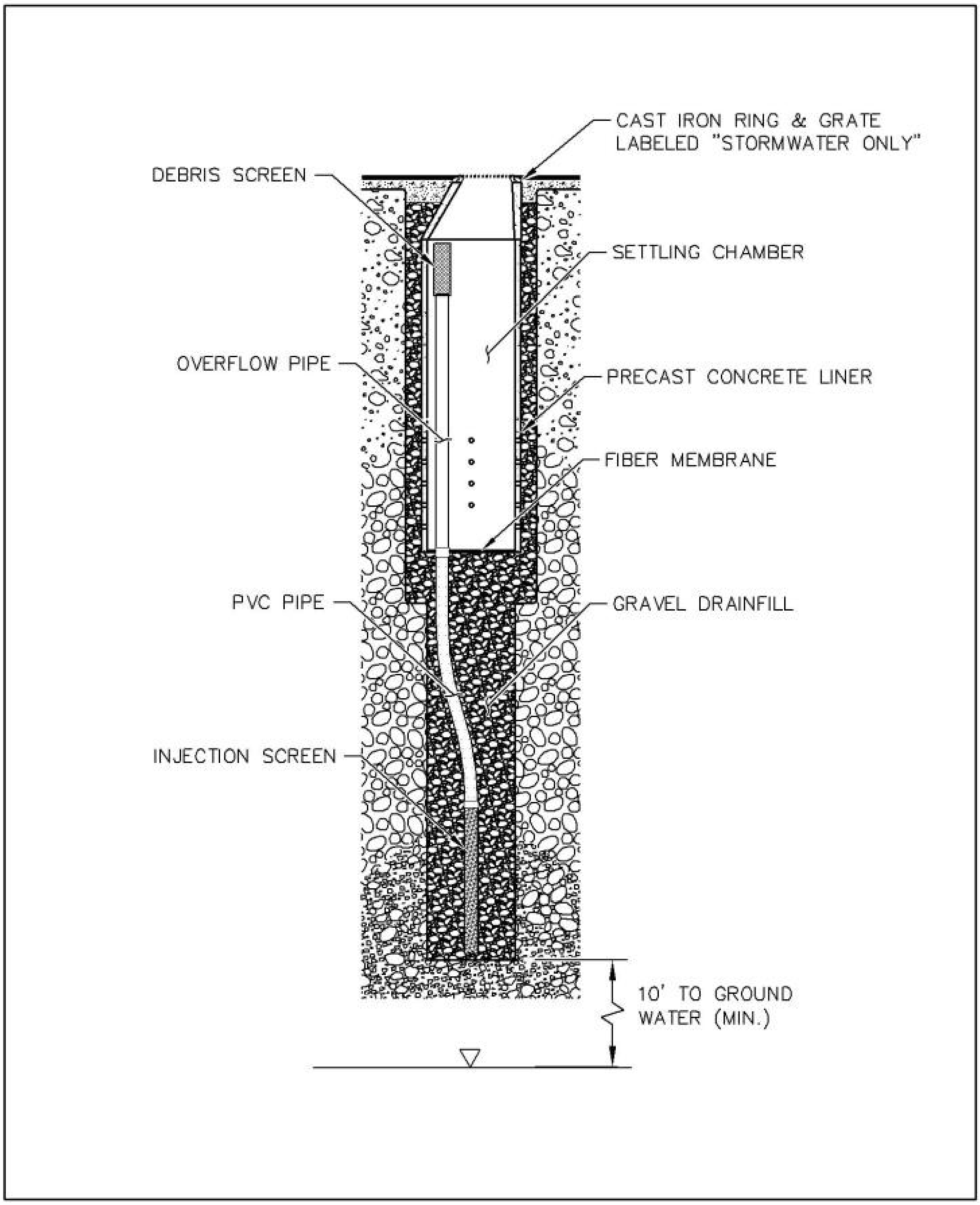
5.8.4.1 Inlet

Inlets should be labeled with the words *Stormwater Only*. The inlet to a dry well may be a drain connected to pretreatment and an underground gravel chamber, or an inlet may simply be the exposed top of the gravel layer at the soil surface. Pretreatment of stormwater for sediment should be provided for the inlet to a dry well, such as filter strips for surface dry wells or a sump (see Figure 49) for underground dry wells. However, vegetation should be prohibited within four feet of the inlet to the drywell to limit the potential for clogging the inlet and allowing for inspection.

The surrounding area should be graded towards the inlet to the dry well with a minimum slope of 0.5%. Some appropriate types of pretreatment in the surrounding area are xeriscaped filter strips or sediment traps. Decomposed granite should not be used in the areas surrounding the dry well because it will clog the infiltration chamber over time.

5.8.4.2 Vegetation

The planting of vegetation next to the dry well is encouraged so that the roots of the vegetation may utilize the infiltrated stormwater, as long as the location of the vegetation does not inhibit regular maintenance of the dry well. See Section 6.14, Vegetation, for additional information on vegetation.



Source: Pima County Regional Flood Control District 2014.

Figure 49. Example dry well design.

5.8.5 Considerations during Construction

- Construct the infiltration practice after construction of the surrounding site if possible, and avoid sediment deposition in the infiltration bed by preventing inflow during construction.
- Prevent heavy equipment from traveling over the site of the infiltration bed by fencing it off during construction of the surrounding site.

- Do not compact the underlying soils once the dry well has been excavated.
- The infiltration trench or dry well may be lined with geotextile fabric before placement of the gravel to prevent fine soil particles from filling the voids in the coarse aggregate.
- The coarse aggregate should be covered with filter fabric during construction to prevent loose sediment from entering the system, and the filter fabric should be removed following construction.

5.8.6 Considerations during Maintenance

Infiltration trenches and dry wells should be inspected at least annually and preferably after large storm events. In addition, a maintenance plan should be put in place, which includes the following:

- Maintenance schedule.
- Type of maintenance activities.

Exhibit showing the location(s) of the drywell(s).

- Contact information of the driller or authorized maintenance professional.

Debris or excess sediment that has accumulated at the surface of the system should be removed. If infiltration rates have decreased substantially, major maintenance may be performed by removing, cleaning, and replacing the top gravel layer or removing the gravel and replacing any clogged filter fabric.

5.8.7 Alternate GI Practices

- Stormwater harvesting basins.
- Bioretention basins.
- Infiltration trenches.
- Cisterns.
- Permeable pavements.

5.8.8 Compatibility with other GI/LID Practices

- Permeable pavement.
- Cisterns.

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6 Common GI Components

6.1 Introduction

Many of the structural GI practices include common elements that support their implementation. For this reason, these common elements are listed below rather than restated in each of the structural GI practice descriptions.

6.2 Geotechnical Considerations

Geotechnical investigations include a desktop analysis and a field survey to fully characterize the structural and hydrologic characteristics of a site. Desktop analyses can be done to generate a conceptual site plan, but they should always be verified with a field investigation. Desktop analyses can help determine the following characteristics:

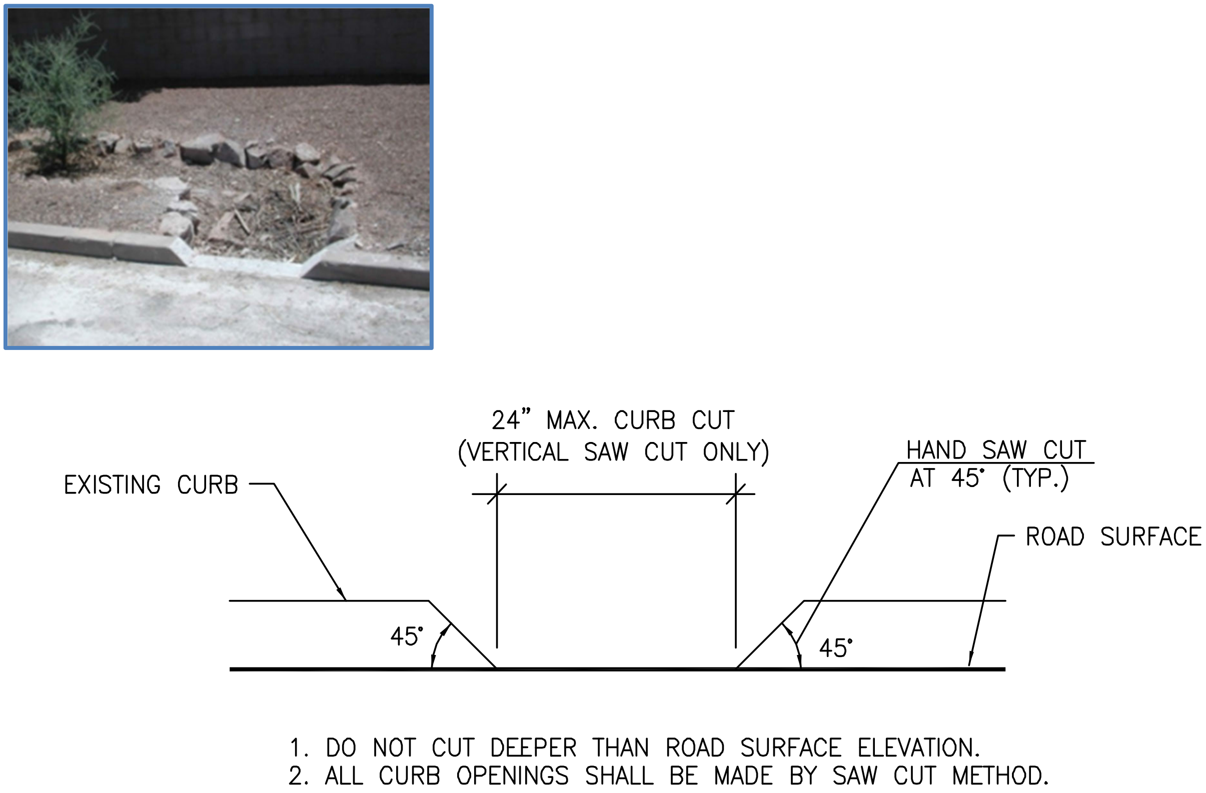
- Underlying geology.
- Proximity to steep slopes.
- Proximity to structural foundations, roadway subgrades, utilities, and other infrastructure.
- Proximity to water supply wells.
- Proximity to septic drain fields.

A licensed soil scientist or geotechnical engineer should perform the field investigations. All testing should be performed at the depth of the proposed subgrade and 3 feet below the proposed subgrade. Sufficient test pits or borings should be done to adequately characterize the site soil conditions. At a minimum, the greater of two samples or one sample per 50,000 square feet of structural GI practice should be collected. The following parameters should be determined or verified through field investigations:

- Infiltration rate of subgrade soils (ASTM D *3385 Standard Test Method for Infiltration Rate of Field Soils Using Double Ring Infiltrometer*, or a comparable method).
- Depth and texture of subsoils.
- Depth to the seasonally high groundwater table.
- Structural capacity of soils.
- Presence of expansive clay minerals.
- Presence of compacted or restrictive layers.
- Underlying geology.
- Proximity to steep slopes.
- Proximity to structural foundations, roadway subgrades, utilities, and other infrastructure.
- Proximity to water supply wells.
- Proximity to septic drain fields.

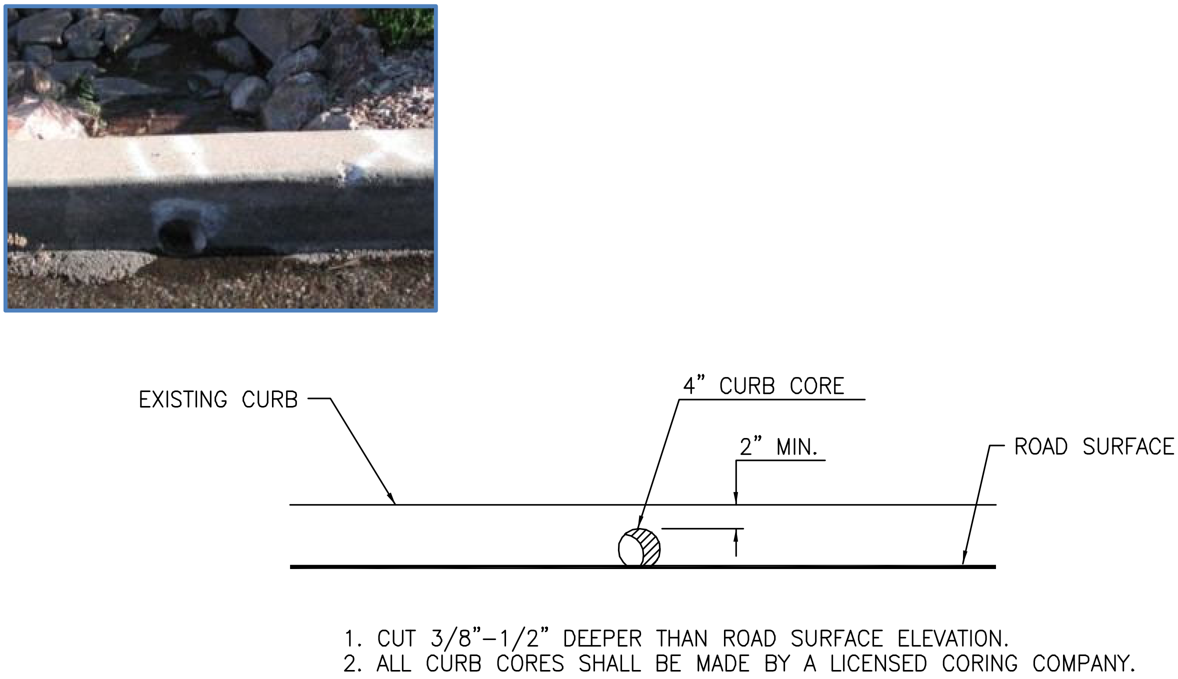
6.3 Inlets and Curb Openings

Inlets and curb opening standards have been developed by the City of Tucson, in coordination with others such as the Watershed Management Group. In particular, three kinds of inlet standards have been developed as shown below in Figure 50 (curb cuts), Figure 51 (curb cores), and Figure 52 (curb slots).



Source: City of Tucson Green Streets Suggested Technical Best Practices

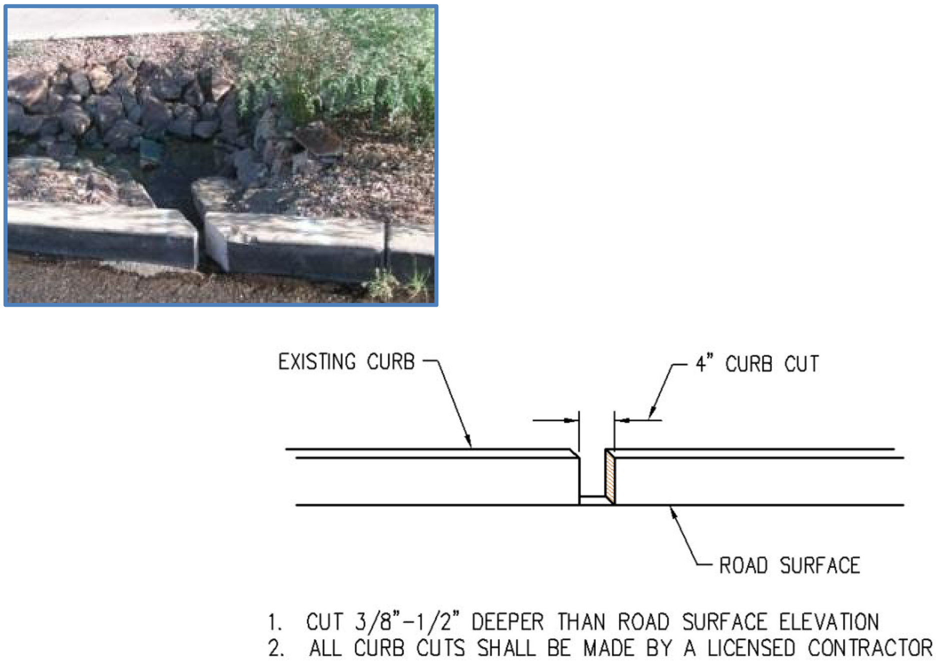
Figure 50. Example curb cut and standard curb cut drawing.



1. CUT 3/8"–1/2" DEEPER THAN ROAD SURFACE ELEVATION.
2. ALL CURB CORES SHALL BE MADE BY A LICENSED CORING COMPANY.

Source: City of Tucson Green Streets Suggested Technical Best Practices

Figure 51. Example curb core and standard curb core drawing.



1. CUT 3/8"–1/2" DEEPER THAN ROAD SURFACE ELEVATION
2. ALL CURB CUTS SHALL BE MADE BY A LICENSED CONTRACTOR

Source: City of Tucson Green Streets Suggested Technical Best Practices

Figure 52. Example curb slot and standard curb slot drawing.

6.4 Overflows and Outlets

There are several types of outlets that facilitate structural GI practices. The overflow/outlets described here are commonly used for stormwater harvesting basins, but they can be used with other structural practices such as swales or infiltration trenches. Outlets should be designed to ensure that flows exiting the basin are compatible with the existing downstream drainage conditions and will not have an adverse impact on the surrounding area.

The four most common types of outlets are:

- An outlet that also functions as an inlet.
- An outlet connected to a storm drain.
- An outlet to the street.
- An outlet that connects other structural GI practices.

6.4.1 Outlet that also functions as an inlet

An outlet that functions as an inlet allows stormwater to enter a basin, and when the basin is at capacity the flow exits through the inlet as shown in (Figure 53). Appropriate inlet protection and sediment traps (as discussed in Section 6.5, Inlet Protection and Sediment Traps) will prevent erosion and transportation of sediment from the basin into the street when the feature drains.

Figure 53. The inlet to this stormwater harvesting basin also functions as an outlet.

6.4.2 Outlet connected to a storm drain

An outlet that is directly connected to a storm drain system (Figure 54), are typically used when the site topography does not support above ground outlets at the basin. These systems require a professional engineer to accurately size the storm drain system.

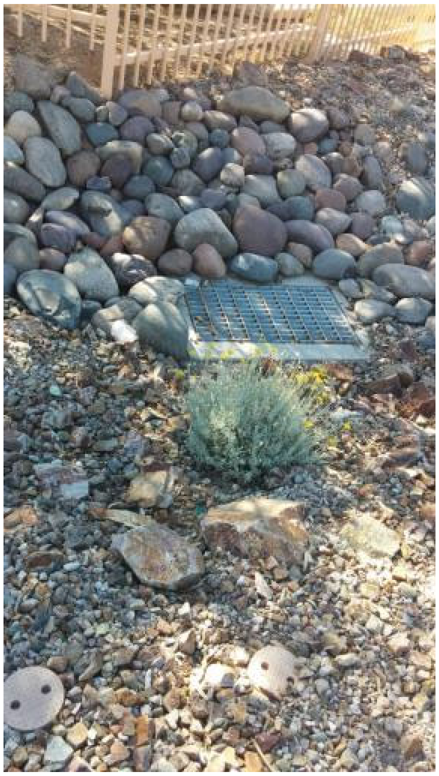


Figure 54. An outlet connected directly to a storm drain at the downstream end of a stormwater harvesting basin.

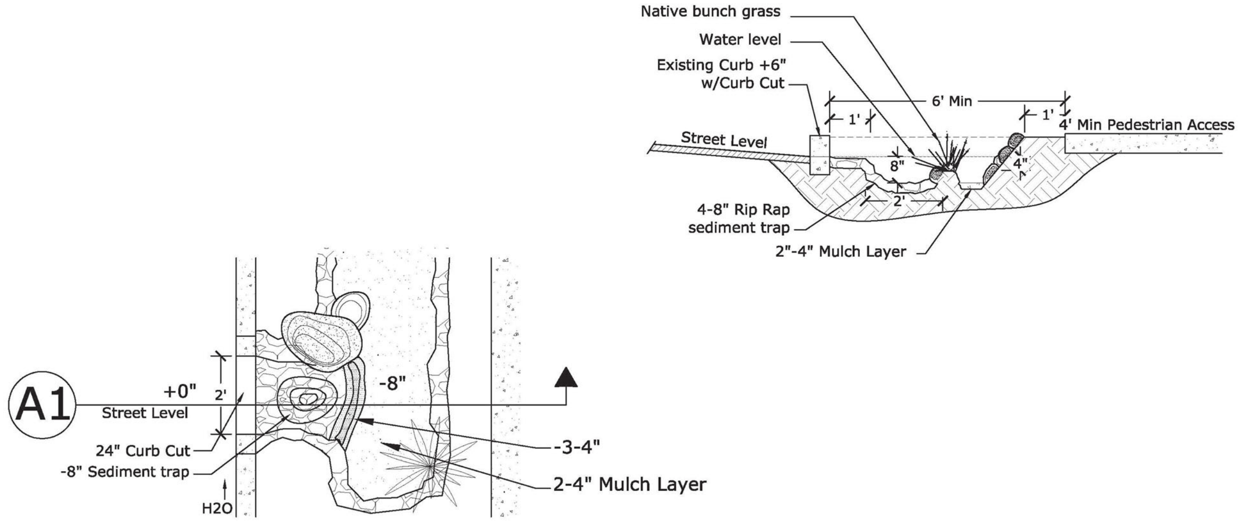
6.4.3 Outlet to the Street

An outlet that that directs flow into the street typically has a grade control that allows sediment to settle prior to the flow exiting the basin. This ensures sediment does not accumulate in the street. When outlets direct flow to a sidewalk or other paved pedestrian pathway a scupper shall be included or other conveyance to prevent sidewalk or pathway overtopping. It is recommended that outlets not be located where flow will be directed over decomposed granite or other erodible pedestrian pathway.

Figure 55. This figure shows the downstream outlet of a stormwater harvesting basin that discharges to the street once the basin is at capacity.

6.5 Inlet Protection and Sediment Traps

Inlets to GI features should be protected from potential erosion and scour from flow entering the basin. Angular rock can be used to armor the basin inlet and dissipate the energy of entering flows. Unless grouted, rock riprap shall be underlain with filter fabric. Sediment traps (Figure 56 and Figure 57) also provide inlet protection and have the added benefit of helping maintain the long term functionality of structural GI features such as bioretention basins and stormwater harvesting basins. Sediment traps provide inlet erosion protection and reduce the energy of water flowing into the feature, allowing entrained sediment to fall out of suspension before entering the basin. Influx of fine-grained sediment can clog the surface of basins and reduce infiltration. Removal of sediment once it is in the basin is difficult and costly. Sediment traps require maintenance and should be constructed to facilitate ease of cleaning. Accumulated sediment should be removed regularly from the trap to prevent it from moving into the basin. Riprap can be hand placed on filter fabric to create a smooth bottom surface, but mortaring riprap is preferable and increases the life span of the trap. The distal end of the sediment trap should be at grade to prevent erosion as flow enters the basin. Sediment traps should always be employed at the inlet of bioretention basins and at the inlet of stormwater harvesting basins that receive flows from areas with the potential to contribute high sediment loads.

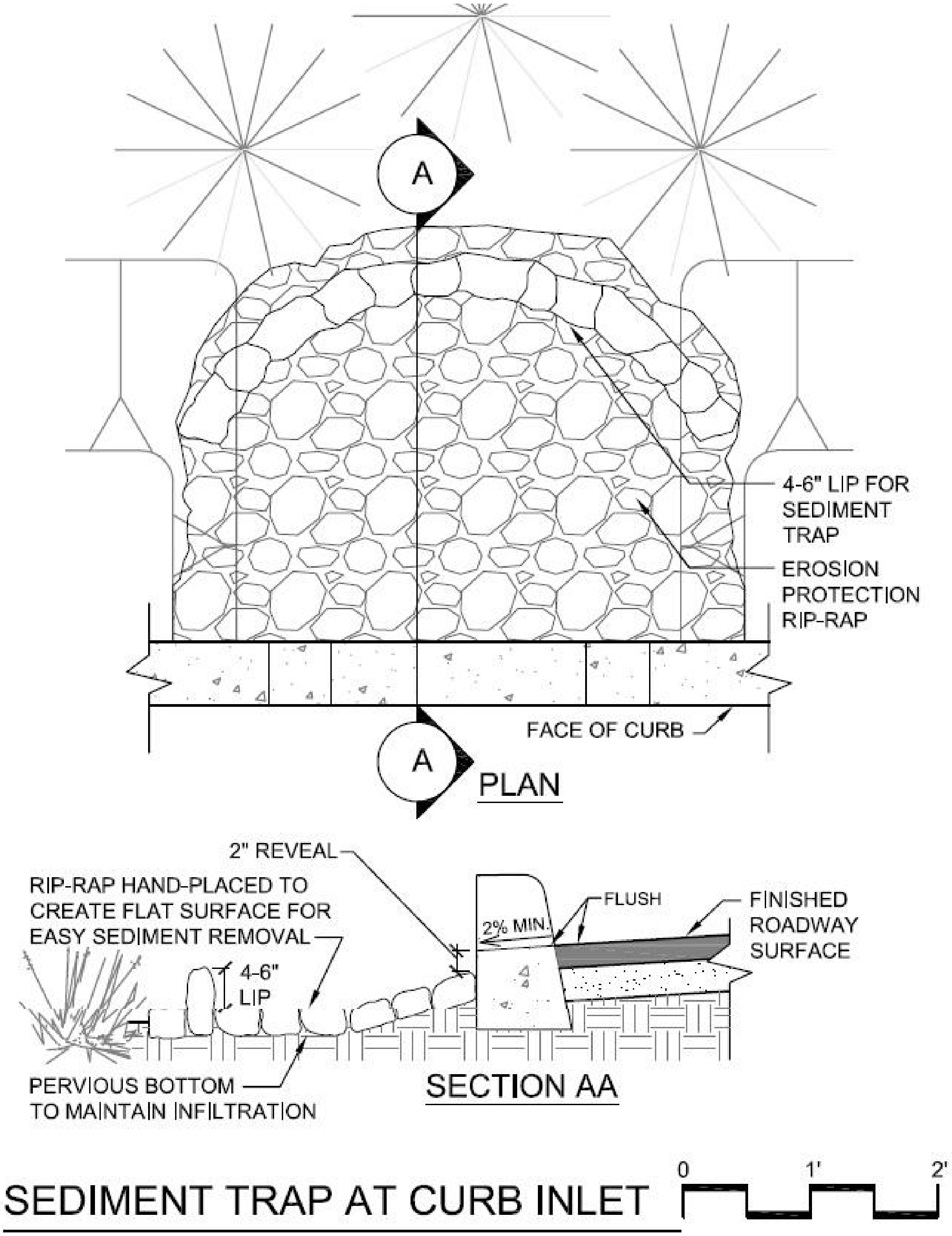


Plan View

Elevation View

Source: Green Infrastructure for Southwestern Neighborhoods, Watershed Management Group, p. 22, Version 1.0, August 2010

Figure 56. Sediment trap details.

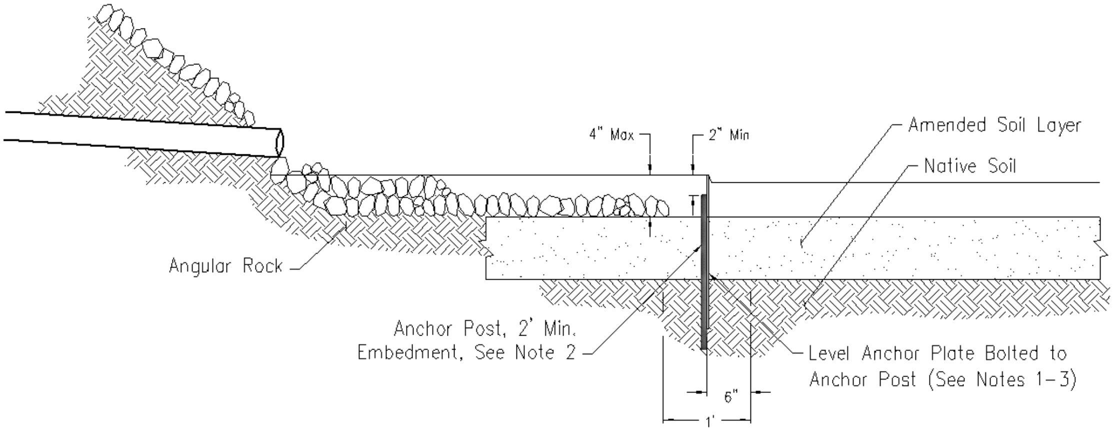


Source: City of Tucson Green Streets Suggested Technical Best Practices

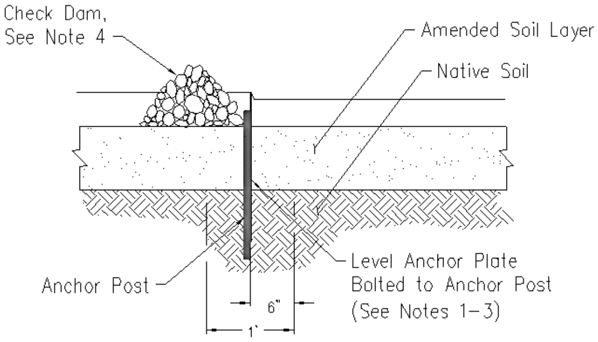
Figure 57. Plan and cross-section views of a sediment trap at a curb inlet.

6.6 Flow Spreaders

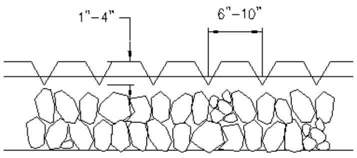
Flow spreaders ensure that stormwater enters stormwater treatment areas as sheet flow that does not cause erosion. An anchored plate flow spreader should be provided at the inlet to the swale. Flow spreader plates can be made of either concrete, stainless steel, fiberglass reinforced plastic, or other durable material. Other methods for spreading flows evenly throughout the width can also be used. Figure 58 shows details for an inlet flow spreader, check dam and flow spreader combination, and V-notched flow spreader.



INLET FLOW SPREADER DETAIL



CHECK DAM AND FLOW SPREADER DETAIL



EXAMPLE:
V-NOTCHED FLOW SPREADER DETAIL

NOTES

1. Top surface of flow spreader should be level and project 2" above ground. V–notches can be placed at 6 to 10 inches on center and 1 to 4 inches deep.
2. Flow spreader anchor posts can be 4–inch square concrete, tubular steel or other material resistant to decay
3. Flow spreader plates can have a row of horizontal perforations at the base of the plate to prevent ponding for long durations.
4. Check dam is recommended to be no higher than 12 inches.

Figure 58. Inlet flow spreader, check dam and flow spreader combination, and V-notched flow spreader detail.

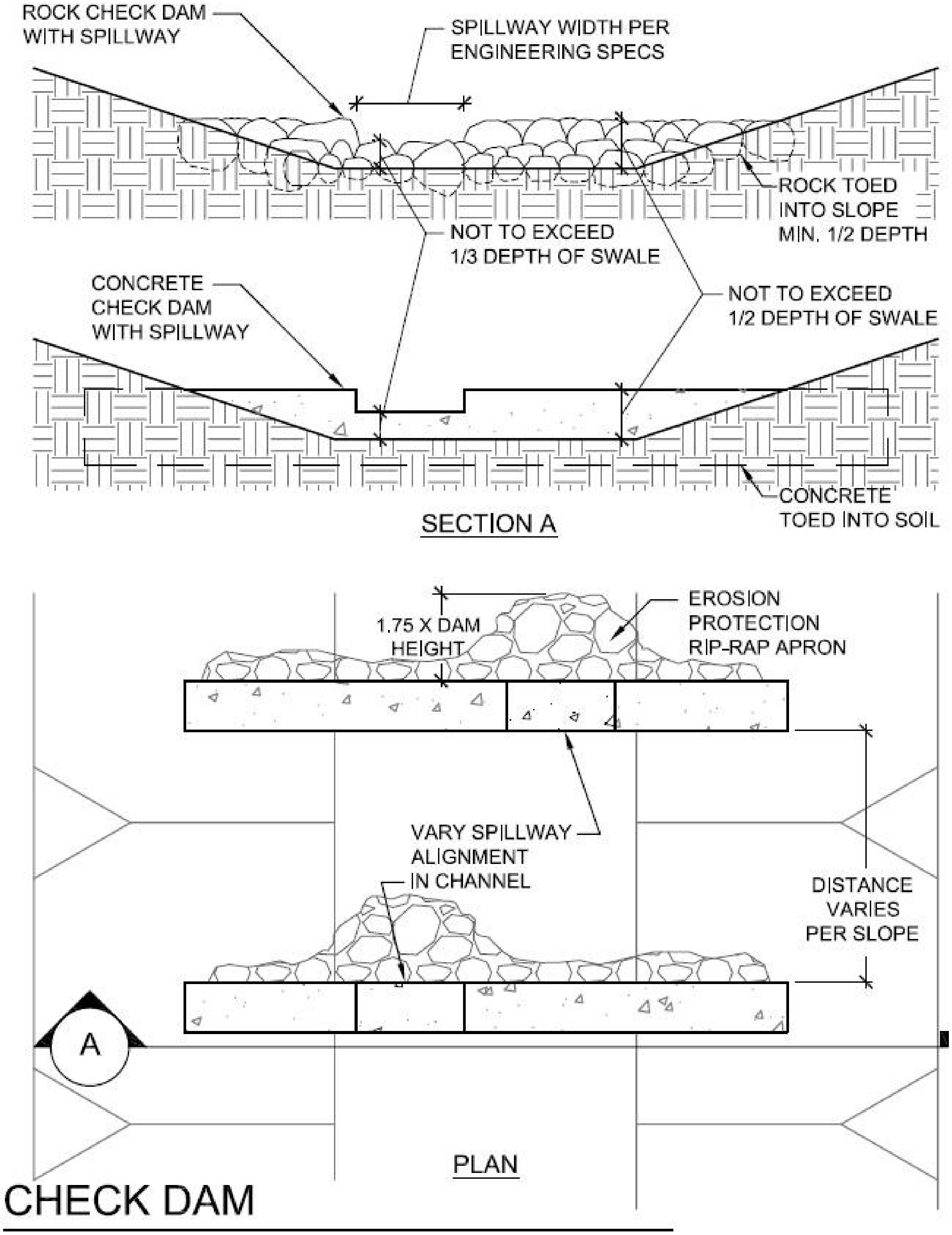
The top surface of the flow spreader plate should be level, projecting a minimum of 2 inches above the ground surface of the swale, or V-notched with notches 6 to 10 inches on center and 1 to 4 inches deep (use shallower notches with closer spacing). A flow spreader plate should extend horizontally beyond the bottom width of the facility to prevent water from eroding the side slope and should have a row of horizontal perforations at the base of the plate to prevent ponding for long durations. The horizontal extent should be such that the bank is protected for all flows up to the 100-yr, 24-hour storm event (on-line swales) or the maximum flow that will enter an off-line swale.

Flow spreader plates should be securely fixed in place. Anchor posts should be 4-inch square concrete, tubular stainless steel, or other material resistant to decay.

6.7 Check Dams

If check dams are used, they can be designed out of a number of different materials, including riprap, or earthen berms (Figure 59). Check dams should be placed as to achieve the desired slope (<6%) at a maximum of 50 feet apart and should be no higher than 12 inches. If riprap is used, the material is recommended to consist of well-graded stone with a mixture of rock sizes. The following is an example of an acceptable gradation:

Diameter	% Passing
24 in.	100
15 in.	75
9 in.	50
4 in.	10



Source: Watershed Management Group

Figure 59. Check dam details.

6.8 Berms

Berms are typically constructed on contour to capture water by building a low permeability soil feature. In general, slopes should be limited to no steeper than 3:1 on the upstream side and 4:1 on the downstream. However, in very cohesive clayey soils, it may be possible to construct up to 2:1. As described in this manual, a berm is not a structural feature like an embankment. However, a berm may be a component of the following structural GI practices:

- Swale (as a flow splitter or to add vertical capacity).
- Water harvesting basin.
- Infiltration trench.

In addition, a berm can be used as a separate feature. Berms can be compacted using construction machinery in order to minimize the potential for erosion and rilling.

6.9 Soil Amendments

Native desert soils are more alkaline with sandy or clay consistency. There also tends to be less organic matter with less nutrient and water holding capacity. Native vegetation has adapted to these conditions, and addition of amendments will contribute to growth habitats not typically associated with these vegetation-types. Native trees and cacti tend to be water-opportunists, and addition of water and nutrients may result in greater than average expected plant growth rates and sizes. Current findings recommend backfilling added vegetation with native soils and placing mulch on the surface rather than amending soil with additional compost or additives. Urban areas will differ in the degree of degradated soil compositions, as previous development practices will vary from location to location making it difficult to prescribe a baseline soil composition. The most important aspect to promote plant growth in urban settings is to protect the soils from compaction resulting in an adequate area for plant root development.

Minimizing soil compaction will increase the soils porosity influencing water retention capabilities and ability for plant roots to expand. Changing the physical characteristics of the soil and addition of appropriate plants will reduce runoff volume and filter pollutants. Healthy plant materials will add to the cycle of site sustainability through leaf drop contributing organic matter to the soil and leaves intercepting rainfall to help reduce peak volume runoff.

Desert soil may include caliche soils, formed from mineral deposits that develop into hardened concrete-like layers. Caliche layers prevent plant roots from spreading, impede drainage, and may eventually suffocate plant roots, killing the plant. If removal of the caliche layer is prohibitive, digging a drainage hole is imperative, or plants cannot survive in this area.

Some soil amendments are appropriate for native desert soils to facilitate plant growth and to facilitate infiltration of stormwater, as described below and in Table 13.

6.9.1 Compost

Compost can be added to soils as a subsurface treatment and as a mulch to provide organic matter, reduce evaporation, reduce soil erosion and improve alkaline desert soils. Compost can be made using available plant wastes including straw and plant trimmings. See Tucson Organic Gardeners (http://www.pima.gov/deq/waste/pdf/HomeCompostingInTheDesert.pdf) for additional information on how to make compost for homeowner use.

6.9.2 Gypsum

Soil stability affects infiltration rates, and soils with an unstable or dispersed structure can benefit from an application of a source of calcium such as gypsum ($CaSO_4 \cdot 2H_2O$) to improve permeability. Gypsum will not improve soil permeability if added to soils with good structure and where low infiltration is due to other factors.

Soil stability may be tested by simply placing 1 tablespoon of soil and 2 cups of water in a jar, shaking, and letting it settle for 15 minutes. If the soil particles do not settle out, the soil is not well-aggregated and may be susceptible to dispersion. In this case, it may be appropriate to apply gypsum. A laboratory soil test for soil adsorption ratio and electrical conductivity is the most appropriate way to determine the gypsum application rate. Gypsum is most effectively applied by physical incorporation into the soil subsurface; however, gypsum is soluble in water and will slowly improve soil structure when applied at the soil surface. Sulfuric acid and elemental sulfur are alternatives to gypsum, but they are only effective in soils with calcium carbonate that can be dissolved to form gypsum and release calcium. See Arizona Cooperative Extension (2006) for additional information.

Table 13. Specifications for soil amendments.

Soil Amendments and their Specifications				
Item	**Depth**	**Cost** *(2008 dollars)*	**Specifications**	**Purpose**
Soil clearing and testing	6 –12 in.	$3–$5/sq. yd. (square yard)	Clearing and grubbing; soil infiltration testing	Evaluate soil compaction and organic nutrient content/requirements
Nitrolized redwood shavings	6–12 in. (i.e., depth to which the shavings should be mixed in)	$95/cu. yd. (cubic yard)	Roto-till shavings into native soil	Increase infiltration rates and water retention properties of soil
Compost/soil conditioners/ fertilizers	6–12 in. (i.e., depth to which the compost, soil, or fertilizers should be mixed in)	$95/cu. yd.	Roto-till into native soil	Increases infiltration rates, water retention properties, and nutrient content of soil
Bark mulch	At grade	$10-$30/cu. yd.	Spread over all planting areas to a depth of 3 in.	Reduced evaporation and increases water retention properties of soil

Source: City of Santa Barbara 2008

6.10 Hydraulic Restriction Layers

Lateral and vertical seepage can cause adverse impacts when structural GI practices are sited adjacent to other infrastructure or where soils do not support infiltration. In such cases, hydraulic restriction layers should be used to restrict movement of water. Three material options exist to create hydraulic restriction layers: geomembranes, concrete, and clay. The specific type of layer should be selected and design on a site-specific basis.

Geomembranes are generally applicable when surrounding areas will not receive heavy loading. They should be sealed per manufacturer recommendations, and loose edges should be securely attached, toed-in, or battened. Concrete hydraulic restriction layers are often preferred adjacent to roadways and other sensitive, load-bearing infrastructure. Root barriers may be needed in some locations to protect utilities and other infrastructure. All hydraulic restriction layers should extend the full depth of the soil media to the base of the drainage layer or to a depth where saturation will not affect any adjacent load-bearing soils.

6.11 GI/LID Features that Calm Traffic

6.11.1 Street-related Features that Calm Traffic

Traffic calming measures along streets in which street water management can be integrated include boulevard islands, rotary islands, traffic circles, street ends, chicanes, road-diets, cycle tracks, and curb extensions. Roadway runoff can be directed into these features via flush curbs or curb inlets into a raised curb. Several GI practices can be used in traffic calming features, including bioretention, infiltration trenches, permeable pavement, sidewalk planters, tree boxes, stormwater harvesting basins, and rock swales.

6.11.2 Stormwater Curb Extensions

Stormwater curb extensions extend into the street from the curb, narrowing the road width, which also increases pedestrian safety and helps calm traffic. They are also commonly known as bulb outs, bulges, chicanes, or chokers. A stormwater curb extension allows water to flow into the landscape stormwater space that can be designed with the physical characteristics of vegetated swales, planters, or rain gardens.

The following design factors should be considered with a curb extension: size of catchment area, dimension of curb inlet, internal storage volume, overflow provisions, street slope, check dams, street type, and existing subgrade conditions. The most significant constraint when implementing stormwater curb extensions into street design is the potential traffic impact and loss of on-street parking space particularly in business districts. Additionally, a conflict with bike travel may arise if adequate space is not allowed between the edge of curb extension and a street’s travel lane. Geotechnical investigation is also required since infiltration rate depends on site condition. Curb extensions are not suitable on fill sites, where groundwater depth is less than 10 feet below ground surface, where a project is located in hillside areas, or where areas are subject to slides or unstable soil. In areas where on-street parking is fully utilized, smaller stormwater curb extensions, spaced more frequently, can be used to minimize parking loss to any individual property. Stormwater curb extensions can also be designed on streets with an angled parking configuration. Accessible pedestrian ramps can also be integrated into the design of stormwater curb extensions to provide safer pedestrian crossings.

Curb extensions can be implemented in a variety of land uses, from low-density residential streets to highly urbanized commercial streetscapes. For steep streets, curb extensions are beneficial because they operate as a *backstop* to capture stormwater runoff from upstream flows. Medians and bumpouts can be used to increase pedestrian safety by reducing the distance of travel across the street and creating refuge. Bumpouts can be used on smaller side streets to change the turning radia of traffic entering neighborhoods and slow cars to lower speed limits. Slowing traffic by adjusting turning radia on large cross streets aids pedestrian safety at crosswalks.

6.12 Additional Considerations

When planning a development, some required infrastructure may conflict with structural GI practices. The designer should be cognizant of these potential conflicts in the early stages of planning in an effort to avoid having to redesign the site lay out. ADA requirements and utility locations are two of the most common types of required infrastructure that should be considered when locating the structural GI practices.

Every commercial and industrial development is required to comply with ADA requirements. When the site layout is designed, the location of flow paths shall not be placed where ADA handicap parking is located. Additionally the ADA ramps shall not be utilized as a flow path. When a stormwater harvesting basin is utilized as a multi-use basin, the ADA requirement shall be used to insure the safety of the basin if the public will enter the basin for passive recreation.

When structural GI practices such as stormwater harvesting basins and swales are located within the ROW potential conflicts can occur with the location of the utility. The depth of the basin or swale shall be compatible with the utility burial depth location.

6.12.1 Other Design Considerations for GI in Transportation Systems

- Street configurations, topography, soil conditions, and space availability are some of the factors that will influence the design of the GI facility.
- Fire codes tend to require that streets have a minimum 20 feet of unobstructed width; a street with parking on both sides would require a width of at least 34 feet.
- Trees are impacted by higher heat levels next to asphalt, leading to increased evapotranspiration and a possible increase in water needs. Tree distance from roadway needs to consider sight visibility triangles, crash safety, and overhanging branches. Trees are known to increase business sales for abutting properties, but challenges may include adverse impacts of roots to sidewalks and utilities. Trees provide the perception to slow down, creating self-regulation by vehicles.
- The soil around street trees often becomes compacted during the construction of paved surfaces and minimized as underground utilities encroach on root space. If tree roots are surrounded by compacted soils or are deprived of air and water by impervious streets and sidewalks, their growth will be stunted, their health will decline, and their expected life span will be cut short. By providing adequate soil volume and a good soil mixture, the benefits obtained from a street tree multiply. To obtain a healthy soil volume, trees can simply be provided larger tree boxes, or structural soils, root paths, or other commercial products can be used under sidewalks or other paved areas to expand root zones. These allow tree roots the space they need to grow to full size.
- Recycled rubber sidewalks are used as an alternative to cracked sidewalks and also help to infiltrate runoff.
- Utility ROWs need to be coordinated for placement that least interferes with GI.
- Gutterpans are not necessary if no drainage structures are present.
- Vegetated xeriscape swales are relatively inexpensive and typically used on residential sites and highway medians. These are practical where topography is not steep and flows are not high. Swales are ideal for residential and commercial streets with long, continuous space to support a

functioning landscape system or oversized parking lots. They are also used for arterial streets and boulevards with unplanted median strips.

- Infiltration trenches are especially useful for ROWs and medians with narrow configurations.
- Planters are generally more expensive than swales due to increased hardscape infrastructure. If designed to treat roof runoff, multiple installation in series may be required. For streets that require on-street parking, planters need to allow adequate space for people to access their vehicles and sidewalks. They are not applicable near building footprints, fill sites, hillside areas, or where areas are subject to slides or unstable soil. Planters are most commonly implemented in commercial streets and parking lots where space is often constricted.

6.13 Minimizing and Mitigation Soil Compaction

Typical construction activities tend to compact native soils and can dramatically decrease infiltration rates. Contractors and construction crews should take care to minimize compaction by using tracked equipment, excavating the last 12 inches using a toothed excavator bucket, minimizing the number of passes over the proposed subgrade, and operating the equipment outside of the structural GI practice area. Earth-moving activities should take place during dry conditions to reduce the occurrence of smearing the underlying soil surface, which can reduce soil permeability. To mitigate compaction and partly restore infiltration capacity to the underlying soil, the subgrade should be treated by scarification or ripping to a depth of 9 to 12 inches (see Figure 60; Tyner et al. 2009). If the design infiltration rate is not restored after scarifying or ripping, trenches can be installed along the subgrade to enhance infiltration. Trenches should be constructed 1-foot-wide by 1-foot-deep on 6-feet centers and filled with a 0.5-inch layer of washed sand, then topped off with pea gravel (Tyner et al. 2009).

Source: NCSU-BAE

Figure 60. For infiltrating practices, mitigate subsoil compaction by ripping grade to a depth of 12 inches.

6.14 Vegetation

Drought-tolerant vegetation native to southern Arizona is the best choice for planting within stormwater structures due to their adaptation to local conditions. It is important to evaluate and select vegetation that tolerates periods of inundation in part due to the increased amount of stormwater typically available during the summer and winter seasons. Terraces may be designed into a basin with water-loving vegetation planted in lower areas and drier vegetation planted on higher terraces. Within any terrace or depression in the basin, vegetation will benefit by being planted on mounds (i.e., 2–4 inches high for shrubs, 4–6 inches high for larger trees) that will allow the roots to be saturated but the stem or trunk flair to remain dry during lower levels of inundation.

Generally, the optimal time of the year to plant is in the fall or early spring to allow ample time for roots to develop and vegetation to become established before the high temperatures and dry period of April, May, and June. Planting just before the monsoon season allows the seasonal rainfall to help with establishment. Soil during the fall months remains warm. Air temperature is moderate, and milder winter rains provide moisture without excessive need for supplemental watering. Although winter months are typically mild enough for planting in the southwest, there is a risk of freezing and associated plant damage.

Mulch should be applied to the soil surface at a depth of 2–3 inches. Soil amendments may facilitate vegetative growth, and guidance on soil amendments is provided in Section 6.9, Soil Amendments.

6.14.1 Tall Pots and Tree Pots

Tall pots and tree pots are growing systems that use containers with a narrower diameter-to growing-pot-height ratio than traditional nursery grown stock. Both are used in Pima County to allow for deeper roots to develop on trees before they are planted and allow for quicker establishment and faster growth once they are in the ground. Commercially available slow water release products are typically placed in the planting hole when using tall pots, and these products can also be used with tree pots. In general, development of plants in tall pots and tree pots allows a longer tap root to develop, while the above ground plant will be less developed compared to nursery grown stock. The growth of the longer tap root allows a deeper root growth before lateral roots begin to spread outward. Both these systems result in higher up-front costs due to possible transport, as well as installation issues. The use of commercially available slow water release products typically narrows the plant palette to the hardiest of site-specific native species. Use of such products can also substantially increase the labor costs for installation as well as first-year maintenance because of the need to refill cartridges; this cost increase can be balanced if only if commercial slow water release products are used for the entire project. Then the entire cost of a hardline automatic irrigation system and its long term maintenance is saved. Another approach is to use both systems. One possible approach is to use tall or tree pots and slow water release products in areas of lower active public use and less visibility, such as areas of restoration. Commercially available slow water release products are also very effective when new plants are integrated into an established stand of vegetation and impacts from trenching are not an option. Actively used areas, such as pathways, trailheads, and seating areas would have hardline irrigation systems installed.

6.14.2 Plant Selection

The following is a selection of trees native to Pima County. A larger list of trees, shrubs, and groundcovers is located in Appendix G. The appendix also contains a selection of websites and references that will provide additional plant selection and valuable information. Check with your local regional transportation and/or parks and recreation landscape architects or arborists as there may be other preferred species by those jurisdictions.

- Catclaw Acacia, *Acacia greggi*
- Whitethorn Acacia, *Acacia constricta*
- Ironwood, *Olneya tesota*
- Palo Blanco, *Acacia willardiana*
- Desert Hackberry, *Celtis pallida*
- Kidneywood, *Eysenhardtia orthocarpa*
- Velvet Mesquite, *Prosopis velutina*
- Screwbean Mesquite, *Prosopis pubescens*
- Western Honey Mesquite, *Prosopis glandulosa*
- Blue Paloverde, *Parkinsonia florida*
- Foothill Paloverde, *Parkinsonia microphylla*
- Desert Willow, *Chilopsis linearis*
- Texas Mountain Laurel, *Sophora secundiflora*

6.14.3 Considerations during Maintenance

Plants in urban areas need additional care and maintenance due to safety and visibility issues associated with pedestrians, bicyclists, and drivers in vehicles. Most desert trees do best with little to no pruning; excessive pruning could do more harm than good. Selection of plant materials should be based on plant growth, form, and location. Palo verde trees photosynthesize sunlight in their green bark areas as well as in their leaves, so excessive pruning of trunk and branches reduces this growth production ability.

Site maintenance needs to include controlling weeds and invasive plants by hand weeding or selective herbicide applications. Supplemental hand watering may be necessary during the establishment period of three to five years post-installation if the region is undergoing a prolonged drought period. Landscaping along major and minor roadway arterials will be maintained by the responsible jurisdictions. Neighborhood and collector roadways will require oversight by adjacent property owners or neighborhood groups/associations.

As previously mentioned, if commercially available slow water release products are used, they will require the dedicated replacement of cartridges to keep plants healthy. The hardiest plants, such as agave, typically receive three cartridges; shrub and tree pits have one cartridge placed in the bottom of the pit and three to five at the surface. Only those near the surface require replenishment. These must be replenished every 30 to 60 days for the seven month growing season (approximately April to October); during rainy periods, the replacements may be suspended. For the greatest success, this practice must continue until the plants are established, which takes from 5 to 7 years. Applications of commercially available slow water release products in commercial settings or other highly visible-use and activity areas have not been fully evaluated; this practice is currently used predominantly in restoration and park projects with large areas of open space.

6.15 Tree Canopy

Trees provide many benefits associated with GI practices. They intercept rainfall with their canopies, diminishing the full impact of rainfall as it hits the earth. The canopy also holds droplets with surface tension, allowing time for evaporation. Trees also transpire water back into the air through their leaves. Evapotranspiration is the combined effects of evaporation and transpiration, which provides an over-all reduction in the volume of excess stormwater runoff in a vegetated area. Tree roots improve the infiltration capacity of the soil, further reducing runoff potential. Street trees in urban areas also improve street aesthetics, provide shade and cooling, and improve air quality.

Trees should be planted contiguously to maximize their influence on runoff. A tree canopy is typically assumed to intercept approximately 10 percent of rainfall, however, interception and evapotranspiration will have a greater effect on runoff volume reduction for small, frequently occurring, low intensity storms than for larger, intense events.

6.15.1 Advantages

- Able to attenuate flow and reduce volume.
- Provide shading and cooling.
- Improve air quality.
- Cost effective method to improve environmental conditions.

6.15.2 Design and Construction Considerations

- Provide adequate space for roots to promote tree development and reach optimal canopy size.
- Use deciduous tree leaf litter as mulch or require clean-up management.
- Select tree species based on location and whether rapid growth will occur.
- Do not compact soils in areas to be planted.
- Roughen surface to improve seed establishment and moisture retention.
- Use mulch to increase water retention and improve soil stability.
- Provide erosion matting or soil stabilizers on steep slopes to prevent erosion, a critical negative issue.

6.16 Pretreatment Devices

This manual’s primary focus is the use of stormwater to supplement and augment the region’s limited potable water supply. The quality of the stormwater runoff from typical development does not inherently need pre-treatment prior to retention and on-site use. However, pre-treatment devices may be used to reduce constituents in the runoff including sediment and floating debris. In addition, retention of stormwater for other use will improve water quality on its own.

In order to address stormwater treatment concerns, a number of devices have been developed that assist in the removal of trash and other floatable debris as well as contaminants such as oils and other petrochemicals. These devices are proprietary and manufacturers will have more data on the capability of their products than this manual can address, so individual devices will not be described here. Therefore, some projects may employ pre-treatment prior to discharging or infiltrating stormwater. Other projects, based on the desire of the owner or the ultimate use of the stormwater, will employ pre-treatment, even if not required. As such, a brief description of the typical pre-treatment devices is provided below.

6.16.1 Filtration Devices

Filtration devices allow stormwater to pass through filter media that is designed to reduce specific stormwater pollutants. Pollutants can be captured physically or through sorption onto the filter media. Filters can either be inserts that are retrofitted into existing catch basins or manholes, or stand-alone units supplied by a manufacturer. The following are the main types of filters:

- Tray type inserts allow flow to pass through filtration media contained in a tray around the perimeter of a catch basin. High flows pass over the tray and into the catch basin directly.
- Bag type (or sock type) inserts (Figure 61) are made of fabric that hangs down below the catch basin grate. Overflow holes are usually provided to allow larger flows to pass without causing flooding at the grate.

Figure 61. Bag or sock type inserts.

- Basket type inserts (Figure 62) can be fitted with packets absorbent material to aid with removal of oil grease and toxic pollutants. Small orifices allow small storm events to weep through, while larger storms overflow the basket.

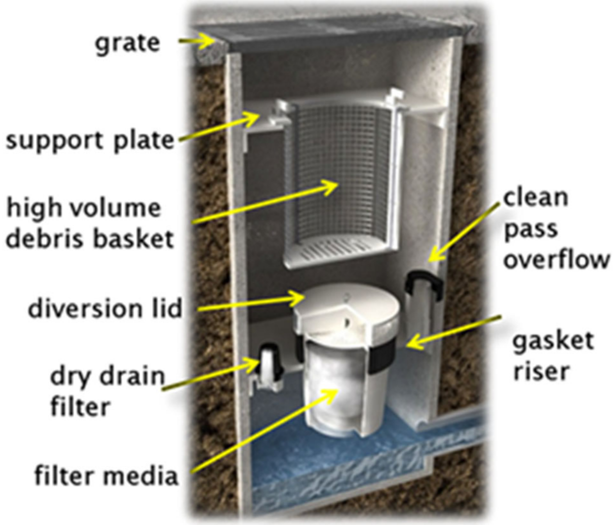


Figure 62. Basket type insert.

6.16.1.1 Media Types

Filter media may be a screen, fabric, activated carbon, perlite, zeolite, or other material. Often a combination of media can be used to target the specific pollutants of interest.

6.16.1.2 Maintenance

Trash and large objects can greatly reduce the effectiveness of filtration devices. Frequent maintenance and the use of screens or grates are necessary to prevent loss of efficiency and bypass of flows.

6.16.2 Hydrodynamic Devices

Hydrodynamic devices (Figure 63) can be used to capture oil, grease, and floatables, although they are predominantly used to remove coarse sediment from the water column by enhancing the rate of sediment settling through the circular motion of the stormwater in the chamber. Pollutant removal can occur through screening and/or through gravity settling. By having the water move in circular fashion, rather than a straight line, it is possible to obtain significant removal of suspended sediment and attached pollutants with less space when compared to other settling devices. Oils and greases can be removed using sorbent media.

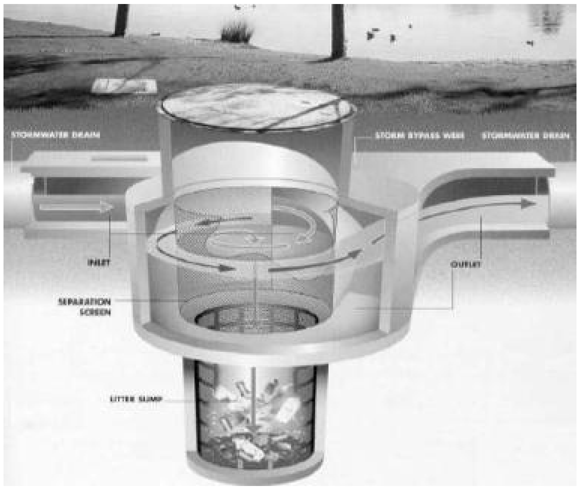


Figure 63. Tray-type insert.

Like filtration devices, hydrodynamic devices are typically designed to provide optimal removal efficiency for smaller, more frequent storms with little pollutant removal in larger, less common storms. These devices are generally proprietary and are designed and installed by the manufacturer.

Maintenance: The maintenance of hydrodynamic devices is not as intensive as it is for filtration devices. Inspections should occur annually and after large storm events, and the sediment should be removed periodically, in accordance with the manufacturer's recommendations.

6.16.3 Information on Individual Proprietary Products

Many different water quality control organizations have developed lists of acceptable proprietary products, their efficacy at removal specific pollutants, and their appropriateness of use for particular situations. The most comprehensive manual describing proprietary products is the CalTrans manual, which can be found here: http://www.dot.ca.gov/hq/env/stormwater/pdf/CTSW-RT-09-239-06.pdf.

6.17 Sources, Citations, and Additional Resources

Arizona Cooperative Extension. Using Gypsum in Southwestern Soils. College of Agriculture and Life Sciences, the University of Arizona, AZ1413, 07/2006.

California Department of Transportation (Caltrans), April 2010. *Treatment BMP Technology Report*, CTSW-RT-09-239.06

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Pavao-Zuckerman, Mitchell A. The Nature of Urban Soils and Their Role in Ecological Restoration in Cities. Restoration Ecology, Dec. 2008. Vol 16, No. 4: 642-649.

Schueler, T. 2000. The Compaction of Urban Soil: The Practice of Watershed Protection. Center for Watershed Protection, Ellicott City, MD. Pages 210-214.

Tucson Organic Gardeners. Home Composting in the Desert. http://www.pima.gov/deq/waste/pdf/HomeCompostingInTheDesert.pdf. Accessed 02/07/2012.

Watershed Management Group, August 2010. *Green Infrastructure for Southwestern Neighborhoods*, p. 22, Version 1.0.

7 Appendices

Appendix A: Analysis of Rainfall Data Collected at the University of Arizona

At the University of Arizona, data from over 4700 events were recorded between 1895 and 2000 resulting in an average of 45 events/year, with approximately 40% of all events being 0.1 inch or less (Figure A1). Approximately 85% of all events are less than 0.5 inch (Figure A2). Because the 85% rainfall event has been identified as a good event for capture of rainfall for stormwater mitigation by ASCE (ASCE, 1998), the region has chosen this 0.5 inch event as a minimum threshold for 'first-flush' retention (Pima County *Design Standards for Storm Water Detention and Retention*).

The 0.5 inch or smaller rainfall events account for approximately 50% of annual rainfall volume (Figure A3). Rainfall events of 1.0 inch or less account for approximately 80% of rainfall volume, and daily rainfall depths of over 2.0 inches of rainfall account for approximately 3% of annual rainfall volume on average. Runoff from the 0.1 inch or less events are minimal because the threshold needed to cause runoff from an impervious surface (0.05" for a CN of 99) eliminates a significant component (Figure A4). Therefore, the greatest volumes of water, which is also usable, occur in the events between 0.3 and 0.5 inches.

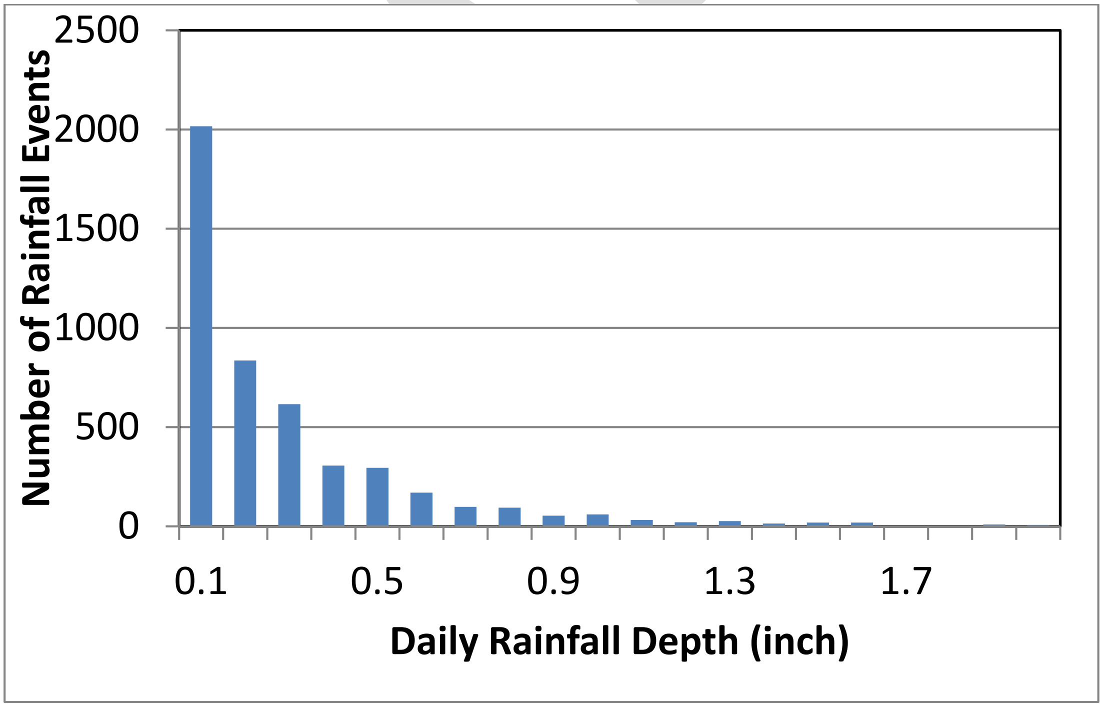

Figure A1 Daily rainfall recorded at the University of Arizona data from 1895-2000

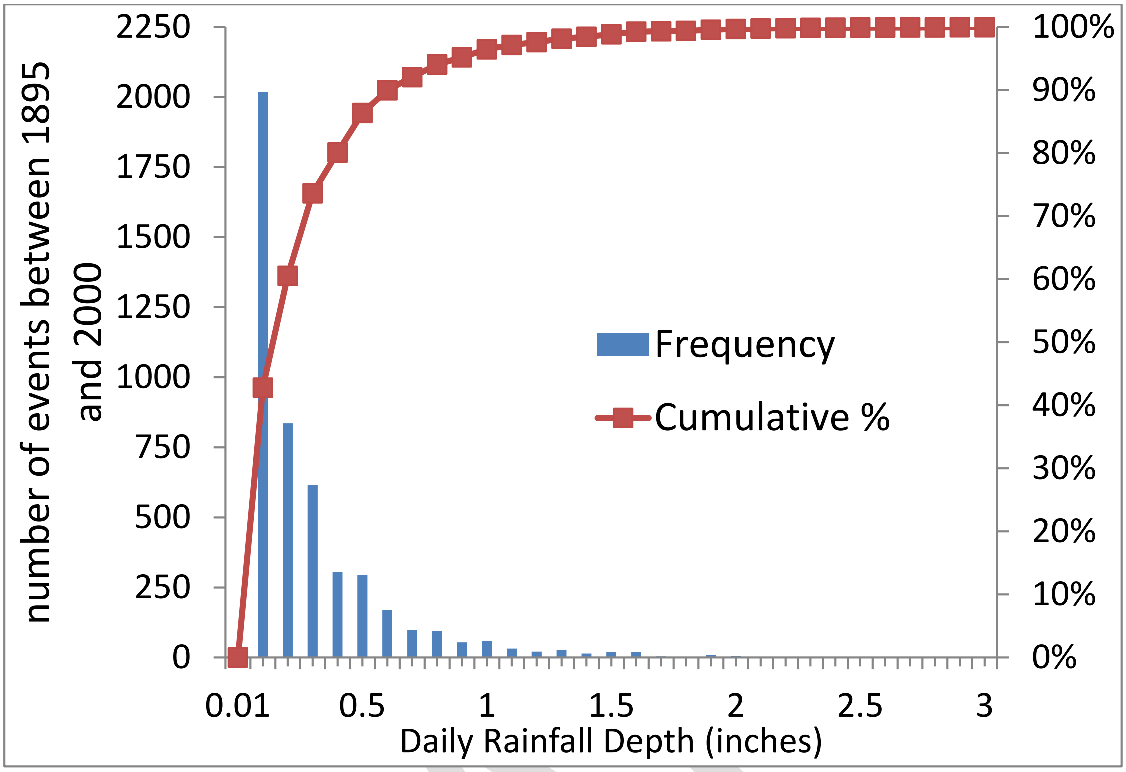

Figure A2 Daily rainfall and cumulative number of events.

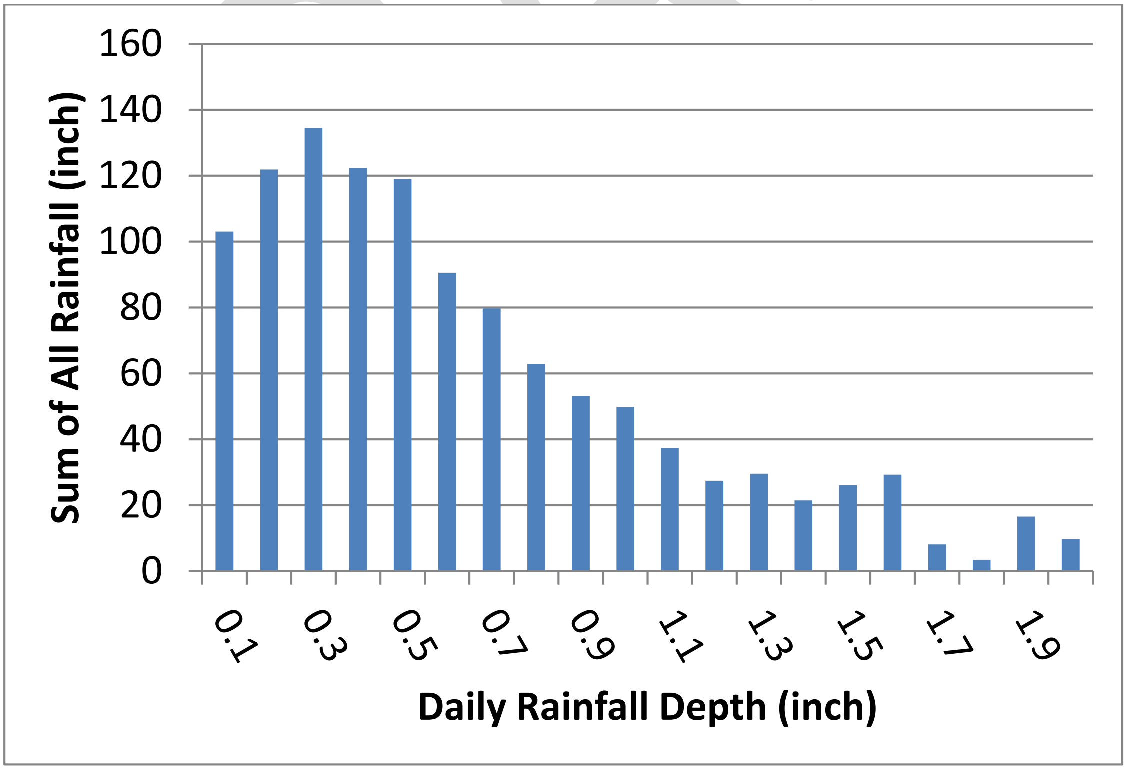

Figure A3 The sum of all rainfall in the events at the University of Arizona

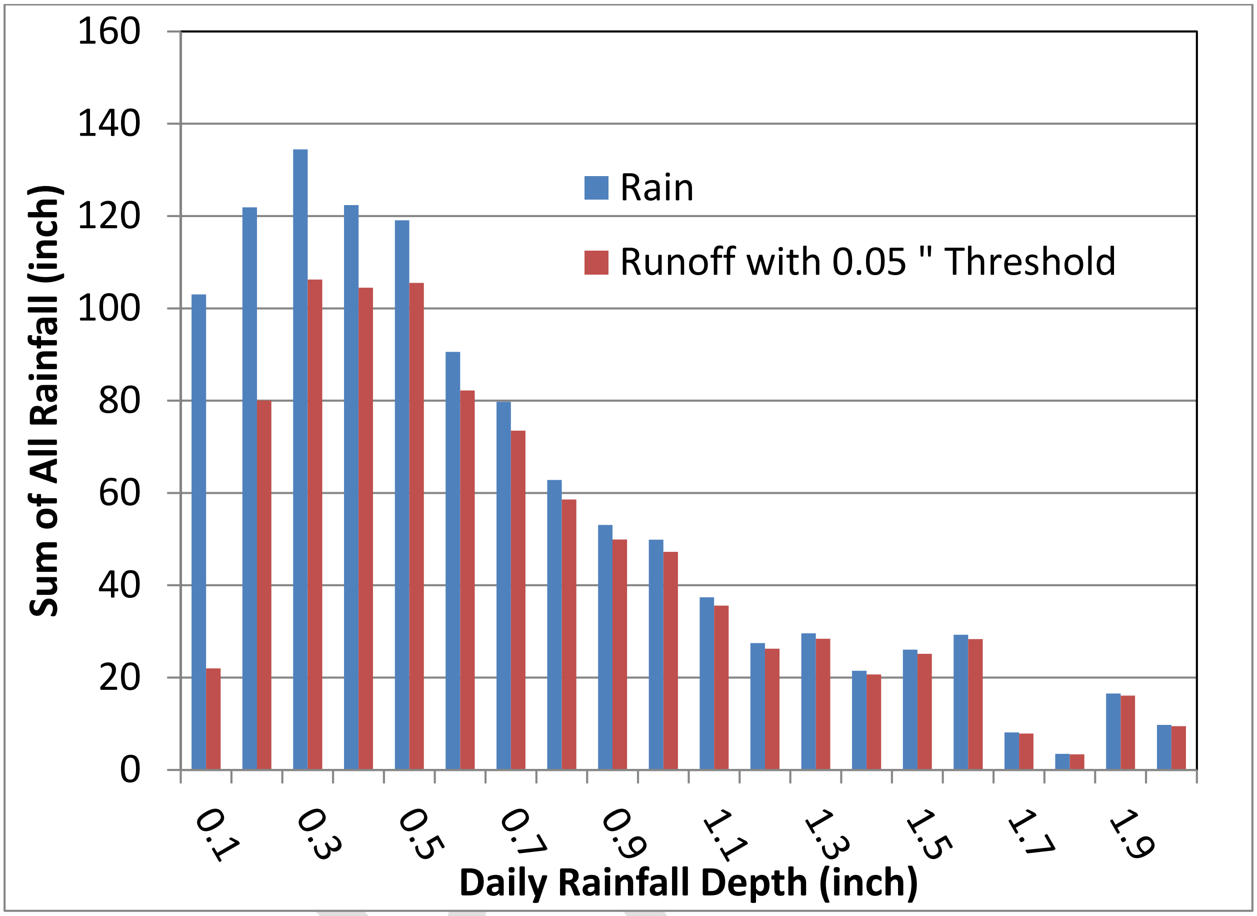

Figure A4 Daily Rainfall and Runoff

Structural GI/LID Practices provide benefits for all rainfall events. However, GI/LID is particularly effective for the frequently occurring smaller rainfall events. An analysis of local rainfall data (Figures A1 to A4) indicates that a large percentage of annual rainfall is attributed to frequently-occurring, smaller rainfall events such as those with a depth of 0.5 inches or less. GI/LID Practices are effective at utilizing these smaller rainfall events for beneficial use by infiltrating stormwater in the root zone of vegetation and are effective in improving stormwater quality by retention and vegetation use, while conventional infrastructure typically drains stormwater offsite.

Appendix B: Sizing Features to Support Vegetative Canopy

For areas that will support vegetation, the water budget should be considered by comparing the evapotranspiration (ET) demands of the anticipated vegetative canopy with the runoff supply that will be available based on the drainage area. Using ET and rainfall data from the University of Arizona, the recommended minimum drainage area to support the anticipated vegetative canopy is approximately 3.5 times the vegetative canopy area when a native low-water use plant palate is proposed. This value is derived below.

The drainage area required to supply the amount of runoff necessary to maintain vegetation can be estimated by calculating the minimum required catchment ratio based on the depths of water demand and rainfall supply by month as:

$$Catchment\ Ratio = \frac{\mathrm{ET}_{month}}{\mathrm{P}_{month}}$$

Where $\mathrm{ET}_{\mathrm{month}}$ = Average ET for specified month in inches

$\mathrm{P}_{\mathrm{month}}$ = Average rainfall depth for specified month in inches

The average monthly reference ET (ET_0) from daily data collected at the University of Arizona Campbell Avenue Farms along with the ET using a crop coefficient of 0.26 for desert vegetation (Table B1). The The average monthly rainfall recorded at the University of Arizona in Tucson for a period of record of approximately 100 years (Table B2). Average ET demand are listed in Table B3.

Table B1 Plant Water Use ET Factors (Waterfall, University of Arizona Cooperative Extension, 2006)

Plant Type	Plant ET Factors	
	High	Low
Low Water Use	0.26	0.13
Medium Water Use	0.45	0.26
High Water Use	0.64	0.45

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Table B2. Average monthly rainfall within Pima County.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg Monthly Rainfall (in)	0.90	0.86	0.77	0.39	0.18	0.27	2.07	2.17	1.18	0.77	0.78	0.97	11.31

Table B3 Average evapotranspiration demand in inches within Pima County.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg Reference ETo	2.63	3.00	4.90	6.81	8.90	9.37	8.80	7.51	6.40	4.79	3.09	2.48	68.69
Avg ET for desert veg. (0.26)	0.68	0.78	1.27	1.77	2.31	2.44	2.29	1.95	1.66	1.24	0.80	0.64	17.86

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The City of Tucson Commercial Water Harvesting Development Standard (DS 10-03.0) accounts for annual, spatial, and depth variability in rainfall by, in effect, multiplying the average monthly rainfall depth by a factor of 50%. The average rainfall and ET from the month of March is used for determining the catchment ratio (ratio of impervious area contributing to plant canopy area) because this is the last month with rainfall prior to an extended dry period. The catchment ratio is multiplied by the vegetative canopy (acres) to estimate the minimum drainage area (acres) necessary to meet the ET demands of the vegetative canopy:

$$Minimum\ Drainage\ Area = (Catchment\ Ratio) \cdot\ (Vegetative\ Canopy)$$

For example, if low-water-use desert vegetation is selected, the average ET for the month of March from the U of Arizona Campbell Avenue Farm is:

$ET_{O,\ March}$ (Plant Water Use Factor) = 4.90 (0.26) = 1.27 inches

Using the average rainfall depth for the month of March, the catchment scale is:

$$Catchment\ Ratio = \frac{\mathrm{ET}_{March}}{Effective\ Precip_{March})} = \frac{1.27\ \mathrm{in}}{(50\%)0.77\ \mathrm{in}} = 3.30$$

For a vegetative canopy with low water use with an area of about 1000 square feet, the minimum drainage area for the practice is:

$$Minimum\ Drainage\ Area = (Catchment\ Ratio) \cdot\ (Vegetative\ Canopy) = (3.30)(1000\ sq.ft.)$$
$$= 3300 sq/ft$$

In other words, *<u>a low water use desert tree needs a catchment contributing area 3.3 times larger than the plant canopy to grow on harvested water</u>.*

In this example, the LID Practice should be located in an area where the area draining to the LID practice will be at least 3 times the anticipated canopy area in order to support the planned area of vegetative canopy. This minimum drainage area serves as a guideline for determining where to locate the LID practice in the watershed. If an LID practice does not have the minimum area draining to it, locating the practice further down the watershed or adjusting grades to increase the catchment area should be considered. Once the approximate location of the LID practice within the watershed has been decided, the design stormwater volume should be determined to assess the flood control benefits of the LID practice.

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Appendix C: Design Volume to Size GI/LID Features for Flood Control Benefits

A histogram of the annual maximum daily rainfall event at the University of Arizona (Figure C1) shows that the most frequent maximum annual rainfall occurs between 1.375 inches and 1.625 inches in the 1.5 inch data bin, and that events greater than this 1.5 inch data bin are rare.

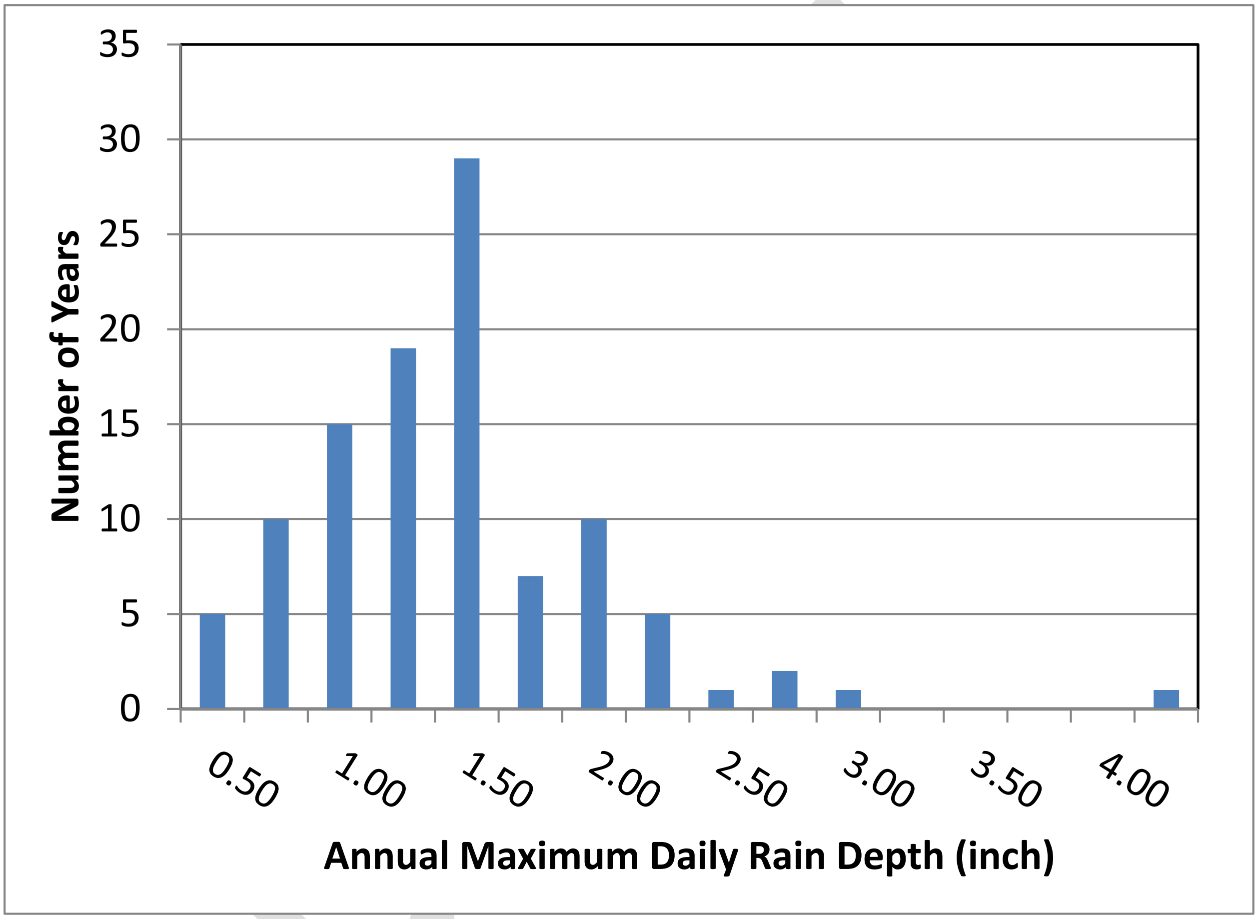

Figure C1 Annual maximum daily rainfall depths at the University of Arizona.

The five-year, one hour rainfall event is approximately 1.50 inches in Tucson (University of Arizona, year). This depth corresponds to the 98.8th percentile storm event from approximately 100 years of University of Arizona rainfall data, meaning that nearly 99% of all rainfall events are expected to be smaller than 1.50 inches at the University. As shown in Figure C1, rainfall depths greater than 1.5 inches are rare.

The 1.50 inches of rainfall depth was selected by using the probability of rainfall events in the University of Arizona rainfall data with the runoff volumes generated from a watershed that is predominantly impervious.

Figure C2 shows an example that frequently-occurring, very small events (i.e. less than 0.10 inches of rainfall) do not contribute much to the long-term cumulative volume of runoff, and very large events have a small probability of occurrence. A significant amount of the long-term cumulative runoff volume is expected to result from 0.25 inches to 1.5 inch rainfall events based on local rainfall data. Therefore, up to 90% of the average annual runoff volume can be captured by designing for the 1 inch rainfall event, and 98% of runoff volume can be captured by designing for the 1.50 inch rainfall event.

The incremental benefits of capturing higher volumes are most apparent when the impacts of design volume on peak flows are considered. The modeled 100-yr outflow hydrographs in Figure C2 show example reductions in peak discharge rates for varying levels of stormwater harvesting modeled from a 29.2 acre residential subdivision in Sierra Vista, AZ. The model was validated using rainfall and runoff data collected by the USGS for the subdivision from 2005 to 2007, and a 1-hour 2.88 inch rainfall storm was applied to generate the 100-yr hydrographs.

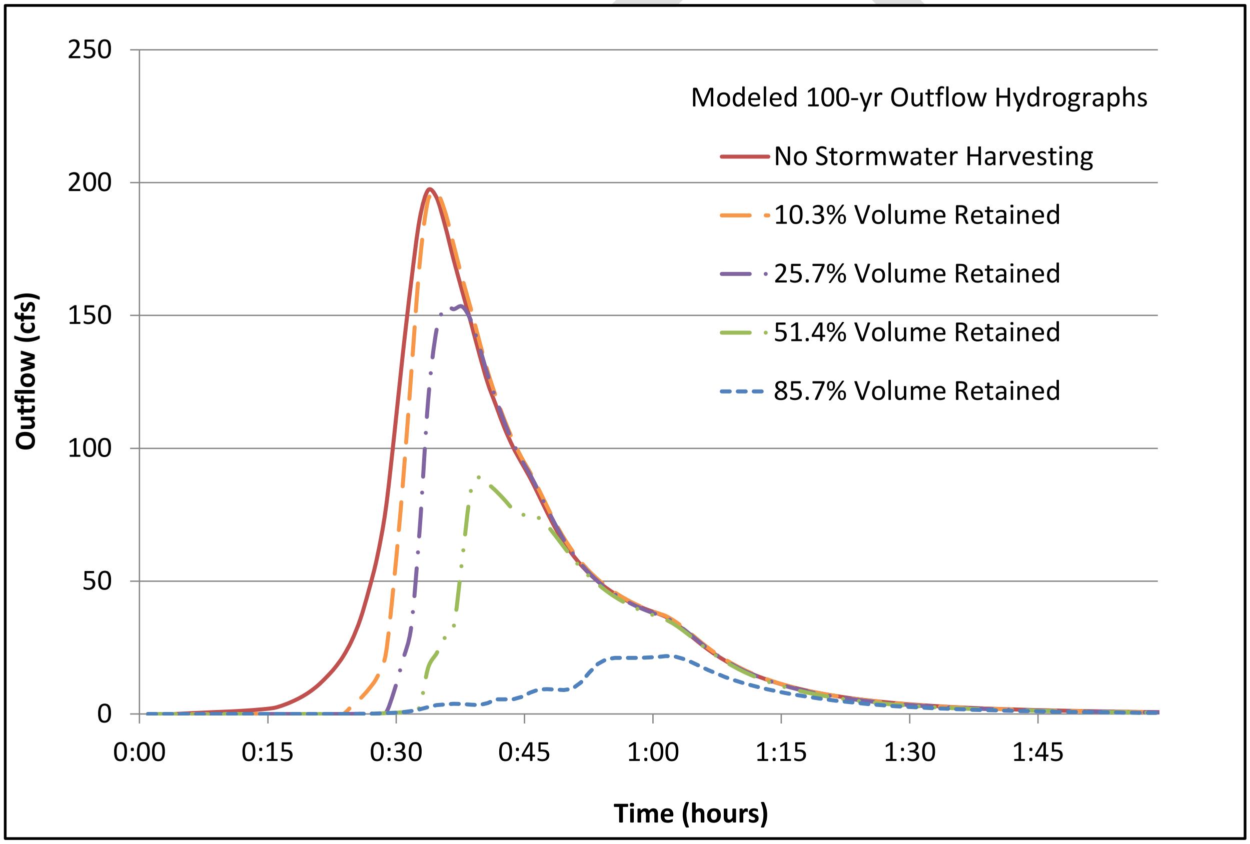

Figure C2 Modeled outflow 100-yr hydrographs for varying degrees of modeled stormwater harvesting distributed within a 29.2 acre residential subdivision.

As another example, a 3-hour, 3.00-inch rainfall event is approximately a 1% annual chance event in Tucson near the University of Arizona. LID Practices designed to retain the total runoff volume from 1.50 inches of rainfall can be expected to retain approximately half the runoff volume of this event. The LID Practices with the 1.50 inch rainfall design volume are expected to reduce peak discharge from a 3-hour, 3.00 inch rainfall event (about a 1% annual chance event) by approximately half using the stormwater harvesting factors in the Draft *Design Standards for Stormwater Detention for Pima County (*Figure C3).

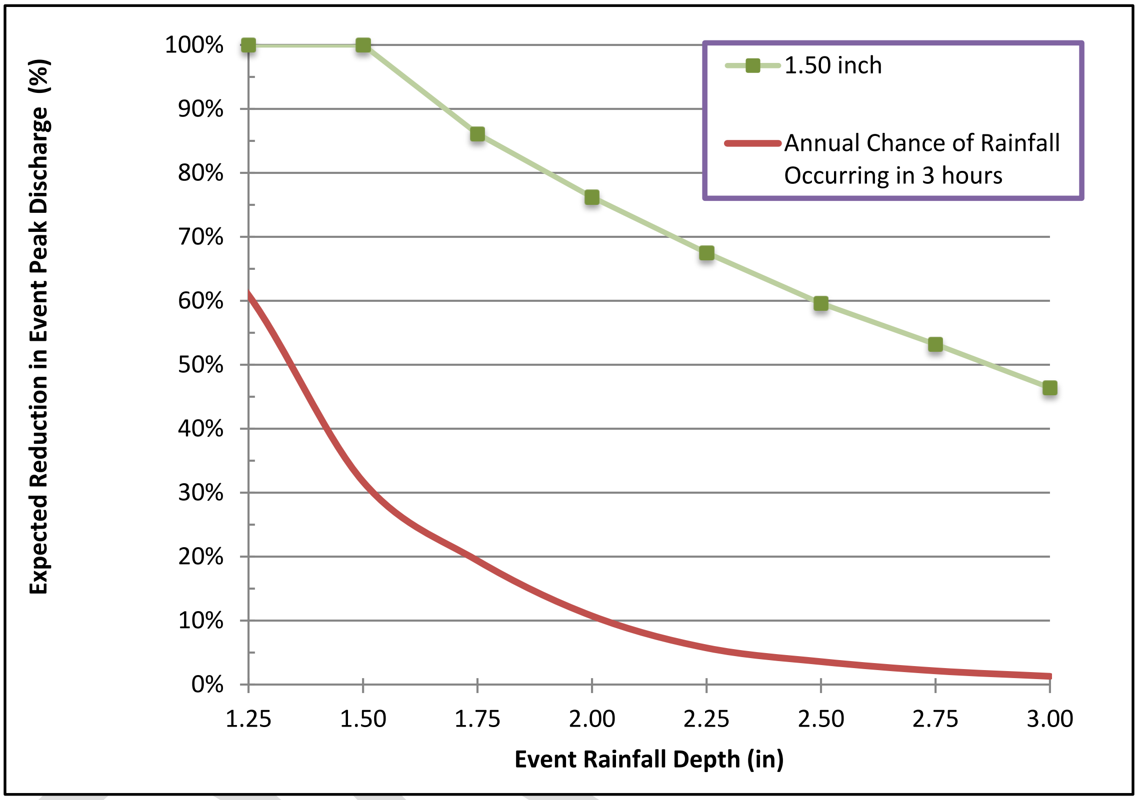

Figure C3 Peak Discharge reduction by GI/LID Practice Design Volume for a 3-hour rainfall event with varying rainfall depths based on Pima County Stormwater Detention Manual stormwater harvesting factors.

This guidance is not regulatory, and a design volume that is larger or smaller may be used for any individual practice. For example, larger design volumes may be used if mitigation of peak discharges from larger flood events is necessary, or smaller design volumes may be used if site constraints limit GI/LID Practice volume. Also, flows from the design volume may be directed to several practices with an overflow leading from upstream practices to downstream practices. When a development is subject to the requirements of the Pima County Stormwater Detention Manual, the designer must ensure the overall site will meet these requirements.

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Appendix D: Derivation of 5 cfs/ac

The value of 5 cfs/acre is derived from the assumption that for small watersheds, the City of Tucson and Pima County use related peak runoff calculation methods based on the Rational Method (Equation 1). This equation relies on a runoff coefficient calculated from the Curve Number, watershed area, and rainfall intensity at the time of concentration.

$Q_p =$ 1.008 q A {Equation 1}

Where,

Q_p is the calculated peak discharge, cubic feet per second or cfs;

1.008 is a factor for converting acre-inches/hour to feet^3/sec;

(1 ac-in/hr x 43,560 ft3/acre-feet x 1 hr/3600 seconds x 1 ft/12 inches = 1.008 cfs);

q is the runoff supply rate, in/hr, at the watershed Time of Concentration; and,

A is the watershed area above the outlet or concentration point, acres.

The runoff supply rate, q, is a function of rainfall intensity and watershed characteristics (soil type, vegetative cover, flow distance, slope, channel roughness, and degree of urban development), and it is expressed as:

q = C_w i {Equation 2}

Where,

q is the runoff supply rate, inches/hour, at the watershed Time of Concentration;

C_w is the Runoff Coefficient or the area-weighted ratio of runoff to rainfall. It is dimensionless, and is a function of the basic Natural Resource Conservation Service-SCS Curve Number (CN) and the 1-hour rainfall depth for a given storm frequency; and,

i is the rainfall intensity, in/hr, calculated at the watershed Time of Concentration for the given discharge frequency.

For smaller urbanized watersheds, with lots of impervious areas (< 5 acres) , the time of concentration is often calculated to be shorter than 5 minutes, but both methods default to the 5 minute rainfall intensity. As such, Cw in Equation 2 is the runoff rate for the 1 hour rainfall using a CN of 99, and i is the 5-minute rainfall intensity

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Appendix E. Simulating Offset of Water Demand from Varying Cistern Volumes

Continuous simulations of daily rainfall data from the University of Arizona for 105 years from 1895 – 2000 was used to provide guidance on appropriate sizing of cisterns. Runoff from the rooftop is modeled from the daily rainfall values using a Curve Number (USDA-SCS, 1986) of 99. The cistern volumes were varied in the simulations. The cistern volumes were normalized by roof area draining to the cistern and given the variable name "Z", with values of Z = 0.05 ft to Z = 0.60 ft evaluated (from 375 gallons to 4500 gallons per 1000 ft^2 of draining roof area).

Any water demand is removed from the cistern daily and any deficit in water volume that must be provided from an additional source is calculated on a daily time step for the years of record. In addition, any overflow volume of runoff leaving the cistern is calculated on a daily time step. The total water deficit and the overflow volumes are summed for each month and monthly averages were calculated for the years of the daily rainfall data for each simulation. The reduction in the total water demand due to the cistern was calculated as the difference in the total water demand to the average deficit water volume on a monthly basis. Currently, water demand curves for irrigating vegetation are simulated.

Simulation of Cistern Volumes for Irrigation

The water demand for irrigating desert vegetation was simulated using a crop coefficient of 0.26 multiplied by the daily reference evapotranspiration (ET_0). Native desert vegetation will survive on rainfall alone; however, the water demand was assumed to be the estimated optimal evapotranspiration rate for desert vegetation such as mesquite trees. Any daily rainfall depth is removed from the evapotranspiration requirement for the vegetated area and the remaining water volume is removed from the cistern or counted as a deficit when the cistern is empty on a daily time step.

The water volume removed from the cistern is simulated as the evapotranspiration rate after accounting for daily rainfall without overwatering; however, in practice a deep watering will occur at an interval that varies by month which in an ideal case would be the sum of the daily evapotranspiration requirement for the interval. The average monthly evapotranspiration in inches for desert vegetation after accounting for the daily rainfall in the period of record is:

Table E1 Average Monthly ET

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg Monthly ET after Rainfall (in)	0.60	0.71	1.17	1.70	2.28	2.37	1.80	1.51	1.46	1.14	0.73	0.56	16.03

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The daily ET is multiplied by the area of vegetation to determine the water demand. The vegetated area was varied as 8%, 20%, 30%, 50%, and 70% of the roof area (or 78 ft^2, 200 ft^2, 314 ft^2, 500 ft^2, 707 ft^2 of the 1000 ft^2 roof).

The most benefit from additional cistern volume in offsetting water demand for irrigation occurs in the months from April through June. Figure E1 and Figure E2 show the monthly offset in irrigation water demand and overflow volumes for varying size cisterns

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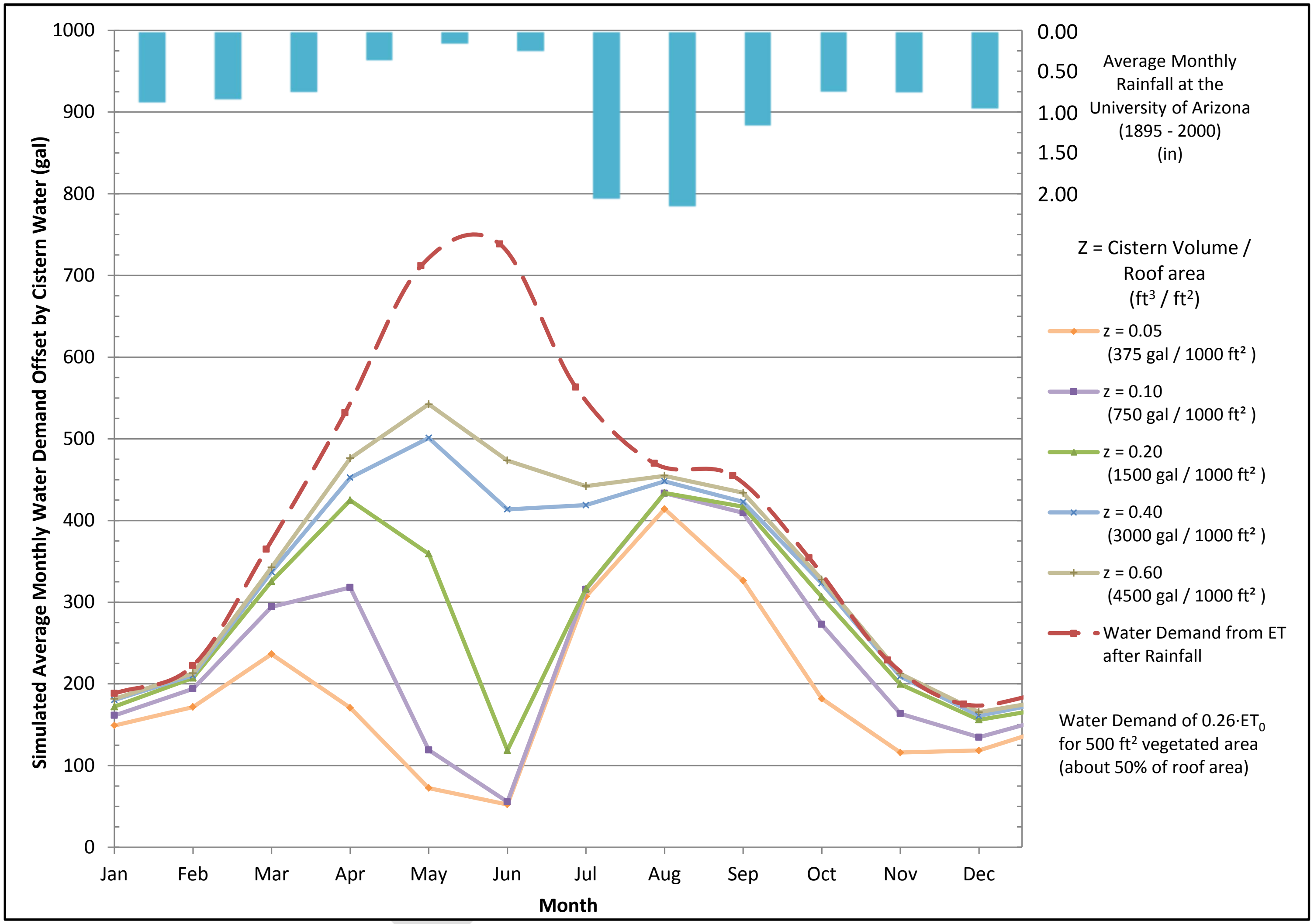

Figure E1. Offset in water demand for irrigation for varying cistern volumes.

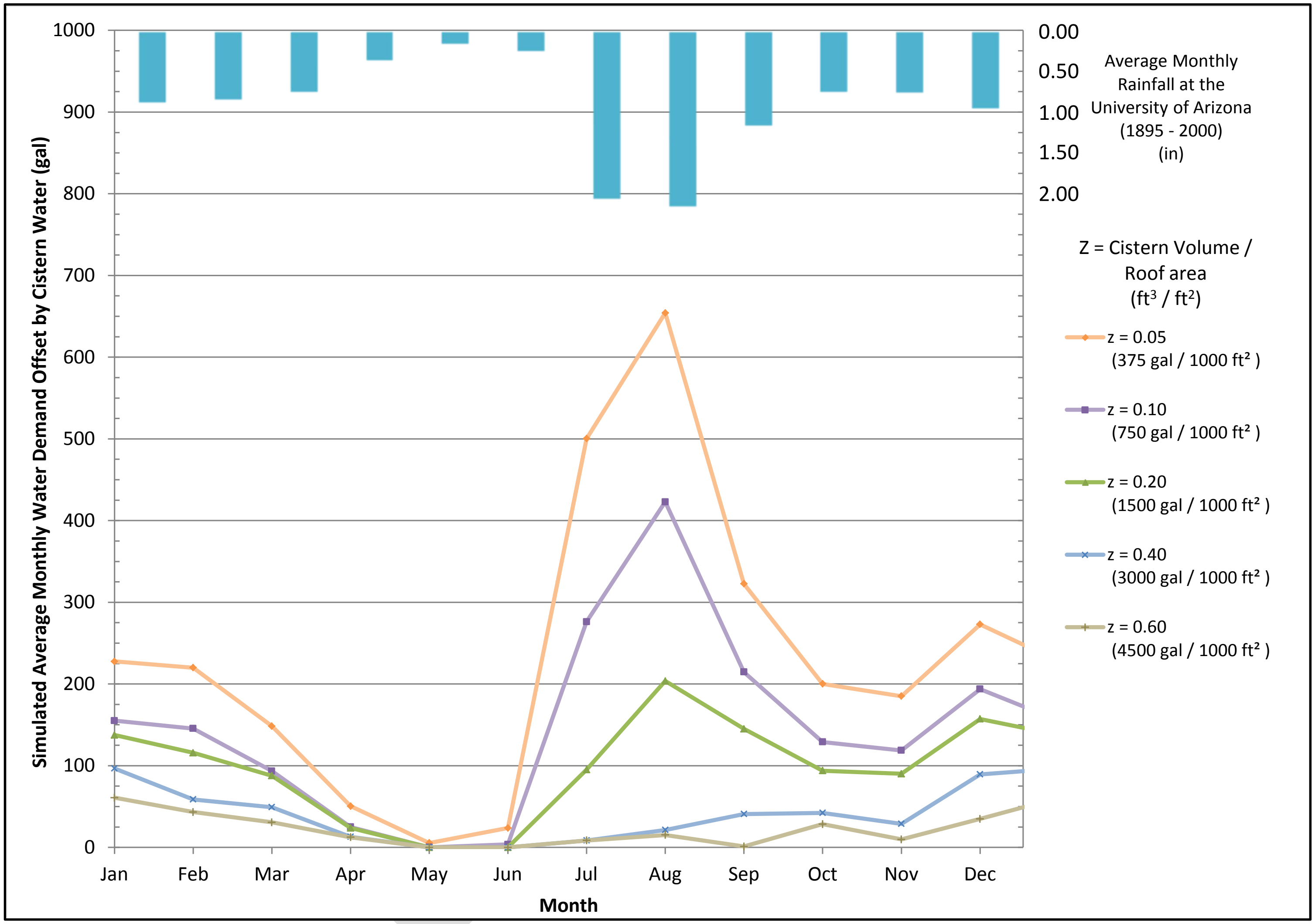

Figure E2. Overflow from cisterns with varying volumes for the demand curve in Figure X.1.

using a demand curve for a vegetated desert area that is 50% of the draining roof area. From the months of August through March, the limiting factor is the rate at which water volume is removed from the tank, and a cistern volume of Z = 0.10 ft (750 gal per 1000 ft^2 of roof) provides nearly as much offset in potable water demand as much larger cisterns (two or four times the volume) for those months when the water use is limited to the evapotranspiration rates of the desert vegetation. However, many additional uses can be found for extra rainwater harvested by larger cisterns during these months which creates available space for harvesting additional water.

The irrigation water demand in the April through June months is offset by increasing cistern size up until a volume of about Z = 0.40, when additional cistern volume shows marginal benefit because rainfall becomes the limiting factor and additional volume does not increase supply. The monthly overflow volumes (Figure E2) show that a cistern volume of Z = 0.40 ft has relatively small overflow volumes that could be retained with a larger cistern volume.

Varying the vegetated area relative to the draining roof area shows the annual offset in water demand for varying demand curves and cistern sizes (Figure E3, and Figure E4). At lower water demands (i.e. irrigated vegetated desert areas up to 30% of roof area), a cistern volume of Z = 0.20 provides over 90% of the annual water demand. For the demand curve of a vegetated area that is around 50% of the draining roof area, doubling the cistern volume shows about a 12% increase in annual water demand offset up until a cistern volume of Z = 0.40. Using the demand curves for irrigated vegetated desert areas of 50% of the roof area or more, the simulation indicates that the largest cistern volumes are limited by rainfall to offset water demand by an average of about 4500 gallons per 1000 ft^2 of draining roof area per year (which includes any overflow volumes due to the demand rate). Higher water demand (i.e. vegetated area that is 50% of roof area and larger) remove water from the tank at a quicker rate which allows additional storage; however, the offset in annual water demand by the cisterns represents a lower percent of the total water demand for larger vegetated areas (Figure E5.).

The most effective method of increasing cistern water supplied to vegetated areas is to increase the area of the roof draining to the cistern. However, the objective of the simulation is to provide guidance on sizing cisterns and therefore it is assumed that the roof area draining to the cistern is constant and has been maximized.

For a given area of vegetation and roof area, the annual irrigation water demand offset by increasing cistern sizes can be approximated from Figure E4. Water demands corresponding to a vegetated area of 30% of the roof area or greater show additional benefit in offsetting annual water demand by increasing cistern size up to a cistern volume of Z = 0.40.

The largest increase in annual offset of water use occurs in the change from no cistern to the smallest cistern considered (Z = 0.05, or 375 gal per 1000 ft^2), because even the smallest cistern considered provides nearly 40% offset in annual water use (or 2600 gal per 1000 ft^2)at the highest demand (70% vegetation area). When increasing cistern volumes above the smallest

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volume considered, the most benefit occurs when increasing from Z = 0.05 to 0.20 (375 to 1500 gal per 1000 ft^2) which corresponds to an increase of about 600 - 1200 gallons per 1000 ft^2 of draining roof area (depending on demand) in offset of annual water use. This indicates that the most return in annual water use offset is from all cistern sizes up to Z = 0.20 (1500 gal / 1000 ft^2).

When looking to increase water supply, constructing an additional cistern to collect from another roof area will likely provide the most volume rather than increasing cistern volume above Z = 0.20 (1500 gal / 1000 ft^2). The cost of an additional cistern should be evaluated compared to increasing cistern size. However, when an additional cistern is cost prohibitive or when additional roof area is not available, increasing the cistern design volume from 0.20 to 0.40 can provide an additional offset in annual water use of approximately 8-12% depending on water use.

To evaluate vegetation with higher crop coefficients than desert vegetation such as citrus trees or vegetables, the area of desert vegetation can assumed to be higher to match the demand curve of higher crop coefficient plants. For example, if citrus trees have a crop coefficient of 0.65 (or a factor of 2.5 higher than the 0.26 for desert vegetation) and the area of the citrus trees will be approximately 10% of the roof area, than the demand of the citrus trees can be approximated as desert vegetation that is 25% of the roof area (or 2.5 times the 10% area) for use with Figures E3 and E4.

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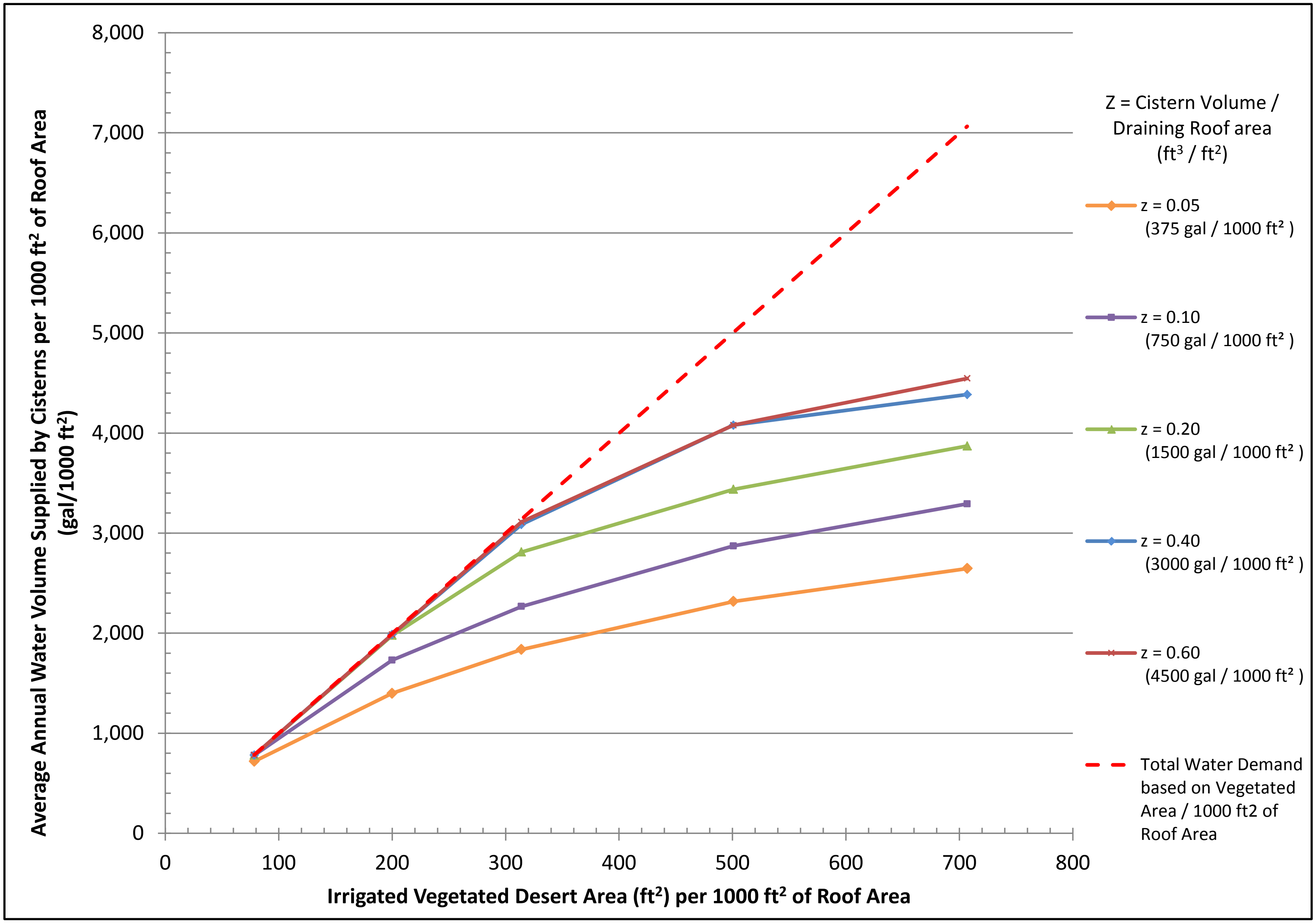

Figure E3. Offset in annual irrigation water demand by vegetated desert area relative to draining roof area.

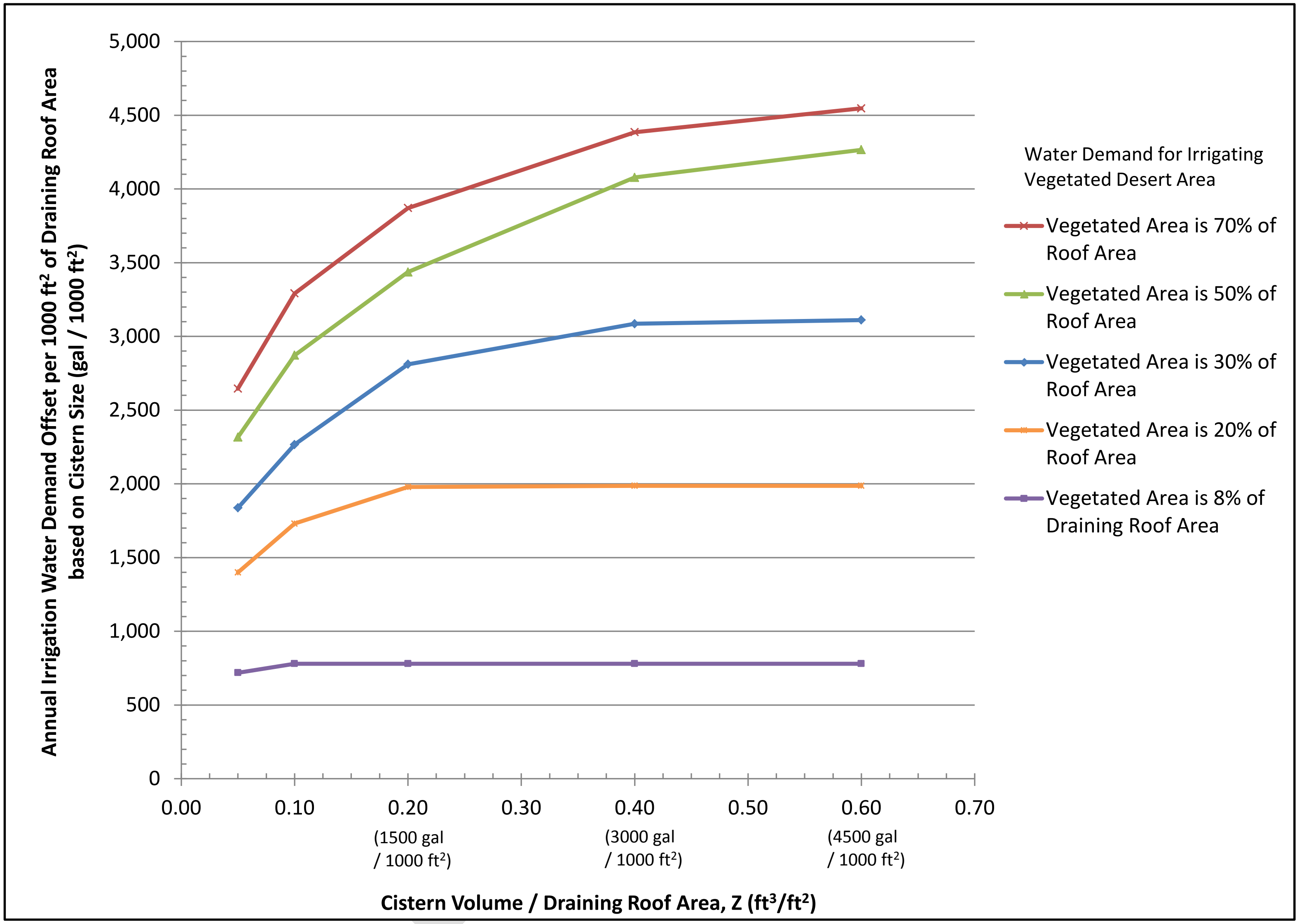

Figure E4. Offset in annual irrigation water demand by cistern size.

Simulation of Cisterns for Indoor Use

The water demand for indoor use of rainwater such as for flushing toilets was simulated as a constant demand in gallons per day. The number of gallons per day was varied as 9 gal/day, 18 gal/day, 36 gal/day, and 72 gal/day. The size of the draining roof area is the source of water and therefore the water demand in gallons per day was normalized by the 1000 ft^2 draining roof area. The simulation results may be applied to other roof areas by determining the water demand in gallons per day per 1000 ft^2 of draining roof area. The deficit water use and overflow volume was calculated from the cisterns using the same method as the above simulation for irrigation.

he simulation shows that for constant water demands the most additional offset in water usage comes from the change from no cistern to having the smallest cistern considered (375 gal/1000 ft^2) which was an average of about 2000 – 3500 gal/1000ft^2 of draining roof area depending on the rate of demand (Figure E6, E7, and E8) . Increasing cistern size up to Z = 0.20 (1500 gal/1000 ft^2) can provide an average annual offset of 3000 – 4500 gal/1000 ft^2, and there is a smaller additional benefit in offset resulting from increasing cistern volume greater than Z = 0.20, similar to the simulation for irrigation use. The simulation indicates that the largest cisterns are limited to an average offset in annual water use of about 4500 gallons/ 1000 ft^2 of draining roof area at relatively high constant water demands.

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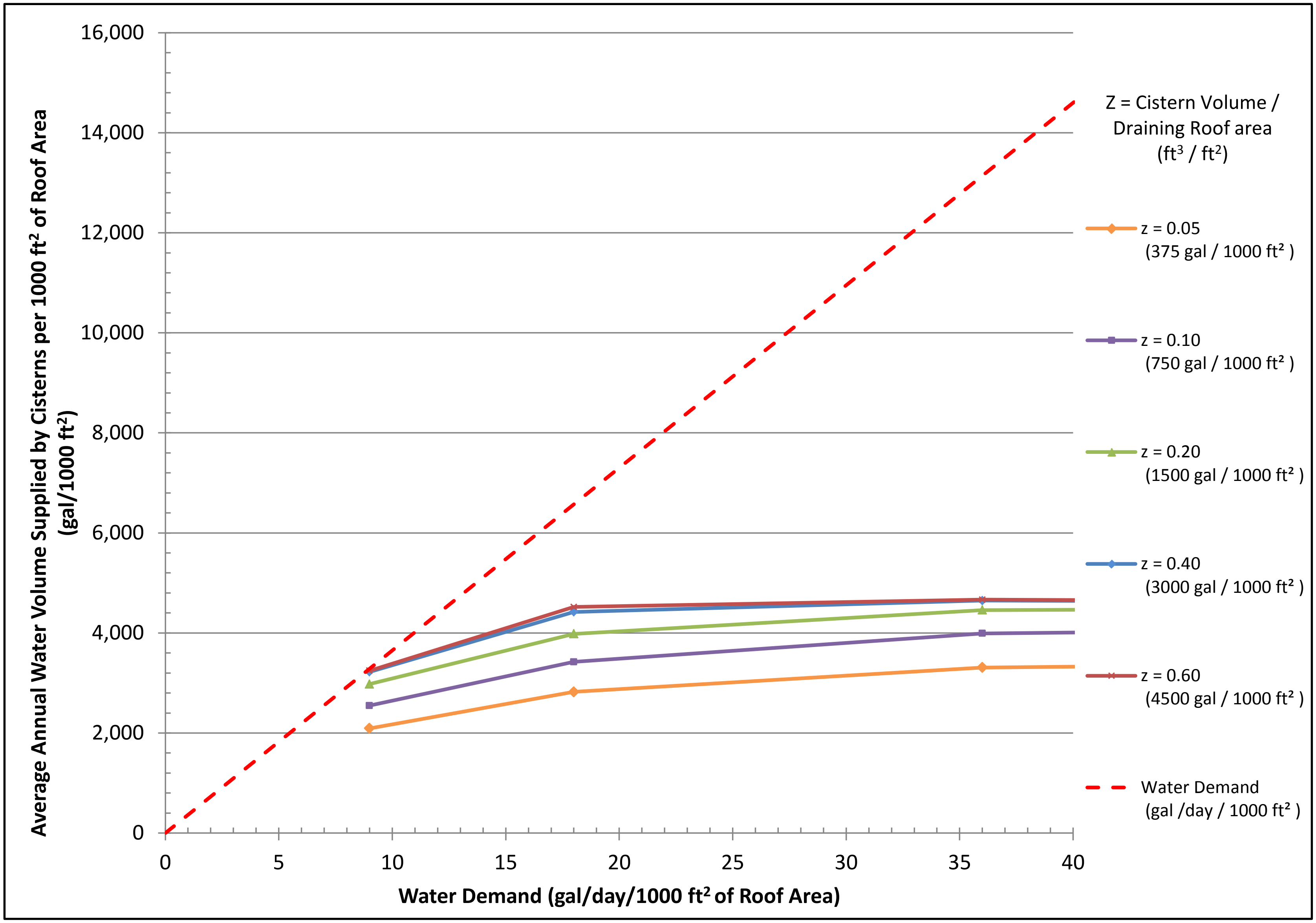

Figure E6. The average annual offset in constant water demand supplied by cisterns for varying levels of water use.

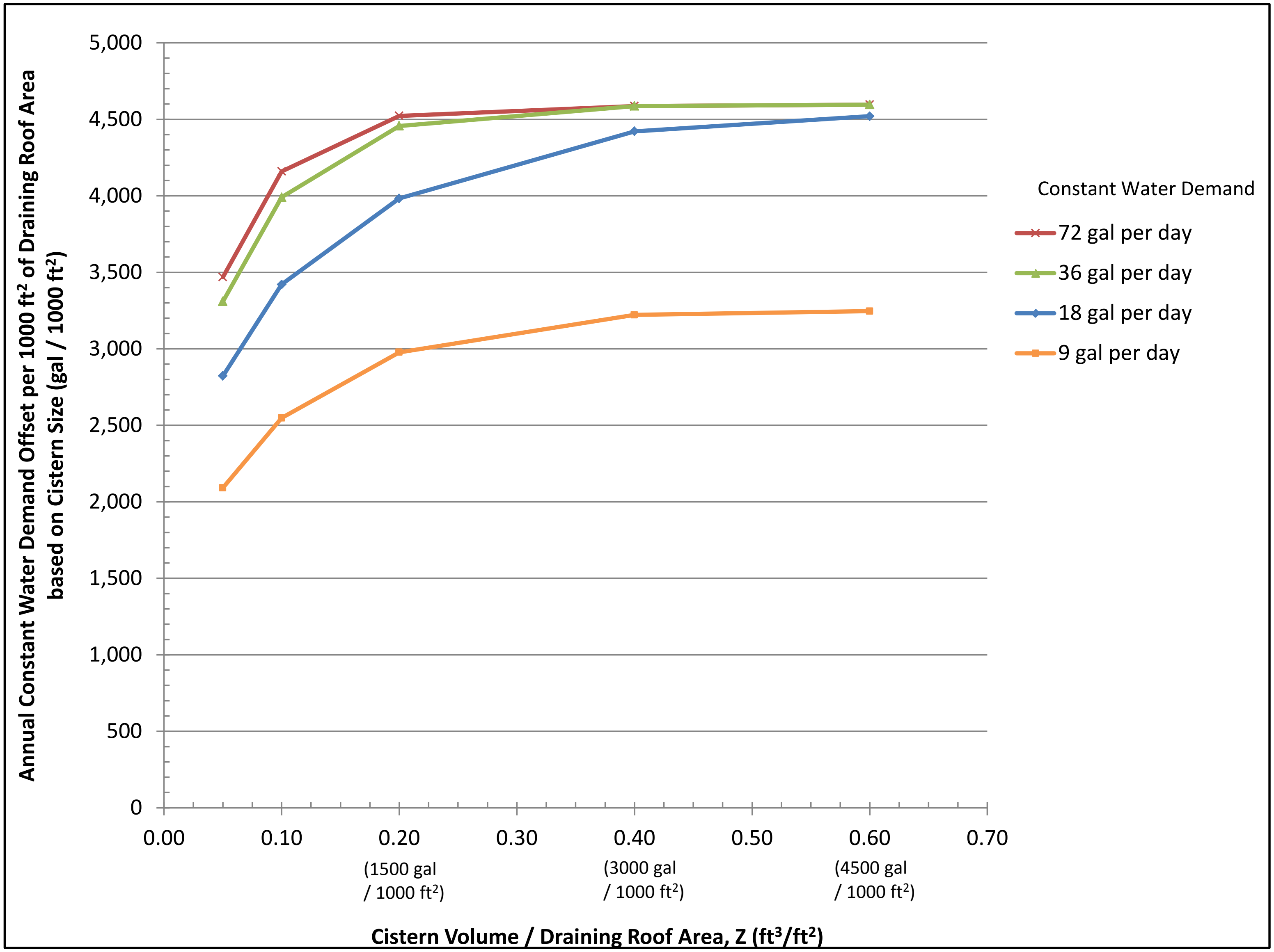

Figure E7. Average annual offset in constant water demand with increasing cistern size.

AutoCASE^{TM} Beta Testing Project

Evaluation of GI/LID Benefits in the Pima County Environment

Report Prepared for:

The Pima County Regional Flood
Control District &
Pima Association of
Governments with the
Cooperation of the City of
Tucson

Report Prepared by:

Impact Infrastructure, LLC
INFORMING IMPACT INVESTMENTS

Stantec

Final Report: July 10, 2014

AutoCASE Beta Testing Project

FOREWORD

Green Infrastructure/Low Impact Development (GI/LID) are key design strategies that will allow our region to build value-added community benefit into upcoming infrastructure projects. Understanding the economics is as important as understanding the planning and technical mechanics of GI/LID stormwater-water infrastructure design solutions. This cost-benefit report, tailored with data specific to the arid southwest, is a tool to evaluate the spending of public funds for GI/LID solutions.

We hope design and construction professionals will review this information, make recommendations and apply GI/LID practices whenever feasible. GI/LID practices are essential tools to make our region more resilient and adaptable to changing natural weather conditions while also improving the quality of life for our residents.

City of Tucson	Pima County RFCD	Pima Association of Governments
Irene Ogata, Urban Landscape Manager, Office Of Integrated Planning	Evan Canfield, Civil Engineering Manager; Akitsu Kimoto, Principal Hydrologist	Claire Zucker, Director Sustainable Environment; Mead Mier, Lead Watershed Planner; Josh Pope, GIS Manager

Background:

In October 2010, the City of Tucson and Pima County completed a joint *Water-Wastewater Infrastructure, Supply and Planning Study, 2011-2015 Action Plan for Water Sustainability*. As part of the Action Plan, Phase 2 Goals and Recommendation included “Goal 5: Increase the use of rainwater and stormwater to reduce demands on potable supplies”; with a subgoal “5.1: Develop design guidelines for neighborhood stormwater harvesting.” As the City and County developed a GI/LID Working Group to assist with development of the *Low Impact Development and Green Infrastructure Guidance Manual* (GI/LID Guidance Manual), the effort became a regional effort. A GI/LID resolution was adopted by the Pima Association of Governments' (PAG) Regional Council of Governments in 2012.

In the summer of 2013, a five person team of the GI/LID working group was able to attend a Climate Leadership Academy on Adaptive Water, Resource and Infrastructure held in Philadelphia, PA. This team brought a wide background of regional knowledge on water conservation, drought, transportation infrastructure, stormwater quality planning, heat impacts and tree resilience, and flood mitigation design performances.

The Academy was put together by the Institute for Sustainable Communities (ISC) and included teams from 11 different communities across the United States. Traveling to Philadelphia, the Tucson team highlighted desert southwest issues (heat, drought and flooding), in contrast with the other communities attending the Academy (excessive rainfall, combined sewer-stormwater overflow systems). Our team's efforts were leading the way for unique arid southwest applications as well as other regions beginning to face climate change.

One of the reasons for developing the GI/LID Guidance Manual was to provide a tool for professional designers, including engineers, landscape architects, planners, developers and non-profit organizations, to utilize and better understand design configurations and the benefits of GI/LID. Economic comparisons and assessments of environmental and social impacts of GI/LID needed to be a part of the Guideline in order to provide information about GI/LID benefits. This comparison then provides a framework for how our community can plan and adapt to become more resilient utilizing GI/LID in stormwater-management.

John Williams II, Chairman and CEO of Impact Infrastructure, LLC (II, LLC) was a part of the Academy’s Resource Team and presented an automated business case evaluator, AutoCASE^{TM}, for infrastructure projects. AutoCASE^{TM} was currently in the beta stage of testing for stormwater infrastructure. Through discussion with Mr. Williams, we found that this tool could provide an affordable cost-benefit analysis into the GI/LID Guidance Manual and that data could be added to calibrate it to be arid southwest region specific.

PC RFCD and PAG provided the funding to contract with II, LLC and Stantec to beta test AutoCASE^{TM} in this region. We were able to add arid southwest specific data and request additional concepts that were not part of the original software design which resulted in a more comprehensive analysis for our region. They evaluated the multibenefits and determined Sustainable Net Present Value (a cost-benefit calculation that also considers environmental and societal benefits) for seven common GI/LID practices as well as a suite of practices used at two different sites to illustrate how the costs and benefits of GI/LID can be considered in our community.

AutoCASE™ Beta Testing Project

Executive Summary

The water scarcity and urban heat island issues facing the City of Tucson and Pima County will also need to be addressed by most areas of the country in the coming decades.

Despite efficient water use, best practices in stormwater management, and water re-use, the population in Pima County is growing and renewable water resources are diminishing due to drought across the Colorado River Basin. It is with this background that the Pima County Regional Flood Control District (PCRFCD), in collaboration with the City of Tucson, has been hosting Low Impact Development (LID) and Green Infrastructure (GI) discussions for desert regions. Together, a working group has developed a Guidance Manual to facilitate the adoption of GI/LID practices in Pima County and the City of Tucson. The City of Tucson and other jurisdictions in Pima County coordinated efforts through the Pima Association of Governments (PAG[1]).

Using green infrastructure for stormwater management has many benefits; stormwater is naturally cleaned of pollutants, flooding is reduced, urban heat island effects are reduced, and property values are enhanced. These are benefits that are quantified and monetized in the AutoCASE™ for Stormwater Management (beta) software. The LID manual-related work was done by Stantec Consulting Services, Inc. and analytical work associated with the use of AutoCASE™ software (an automated business case analysis tool) was done by Impact Infrastructure, LLC. The services were funded under two contracts from PAG and Pima County with Stantec Consulting Services, Inc. As beta test clients the City, PCRFCD and PAG evaluated several GI/LID features from the LID Manual to understand their full economic, social and environmental value (Table 1). Two sample sites were also studied, a commercial site and a road re-design that incorporated some of the GI/LID features. The local team representing the concerns of the Tucson metro area suggested additional benefits of GI/LID features not previously included in AutoCASE™ in terms of traffic calming, reduced accidents, road surface life, as well as desert based water concerns. These incremental benefits were also estimated and added to the overall value.

There are several local characteristics that make the City of Tucson and Pima County, hereafter the Tucson region, unique when compared to other areas that have used GI/LID features to manage stormwater. The Tucson region does not have combined sanitary sewers/storm sewer systems and so does not suffer from combined sewer overflow problems that give other

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[1] Pima Association of Governments (PAG) is metropolitan planning organization which coordinates the local jurisdictions in PAG's nine-member Regional Council composed of representatives from the local, state and tribal governments. PAG's programs and committees focus on regional planning issues, such as stormwater quality, economic vitality, drought planning, and transportation infrastructure. As a partner on this project, PAG can inform and disseminate information to all its regional partners and leaders.

regions cause to implement GI/LID; however, the desert environment does experience monsoons with potential for severe flooding and also seeks the beneficial use of stormwater for irrigation. The development of AutoCASE^{TM} was significantly enhanced, as a result of this study, by including these unique regional aspects. AutoCASE^{TM} was made more useful to desert regions through this process by calculating the cost and benefit based on these conditions common to the arid Southwest.

The Institute for Sustainable Infrastructure (ISI), through its Envision rating system, is giving credit for projects such as those stormwater management initiatives being undertaken in the Tucson region. This study used AutoCASE^{TM} to make the business case for the GI/LID features in the Guidance Manual. The value estimated was mapped to the Envision rating categories and this report provides the Tucson region guidance on how Envision may be used in the future.

The business case analysis provides a comprehensive assessment and takes a broad perspective, looking at the value to the community, government, and the environment. The analysis makes the case that these investments pay back in more than cash terms, and the benefits cited above all have value to a wide range of stakeholders. Details on the AutoCASE^{TM} methodology are provided in Appendix IV of this report.

This report demonstrates that the approach used in AutoCASE^{TM} can calculate comprehensively defined value using regionally specific values and that the calculations can be run inexpensively as the design changes. By not considering these normally omitted costs, benefits and risks, the benefits may not be realized, resulting in potential negative impacts on the community.

Finding of the study and recommendations are summarized below.

- GI/LID features are not equal in terms of their financial and sustainability benefits. Broader consideration of value, beyond capital and operating costs, to include flood risk, safety, heat island mitigation, property value, and environmental benefits allow for an objective comparison.
- Stormwater Harvesting Basins, Xeriscape Swales and Infiltration Trenches have a greater than 50% probability of achieving a positive Sustainable Net Present Value (SNPV), which indicates the overall societal, environmental and economic benefits will exceed the costs of the project, after adjusting for the opportunity cost of capital[2].

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[2] Most costs, such as capital expenditures, are paid early in a project's life, while most benefits, such as reduced air pollution or traffic calming, are accrued over the life of the project. A Net Present Value (NPV) calculation discounts value by a greater factor as the value is realized further into the future. Therefore, a NPV of zero would imply that the nominal benefits significantly outweigh the costs

- While Pervious Pavement had a negative SNPV, Concrete and Asphalt Paving have highly negative SNPV. This is partly due to capital expenditure costs, and partly due to the benefits that Pervious Pavement brings. These benefits offset some of its cost, unlike concrete and asphalt.
- In terms of sustainability metrics, GI/LID features, when combined into designs for a representative commercial site and a roadway re-design, are beneficial.
    - Implementation of the selection of practices at the commercial site has an 80% probability of achieving a positive SNPV. The inclusion of GI/LID features shows that the value of the site is significantly higher when compared with the base case of using concrete. There is a large difference in social and environmental value. The LID features selected have multiple social and environmental benefits. All help to reduce flood risk in the area during extreme storm events. Other benefits include a reduction in carbon emissions and air pollution, increasing local property values, reducing heat mortality, and a lower requirement for on-site irrigation.
    - The re-design of a ½ mile segment of Silverbell Road to incorporate new trees, bio retention, and water harvesting basins reveals that the SNPV of the project is a highly positive SNPV. The most substantial benefits are reduced heat stress mortality and traffic calming due to the installation of a roundabout and curb extension. These benefits are measuring direct impacts on human life, either in terms of reduced heat island effects or reduced likelihood and severity of traffic accidents.
- Ignoring the multi-benefits of GI/LID features would mean making incorrect decisions. GI/LID features have a payback to governments, the environment, the economy and the community. A large benefit of approach used to value GI/LIDs is the ability to allocate the full value of a project amongst relevant stakeholder groups so that all parties can understand how they are affected.

Recommendations:

- The City of Tucson, Pima County, and PAG (the Tucson region) should continue to measure the full value of its GI/LID initiatives and use this information to make decisions. This approach will be a useful tool in demonstrating the full value of GI/LID practices as projects are planned and designs are developed.
- The Tucson region should consider the use of Envision to communicate those benefits to outside stakeholders.

Contents

Introduction

Project Background

The Pima County Regional Flood Control District (PCRFCD), in collaboration with the City of Tucson, has been creating a Low Impact Development and Green Infrastructure Guidance Manual to facilitate the adoption of GI/LID practices in Pima County, the City of Tucson, and Pima Association of Governments (PAG) member jurisdictions. As a partner on this project, PAG can inform and disseminate information to all its regional partners and leaders with a regional planning perspective.

In other parts of the country with combined sewer systems, GI/LID practices are cost-effective because they enhance the potential for reducing or eliminating the risk of sewer overflows. The GI/LID solutions are often funded as mitigation for overflows. In contrast, in the Tucson region, roadways are often used as stormwater conveyance pathways, and the stochastic monsoon events cause considerable flooding concern. Furthermore, the potential for contaminant migration in stormwater to perennial waterways or groundwater tends to be more limited in the Tucson environment because water bodies are few and groundwater is deep. In contrast, stormwater management in the Tucson region has particular importance because use of stormwater can offset the need for potable water. Furthermore, vegetation watered with stormwater has the potential to decrease energy use and improve the quality of life by helping to mitigate effects from the urban heat island. Additionally, the increasing rareness of perennial desert waters and the high ecological value of habitat along intermittent and ephemeral waterways make them particularly important to protect from contamination and erosion.

Project Purpose

The goal of this beta testing project was to evaluate GI/LID costs and benefits in the Pima County environment. AutoCASE^{TM} uses economic and risk analysis to evaluate costs and multi-benefits using Autodesk's AutoCAD Civil 3D files of GI/LID practices to inform business cases. Because the motivating factors for use of GI/LID are different in Pima County than in other parts of the country, there was a need to evaluate the costs and multi-benefits of these features in this environment.

AutoCASE^{TM} History

For decades, cost-benefit analysis has helped municipal, state/provincial, and federal governments to justify infrastructure investments and communicate the benefits of these investments. Cost-benefit analysis can be used to prioritize spending and allocate funding to projects that are the most cost-effective and create the most public value. With multiple-account cost-benefit analysis, governments can communicate the benefits of infrastructure spending to different groups. One description is as follows:

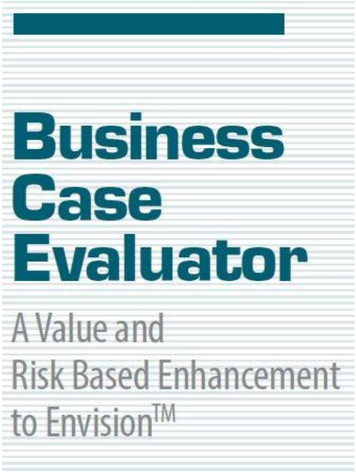
> "Cost–benefit analysis (CBA) is the systematic and analytical process of comparing benefits and costs in evaluating the desirability of a project or program – often of a social nature. CBA is fundamental to government decision making and is established as a formal technique for making informed decisions on the use of society's scarce resources. It attempts to answer such questions as whether a proposed project is worthwhile, the optimal scale of a proposed project and the relevant constraints. CBA can be applicable to transportation projects, environmental and agricultural projects, land-use planning, social welfare and educational programs, urban renewal, health economics and others."[3]

For example, a new Low Impact Development (LID) or Green Infrastructure (GI) stormwater management system may lead to reduced flood risk, increased regional aesthetic value, increased recreational opportunities, reduced carbon emissions, better air quality, and an increase in property value; detailed cost-benefit analysis can reveal these benefits so that government leaders can communicate these benefits to stakeholders.

Impact Infrastructure has two powerful risk analysis based cost benefit tools that can be integrated into feasibility, planning, and design stages of infrastructure projects. The first is the Business Case Evaluator (BCE) – a free, Excel-based model. The second is AutoCASE™ - a web-based engine, database, and reporting application for evaluating sustainable infrastructure, with an interface into Autodesk's powerful design and visualization software.

Business Case Evaluator

The Business Case Evaluator is a free Excel spreadsheet. The Model, its Documentation, and an Example is available from the Institute for Sustainable Infrastructure (ISI) or Impact infrastructure (II).



Business
Case
Evaluator
A Value and
Risk Based Enhancement
to Envision™

Figure 1 BCE Manual

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[3] E.J. Mishan and Euston Quah, Cost-Benefit Analysis, 5th edition (New York: Routledge, 2007).

In September of 2013, founders from Impact Infrastructure, LLC presented the Business Case Evaluator (BCE) for Stormwater Management at the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design to industry membership of the program's Sustainable Infrastructure Advisory Board and members of the ISI.

The BCE is an economic companion tool to the Envision^{TM} Rating System, and its primary purpose is to produce risk-adjusted, dollar-based metrics for infrastructure projects based on their costs, benefits, and sustainable design features.

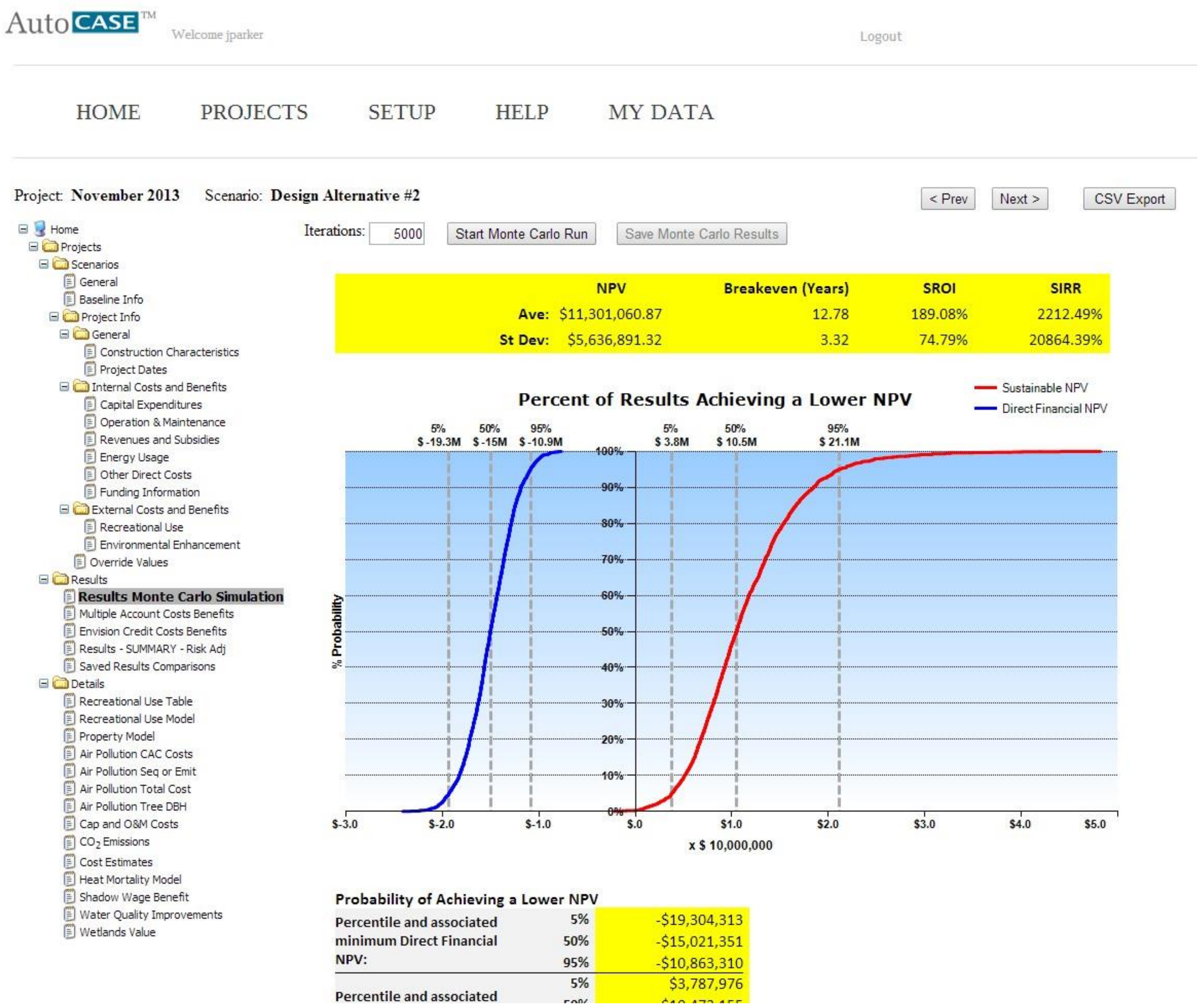
The BCE also breaks down the value of a project among different stakeholder groups, showing which groups (e.g., government, residents, local businesses, and the environment) will be affected and to what degree. In addition, the BCE maps the value of a project to Envision^{TM} credits, showing how the value gets distributed within the Envision^{TM} Rating System.

AutoCASE^{TM}

AutoCASE^{TM} is a web-based database and model that is integrated with Autodesk's AutoCAD Civil 3D software. It has a multi-user, scalable architecture with many advanced features and analysis capabilities above and beyond those offered by the BCE.

Figure 2 AutoCASE^{TM} Start Screen

AutoCASE^{TM} builds on the BCE for Envision^{TM}. It is a web-based application that can be run through a project's life cycle, beginning with the earliest stages, including the early feasibility or planning stages. It can be run with minimal information, drawing on standard but regionally-specific inputs and best practice data.



Project: **November 2013** Scenario: **Design Alternative #2**

Iterations: 5000

	NPV	Breakeven (Years)	SROI	SIRR
Ave:	$11,301,060.87	12.78	189.08%	2212.49%
St Dev:	$5,636,891.32	3.32	74.79%	20864.39%

Probability of Achieving a Lower NPV

Percentile and associated minimum Direct Financial NPV:	5%	-$19,304,313
	50%	-$15,021,351
	95%	-$10,863,310
Percentile and associated	5%	$3,787,976

Figure 3 Example of the probability curves for the SNPV of an early stage planned project.

> Note on Figure 3: Shown above is an example of the probability curves for the SNPV (Sustainable Net Present Value) of an early stage planned project. The first curve is the Direct Financial NPV (Net Present Value), which only includes the direct costs and benefits such as capital expenditures, revenues, etc., and does not include other costs and benefits such as air pollution, carbon emissions, water quality benefits, etc. The second curve is the Sustainable NPV and incorporates all costs and benefits in the model, including impacts on the local economy, society, and the environment.

AutoCASE™ enables integration with Autodesk's AutoCAD Civil 3D software to extract design information from a project and incorporate that information into its associated business case. This means that as an engineer or planner/designer is working on the design of a project, AutoCASE™ can update the project's business case and financial metrics in *real time*.

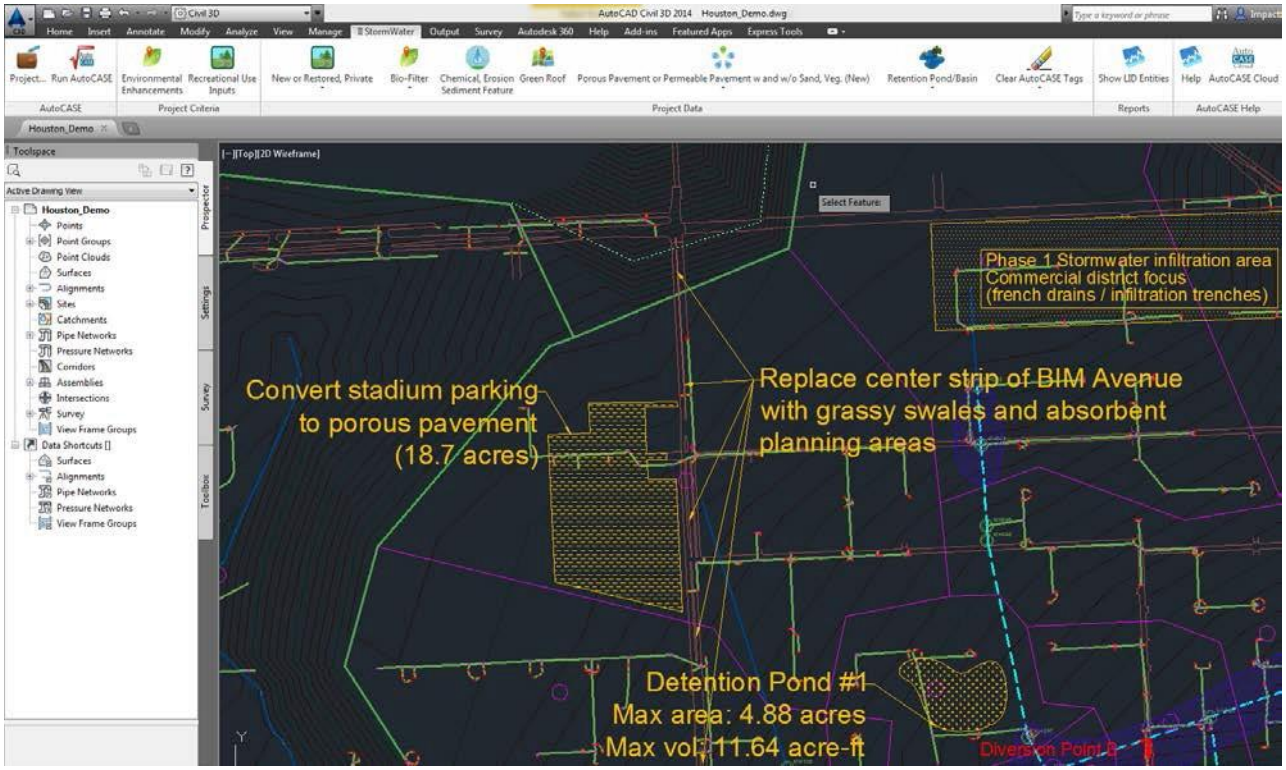
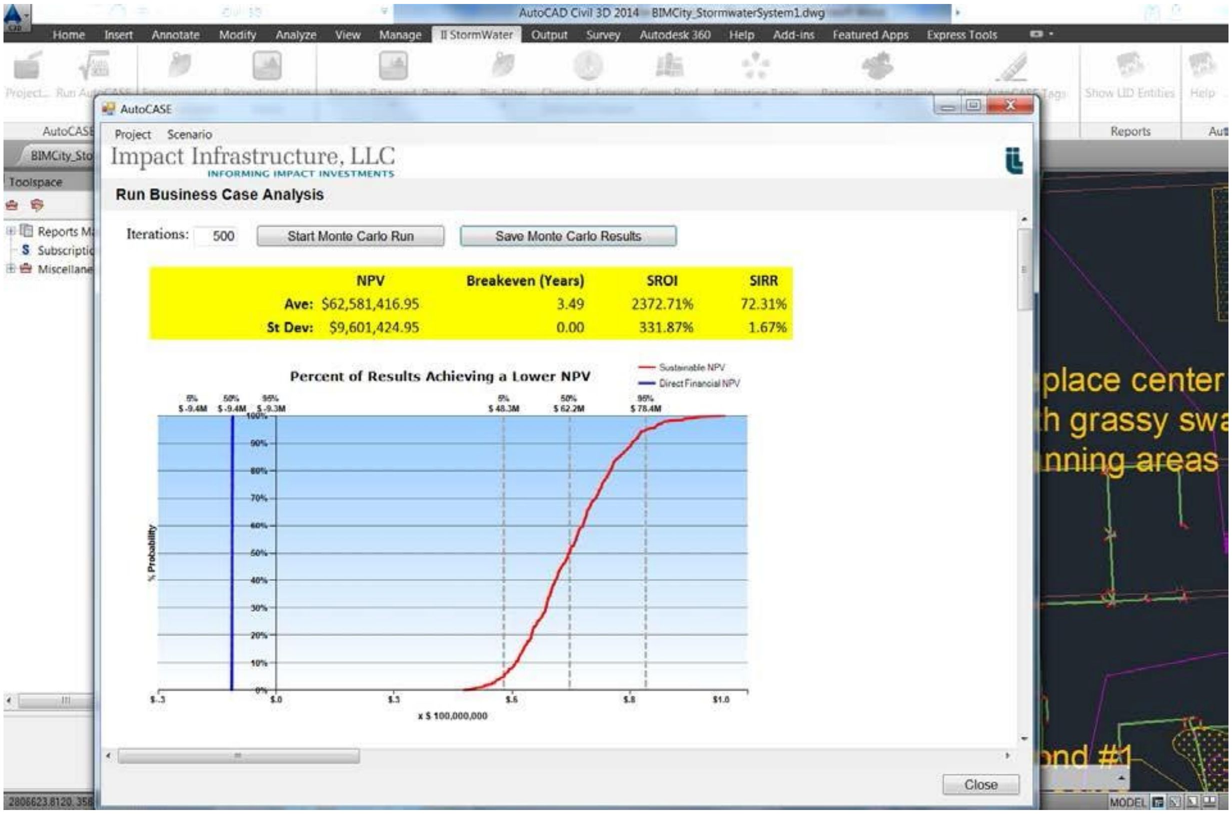


Figure 4 Shown above is an example of selecting the green infrastructure design feature of porous pavement from within AutoCAD Civil 3D.



Iterations: 500

	NPV	Breakeven (Years)	SROI	SIRR
Ave:	$62,581,416.95	3.49	2372.71%	72.31%
St Dev:	$9,601,424.95	0.00	331.87%	1.67%

Figure 5 Shown above is an example of the same probability curves for the SNPV of the project as shown for the early stage project but now linked to the design drawing of the project.

Once all of the project's GI/LID features are selected and any additional relevant information is entered into AutoCASE^{TM}, the project's Sustainable Net Present Value (SNPV) can be calculated with the click of a button.

AutoCASE^{TM} was released in beta (preliminary version) to Pima/Tucson at the beginning of the project (January 2014). Access was given to 16 users and a training session was held in Tucson in April 2014 to some 20 participants. A combination of AutoCASE^{TM}, the BCE, and other models developed specifically at the request of Tucson/Pima were used for this project.

The data used for this study were input into a version of the BCE that was modified for the arid Southwest. This version added traffic calming and pavement life extension benefits. The delivered spreadsheets (ii_BCE_Arid_Southwest_2.0.1_July_2014.zip) were based on the July 2014 version of Envision's^{TM} Economic Companion Tool - the Business Case Evaluator for Stormwater Management (version 2.0.1). The BCE model and Manual are included in the package of files.

Individual GI/LID Practices

Data Collection for Individual Practices

Individual green infrastructure and low impact development practices were researched and reviewed as described in the non-regulatory *Low Impact Development and Green Infrastructure Guidance Manual*, and the draft Detention/Retention Manual, March 2014. Approximately 61 resources, along with the aforementioned manuals, were consolidated at a Stantec FTP site with access available to Pima County, City of Tucson, and PAG staff participating in the AutoCASE^{TM} project. A full list of references can be found in the annotated bibliography at the end of this report. These resources were a fraction of the GI/LID information that is currently available nationally; therefore, our research focused on regional applicability and limited the document/data research to the specific GI & LID practices analyzed in the AutoCASE^{TM} beta test project. Details of the AutoCASE^{TM} methodology are provided in Appendix IV. The following nine GI/LID practices were selected for the AutoCASE^{TM} application.

Selected GI/LID Practices

Water Harvesting Basins

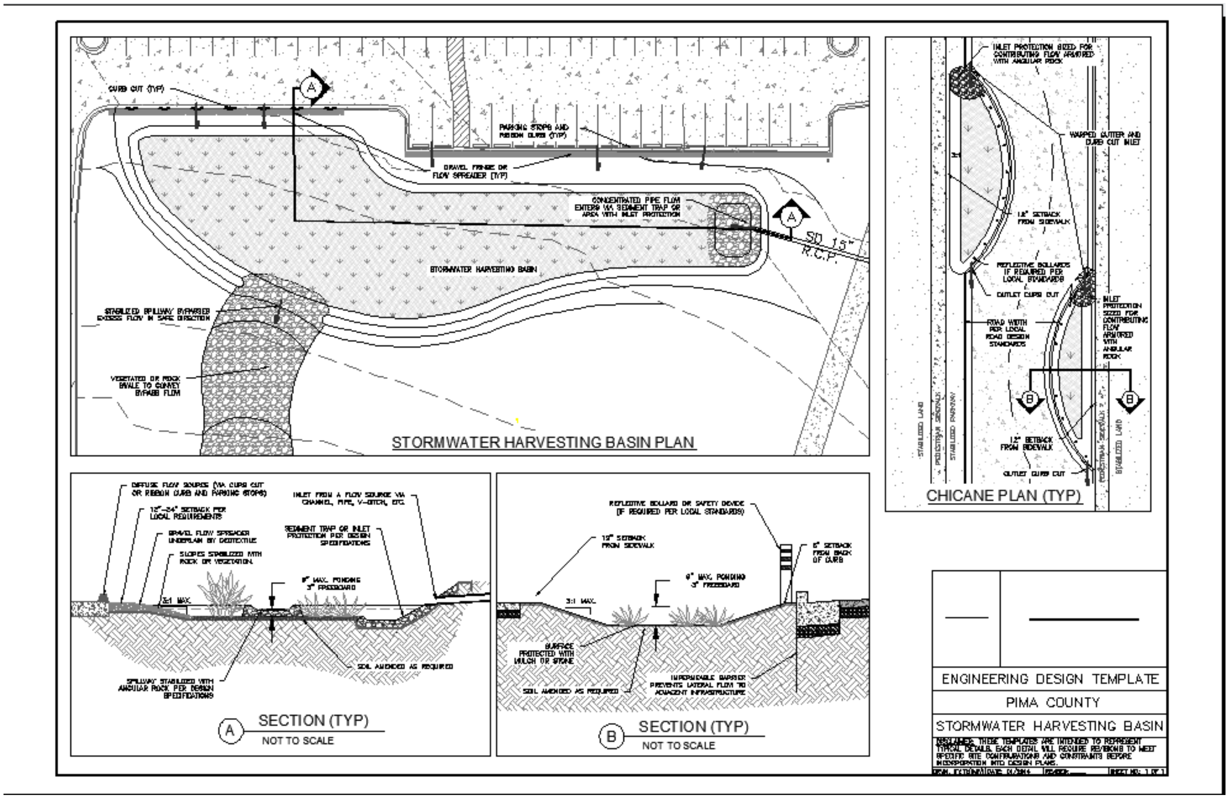


Figure 6 Water Harvesting Basin Design

Figure 7 Water Harvesting Basin Example (Photo credit: Lester Grant McCormick)

Bio Retention Basin

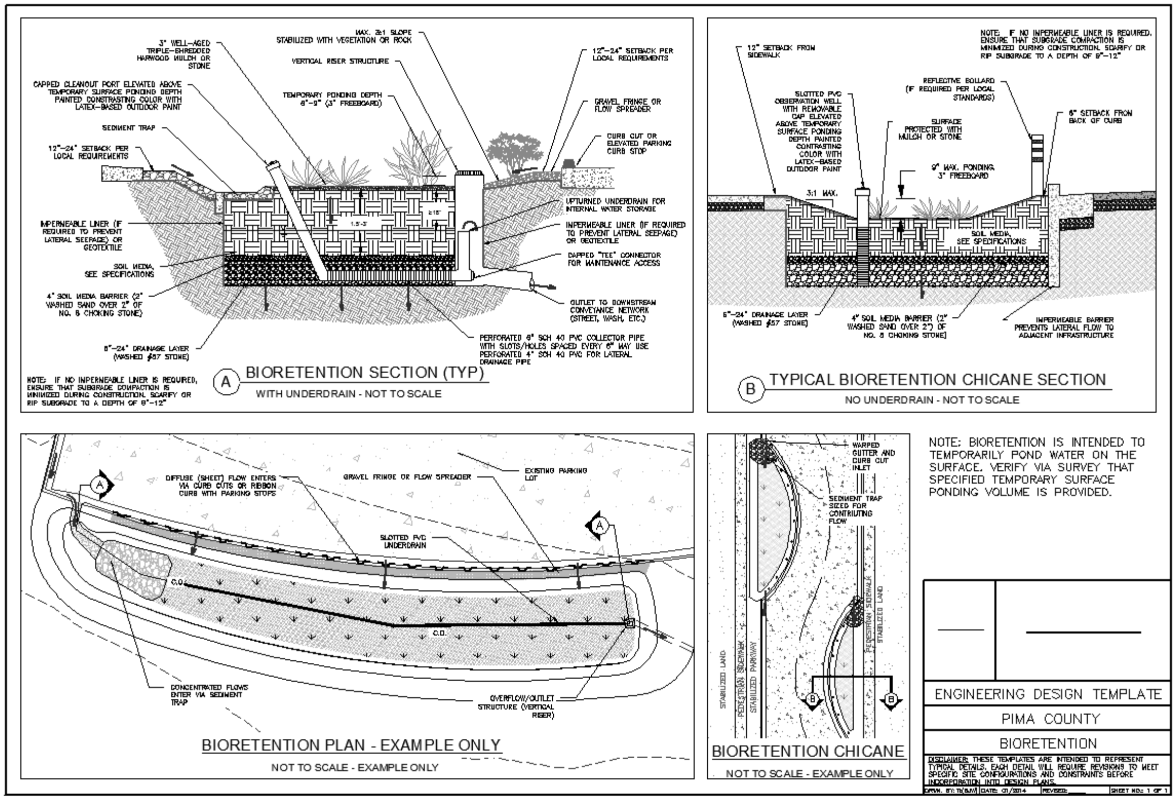


Figure 8 Bio Retention Basin Design

Figure 9 Bio Retention Basin Example (Source: Pima County and City of Tucson Low Impact Development and Green Infrastructure Guidance Manual October 2013 – Draft p.8)

Xeriscape Swale

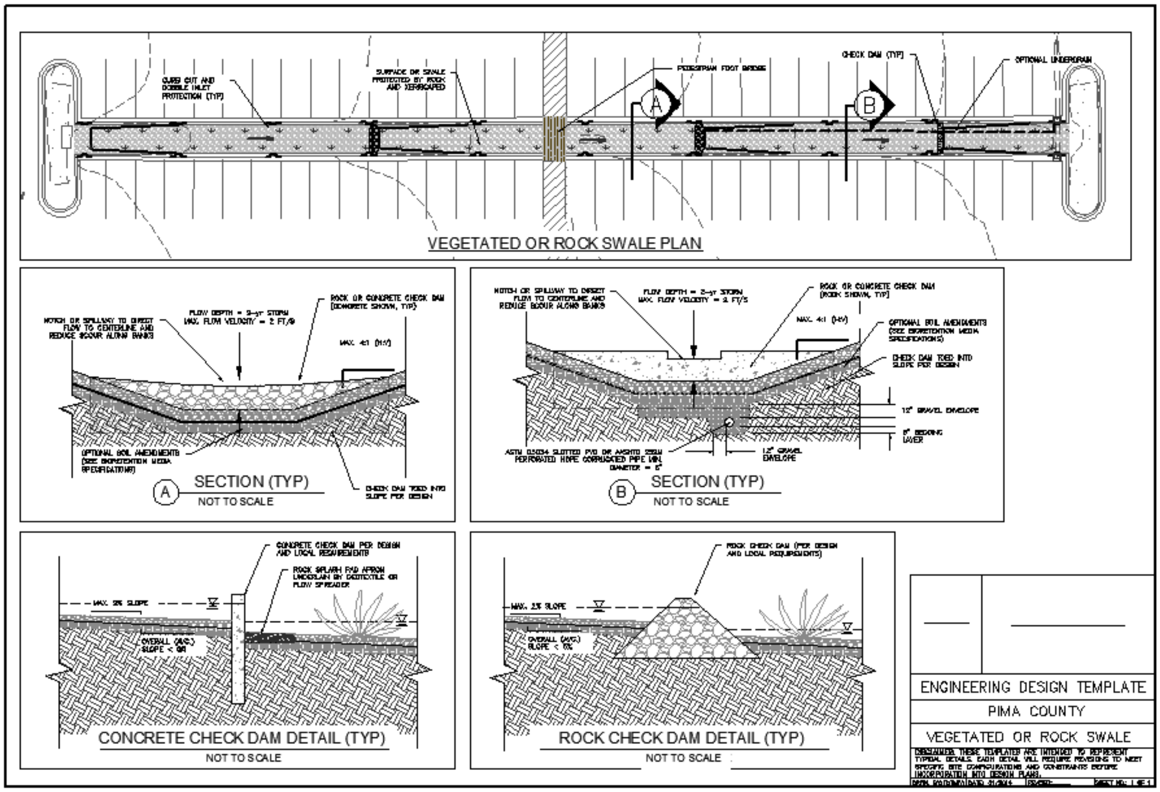
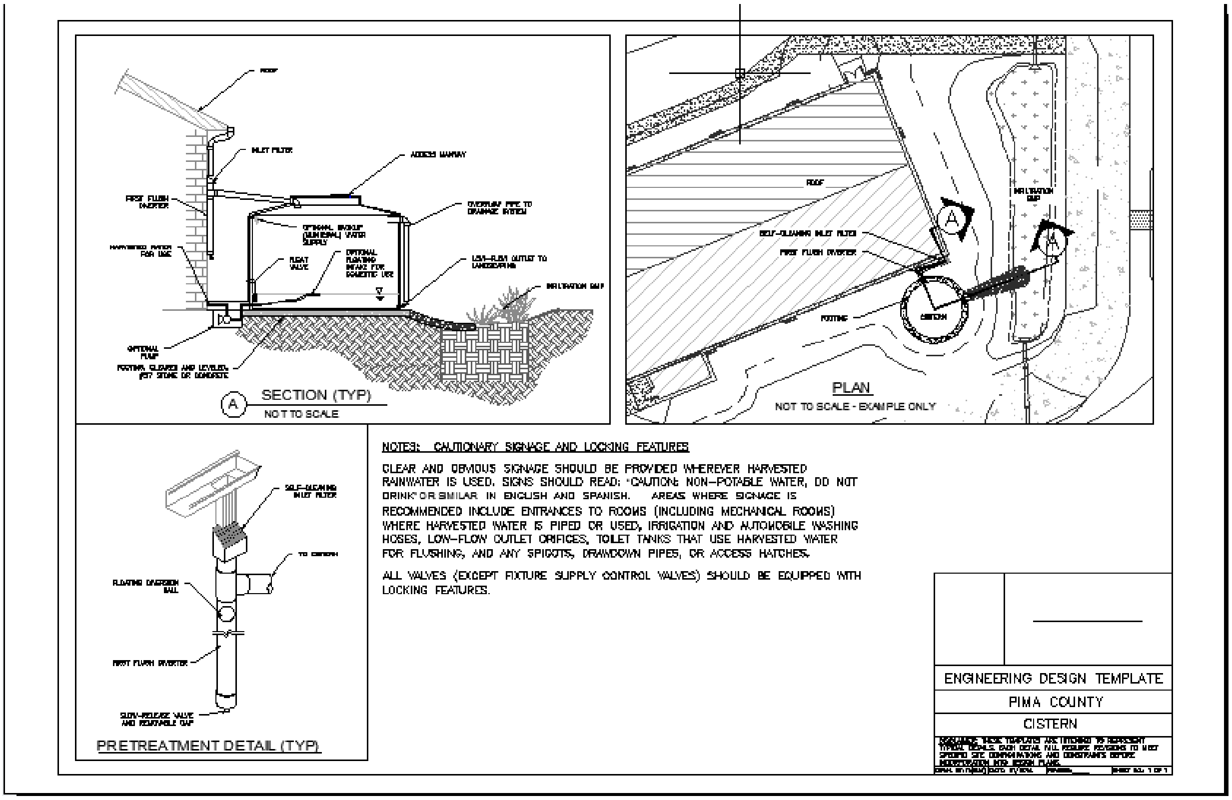


Figure 10 Xeriscape Swale Design

Figure 11 Xeriscape Swale Example (Photo credit: Sandy Bolduc, Pima County)

Cistern



NOTES: CAUTIONARY SIGNAGE AND LOCKING FEATURES

CLEAR AND OBVIOUS SIGNAGE SHOULD BE PROVIDED WHEREVER HARVESTED RAINWATER IS USED. SIGNS SHOULD READ: "CAUTION: NON-POTABLE WATER, DO NOT DRINK" OR SIMILAR IN ENGLISH AND SPANISH. AREAS WHERE SIGNAGE IS RECOMMENDED INCLUDE ENTRANCES TO ROOMS (INCLUDING MECHANICAL ROOMS) WHERE HARVESTED WATER IS PIPED OR USED, IRRIGATION AND AUTOMOBILE WASHING HOSES, LOW-FLOW OUTLET ORIFICES, TOILET TANKS THAT USE HARVESTED WATER FOR FLUSHING, AND ANY SPIGOTS, DRAWDOWN PIPES, OR ACCESS HATCHES.

ALL VALVES (EXCEPT FIXTURE SUPPLY CONTROL VALVES) SHOULD BE EQUIPPED WITH LOCKING FEATURES.

ENGINEERING DESIGN TEMPLATE
PIMA COUNTY
CISTERN

Figure 12 Cistern Design

Figure 13 Cistern Example (Photo credit: Evan Canfield, Pima County)

Infiltration Trench

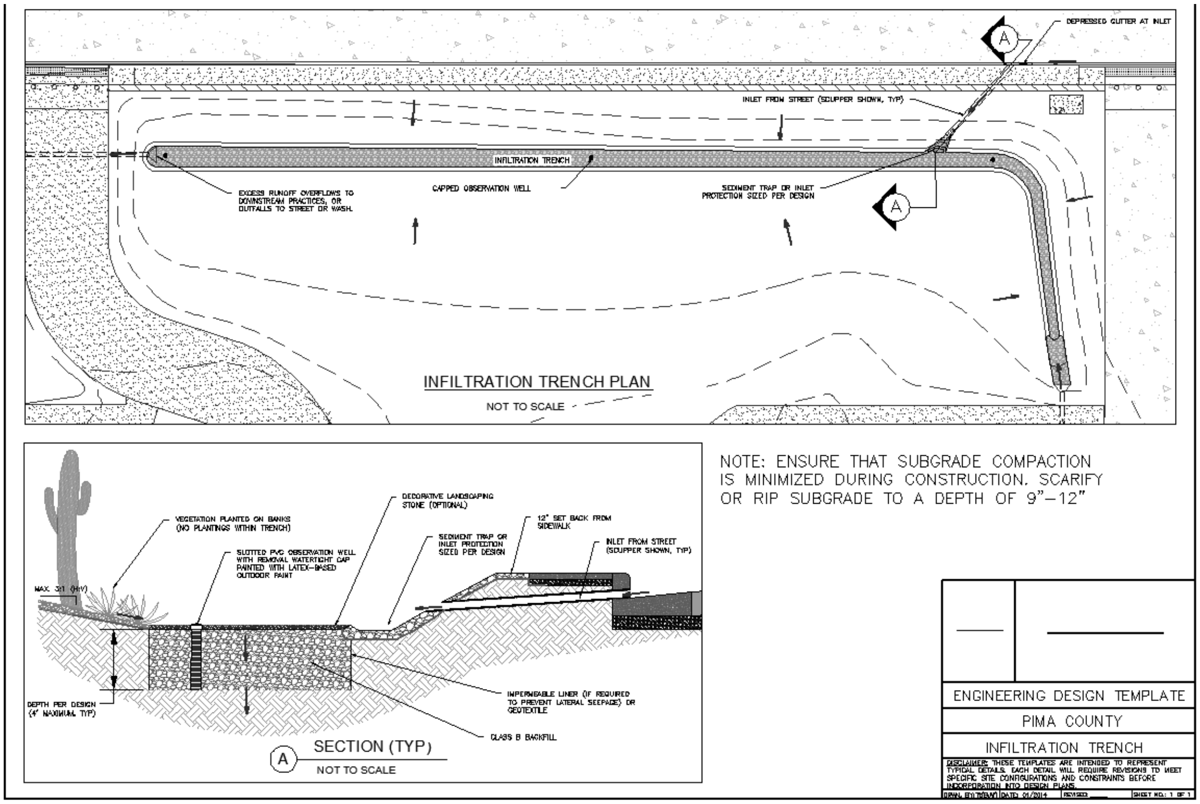


Figure 14 Infiltration Trench Design

Figure 15 Infiltration Trench Example (Photo credit: Laura Mielcarek)

Detention Basins (or Extended Detention Basins)

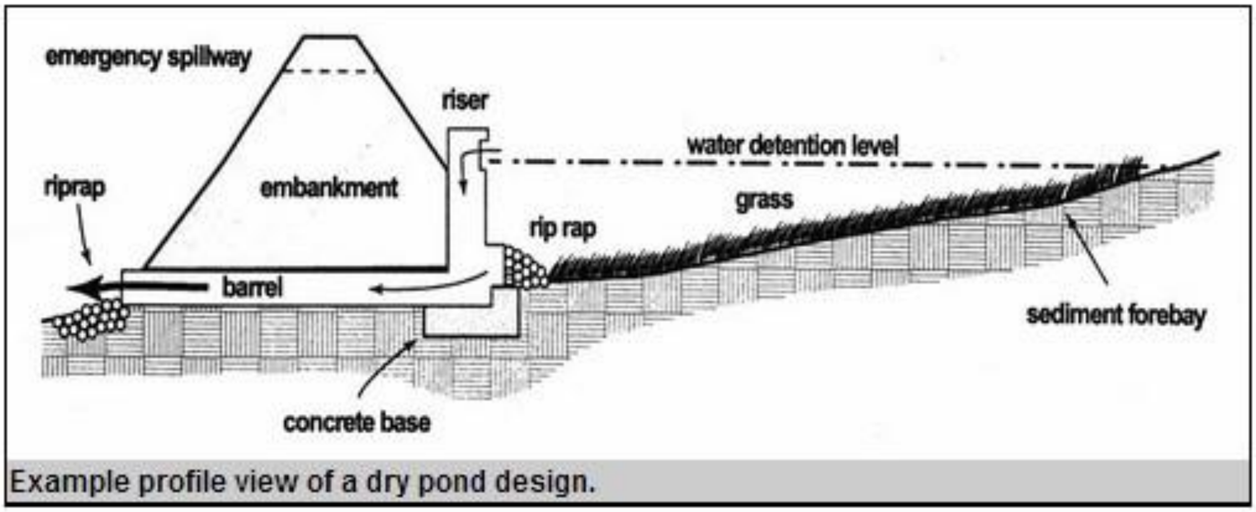
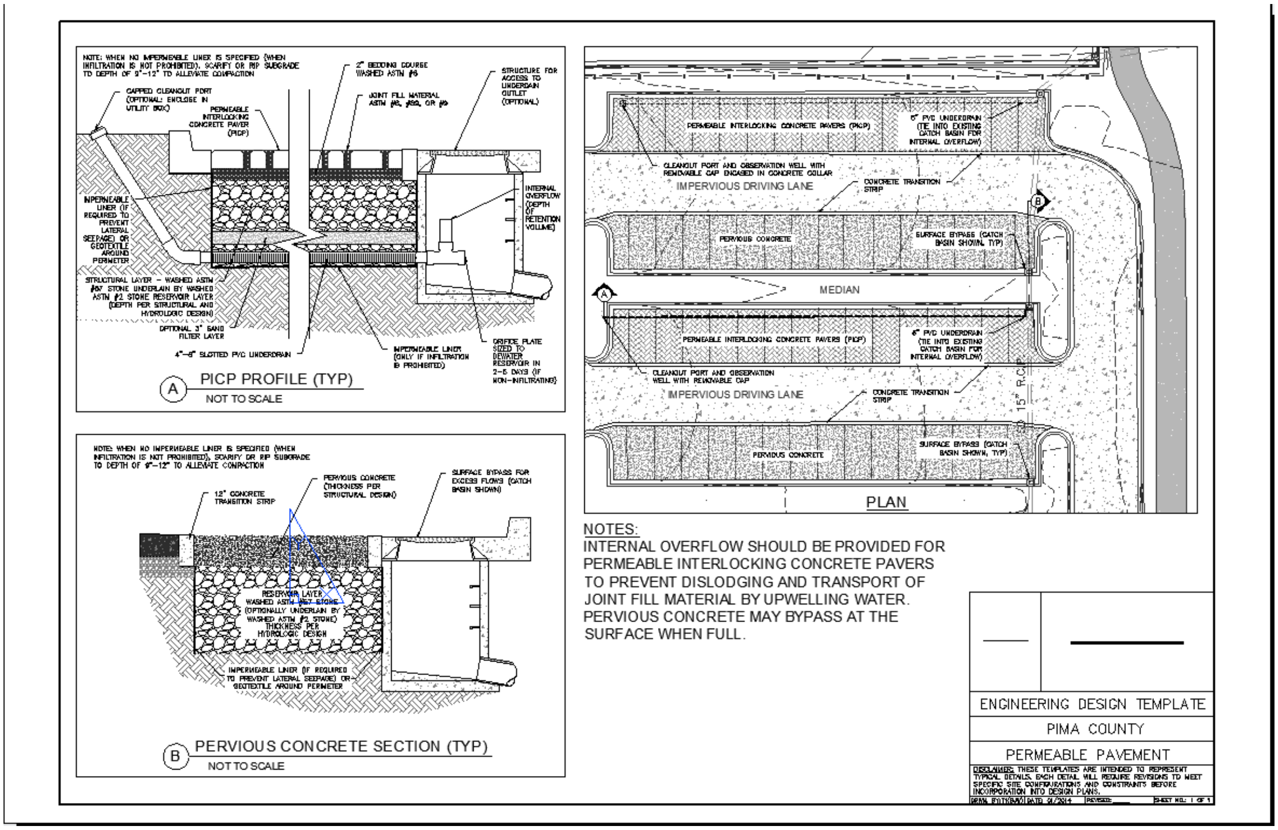


Figure 16 Detention Pond Design

Pervious Pavers



NOTES:
INTERNAL OVERFLOW SHOULD BE PROVIDED FOR PERMEABLE INTERLOCKING CONCRETE PAVERS TO PREVENT DISLODGING AND TRANSPORT OF JOINT FILL MATERIAL BY UPWELLING WATER. PERVIOUS CONCRETE MAY BYPASS AT THE SURFACE WHEN FULL.

DISCLAIMER: THESE TEMPLATES ARE INTENDED TO REPRESENT TYPICAL DETAILS. EACH DETAIL WILL REQUIRE REVISIONS TO MEET SPECIFIC SITE CONFIGURATIONS AND CONSTRAINTS BEFORE INCORPORATION INTO DESIGN PLANS.

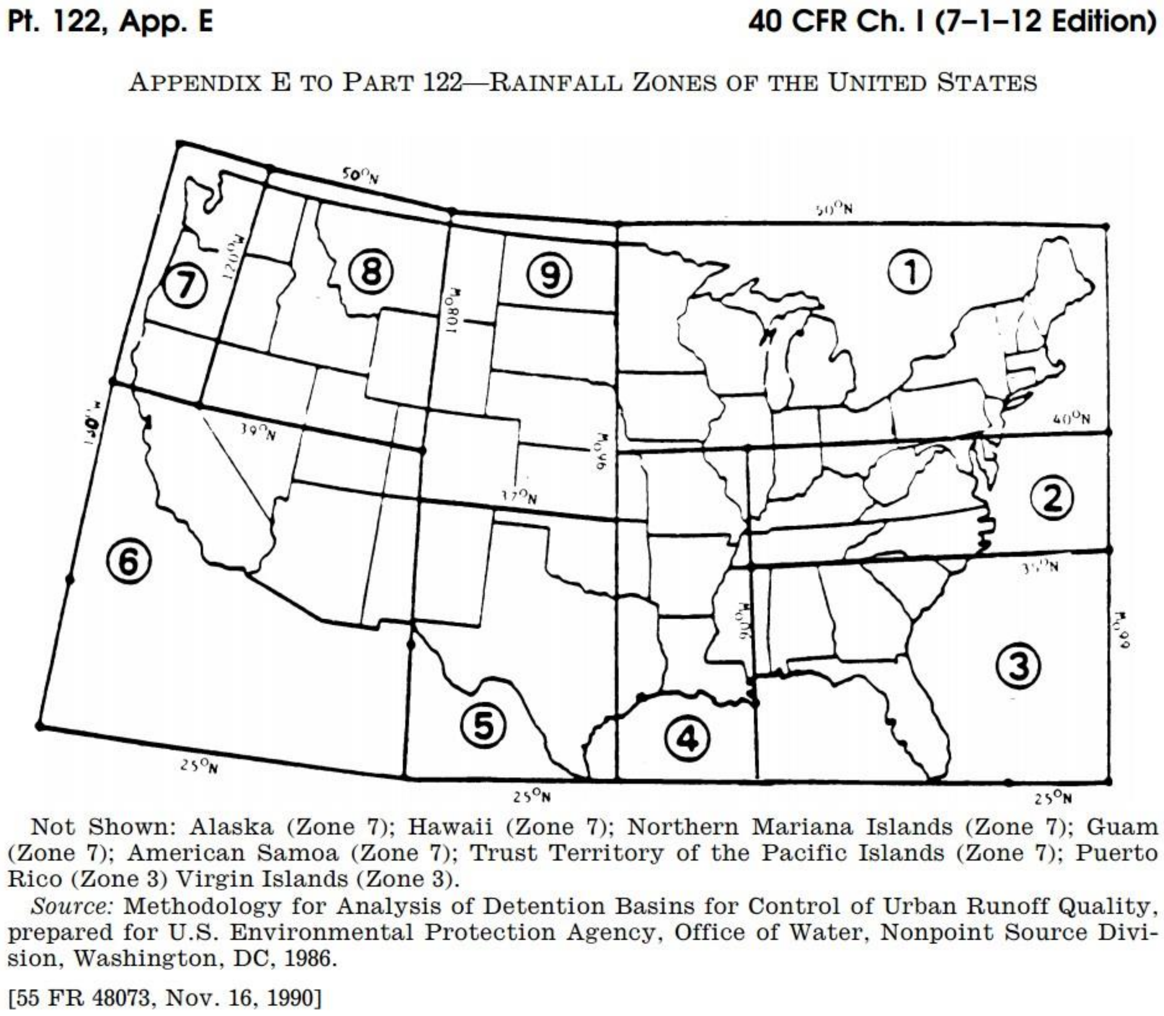
Figure 17 : Pervious Pavers Design

Figure 18 Pervious Pavers Example (Photo credit - Belgard Pavers)

Initial parameters

The individual GI/LID's were, to the extent possible, evaluated on a consistent basis using the same area (1,000 square feet or 0.02296 acres).

Capital and O&M costs used AutoCASE's database of costs that is made up of information from Philadelphia, Maryland and the International Stormwater BMP Database (July 2007 Database Release) but it a) excluded Philadelphia as a source of data because it has combined sewer overflow (CSO) problems and b) used costs specific to low rainfall areas of: AZ, Southern CA, Southern Utah, NV and Western NM.



Pt. 122, App. E **40 CFR Ch. I (7–1–12 Edition)**

APPENDIX E TO PART 122—RAINFALL ZONES OF THE UNITED STATES

Not Shown: Alaska (Zone 7); Hawaii (Zone 7); Northern Mariana Islands (Zone 7); Guam (Zone 7); American Samoa (Zone 7); Trust Territory of the Pacific Islands (Zone 7); Puerto Rico (Zone 3) Virgin Islands (Zone 3).

Source: Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality, prepared for U.S. Environmental Protection Agency, Office of Water, Nonpoint Source Division, Washington, DC, 1986.

[55 FR 48073, Nov. 16, 1990]

Figure 19 US Rainfall Zones. Source: NPDES Phase I regulations, 40 CFR Part 122, Appendix E (US EPA, 1990).

Water Harvesting Basin

- 1,000 square feet (.02296 acres)
- 18,856 cubic feet capacity
- Input in model as "Infiltration Basin"
- Expected Capital Expenditure (CapEx) cost of $5,171/acre
- Annual Operation and Maintenance (O&M) cost expected at $21/acre/year
- Residual capacity of basin – empty/negligible

Bio Retention Basin

- 1,000 square feet (.02296 acres)
- CapEx expected at $68,519/acre
- Annual O&M cost at $1,179/acre/year

Xeriscape Swale

- 1,000 square feet (.02296 acres)
- Expected CapEx cost of $16,982/acre
- Annual O&M cost expected at $540/acre

Cistern

- Price:
    - Low - $1,600 for 350 cubic feet tank
    - Medium - $2,600 for 350 cubic feet tank
    - High - $5,200 for 350 cubic feet tank
- Capacity: 350 cubic feet
- Average residual capacity at start of rainfall event – 37.7%
- Roof area – 3000 square feet

Infiltration Trench

- 1,000 square feet (.02296 acres)
- Expected CapEx cost of $117,221/acre
- Annual O&M cost expected at $518/acre

Detention Basin (or Extended Detention Basin)

- 1,000 square feet (.02296 acres)
- 45,345 cubic feet capacity
- Expected CapEx cost of $54,352/acre
- Annual O&M cost expected at $614/acre
- Residual capacity of basin – empty/negligible

Pervious Pavers

- 1,000 square feet (.02296 acres)
- Expected CapEx cost of $199,172/acre
- Annual O&M cost expected at $2,614/acre

Curb Extensions (new and retrofit chicanes, medians, traffic circles, and road diets with inlets to gather street water)

- One roundabout on Silverbell Road and one chicane on Cerada De Beto
- Cost per Vehicle Mile Travelled (VMT) of approximately $0.48 social costs due to prevalence and severity of car-pedestrian crashes (see Appendix II for details)
- 10,000 cars per day using roundabout on Silverbell Road
- 500 cars per day using chicane on Cerada De Beto

Tree Benefits

- Expected number of trees planted
- Diameter at breast height (D.B.H.) of trees – assumed to be 2”
- Lifespan average 25 years (max. 40 years)
- Increased pavement longevity due to shading - $0.66/ft^2 ($7.13/meter^2) over 30 year period
- Medium trees (e.g. Chilean mesquite trees) are 20-40 ft. tall[4]. Medium trees save 180 kWh in electricity and 58 kBTU per year in natural gas due to a reduced need for air conditioning near the site containing the trees.
- Small trees (e.g. Sweet acacia trees) are < 20 ft. tall. Small trees save 74 kWh in electricity and 2 kBTU per year in natural gas due to a reduced need for air conditioning near the site containing the trees

Water Costs

- Reduced need for irrigation due to use of LID features and cisterns
- Financial cost of water - $2.77 per CCF (Commercial rate of $2.22/CCF + CAP charge ($0.48/CCF) + Conservation charge ($0.07/CCF)[5]

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[4] Canopy areas are in Figure 5 in McPherson et al. "Desert Community Tree Guide: Benefits, Costs, and Strategic Planting." Arizona State Land Department Natural Resources Division. July 2004

[5] http://www.tucsonaz.gov/water/rates/potable

- Social cost of water - \$5.29[6] per CCF, leading to a marginal social cost of water of \$5.29 - \$2.77 = \$2.52 per CCF

Arid Southwest Specific Interest

Reduced Water Use

- *Reduced irrigation due to the use of Cisterns:* Reduced irrigation required as a result of using cisterns is dependent on the capacity of the cistern, the roof area feeding into the cistern, the flow rate, and the rainfall patterns in the region. Using daily rainfall data from 1895 to 2000, assuming a 350 cubic foot cistern, flow rate at the rate of required water from irrigated plants, and a roof area of 3,000 square feet, the reduced irrigated water was calculated.
- *Reduced irrigation due to the use of Water Harvesting Basins:* Using Tucson's Commercial Rainwater Ordinance, it was determined that plants being planted at the Silverbell Road site would require 20 inches of water per square foot of plant canopy each year (assumed low water requirement plants). The water required by irrigation was calculated as the difference between the total water requirement of 20 inches and the average annual precipitation in Tucson of 12 inches. Therefore, the volume of reduced irrigation in any given year is equal to 8 inches multiplied by the surface area of new vegetation on the site.

Energy Savings

- *Tree Energy Savings:* Trees provide shade and reduce temperatures on hot days. This reduction in temperatures reduces the need for air conditioning, thereby reducing both the direct costs of energy, as well as the externalities produced by using energy. The trees relevant to Silverbell Road were determined to be both "Small" and "Medium" sized trees, as described by a study by McPherson et. al; medium trees save 180 kWh in electricity and 58 kBTUs in natural gas each year, while small trees

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[6] The total social value of water is taken as the sum of the current gross margin plus the cost of water extraction and purification from alternative water sources. The cost of water from alternative sources was found in "Arizona's Next Century: A Strategic Vision for Water Supply Sustainability" (http://www.azwater.gov/AzDWR/Arizonas_Strategic_Vision/documents/OpportunitiesandChallengesforArizona.pdf) . It was assumed that the cheapest sources would be used first.

save 74 kWh and 2 kBTUs in energy each year[7]. Based on current rates, it is assumed that the direct cost of electricity is $0.10/kWh and $0.001/kBTU.

Operation & Maintenance

- *Direct costs of water:* Tucson's water rates were used: $2.77/CCF
- *Social marginal cost of water:* The social marginal cost of water was taken to be the difference between the current cost of water and the cost of water if current sources run dry. Future and alternative sources of water include primarily desalination plants[8], which are much more expensive sources of fresh water than direct extraction from ground sources such as aquifers. Using these costs and the implied current gross margins, the Social Cost of Water was calculated as $5.29, implying a Social Marginal Cost of Water of $2.52/CCF.
- *Overall Reduced Irrigation Costs:* The reduced costs for both direct costs and indirect costs were determined for each site by multiplying the relevant cost per CCF by the CCFs saved as a result of using LID features. This calculation produced annual values which were extrapolated out to 40 years from now. As a final step, the value of reduced irrigation for years 1-3 was subtracted from the overall benefit, as it is expected that reduced irrigation will not become a realized benefit until year 4.
- *O&M costs for trees:* $11/year[9].

Supplemental Local Costs Data

- *Capital Expenditures (CapEx) and Operations and Maintenance (O&M) costs:* To estimate the capital expenditure and O&M costs, AutoCASE™ uses a database of real project costs for each LID feature. To better cater the results to the Tucson region specifically, the database being used was narrowed down to EPA Region 6 data, providing data for regions with low rainfall.

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[7] McPherson et al. Op. Cit.

[8] http://www.azwater.gov/AzDWR/Arizonas_Strategic_Vision/documents/OpportunitiesandChallengesfor_Arizona.pdf

9 McPherson et al. Ibid.

Arid Southwest Additional Costs/Benefits Evaluation

Flood Mitigation Benefit

Flood mitigation benefits were analyzed from three primary components: rainfall analysis, analysis of value at risk and total flood risk mitigated.

Rainfall Analysis

- Historical rainfall data in the Tucson region was used to model expected future rainfall on each site for the next 100 years. Using the historical data, expected rainfall (in inches) for each year can be equated to the storm repeat rate. The storm repeat rate describes how often a storm of that strength is expected to appear. For example, a 25 year storm is a storm that would be expected to occur once every 25 years or more. The storm repeat rate is used in the next step to estimate the value at risk.

Analysis of Value at Risk

- Using historical property damage due to flooding for the state of Arizona, a function is used that relates storm repeat rate to percent of expected property damage. This function is applied to each year in the 100 year forecast to determine the percent property damage expected and, hence, the value of the damage.

Total Flood Risk Mitigated

- The sites being analyzed are incorporated by estimating the reduced on site flooding in a storm event. This reduction in flooding may be the result of higher infiltration rates, greater on-site storage capacity, or increased grey infrastructure capacity, thereby removing water from the site at a faster rate. This reduction in flooding on the site is then compared to the total projected flooding in the City of Tucson. The ratio is equivalent to the flood risk mitigated. Multiplying the flood risk mitigated by the total value at risk due to flooding produces the value of flood risk mitigated for each year. Discounting these values back (to factor in the social cost of capital) and summing produces the total NPV of the reduced flood risk.

Transportation – Traffic Calming Benefits

- Both roundabouts and curb extensions have been shown to reduce the prevalence and severity of crashes. To quantify the benefits of these features, the variables included the following: current crash rates and severity of crashes, distance of mitigated risk, and number of cars passing by feature each day. The current crash rates and severity of crashes were found in Arizona's 2012 Motor Vehicle Crash Costs document[10]. The distance of mitigated risk was conservatively assumed to be 5 meters on either side of a roundabout and, similarly, 5 meters for the curb extension. The number of cars passing by each feature was found to be 10,000 per day (two-way traffic count) for Silverbell Road and the roundabout, while the number of cars was estimated at 500 per day for Cerada de Beto and the curb extension[11]. More details on the calculation of the traffic calming benefit can be found in Appendix II: Traffic Calming Assumptions and Calculations.

Heat Island Benefit

- Green infrastructure reduces the severity of extreme heat events by creating shade, by reducing the amount of heat absorbing surfaces, and by emitting water vapor to cool the air. This cooling effect can reduce heat stress-related fatalities in the city during extreme heat wave events.
- The benefits of GI/LID on urban heat island is estimated by valuing the reduced mortality associated with lowering the air temperature. The methodology is described below and also in Appendix VII: Heat Island Benefit Calculation.
- Heat Stress and Related Premature Fatalities Avoided Methodology – "Arizona is one of the hottest places on earth from May to September. Heat-related illnesses are common during the summer. Year after year, nearly 2,000 people visit Arizona emergency rooms because of heat-related illnesses. Some heat-

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[10] "2012 Motor Vehicle Crash Facts for the State of Arizona". The Arizona Department of Transportation. Accessed June 5, 2014. http://www.azdot.gov/docs/default-source/mvd-services/12crashfacts.pdf?sfvrsn=2

[11] "2012 Traffic Volumes in Metropolitan Tucson and Eastern Pima County". Pima Association of Governments. Accessed June 6, 2014. http://www.pagnet.org/documents/rdc/gis/maptrafficcount2012.pdf

related illnesses could even be fatal. Over 1,500 deaths from exposure to excessive natural heat have occurred in Arizona from 2000 to 2012[12].” These events may be more frequent and severe in the future due to climate change. “The urban heat island (UHI) effect compromises human health and comfort by causing respiratory difficulties, exhaustion, heat stroke and heat-related mortality. Various studies have estimated that trees and other vegetation within building sites reduce temperatures by about 5^{o}F when compared to outside non-green space. At larger scales, variation between non-green city centers and vegetated areas has been shown to be as high as 9^{o}F.”[13]

- The approach used in AutoCASE^{TM} is to link GI/LID to reduced temperatures by:
    - Determining the total acres of increased vegetation, and dividing by the total acres in the town/city that the project is being built in to calculate an overall percentage increase in vegetation.
    - Linking 10% increase in vegetation to reductions in temperatures (0.39 to 0.70^{o}F, according to multiple studies determining the impacts of GI/LID projects on urban temperatures)
    - Calculating the overall reduction in temperature as a result of the project
- Then, linking reduced temperatures to avoided deaths by:
    - Calculating the reduction in the average annual mortality rate based on local weather, the local, Tucson region, mortality rate, and the local temperature threshold at which the impacts of heat on mortality can be detected (called the Minimum Mortality Temperature, or MMT).
        - Calculating the change in the days each year when the city is over the MMT, as well as the change in the average temperature for the days that are still over the MMT after the project is implemented.

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[12] Arizona Department of Health Services - http://www.azdhs.gov/phs/oeh/heat/extreme.htm

[13] Center for Neighborhood Technology, 2010, The Value of Green Infrastructure A Guide to Recognizing Its Economic, Environmental and Social Benefits http://www.cnt.org/media/CNT_Value-of-Green-Infrastructure.pdf

        MMT has been found to correlate with latitude, so more southern locations have a higher MMT and more northern locations have a lower MMT.
        - Using the change in days over MMT and the change in the temperature for days over the MMT to calculate a new average annual mortality rate.
    - AutoCASE^{TM} uses local weather patterns extrapolated from history – daily data from 1981- 2010 - for approximately 1,500 weather stations across the United States. The data were used to determine a distribution of temperature values for each city for every month of the year. Data for three weather stations in the Tucson region were tested for use in this project. Since there were no material differences in the results the AutoCASE^{TM} default of the closest weather station was used.
- Finally, AutoCASE^{TM} calculates the annual lives saved from the project by using the Value of Statistical Life to quantify the benefit of reduced heat mortality rates. The value of a statistical life seems to be widely used in the regulatory impact analysis and cost benefit studies for federal government cost benefit analyses (e.g. safety improvements in rail and roadways). A range of $5-$13 million with a median around $9 million seems to be accepted.

Results for Individual GI/LID Practices

The analysis of individual GI/LID features shows that the three LID features with a probability of achieving a net social benefit (when their social and environmental benefits outweigh the costs) that is greater than 50% include Infiltration Trenches, Xeriscape Swale, and Water Harvesting Basins. This can be seen in Figure 20.

In contrast, traditional features like Concrete and Asphalt have a highly negative SNPV, indicating that the costs far outweigh any benefits. For that reason, Pervious Pavers provide a significantly improved SNPV, even though its SNPV is also negative.

Table 1 Summary Results for Individual GI/LID Features (per 1000 sq. ft., Cistern is for 350 cubic feet) – Median (50th percentile) Results

	Net Present Values – Median (50th Percentile)								
	Costs		Benefits						
	CapEx Cost	O&M Costs	Flood Risk Reduction	Property Value Uplift	Heat Mortality Risk Reduction	Reduced CO_2 Emissions	Reduced Other Costs	Direct Financial NPV	**Total SNPV**
Bioretention	($2,096)	($377)	$169	$49	$515	$0	$0	($2,473)	**($1,740)**
Pervious Pavers	($2,496)	($834)	$168	$51	$513	$0	$0	($3,330)	**($2,597)**
Detention Basin / Extended Detention	($1,215)	($194)	$234	$50	$514	$0	$0	($1,409)	**($612)**
Water Harvesting Basin*	($132)	($7)	$200	$52	$518	$0	$0	($139)	**$631**
Cistern	($2,685)	$0	$95	$0	$0	$0	$448	($2,685)	**($2,142)**
Xeriscape Swale	($383)	($173)	$159	$51	$512	$0	$0	($556)	**$167**
Infiltration Trench	($701)	($167)	$200	$50	$515	$0	$0	($868)	**($102)**
Pavement	($10,817)	$0	($424)	$0	$0	$0	$0	($10,817)	**($11,241)**
Concrete	($14,106)	$0	($379)	$0	$0	($1,346)	$0	($14,106)	**($15,831)**
	*Entered as Infiltration Basin								

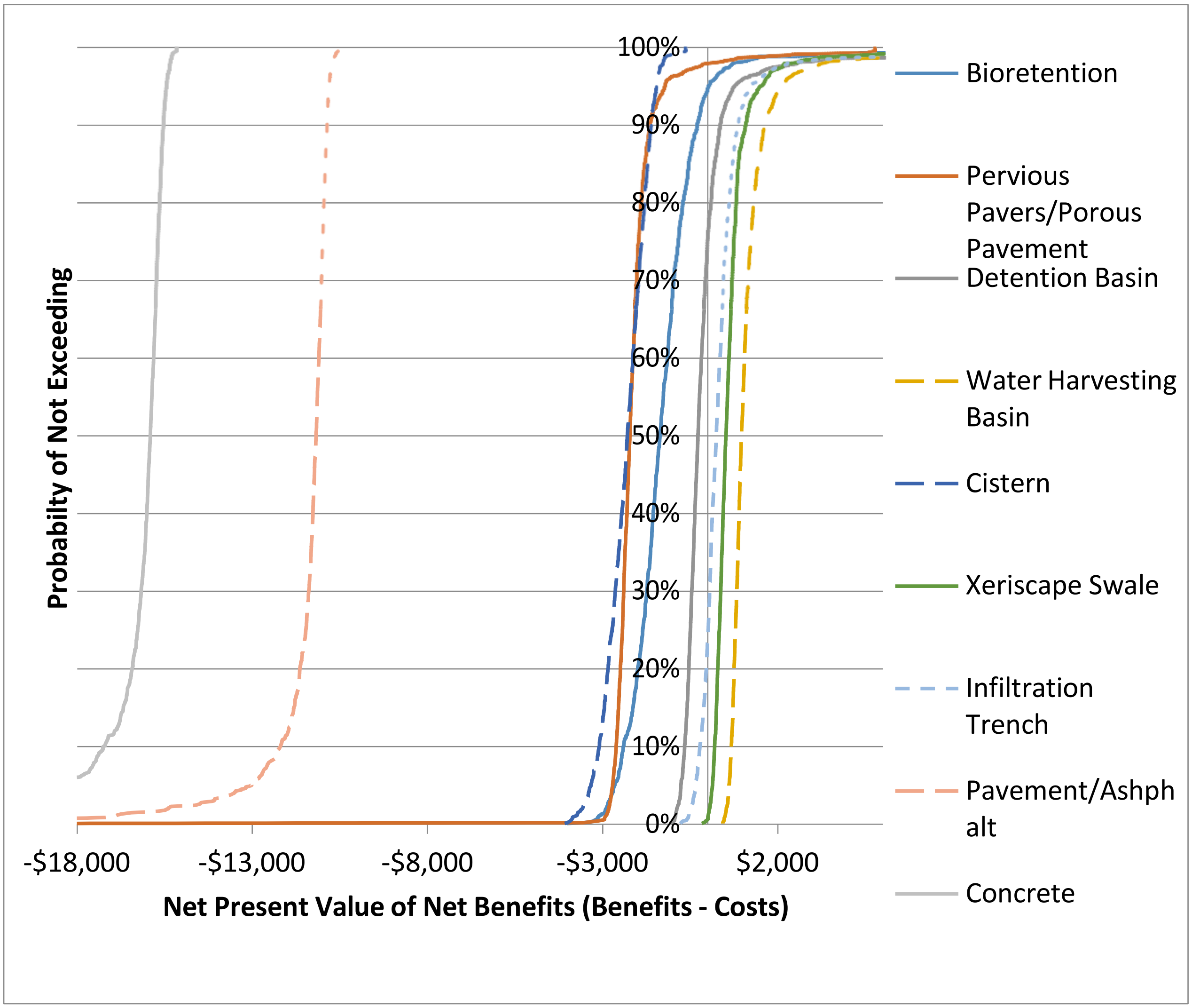


Figure 20 Probability Curves for the Sustainable Net Present Value (SNPV) of Individual GI/LID Features.

Note on Figure 20*:* These curves include all of the costs and benefits (internal or direct cash value which is made up of any revenues or subsidies minus capital and operating costs – such as reduced irrigation costs, in addition to external or non-cash benefits such as reduced flooding, property value increase, reduced heat mortality, reduced emissions, and increased water quality) of the features. The steepness of the curve shows the certainty around the estimate – the steeper the curve, the more certain, the wider the curve, the more risk in the estimate. The curves allow for probability statements about the estimates to be made – for example, there is a 90% probability that the SNPV of pavement/asphalt will not exceed -$10,900, there is a 50% probability that the SNPV will not exceed -$11,200, and there is a 10% probability that the value will not exceed $12,200. The curves are generated from a 1,000 iteration Monte Carlo simulation. More information can be found in Appendix IV.

Site Specific Evaluations – GI/LID Clustered Scenarios

Initial Parameters

The initial parameters and suggested categories for review included the following GI/LID practices:

- **Permeable Pavers** (pollutant removal & water quality improvement)
- **Urban Heat Island Effect** (provide shade for heat mitigating effect)
- **Green Roof** (reflective shading materials and vegetation)
- **Traffic Calming** (Curb Extensions, Chicanes, Traffic Circles, Lane Widths)
- **Street Trees** (Streetscapes)
- **Protected Bike Lanes** (safety and business booster)
- **Water Harvesting Basins/Infiltration Basin** (retention of rainwater, meeting water supply needs)
- **Bio Retention Basin** (water conservation & water quality improvement)
- **Xeriscape Swale/or Grass Swale** (runoff collection, infiltration & conveyance)
- **Cistern** (water conservation, reduced irrigation needs)
- **Infiltration Trench** (runoff storage & infiltration)
- **Detention Basin or Extended Detention Basin** (runoff storage & flood risk reduction)

Commercial property

A 7.3 acre commercial property for a gas station/convenience store in the northeast edge of the City of Tucson was chosen for analysis. Green Infrastructure modification to the site designs were added for purposes of scenario testing only and are not associated with any current proposed changes at the existing site. The site shown is for illustration purposes only. The site is surrounded by suburban land uses.

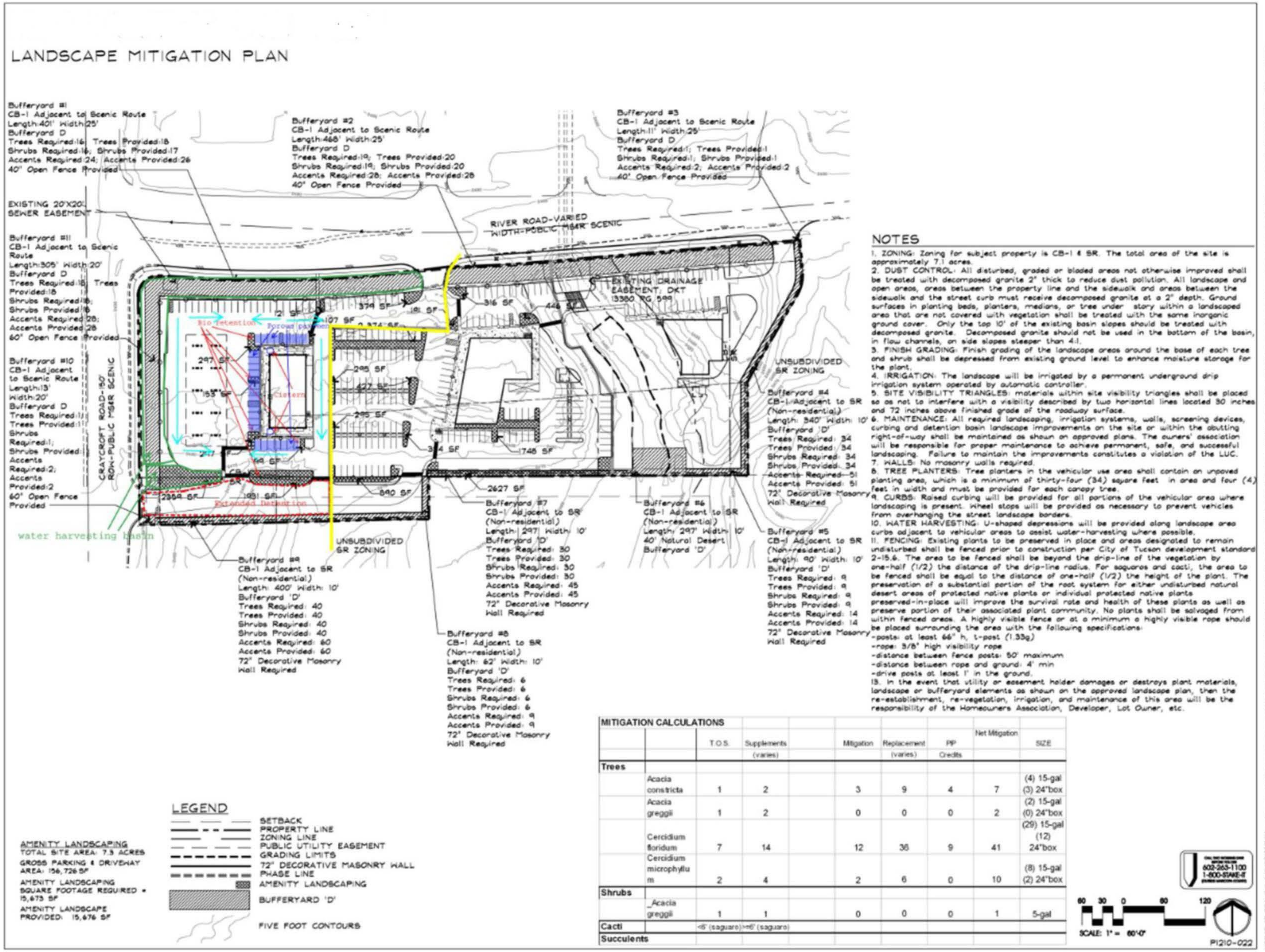
Figure 21 Commercial site location from Google Maps

Figure 22 Commercial site from Google Maps

Figure 23 Commercial Site Detail from Google Maps

The plans for the property were modified to include green infrastructure features (these modifications were added for purposes of analysis only and are not associated with any proposed changes):

- Water Harvesting Basins
- Bio Retention Basin
- Cistern
- Pervious Pavers
- Detention Basins (or Extended Detention Basins)



NOTES

1. ZONING: Zoning for subject property is CB-1 & SR. The total area of the site is approximately 7.1 acres.
2. DUST CONTROL: All disturbed, graded or bladed areas not otherwise improved shall be treated with decomposed granite 2" thick to reduce dust pollution. All landscape and open areas, areas between the property line and the sidewalk and areas between the sidewalk and the street curb must receive decomposed granite at a 2" depth. Ground surfaces in planting beds, planters, medians, or tree under story within a landscaped area that are not covered with vegetation shall be treated with the same inorganic ground cover. Only the top 10' of the existing basin slopes should be treated with decomposed granite. Decomposed granite should not be used in the bottom of the basin, in flow channels, on side slopes steeper than 4:1.
3. FINISH GRADING: Finish grading of the landscape areas around the base of each tree and shrub shall be depressed from existing ground level to enhance moisture storage for the plant.
4. IRRIGATION: The landscape will be irrigated by a permanent underground drip irrigation system operated by automatic controller.
5. SITE VISIBILITY TRIANGLES: materials within site visibility triangles shall be placed so as not to interfere with a visibility described by two horizontal lines located 30 inches and 72 inches above finished grade of the roadway surface.
6. MAINTENANCE: All required landscaping, irrigation systems, walls, screening devices, curbing and detention basin landscape improvements on the site or within the abutting right-of-way shall be maintained as shown on approved plans. The owners' association will be responsible for proper maintenance to achieve permanent, safe, and successful landscaping. Failure to maintain the improvements constitutes a violation of the LUC.
7. WALLS: No masonry walls required.
8. TREE PLANTERS: Tree planters in the vehicular use area shall contain an unpaved planting area, which is a minimum of thirty-four (34) square feet in area and four (4) feet in width and must be provided for each canopy tree.
9. CURBS: Raised curbing will be provided for all portions of the vehicular area where landscaping is present. Wheel stops will be provided as necessary to prevent vehicles from overhanging the street landscape borders.
10. WATER HARVESTING: U-shaped depressions will be provided along landscape area curbs adjacent to vehicular areas to assist water-harvesting where possible.
11. FENCING: Existing plants to be preserved in place and areas designated to remain undisturbed shall be fenced prior to construction per City of Tucson development standard 2-15.6. The area to be fenced shall be beyond the drip-line of the vegetation by one-half (1/2) the distance of the drip-line radius. For saguaros and cacti, the area to be fenced shall be equal to the distance of one-half (1/2) the height of the plant. The preservation of a substantial portion of the root system for either undisturbed natural desert areas of protected native plants or individual protected native plants preserved-in-place will improve the survival rate and health of these plants as well as preserve portion of their associated plant community. No plants shall be salvaged from within fenced areas. A highly visible fence or at a minimum a highly visible rope should be placed surrounding the area with the following specifications:
-posts: at least 66" h, t-post (1.33g)
-rope: 3/8" high visibility rope
-distance between fence posts: 50' maximum
-distance between rope and ground: 4' min
-drive posts at least 1' in the ground.
13. In the event that utility or easement holder damages or destroys plant materials, landscape or bufferyard elements as shown on the approved landscape plan, then the re-establishment, re-vegetation, irrigation, and maintenance of this area will be the responsibility of the Homeowners Association, Developer, Lot Owner, etc.

MITIGATION CALCULATIONS

		T.O.S.	Supplements (varies)		Mitigation	Replacement (varies)	PP Credits	Net Mitigation	SIZE
Trees									
	Acacia constricta	1	2		3	9	4	7	(4) 15-gal (3) 24"box
	Acacia greggii	1	2		0	0	0	2	(2) 15-gal (0) 24"box
	Cercidium floridum	7	14		12	36	9	41	(29) 15-gal (12) 24"box
	Cercidium microphyllum	2	4		2	6	0	10	(8) 15-gal (2) 24"box
Shrubs									
	_Acacia greggii	1	1		0	0	0	1	5-gal
Cacti		<6' (saguaro)	>=6' (saguaro)						
Succulents									

Figure 24 Commercial Site Design

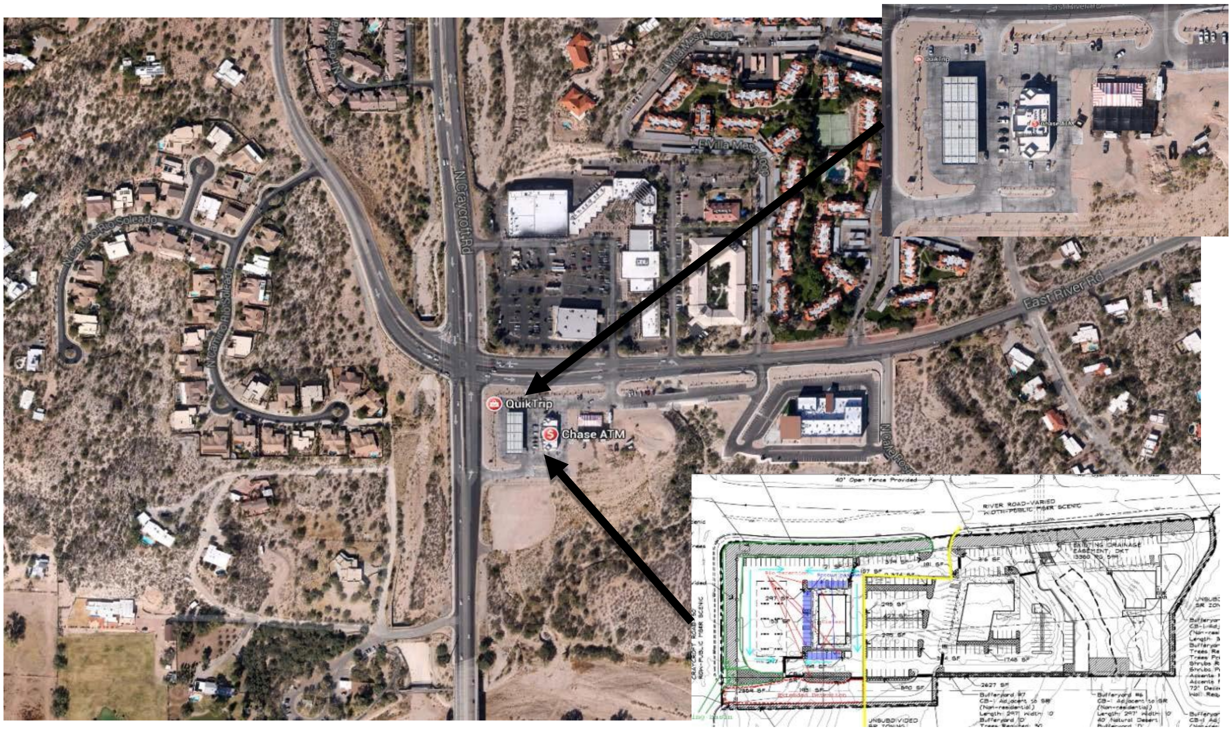


Figure 25 Commercial Site location, site and plan

Transportation Corridor project

Silverbell Road from Grant Road to Goret is being re-designed. The four northerly sections of Silverbell Road from Goret Road north were chosen for the beta test. The intersection of Silverbell Road and Goret Road (2501-2519 W Goret Rd Tucson, AZ 85745, USA) is at coordinates 32.2629394, -111.0211001.

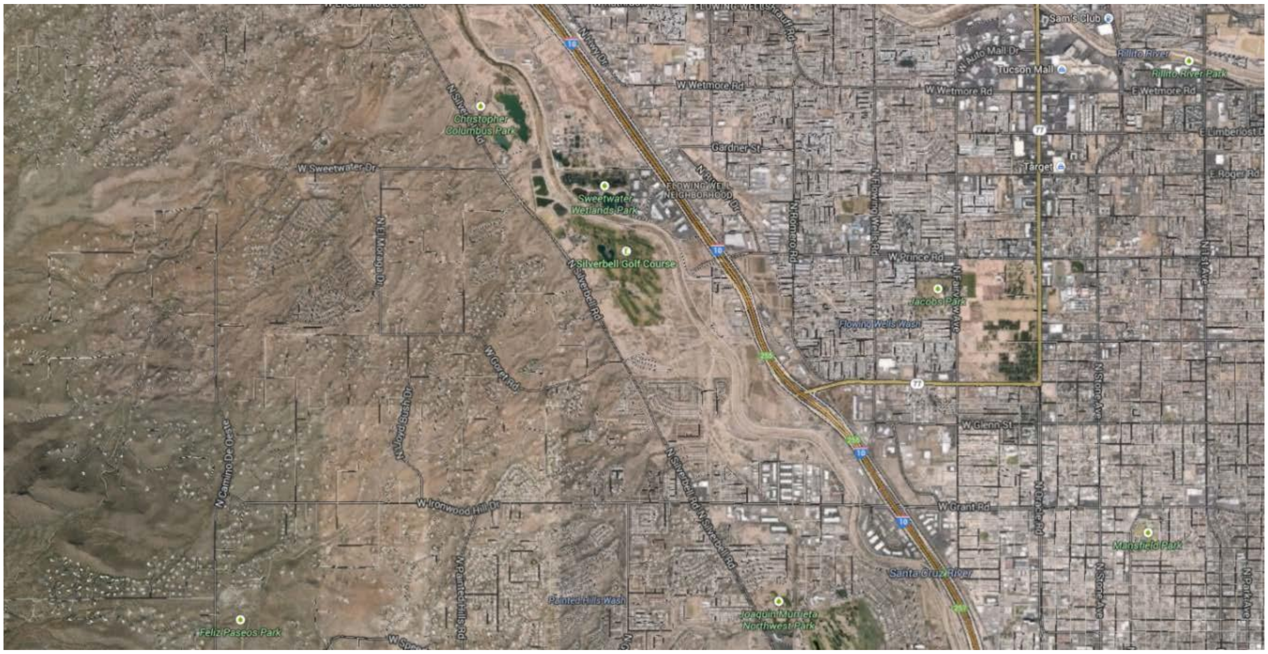


Figure 26 Silverbell Road Location from Google Maps

Figure 27 Silverbell Road Site from Google Maps

Figure 28 Silverbell Road Site Detail from Google Maps

The following Green infrastructure features were added to the design for purposes of analyses and are not associated with any proposed changes:

- Water Harvesting Basins
- Infiltration Trench
- Curb Extensions (new and retrofit chicanes, medians, traffic circles and road diets with inlets to gather street water)
- Trees

Figure 29 Silverbell Road Sections and Google Map View

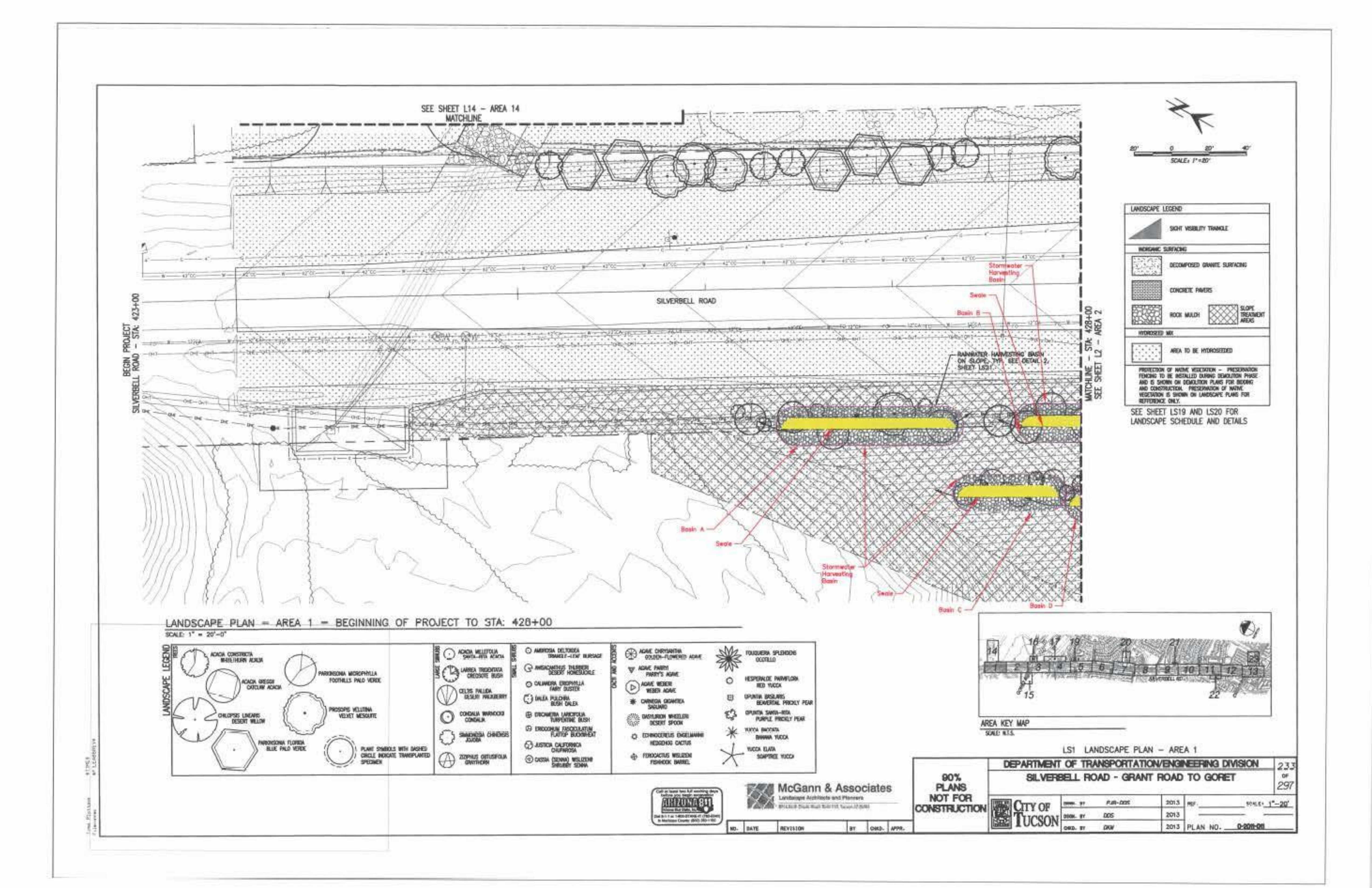


Figure 30 Silverbell Road Section 1 Design

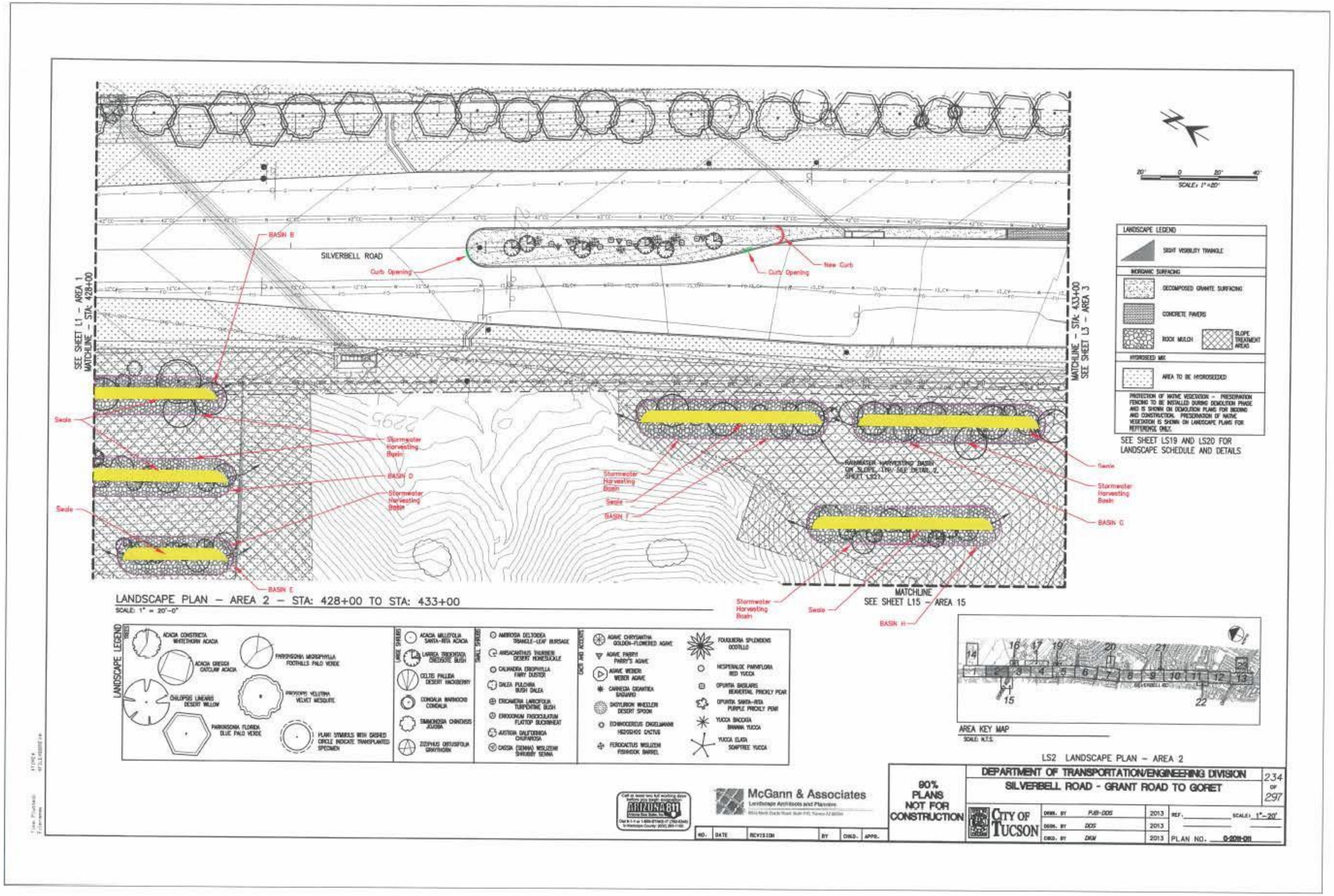


Figure 31 Silverbell Road Section 2 Design

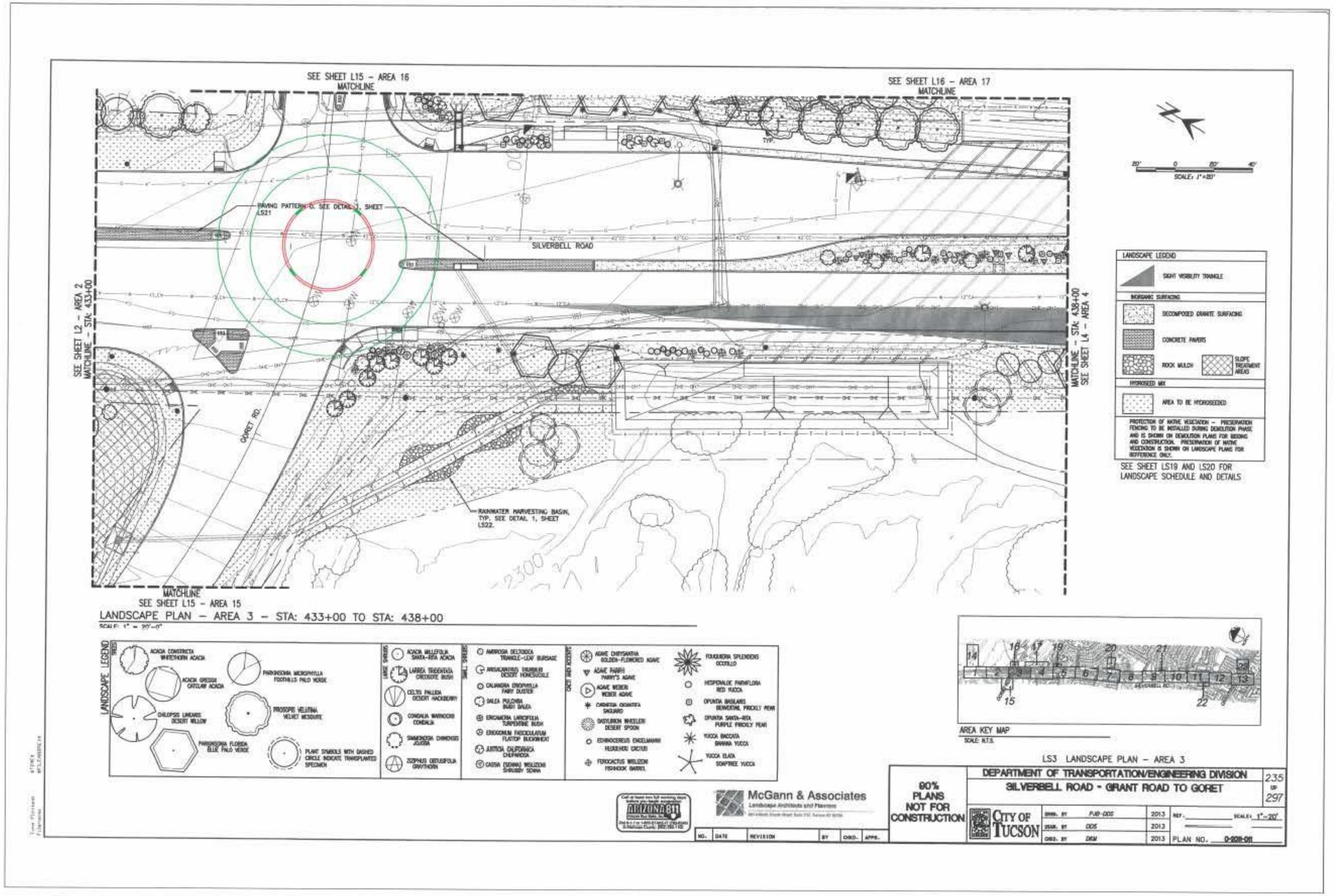


Figure 32 Silverbell Road Section 3 Design

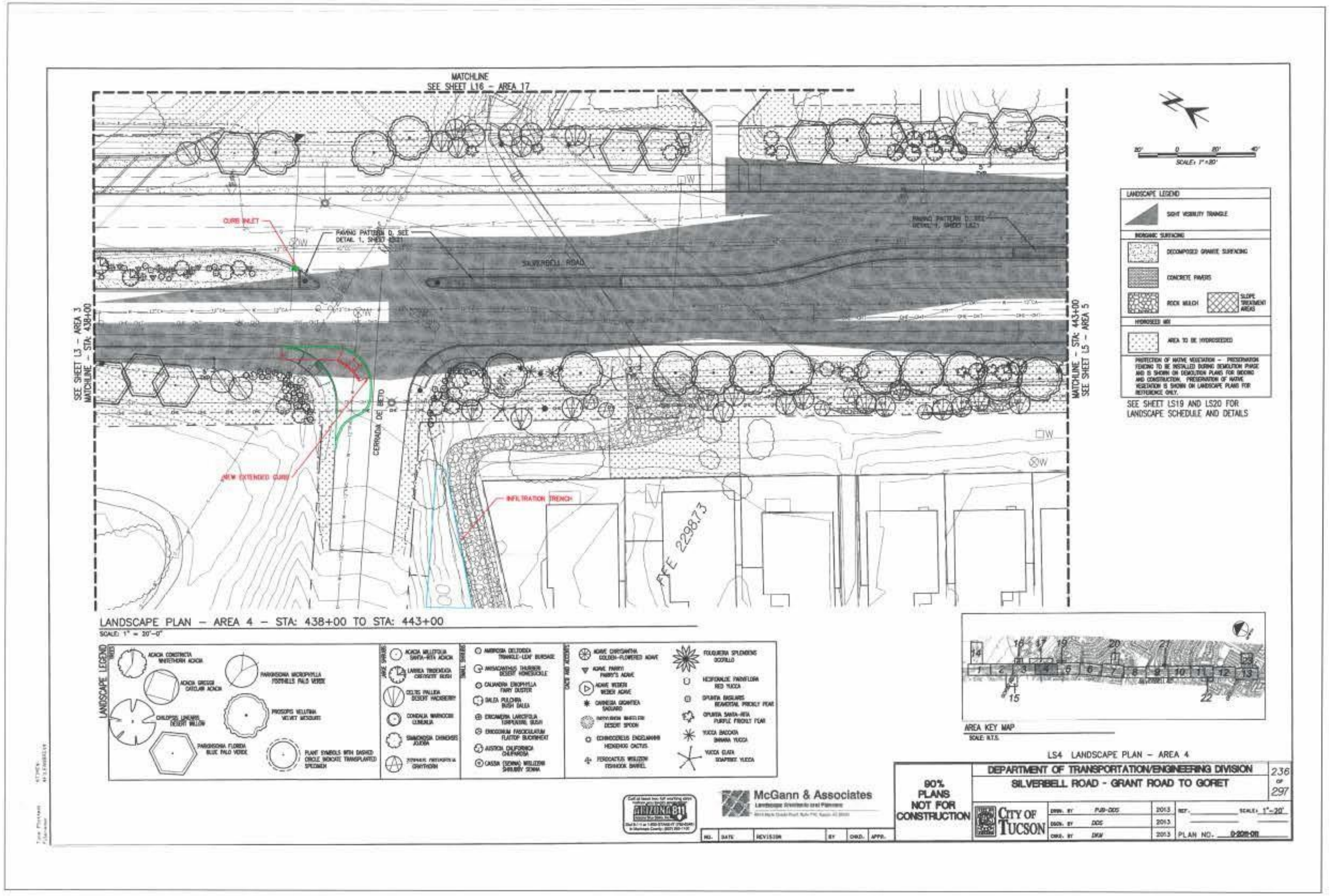


Figure 33 Silverbell Road Section 4 Design

Results for Site Specific Evaluations

The commercial site (a gas station and convenience store), was modified to incorporate rainwater harvesting cisterns, trees, bio retention, detention basins, and porous paving in some parking spots. The addition of the green infrastructure features is for analysis purposes only and do not reflect any proposed changes to the existing development.

The inclusion of these LID features shows that the value of the site is significantly higher when compared with the base case of using concrete. As can be seen in Figure 34, both the direct financial net present value (NPV) and the sustainable NPV (SNPV) are lower for the base case. This is primarily because the capital expenditure costs of concrete are higher than the green LID features selected. However, there is also a large difference in social and environmental value. The SNPV for concrete is negatively skewed because concrete is an impervious surface and can increase flood risk in a region. In contrast, the LID features selected have multiple social and environmental benefits. Cisterns, trees, bio retention, detention basins, and porous paving all help to reduce flood risk in the area during extreme storm events. Other benefits include a reduction in carbon emissions and air pollution, increasing local property values due to enhanced aesthetics, and reducing heat mortality due to mitigated urban heat island effects. Another benefit due to the use of cisterns is a lower requirement for on-site irrigation. This benefit is divided between a reduced requirement to pay for water, as well as social benefits that result from decreasing water use in water scarce areas such as the Tucson region.

One item of particular note is that the SNPV becomes positive with a probability of approximately 20%. In other words, when including the social and environmental benefits of using LID features, the net value of the project (including the upfront costs and maintenance costs) has an 80% probability of being greater than $0. This is important as most alternatives, such as the use of concrete or pavement, have high up-front costs but then fail to generate much social or environmental value, hence leading to negative NPVs. This can be clearly seen in Figure 34.

A summary of the benefits realized by the commercial site, as well as the capital expenditure and operations and maintenance (O&M) costs can be seen in Table 2.

Table 2 Summary Results for Commercial Site

Summary Results	**Net Present Value of Benefits - Commercial Site**
Capital Expenditures	*-$81,685*
O&M Costs	*-$26,640*
Direct Financial NPV	***-$108,325***
Reduced Flood Risk	*$6,203*
Change in Property Values	*$3,059*

Summary Results	Net Present Value of Benefits - Commercial Site
Reduced Heat Stress Mortality	*$69,162*
Value of Reduced CO2 Emissions	*$15,043*
Value of Reduced Air Pollution	*$26,088*
Reduced Direct Costs of Water	*$896*
Reduced Marginal Social Costs of Water Use	*$815*
S-NPV	***$12,941***

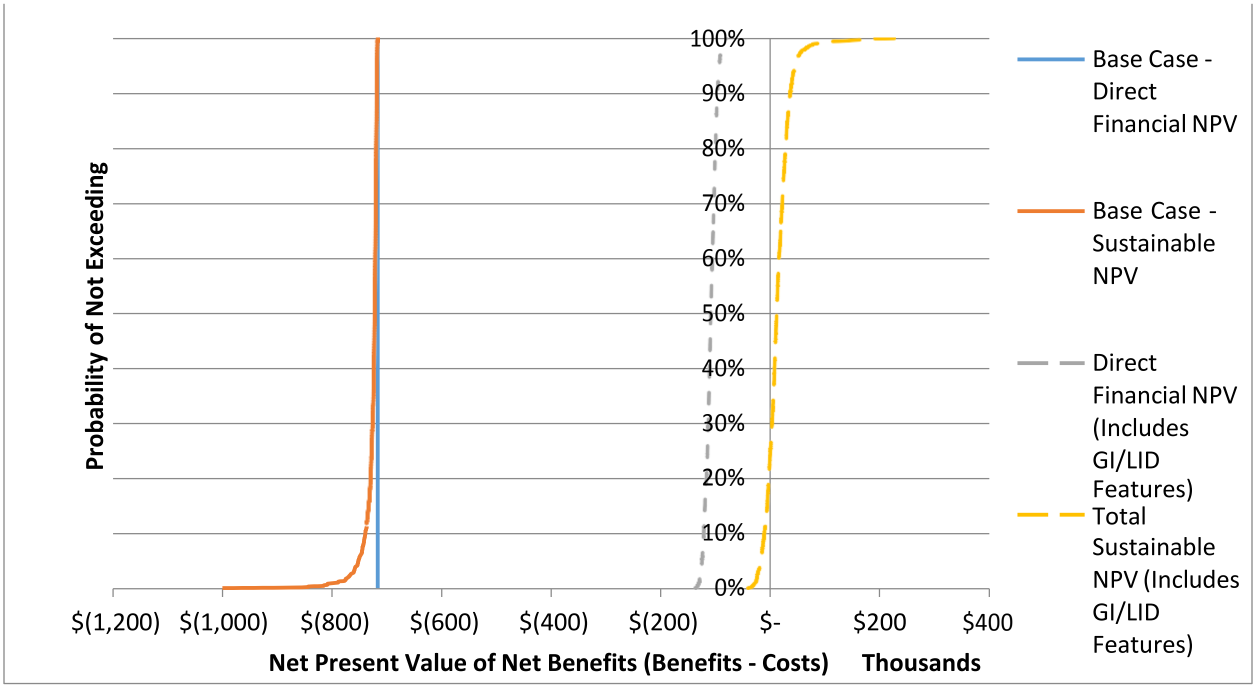


Figure 34 Probability Curves for Commercial Site

> Note on NPV charts: The Direct Financial NPV includes all costs and benefits that are seen as having direct monetary impacts over the value of a project. These include capital expenditure costs and operations and maintenance costs. The Sustainable NPV combines the value of the Direct Financial NPV with the value of all of the social and environmental costs and benefits of the project. Therefore, the Sustainable NPV includes capital expenditures, operations and maintenance costs, reduced energy costs, flood risk mitigation, property value uplift, heat stress mortality reduction, reduced air pollution and carbon emissions, reduced direct costs of water, and reduced social costs of water.

The exercise of additional green infrastructure elements to a ½ mile segment of Silverbell Road included incorporating new trees, bio retention, and water harvesting basins revealed that the

SNPV of the site, including the LID features selected, leads to a highly positive SNPV. The most substantial benefits are reduced heat stress mortality and traffic calming due to the installation of a roundabout and curb extension. Unlike the other benefits, these benefits are measuring direct impacts on human life by increasing the safety of a region, either in terms of reduced local temperatures or reduced likelihood of cars hitting pedestrians. The value of life-related costs have a large value over time and, as shown in Table 3, are more substantial than the other benefits as a result.

Table 3 Summary Results for Silverbell Road

Summary Results	**Net Present Value of Benefits - Silverbell Road**
Capital Expenditures	*-$42,125*
O&M Costs	*-$3,897*
Direct Financial NPV	***-$46,022***
Reduced Electricity Costs	*$20,331*
Reduced Natural Gas Costs	*$57*
Reduced Flood Risk	*$25,645*
Change in Property Values	*$1,592*
Reduced Heat Stress Mortality	*$84,634*
Value of Reduced CO2 Emissions	*$12,095*
Value of Reduced Air Pollution	*$17,588*
Reduced Direct Costs of Water	*$43,823*
Reduced Marginal Social Costs of Water Use	*$39,868*
Increased Pavement Longevity Benefit	*$1,763*
Traffic Calming - Roundabouts and Curb Extension	*$117,737*
Other Benefits	*$3,412*
S-NPV	***$322,523***

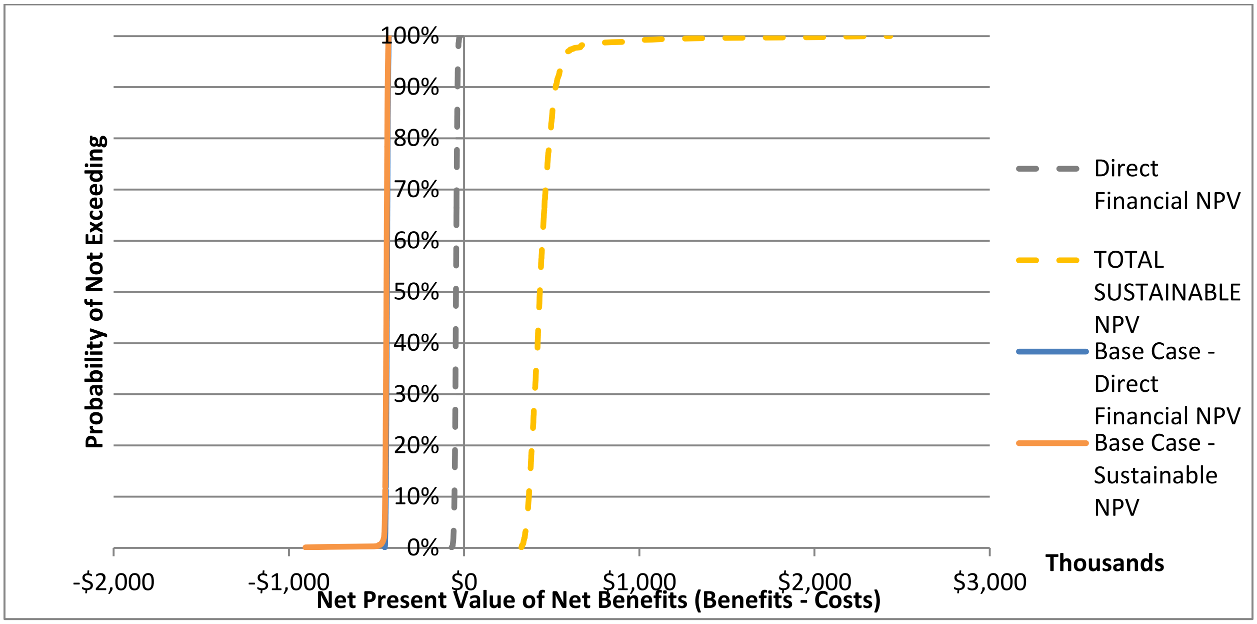


Figure 35 Probability Curves for Silverbell Road

Note on Figure 35 Probability Curves for Silverbell Road - the Base Case Direct Financial NPV and the Base Case Sustainable NPV overlap for most of their range and so are indistinguishable in the chart.

The Tucson region is a bellwether. The Tucson region is teaching the world that infrastructure money must be spent to deal with low probability, large impact events such as flooding. Because of its many benefits, including reduced loss of life, nature's green infrastructure, based on business case analysis, was determined to be the best solution. The implementation of green infrastructure elements can be an effective way to deal with problems of water quality, flooding, safety, urban heat islands, and preserving water as the precious (but undervalued) resource that it is.

AutoCASE^{TM} Summary

Application of the Use to Pima County

Commercial Site

AutoCASE^{TM} was implemented for a commercial site with a gas station and convenience store. The site was modified to incorporate rainwater harvesting, cisterns, trees, bio retention, detention basins, and porous paving in some parking spots. The result led to a large increase in social and environmental value for the site. The division of these benefits can be seen Figure 36.

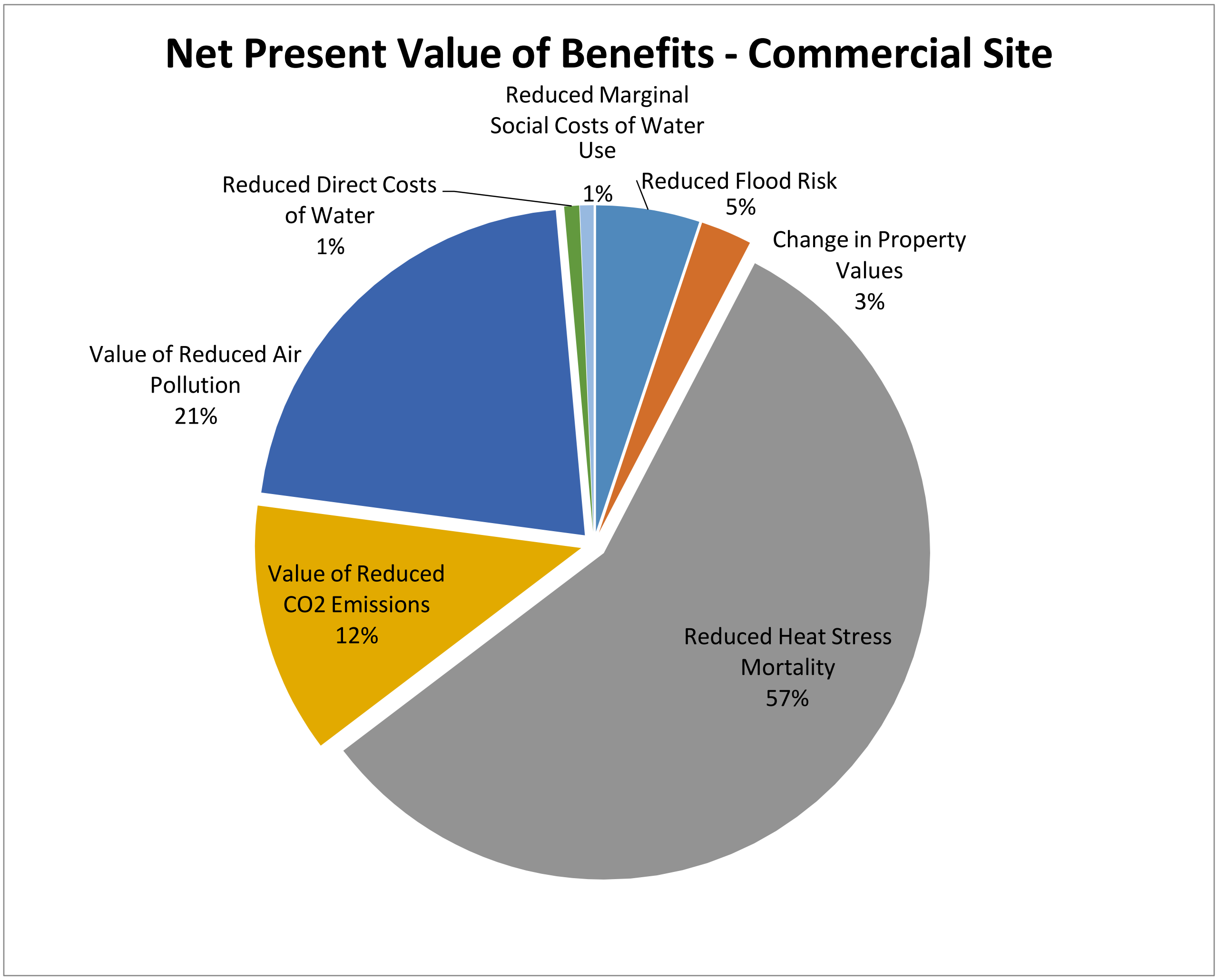


Figure 36 Benefits Breakdown - Commercial Site

As can be seen, the reduced heat stress mortality benefit is the source of most of the value due to the inclusion of LID features. This is largely due to that benefit's direct quantification of the value of increased health and safety that results from a mitigated heat island effect. In other words, the value of a human life saved from reduced temperatures is much greater than lower carbon or air pollutants emissions.

The costs of the project are in line with what would be expected; capital expenditure costs are over 75% of the total lifetime project costs, while operations and maintenance costs account for the remaining 25%. This division of costs can be seen in Figure 37.

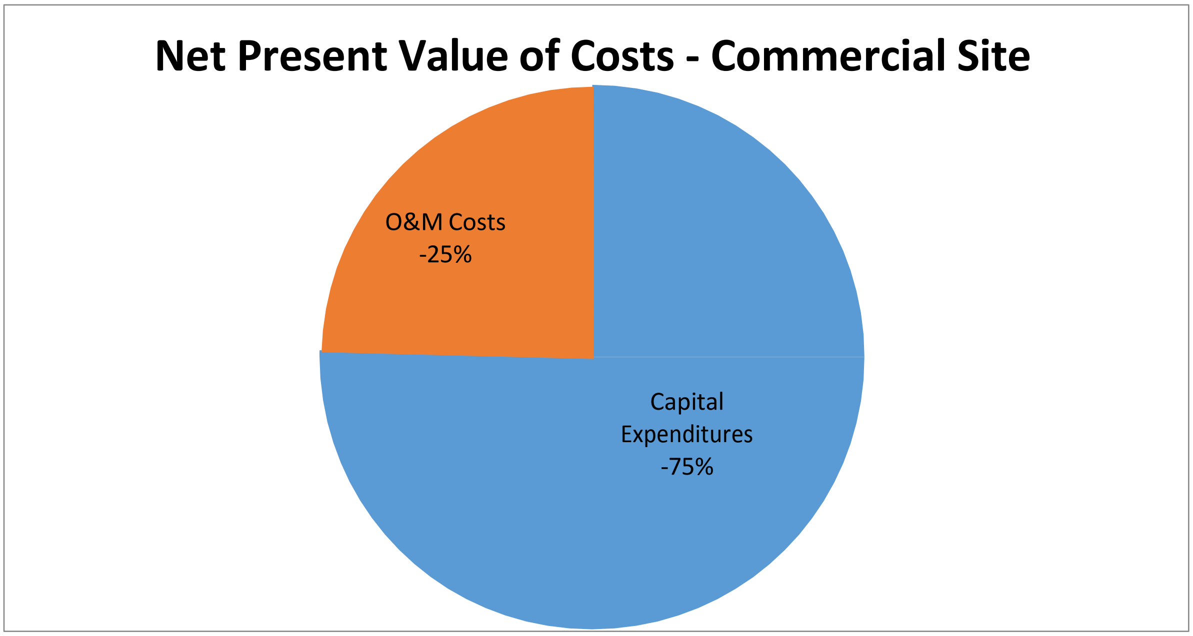


Figure 37 Costs Breakdown - Commercial Site

A large benefit of AutoCASE^{TM} is its ability to allocate the value of a project amongst relevant stakeholder groups so that all parties can understand how they are affected. Shown in Figure 38, direct financial value is the largest proportion of value, although it should be noted that this represent negative value. In other words, this is the net costs of the project. The pie chart shows that the costs represent a smaller proportion of the project's value than the benefits, implying a net positive social value of the project. The negative financial value is the result of the capital expenditure and O&M costs, without a balancing revenue stream or decrease in costs.

When analyzing the stakeholder groups that are benefiting from the project, the government, community, and the environment are all benefiting from the use of LID practices. The government has lower use of potable water for irrigation, higher economic activity due to reduced heat mortality rates and lower health costs due to air pollution. At the same time, the community also benefits from lower mortality rates and better health, while the environment benefits from reduced pollution and carbon emissions.

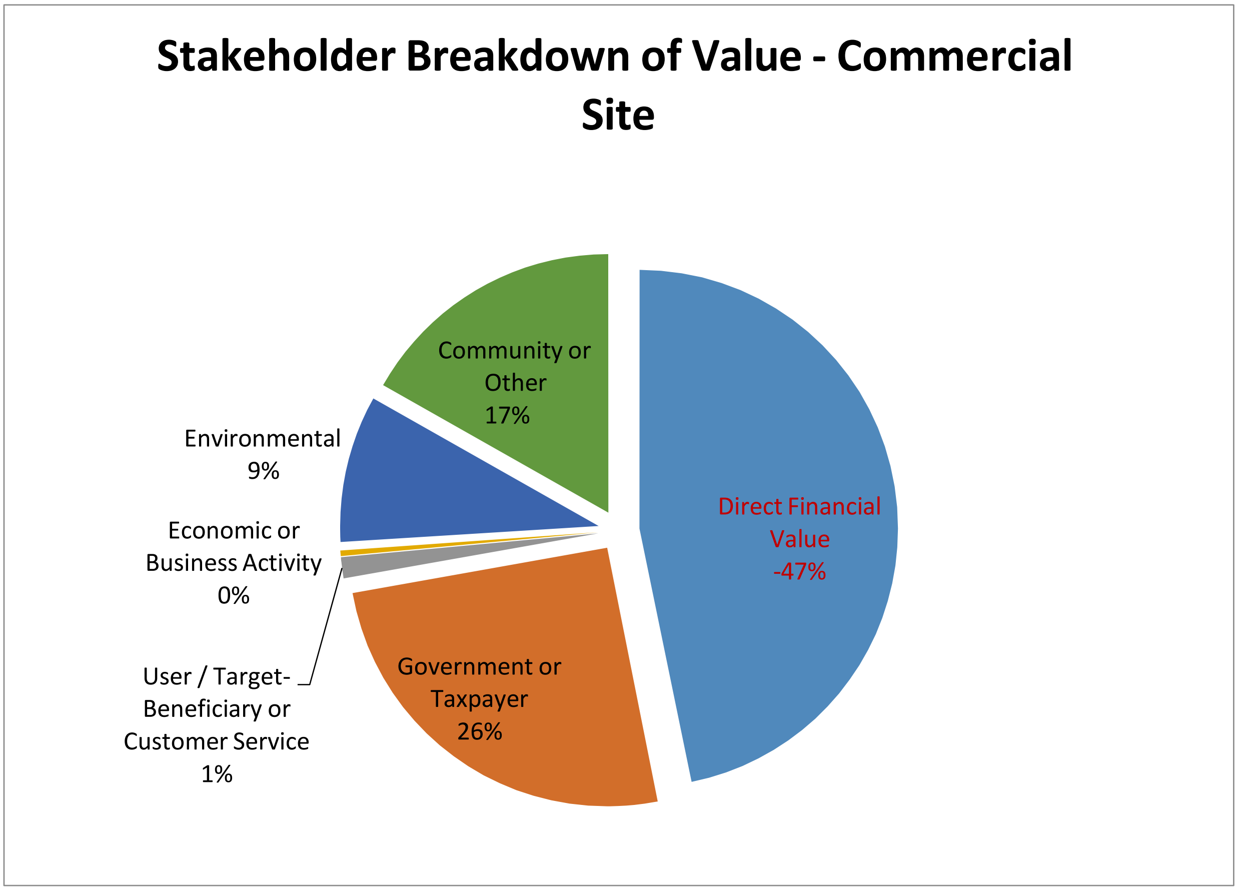


Figure 38 Stakeholder Value Breakdown - Commercial Site

Silverbell Road

At Silverbell Road, the re-design of a ½ mile segment included new trees, bio retention, and water harvesting basins. Traffic calming features, including a roundabout and a curb extension, were also included. These features are projected to produce many benefits, with the highest proportion of benefits derived from traffic calming, reduced heat mortality, and water conservation (see Figure 39). The traffic calming features translate to a lower risk of car crashes with pedestrians. Although these are rare, the social costs of these events are very high as pedestrian crashes have high damage costs[14]. Therefore, even a small reduction in the probability of these events produces a large amount of value. Similarly, reduced heat mortality is also a large portion of the benefits as it is measuring the incremental value due to a lower probability of heat-related deaths.

Water conservation due to the use of bio retention and water harvesting basins leads to a reduced need for potable water use for irrigation. In this analysis, it was assumed that the reduced need for potable water irrigation would begin 3 years into operations and would

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[14] http://www.azdot.gov/docs/default-source/mvd-services/12crashfacts.pdf?sfvrsn=2

remain for the remaining 37 years of the project's effective life. As a result, reduced water costs were counted for years 3-40[15]. Going hand in hand with this is the reduced social cost of water. Since the reduction in irrigation requirements is not expected to be realized until year 3, the Social Marginal Cost of Water benefit was calculated for years 3-40.

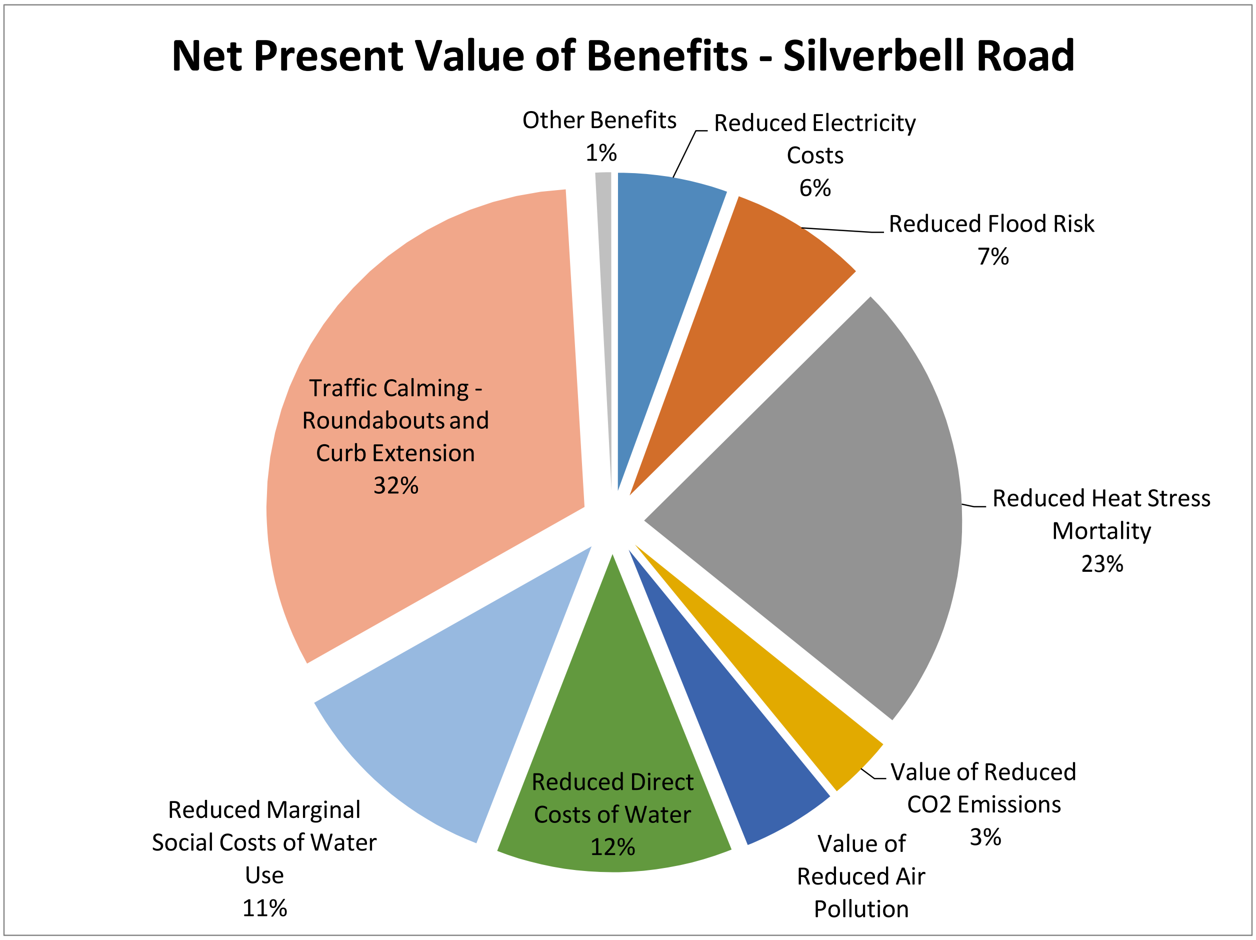

Figure 39 Benefits Breakdown – Silverbell Road

As with the costs for the commercial test site, the vast majority of the costs for Silverbell Road are due to Capital Expenditures. Operations and Maintenance costs comprise the remainder (see Figure 40 Costs Breakdown - Silverbell Road).

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[15] Forty years is used in the analysis for all base case (concrete) and GI/LID features as an estimate of the longest-lived of these assets.

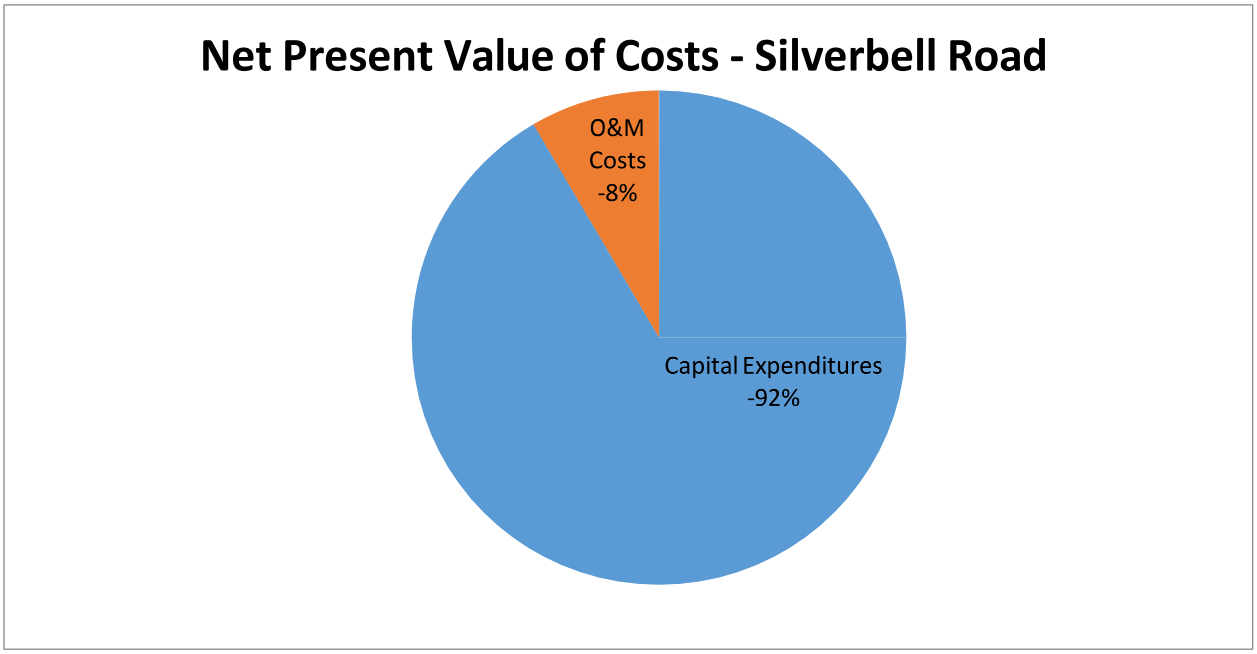


Figure 40 Costs Breakdown - Silverbell Road

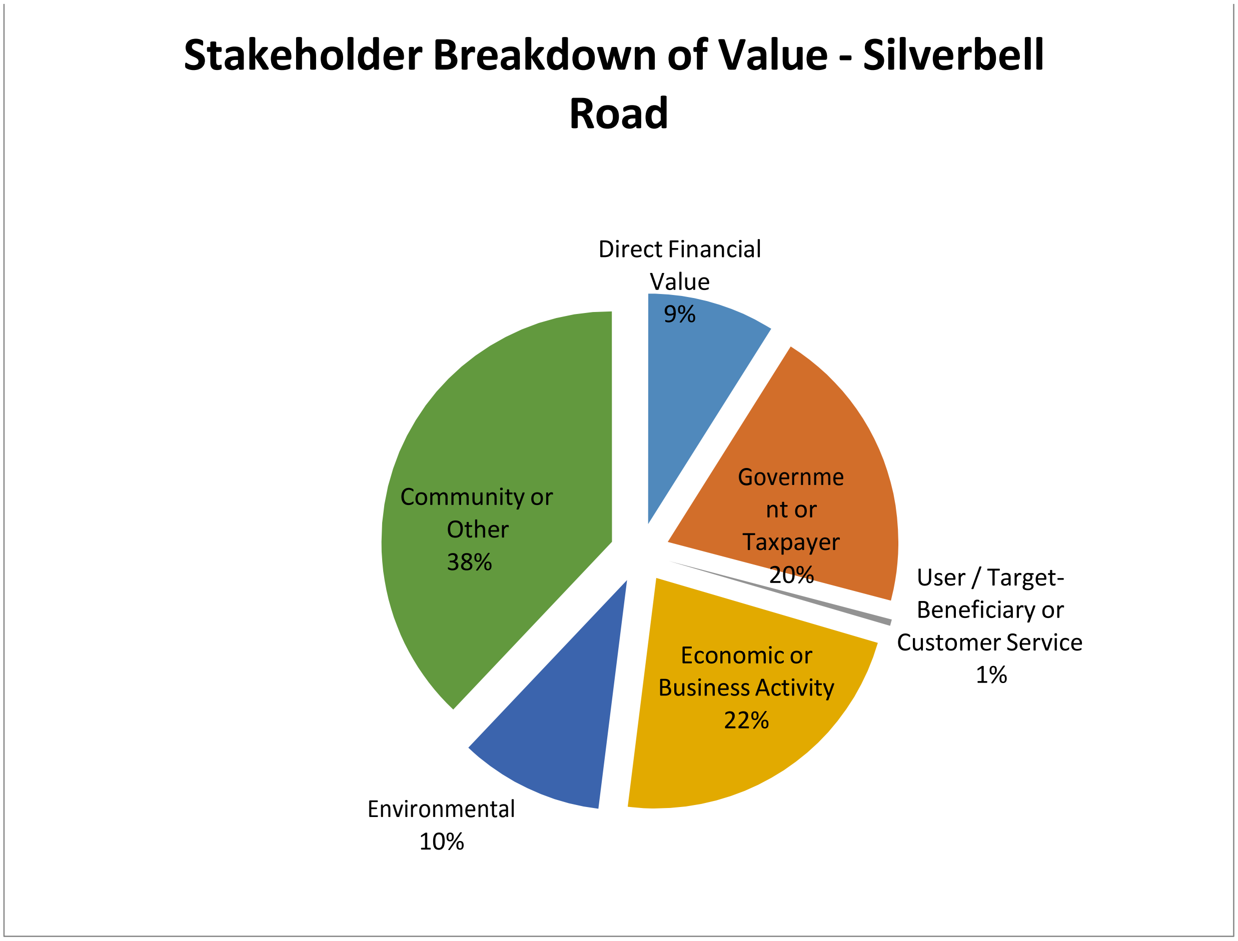


Figure 41 Stakeholder Value Breakdown - Silverbell Road

Figure 41 shows AutoCASE's division of the value from Silverbell Road between the relevant stakeholder groups. Most of the value of this project is realized by the community, the government, and the local economy. The community benefits most from the marginal social cost of water and traffic calming benefits. These benefits reduce the community's risk of water shortages as well as improving quality of life by increasing safety. The government benefits from reduced heat mortality rates of local residents, decreased local flood risk (thereby lowering costs), and reduced carbon and air pollution. Finally, the economy benefits most from the reduced social cost of water, as well as the traffic calming features of the roundabout and curb extension. The traffic calming causes increased economic activity because it is leading to a reduction in accidents, which leads to a decrease in lost economic activity; put another way, there is a net increase in economic activity when compared with having no traffic calming features in place.

Link between AutoCASE^{TM} and Envision

Overview

One of the most valuable features of AutoCASE^{TM} is its ability to express the value of a project in the context of the Envision^{TM} Rating System. Envision^{TM} allows users to rate the level of sustainability and resiliency of an infrastructure project. As an example, for a city designing a new stormwater management system, Envision^{TM} requires the designers of the project to answer questions about the project and its local impacts and design characteristics. This may include the level of resiliency of the design, the degree of sustainable materials used, noise and aesthetic impacts on the local community, impacts on carbon emissions, and so on. At the end, the designers are given a score that is purely points based. This tells them that they achieved a certain level of sustainability, but it does not have the analytical capabilities to determine the project's true value in risk-adjusted dollar values. This is where AutoCASE^{TM} comes in. By answering a few additional questions in AutoCASE^{TM}, planners, designers, and project owners can understand the Sustainable Net Present Value (SNPV) of the project. This metric looks at the holistic value of the project, including its impacts on society and the environment, as well as direct costs in the form of upfront and operating costs.

What Envision^{TM} lacks in quantitative analysis, AutoCASE^{TM} can supply, and where AutoCASE^{TM} lacks in qualitative considerations, Envision^{TM} has thoroughly covered. Together, they are a powerful sustainable infrastructure planning package.

How AutoCASE^{TM} links with Envision

AutoCASE^{TM} divides up the value of a project between the five overall credit categories within Envision^{TM}: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate. The approach to creating this link was by going through each credit and sub-credit within Envision, and, if possible, creating a link to the relevant costs and benefits within AutoCASE^{TM}. As an example, under “Climate and Risk”, CR1.1, which is the credit promoting “Reduced greenhouse gas emissions”, has been linked to the Reduced CO_2 Emissions benefit within AutoCASE^{TM}. Similarly, CR2.4, “Prepare for short-term hazards”, has been linked to the Flood Risk Mitigation benefit within AutoCASE^{TM}. This approach has been taken with all of the costs and benefits and credit categories in AutoCASE^{TM} and Envision^{TM}, respectively. Some credits in Envision were unable to be mapped to benefits in AutoCASE^{TM}. An example of this is LD1.4 (in the Leadership category), “Provide for Stakeholder Involvement”. Although this may be an attribute of a project running in AutoCASE^{TM}, this answer is qualitative and cannot be easily linked to a benefit quantified in AutoCASE^{TM}. As a result, this credit would not be allocated any of the project’s value. Conversely, some benefits in AutoCASE^{TM} are applicable to several credits in Envision^{TM}. An example of this is the Water Quality Enhancement benefit. This benefit is relevant to a range of credits within the Natural World category of Envision; however, it is also relevant to RA3.1 (in the Resource Allocation category), “Protect fresh water availability”. As such, the value of any Water Quality Enhancement is split between the Natural World and Resource Allocation categories. The full mapping of these costs and benefits to the Envision^{TM} credit categories can be found in Appendix III.

Envision’s^{TM} breakdown of value – Results for Commercial Site and Silverbell Road

The analysis on the commercial site produced the results shown in Figure 42. As can be seen, the majority of the value was shared between Climate and Quality of Life. This is in line with the results in Figure 36, showing that most of the value of the commercial site project is split between reduced carbon emissions (Climate), reduced air pollution (Climate), and reduced heat mortality (Quality of Life).

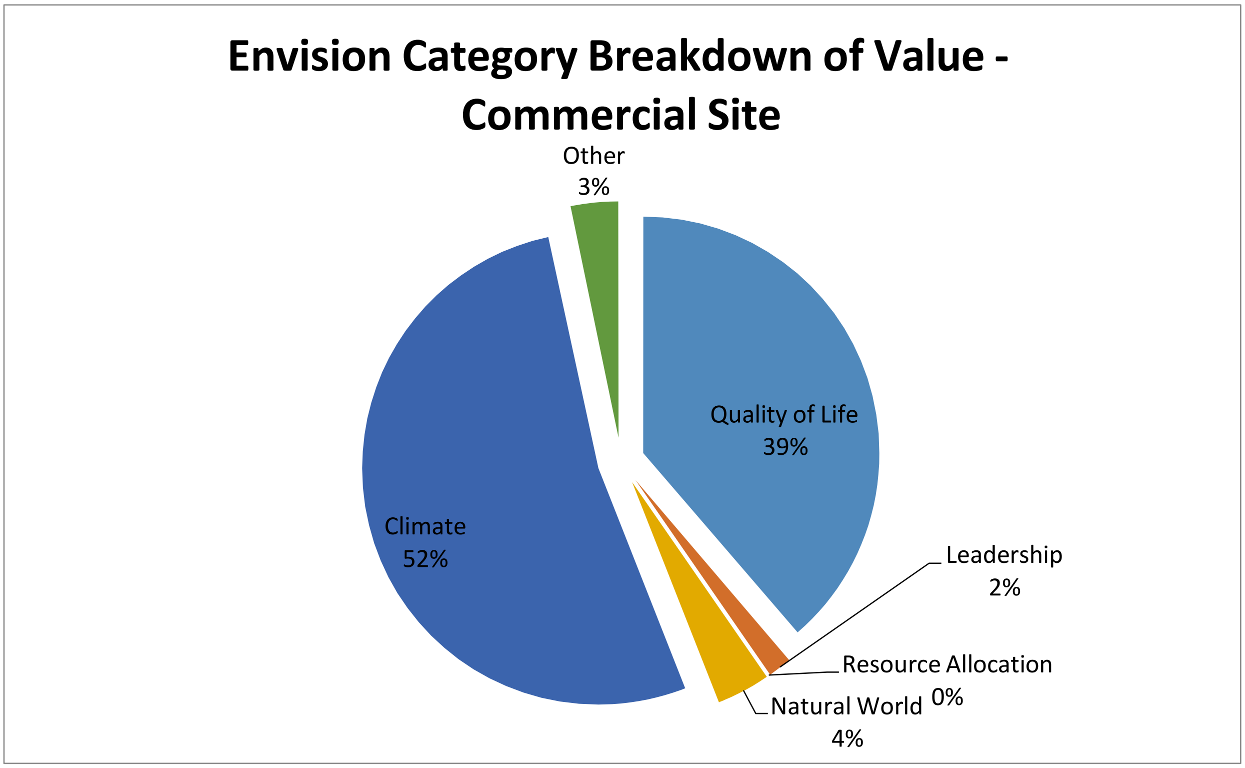


Figure 42 Envision Breakdown of Value - Commercial Site

The analysis on Silverbell Road found that Quality of Life remained the credit category realizing the highest value from the project, while the Climate and Natural World categories consisted of the majority of the remaining Envision value (Figure 43). This is in line with the results in Figure 41, as most of the value is attributed to increased pedestrian safety due to traffic calming (Quality of Life), reduced heat mortality (Quality of Life), reduced social cost of water (Natural World), and lower carbon and air pollution (Climate).

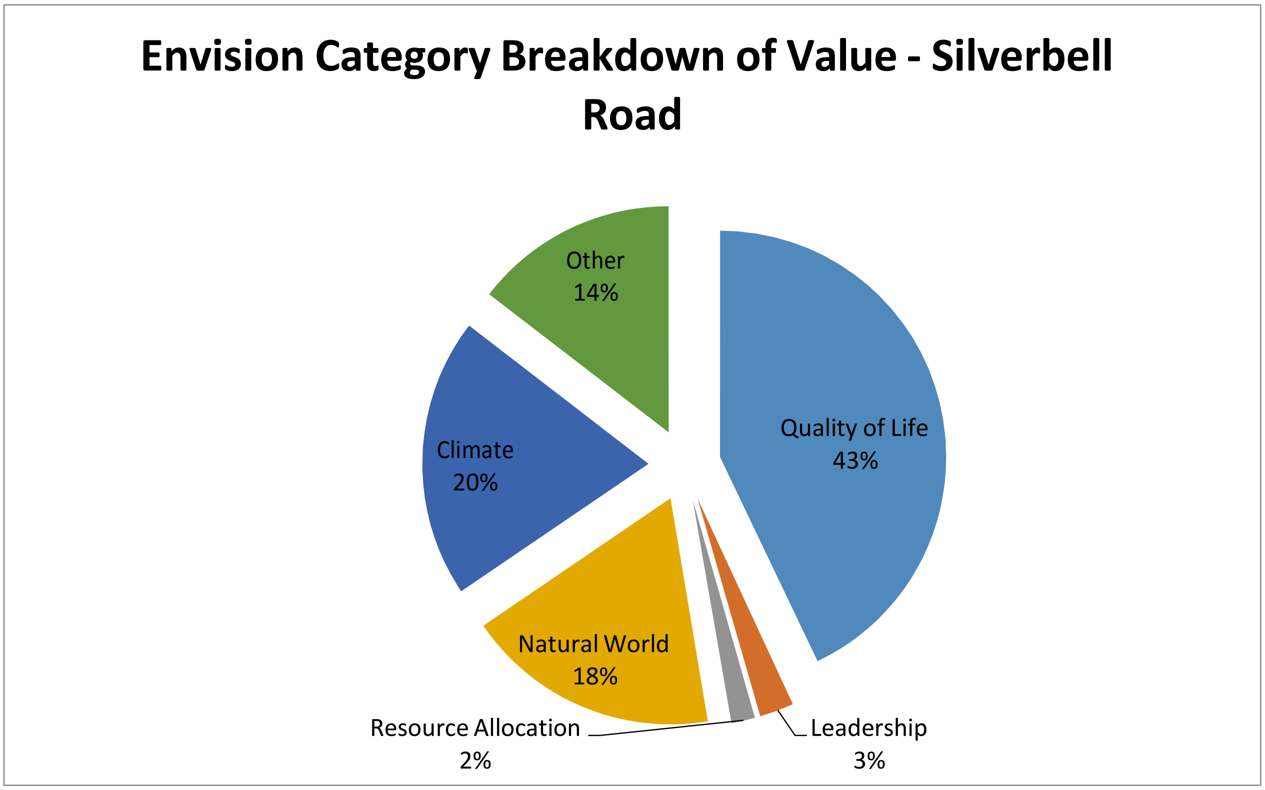


Figure 43 Envision Breakdown of Value - Silverbell Road

Findings and Recommendations

The Tucson region is a leader in advocating for and implementing green infrastructure or low impact development (GI/LID) features in stormwater management. Evaluation of the individual GI/LID features and the added elements at the two sites show that:

- GI/LID features are not equal in terms of their financial and sustainability benefits. Broader consideration of value, beyond capital and operating costs, to include flood risk, safety, heat island mitigation, property value, and environmental benefits allow for an objective comparison.
- Stormwater Harvesting Basins, Xeriscape Swales and Infiltration Trenches have > 50% probability of achieving a Sustainable Net Present Value (SNPV), which indicates the overall societal, environmental and economic benefits will exceed Net Present Value (NPV – i.e., only including direct costs and benefits such as capital expenditures, revenues, etc., and not including other costs and benefits such as air pollution, carbon emissions, water quality benefits, etc.).

- While Pervious Pavement had a negative SNPV, Concrete and Asphalt Paving have highly negative SNPV indicating that Pervious Pavement has a lower overall cost.
- In terms of sustainability metrics, GI/LID features, when combined into designs for a representative commercial site and a roadway re-design, are beneficial.
- Ignoring the multi-benefits if GI/LID features would mean making incorrect decisions. GI/LID features have a payback to governments, the environment, the economy and the community.

Recommendations:

- The City of Tucson, Pima County and PAG (the Tucson region) should continue to measure the full value of its GI/LID initiatives and use this information to make decisions.
- The Tucson region should consider the use of Envision^{TM} to communicate those benefits to outside stakeholders.

Appendix I: Individual GI/LID Practices

Water Harvesting Basins

Table 4 Summary Results - Water Harvesting Basin - Median Values (50th Percentile)

Net Present Value for 1,000 Sq. Ft of LID	
CapEx Cost	*-$132*
O&M Costs	*-$7*
Direct Financial NPV	***-$139***
Flood Risk Reduction	*$200*
Property Value Uplift	*$52*
Heat Mortality Risk Reduction	*$518*
Reduced CO_2 Emissions	*$0*
Reduced Air Pollution	*$0*
S-NPV	***$631***

Bio Retention Basin

Table 5 Summary Results -Bio Retention Basin - Median Values (50th Percentile)

Net Present Value for 1,000 Sq. Ft of LID	
CapEx Cost	*-$2,096*
O&M Costs	*-$377*
Direct Financial NPV	***-$2,473***
Flood Risk Reduction	*$169*
Property Value Uplift	*$49*
Heat Mortality Risk Reduction	*$515*
Reduced CO_2 Emissions	*$0*
Reduced Air Pollution	*$0*
S-NPV	***-$1,740***

Xeriscape Swale

Table 6 Summary Results - Xeriscape Swale - Median Values (50th Percentile)

Net Present Value for 1,000 Sq. Ft of LID	
CapEx Cost	*-$383*
O&M Costs	*-$173*
Direct Financial NPV	***-$556***
Flood Risk Reduction	*$159*
Property Value Uplift	*$51*
Heat Mortality Risk Reduction	*$512*
Reduced CO_2 Emissions	*$0*
Reduced Air Pollution	*$0*
S-NPV	***$166***

Cistern

Table 7 Summary Results - Cistern - Median Values (50th Percentile)

Net Present Value for a 350CF Cistern	
CapEx Cost	*-$2,685*
O&M Costs	*$0*
Other Benefits (irrigation)	*$188*
Direct Financial NPV	***-$2,497***
Flood Risk Reduction	*$95*
Property Value Uplift	*$0*
Heat Mortality Risk Reduction	*$0*
Reduced CO_2 Emissions	*$0*
Reduced Air Pollution	*$0*
S-NPV	***-$2,402***

Infiltration Trench

Table 8 Summary Results - Infiltration Trench - Median Values (50th Percentile)

Net Present Value for 1,000 Sq. Ft of LID	
CapEx Cost	*-$701*
O&M Costs	*-$167*
Direct Financial NPV	***-$868***
Flood Risk Reduction	*$200*
Property Value Uplift	*$50*
Heat Mortality Risk Reduction	*$515*
Reduced CO_2 Emissions	*$0*
Reduced Air Pollution	*$0*
S-NPV	***-$103***

Detention Basins (or Extended Detention Basins)

Table 9 Summary Results - Detention Basin - Median Values (50th Percentile)

Net Present Value for 1,000 Sq. Ft of LID	
CapEx Cost	*-$1,215*
O&M Costs	*-$194*
Direct Financial NPV	***-$1,409***
Flood Risk Reduction	*$234*
Property Value Uplift	*$50*
Heat Mortality Risk Reduction	*$514*
Reduced CO_2 Emissions	*$0*
Reduced Air Pollution	*$0*
S-NPV	***-$611***

Pervious Pavers

Table 10 Summary Results - Porous Pavers - Median Values (50th Percentile)

Net Present Value for 1,000 Sq. Ft of LID	
CapEx Cost	*-$2,496*
O&M Costs	*-$834*
Direct Financial NPV	***-$3,330***
Flood Risk Reduction	*$168*
Property Value Uplift	*$51*
Heat Mortality Risk Reduction	*$513*
Reduced CO_2 Emissions	*$0*
Reduced Air Pollution	*$0*
S-NPV	***-$2,598***

Curb Extensions

New and retrofit chicanes, medians, traffic circles and road diets with inlets to gather street water (see Appendix II for full calculations).

Table 11 Summary Results – Curb Extensions - Median Values (50th Percentile)

Traffic Calming - Roundabouts and Curb Extension	*$117,737*

Pavement

Table 12 Summary Results - Pavement - Median Values (50th Percentile)

Net Present Value for 1,000 Sq. Ft	
CapEx Cost	*-$10,817*
O&M Costs	*$0*
Direct Financial NPV	***-$10,817***
Flood Risk Reduction	*-$424*
Property Value Uplift	*$0*
Heat Mortality Risk Reduction	*$0*
Reduced CO_2 Emissions	*$0*
Reduced Air Pollution	*$0*
S-NPV	***-$11,241***

Concrete

Table 13 Summary Results – Concrete - Median Values (50th Percentile)

Net Present Value for 1,000 Sq. Ft	
CapEx Cost	*-$14,106*
O&M Costs	*$0*
Direct Financial NPV	***-$14,106***
Flood Risk Reduction	*-$379*
Property Value Uplift	*$0*
Heat Mortality Risk Reduction	*$0*
Reduced CO_2 Emissions	*-$1,346*
Reduced Air Pollution	*$0*
S-NPV	***-$15,831***
Assuming 1 foot deep = 1,000 cubic feet	
1 cubic foot = 150 lbs.	

Appendix II: Traffic Calming Assumptions and Calculations

Table 14 Traffic Calming Assumptions and Calculations

Crashes/injuries per 100 million Vehicle Miles Travelled (VMTs)	Pedestrian Crashes/ Injuries per 100 million VMTs	Pedal cycle Crashes/Injuries per 100 million VMTs	% of Category	Pedestrian Crashes/Injuries per 100 million VMTs	Pedal cycle Crashes/ Injuries per 100 million VMTs	Economic Cost	Product	Cost per VMT
Property damage only	*27.7*	*62.9*	*100%*	*27.7*	*62.9*	*$9,282*	*$841,423*	*$0.008*
Possible injuries	*226.0*	*293.0*	*55.52%*	*125.5*	*162.7*	*$13,056*	*$3,762,301*	*$0.038*
Non-incapacitating injuries			*35.52%*	*80.3*	*104.1*	*$23,154*	*$4,268,673*	*$0.043*
Incapacitating injuries			*8.96%*	*20.3*	*26.3*	*$71,910*	*$3,344,192*	*$0.033*
Fatalities	*21.9*	*3.0*	*100%*	*21.9*	*3.0*	*$1,448,400*	*$36,028,648*	*$0.360*

Source: http://www.azdot.gov/docs/default-source/mvd-services/12crashfacts.pdf?sfvrsn=2

TOTAL Cost per VMT: *$ 0.48*

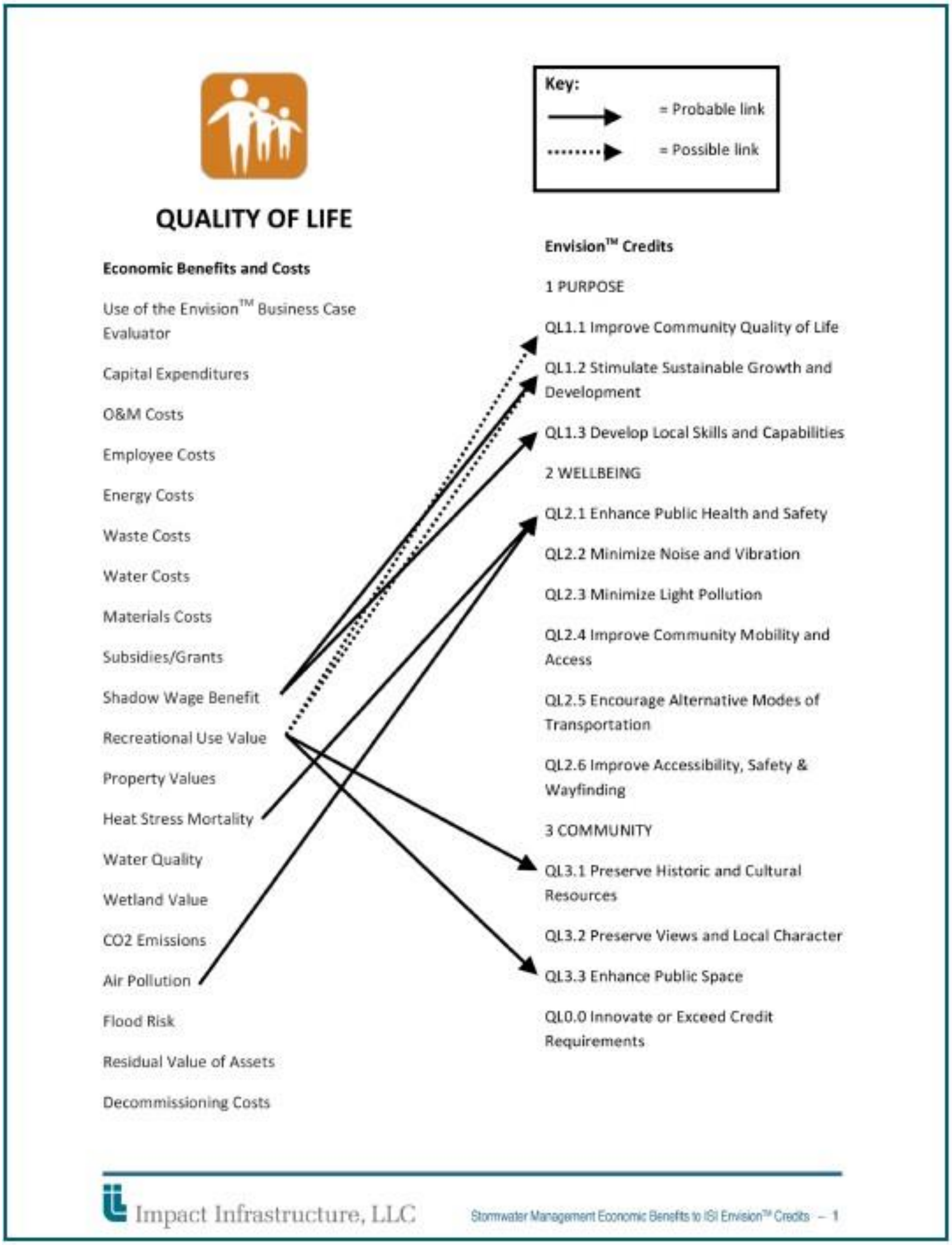
Assumptions			Total Distance with Mitigated Crash Risks (m)	Total Distance with Mitigated Crash Risks (miles)	Cars per Day*	Vehicle Miles Travelled VMTs in Risk-Mitigation Area/Day	Daily Value of Risk	Risk Mitigated (%) **	Risk Mitigated ($)
Roundabout	*5*	*m*	*10*	*0.00625*	*10000*	*62.5*	*$30.15*	*75%*	*$22.61*
Curb Extension	*5*	*m*	*5*	*0.003125*	*500*	*1.5625*	*$0.75*	*25%*	*$0.19*
							Total Daily Risk Mitigated		*$22.80*
							Total Annual Risk Mitigated		***$8,323.25***
							@ 6.5% real discount rate, NPV (40 yrs.):		**$117,736.69**

*Two-way daily traffic count- Source: http://www.pagnet.org/documents/rdc/gis/maptrafficcount2012.pdf

**Source: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1447993/pdf/0931456.pdf

Appendix III: Envision™ to AutoCASE™ Mapping

AutoCASE™ costs and benefits listed on the left were mapped to Envision™ credits, listed on the right.



QUALITY OF LIFE

Economic Benefits and Costs

Use of the Envision™ Business Case Evaluator

Capital Expenditures

O&M Costs

Employee Costs

Energy Costs

Waste Costs

Water Costs

Materials Costs

Subsidies/Grants

Shadow Wage Benefit

Recreational Use Value

Property Values

Heat Stress Mortality

Water Quality

Wetland Value

CO2 Emissions

Air Pollution

Flood Risk

Residual Value of Assets

Decommissioning Costs

Key:

→ = Probable link

⋯▶ = Possible link

Envision™ Credits

1 PURPOSE

QL1.1 Improve Community Quality of Life

QL1.2 Stimulate Sustainable Growth and Development

QL1.3 Develop Local Skills and Capabilities

2 WELLBEING

QL2.1 Enhance Public Health and Safety

QL2.2 Minimize Noise and Vibration

QL2.3 Minimize Light Pollution

QL2.4 Improve Community Mobility and Access

QL2.5 Encourage Alternative Modes of Transportation

QL2.6 Improve Accessibility, Safety & Wayfinding

3 COMMUNITY

QL3.1 Preserve Historic and Cultural Resources

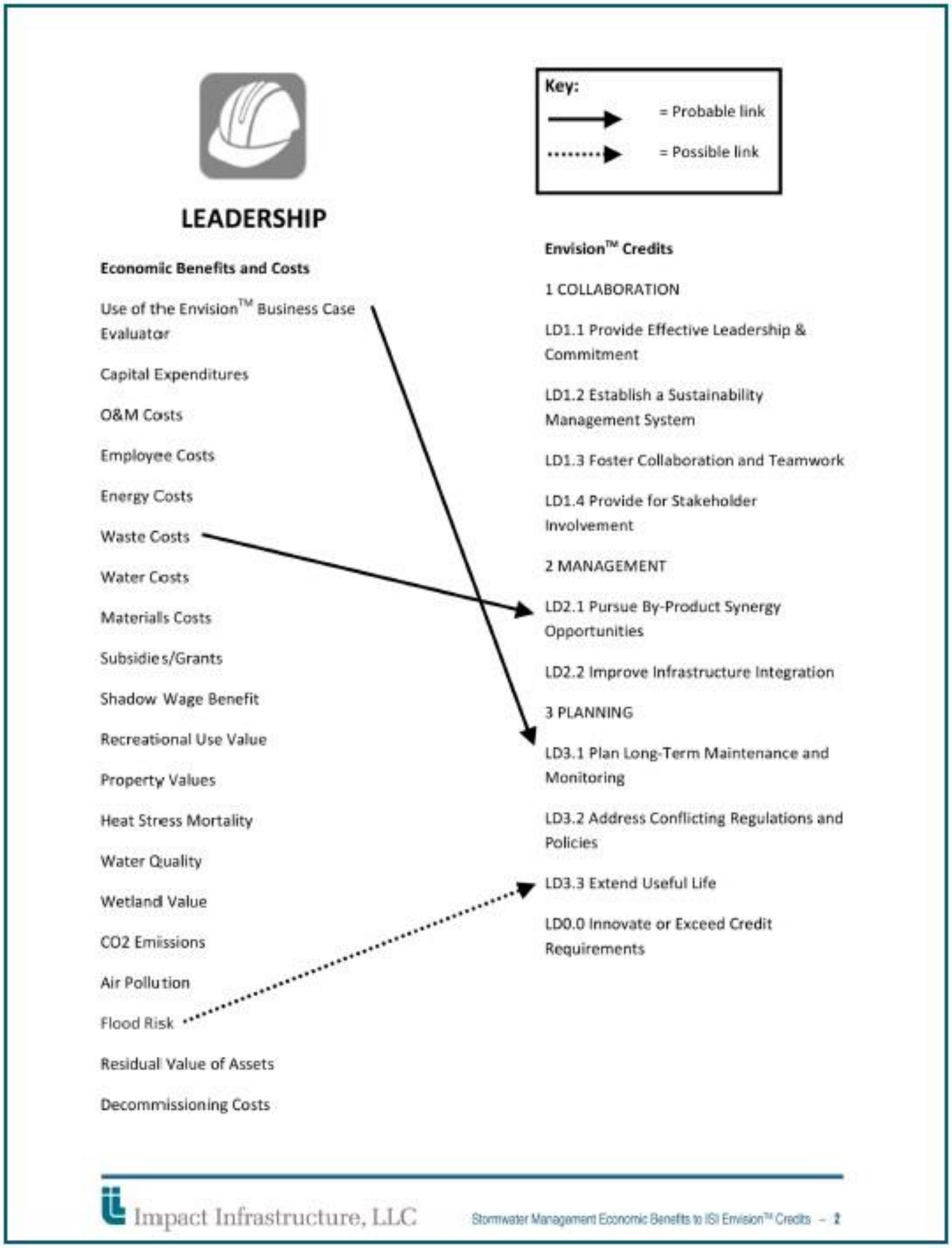
QL3.2 Preserve Views and Local Character

QL3.3 Enhance Public Space

QL0.0 Innovate or Exceed Credit Requirements

Impact Infrastructure, LLC

Stormwater Management Economic Benefits to ISI Envision™ Credits – 1



Key:
→ = Probable link
⋯▶ = Possible link

LEADERSHIP

Economic Benefits and Costs

Use of the Envision™ Business Case Evaluator

Capital Expenditures

O&M Costs

Employee Costs

Energy Costs

Waste Costs

Water Costs

Materials Costs

Subsidies/Grants

Shadow Wage Benefit

Recreational Use Value

Property Values

Heat Stress Mortality

Water Quality

Wetland Value

CO2 Emissions

Air Pollution

Flood Risk

Residual Value of Assets

Decommissioning Costs

Envision™ Credits

1 COLLABORATION

LD1.1 Provide Effective Leadership & Commitment

LD1.2 Establish a Sustainability Management System

LD1.3 Foster Collaboration and Teamwork

LD1.4 Provide for Stakeholder Involvement

2 MANAGEMENT

LD2.1 Pursue By-Product Synergy Opportunities

LD2.2 Improve Infrastructure Integration

3 PLANNING

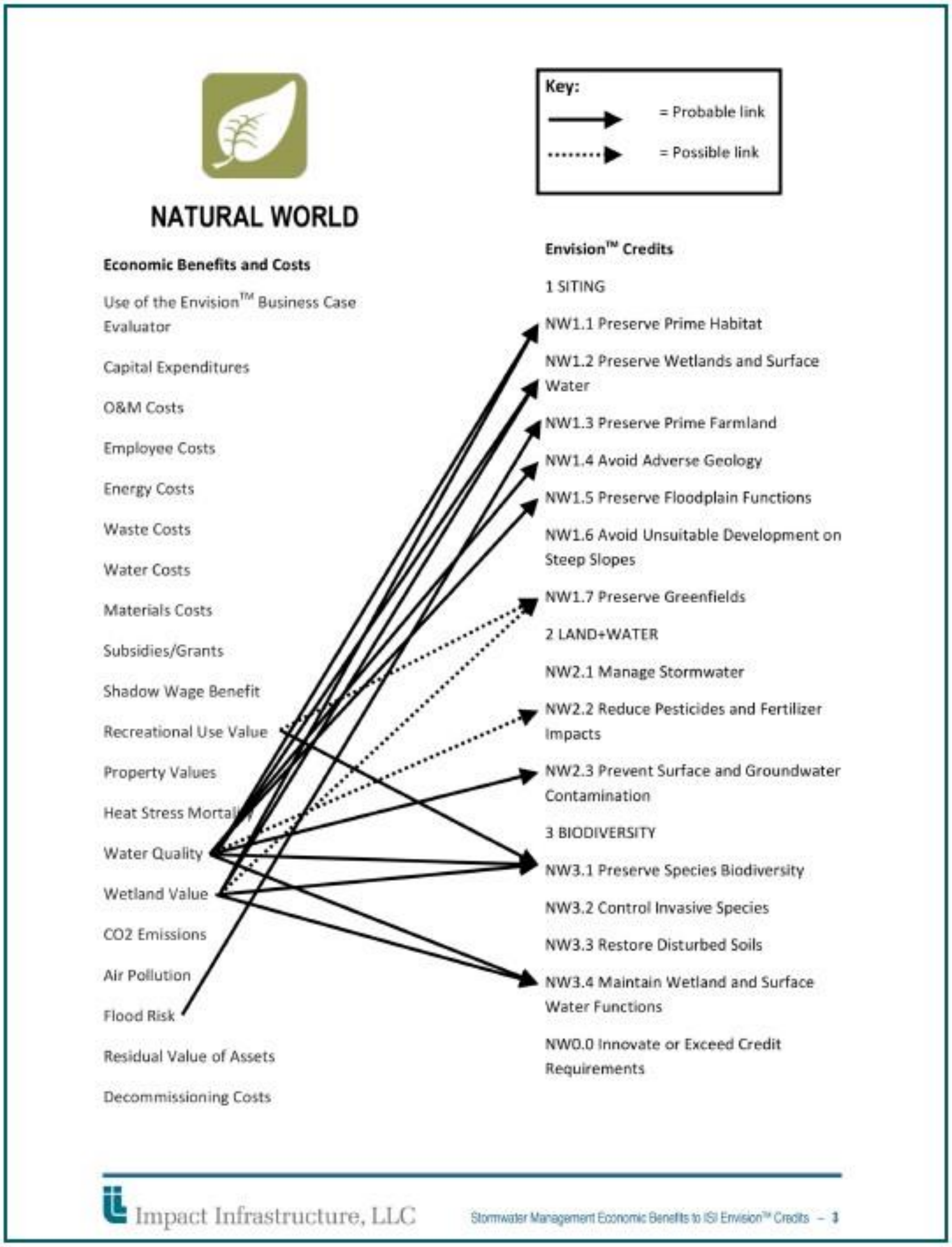
LD3.1 Plan Long-Term Maintenance and Monitoring

LD3.2 Address Conflicting Regulations and Policies

LD3.3 Extend Useful Life

LD0.0 Innovate or Exceed Credit Requirements

Impact Infrastructure, LLC   Stormwater Management Economic Benefits to ISI Envision™ Credits – 2



NATURAL WORLD

Key:
→ = Probable link
⋯▶ = Possible link

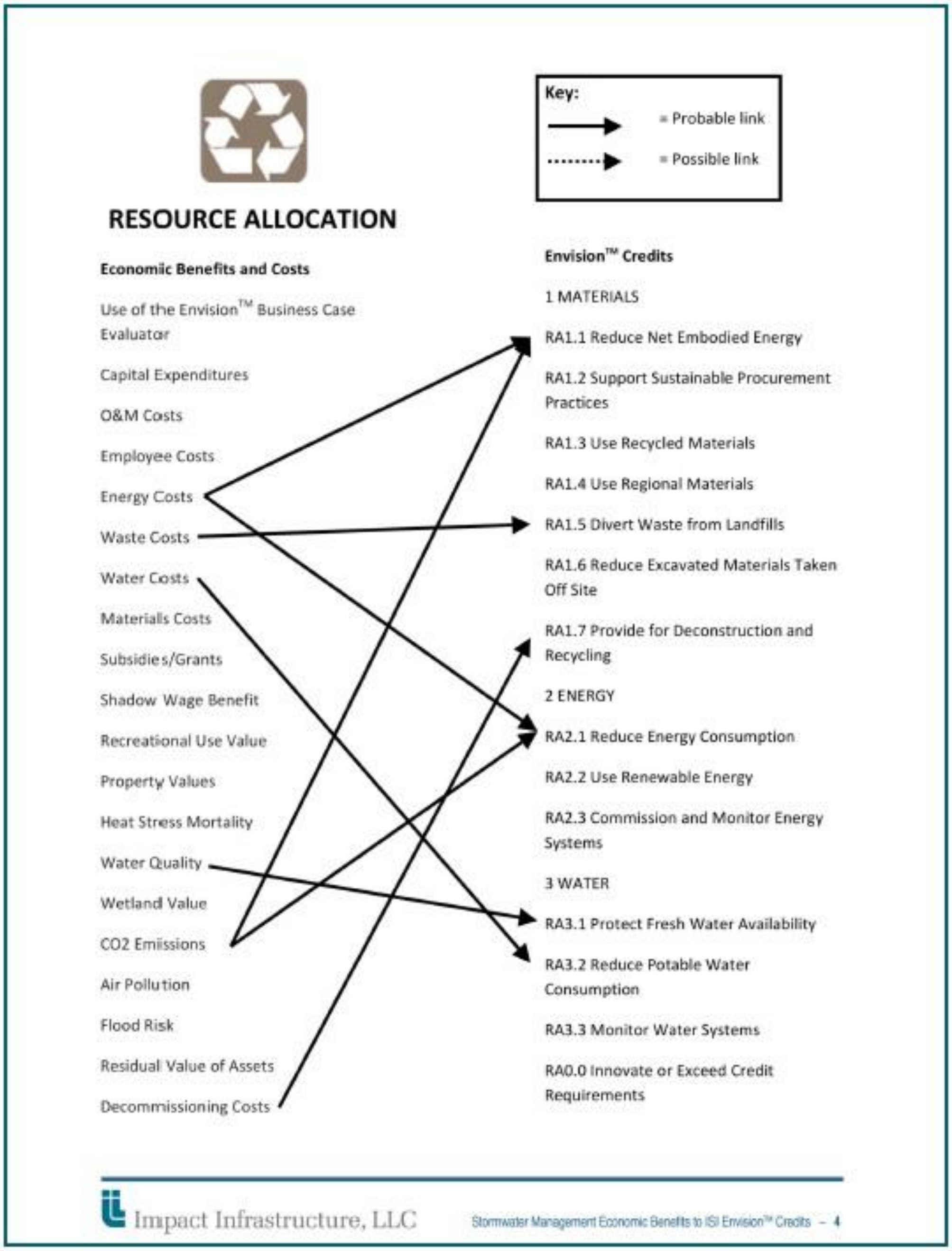
Economic Benefits and Costs

Use of the Envision™ Business Case Evaluator
Capital Expenditures
O&M Costs
Employee Costs
Energy Costs
Waste Costs
Water Costs
Materials Costs
Subsidies/Grants
Shadow Wage Benefit
Recreational Use Value
Property Values
Heat Stress Mortality
Water Quality
Wetland Value
CO2 Emissions
Air Pollution
Flood Risk
Residual Value of Assets
Decommissioning Costs

Envision™ Credits

1 SITING
NW1.1 Preserve Prime Habitat
NW1.2 Preserve Wetlands and Surface Water
NW1.3 Preserve Prime Farmland
NW1.4 Avoid Adverse Geology
NW1.5 Preserve Floodplain Functions
NW1.6 Avoid Unsuitable Development on Steep Slopes
NW1.7 Preserve Greenfields
2 LAND+WATER
NW2.1 Manage Stormwater
NW2.2 Reduce Pesticides and Fertilizer Impacts
NW2.3 Prevent Surface and Groundwater Contamination
3 BIODIVERSITY
NW3.1 Preserve Species Biodiversity
NW3.2 Control Invasive Species
NW3.3 Restore Disturbed Soils
NW3.4 Maintain Wetland and Surface Water Functions
NW0.0 Innovate or Exceed Credit Requirements

Impact Infrastructure, LLC   Stormwater Management Economic Benefits to ISI Envision™ Credits – 3



RESOURCE ALLOCATION

Key:
→ = Probable link
⋯▶ = Possible link

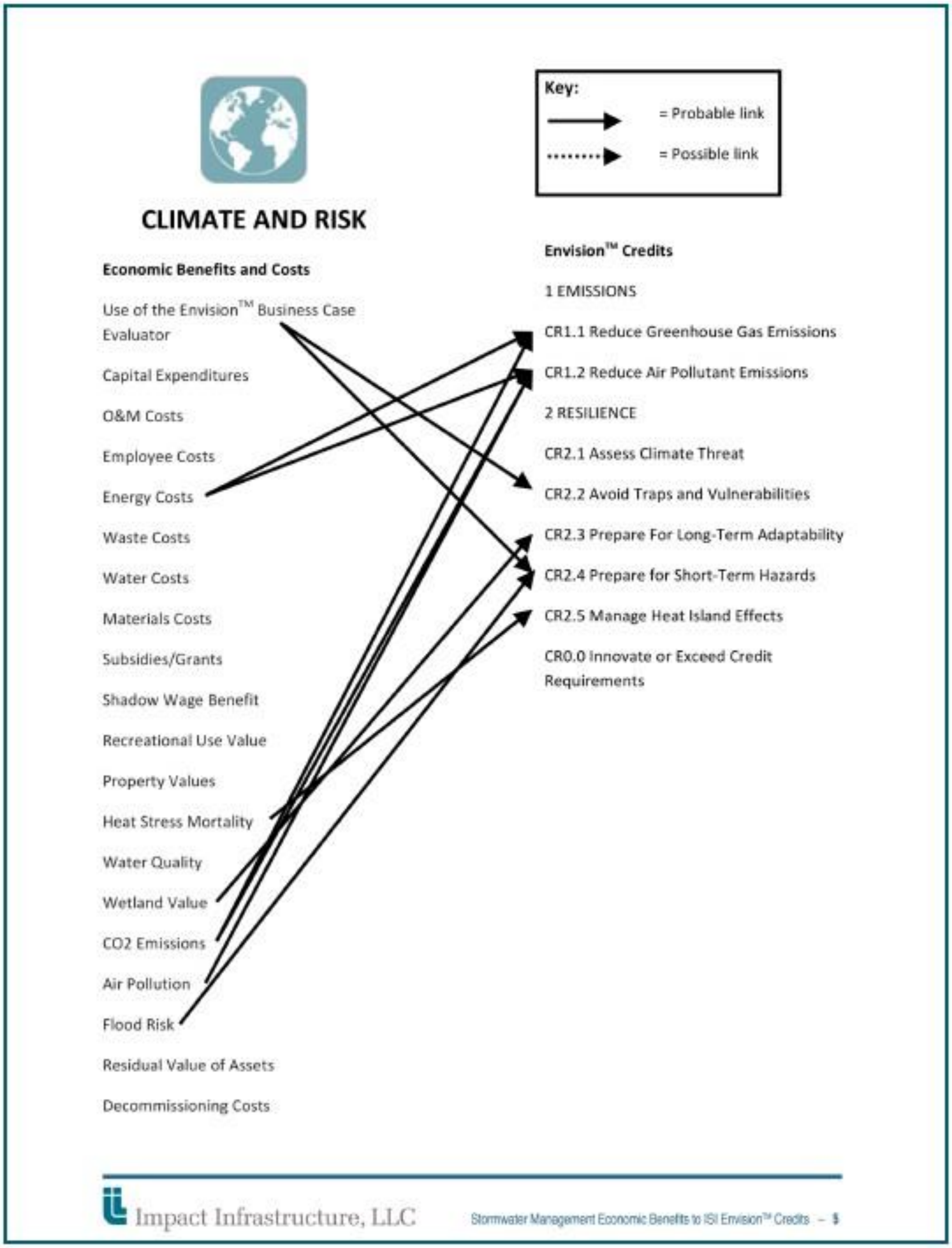
Economic Benefits and Costs

Use of the Envision™ Business Case Evaluator
Capital Expenditures
O&M Costs
Employee Costs
Energy Costs
Waste Costs
Water Costs
Materials Costs
Subsidies/Grants
Shadow Wage Benefit
Recreational Use Value
Property Values
Heat Stress Mortality
Water Quality
Wetland Value
CO2 Emissions
Air Pollution
Flood Risk
Residual Value of Assets
Decommissioning Costs

Envision™ Credits

1 MATERIALS
RA1.1 Reduce Net Embodied Energy
RA1.2 Support Sustainable Procurement Practices
RA1.3 Use Recycled Materials
RA1.4 Use Regional Materials
RA1.5 Divert Waste from Landfills
RA1.6 Reduce Excavated Materials Taken Off Site
RA1.7 Provide for Deconstruction and Recycling
2 ENERGY
RA2.1 Reduce Energy Consumption
RA2.2 Use Renewable Energy
RA2.3 Commission and Monitor Energy Systems
3 WATER
RA3.1 Protect Fresh Water Availability
RA3.2 Reduce Potable Water Consumption
RA3.3 Monitor Water Systems
RA0.0 Innovate or Exceed Credit Requirements

Impact Infrastructure, LLC   Stormwater Management Economic Benefits to ISI Envision™ Credits – 4



CLIMATE AND RISK

Key:
——▶ = Probable link
········▶ = Possible link

Economic Benefits and Costs

Use of the Envision™ Business Case Evaluator

Capital Expenditures

O&M Costs

Employee Costs

Energy Costs

Waste Costs

Water Costs

Materials Costs

Subsidies/Grants

Shadow Wage Benefit

Recreational Use Value

Property Values

Heat Stress Mortality

Water Quality

Wetland Value

CO2 Emissions

Air Pollution

Flood Risk

Residual Value of Assets

Decommissioning Costs

Envision™ Credits

1 EMISSIONS

CR1.1 Reduce Greenhouse Gas Emissions

CR1.2 Reduce Air Pollutant Emissions

2 RESILIENCE

CR2.1 Assess Climate Threat

CR2.2 Avoid Traps and Vulnerabilities

CR2.3 Prepare For Long-Term Adaptability

CR2.4 Prepare for Short-Term Hazards

CR2.5 Manage Heat Island Effects

CR0.0 Innovate or Exceed Credit Requirements

Impact Infrastructure, LLC Stormwater Management Economic Benefits to ISI Envision™ Credits – 5

Appendix IV: AutoCASE^{TM} Methodology

To make a sensible comparison between green infrastructure, or low impact development (LID), and traditional grey infrastructure, or pipe and water processing facilities, one needs a common metric. Engineering methods can often quantify the differences in gallons of water or kWh of electricity saved; economic methods help to put a price on these quantities so that a monetary equivalent value (price x quantity) can be used in the decision-making.

Engineers have at their disposal tools to calculate water and energy saved from sustainable design. Valuation in terms of the social costs (the damage or benefit to human health, buildings, crops, animals, and the environment) of the improvements is the missing link to value the benefits of sustainable projects.

Because the economics is often similar across projects, AutoCASE^{TM} has codified the economics and made it available to designers, engineers, and their project sponsors, public funding sources and the private investment community so that they can understand the full economic value of their projects. In this way, engineers have access to tools that help them design the project to yield optimal outcomes.

Envision^{TM} attempts to help the design process so that the project is done right from financial and sustainability perspectives. It also helps to make sure that the right project is done.
To compare the value and make decisions regarding the right project, one also needs to understand the risks associated with the choices. The methodology combines economic cost-benefit analyses with risk analysis so that risk adjusted values are calculated, allowing informed decision making.

Sometimes the services green infrastructure provides have no price that can be directly observed as the outcome of market transactions. Economics uses several methods to value these non-market externalities. The table below shows how the various benefits from wetlands creation can be valued.

Table 1. Examples of Valuation Techniques for Wetland Services

Benefit Type	**Valuation Method**
Habitat for commercial species	Market prices for commercial species and productivity per acre
Habitat for wildlife and visual/cultural benefits	Prices paid by government agencies to protect wetlands
Wetland conservation	Opportunity costs; i.e., benefits of wetland conversion
Amenity or aesthetic value	Hedonic property price model
Recreation value	Travel cost method; Participation model using

Benefit Type	Valuation Method
	unit-day values; Contingent valuation
Water purification	Reduced treatment costs by alternative methods
Non-use and option value	Contingent valuation

Table Source: Adapted from David W. Pearce and R. Kerry Turner. 1990. Economics of Natural Resources and the Environment. Baltimore: Johns Hopkins University Press. pp. 226-235.

While methodologies for valuation may not vary for similar projects, often the values themselves will vary by region of the country or by income or demographics of those affected. By using meta-analyses[16] that synthesize many studies, we hope to include the most important variations in these values so that if, for example, the social cost of water is high in the South West due to scarcity, this can be captured in the analysis.

As shown in the table above, **non-market valuation methods** are used to value things that people may never use:

- **Revealed preference methods**: Infer the value of a non-market good or service using other market transactions. For example, the price of a house may be used to determine the value of transit services. Hedonic pricing methods start from the premise that the price of a good is a function of the service's characteristics. A regression model then determines the contribution of each characteristic to the market price.

- **Stated preference methods**: Contingent valuation studies survey people on how much they are willing to pay to get access to a good or service or how much they would be willing to accept as compensation for a given harm or lack of access.

- **Market-based methods are** used to measure value from the perspective of what you would have spent had you taken another approach:

- **Avoided cost analysis**: This methodology looks at "the marginal cost of providing the equivalent service in **another way. For exa**mple, rainfall retention and infiltration can offset a water utility's cost to capture, transport, treat and return each additional gallon of runoff."[17] Rather than the avoided cost of not building facilities, it may be more appropriate to consider the converse, what the cost would be of damages be if the project does not go ahead.

Risk Analysis Approach

For each set of inputs, including most values used in the methodologies themselves, high, medium and low values are collected to reflect the range of uncertainty around the inputs. Default values for coefficients or assumptions in the methodologies are taken from current literature. Using the three points, distributions can be generated around each input (either the 95% confidence interval for a normal distribution, a beta distribution, or a triangular distribution. If the distribution type is not specified, it defaults to a beta distribution). When the Monte Carlo simulation is running, a random value from each of the inputs' distributions is

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[16] "a meta-analysis refers to methods focused on contrasting and combining results from different studies, in the hope of identifying patterns among study results, sources of disagreement among those results, or other interesting relationships that may come to light in the context of multiple studies." Meta-analysis from Wikipedia, the free encyclopedia - http://en.wikipedia.org/wiki/Meta-analysis

[17] The Value of Green Infrastructure - A Guide to Recognizing Its Economic, Environmental and Social Benefits, Center for Neighborhood Technology 2010, p. 14, downloaded from: http://www.cnt.org/repository/gi-values-guide.pdf January 22nd 2013. (referred to as CNT below)

selected and plugged into the model. A result is calculated and saved, and the process repeats itself. AutoCASE^{TM} runs 1000 iterations to produce a probability distribution of potential outcomes. These probability distributions are portrayed as the "S curves" shown throughout this report.

The AutoCASE^{TM} business case evaluator aims to, as much as possible:

- Be **a comprehensively exhaustive list of economic benefits (where data exists)**. Avoiding double counting and correctly defining the scope of the project and the benefits, costs and risks to be counted is crucial to ensuring that the calculation is credible.

- To avoid error in the ultimate estimation of the total economic value associated with a given project, it will be important to avoid the potential error associated with counting a benefit/credit associated with a given project more than once. We have tried to avoid the temptation to create a 'grab bag' of all possible benefits/credits associated with these projects. We have focused attention on those benefits/credits that are most readily monetized and where data is available. Economists often agonize over double counting and there are some rules of thumb that have emerged in cost benefit studies. For transit, for example, hedonic house price models that attempt to capture the benefit of access to transit that is embedded in houses prices might already be accounted for in travel time savings that are also counted as a benefit. In this case 50% of the property price increase is counted as incremental to the other benefits. The 50% rule has also been used in the Philadelphia stormwater management project evaluation.

- There is a need to provide a clear definition of the boundary for measuring the 'project impact' in order to consistently measure benefit/credits across categories. For instance, is the boundary of impact spatial or non-spatial? A clear understanding/method for estimating the project boundary will be needed. This will directly impact the inclusion/exclusion of project benefits/credits.

- Measure the **risk associated with the business case costs and benefits**.

- There are often many ways to measure the same benefit. Often, meta-analyses of benefits use studies that mix several techniques. In theory, willingness to pay (WTP) and willingness to accept (WTA) should give the same results but in experiments they have shown that measures of WTA greatly exceed measures of WTP. As meta-analyses have done, we average results over several methodologies (but also capturing the range that is produced from these methodologies too). For a particular benefit, one methodology for measurement and monetization may dominate and in another a range of methodologies may be used. The objective is to use the state of the art in measurement of these externalities. In this regard transparency trumps consistency of one particular method.

- Be a reference document that **documents the sustainable return of the infrastructure project**. The analysis is done relative to a reference case, which is equivalent to the status quo or a "do nothing" scenario. Often, refurbishment or increased operations and maintenance costs of an existing facility are required if a project does not go ahead. These expenditures should be included in the reference case. The evaluator also has the capacity for individual projects to be compared against each other, so that if a "do nothing" scenario is not a viable option, then results valuing different project options against each other may be obtained.

Each cost or benefit that is quantified in the AutoCASE^{TM} business case evaluator has been included because it:

- Is significant on a list of costs and benefits that aims to be comprehensively exhaustive when describing the impacts of GI/LID projects
- Has substantial literature surrounding its quantification so that reliable and consistent values can be obtained, even as the model is applied across different geographical regions.

A full list of the costs and benefits that are evaluated in the AutoCASE^{TM} app are shown in the table below:

Cost or Benefit Type	Valuation Method
Revenues	Direct revenue impacts
Capital Expenditures	Direct capital expenditure costs
Operations and Maintenance Costs (O&M)	Direct projected O&M costs
Employee Costs	Direct employee costs
Energy Costs	Direct energy costs
Waste Costs	Direct waste disposal costs
Water Costs	Direct water costs
Materials Costs	Direct materials costs
Subsidies	One-time and recurring subsidies obtained
Shadow Wage Benefit	Shadow wage conversion factor incorporating projected construction wages and wages of employees during operation, local unemployment rate, and local tax rates
Recreational Use Value	Willingness-to-pay per use x new user days per year
Property Value Benefit	Increase in local green acreage, implied

Cost or Benefit Type	Valuation Method
	property uplift percentage, average value of local homes, and number of local homes affected
Reduced Heat Stress Mortality Benefit	Increased green acreage, reduced local temperatures during excessive heat events, implied reduction in local mortality rates, leading to total lives saved and total value of lives saved
Water Quality and Habitat Enhancement	Meta-analytical function used to estimate willingness-to-pay for improvements in local bodies of water
Wetland Enhancement	Meta-analytical function used to estimate value per acre of wetlands created or restored, incorporating wetland type and functions into the estimation
CO_2 Emissions	Includes a reduction in carbon emissions due to decreased energy usage, as well as the effects of carbon sequestration as a result of increased planted vegetation
Air Pollution	Includes a reduction in air pollutants due to decreased energy usage, as well as the effects of air pollutant sequestration as a result of increased planted vegetation

Appendix V: Envision™ Ration System in the Tucson Region

AutoCASE™, Business Case Evaluator, and Envision™

The Institute for Sustainable Infrastructure's (ISI's) Envision™ Rating System shows the benefits of green infrastructure in holistic terms through a standard indicating how new horizontal infrastructure should be planned, designed, and built to incorporate sustainable and resilient designs.

The Envision™ system was developed in partnership between the ISI and the Harvard University Graduate school of Design. The ISI is a non-profit association of the American Society of Civil Engineers (ASCE), the American Council of Engineering Companies (ACEC) and the American Public Works Association (APWA). Envision™ is similar in some ways to LEED™ for buildings, although it is designed to consider the entire lifecycle of projects at a systems level within its' points-based ratings system. As a relatively new system, Envision™ plans to become the industry standard for sustainable rating systems in the infrastructure space. Simultaneously, leaders in the ISI have recognized the need for business case analysis as a partnering tool with Envision's™ points-based system which is now being more substantively addressed through its' Business Case Evaluator (BCE) and AutoCASE™.

The Envision™ system evaluates projects in 5 categories:

1. Quality of life
2. Leadership
3. Resources Allocation
4. Natural World
5. Climate and Risk

The levels of achievement in each category/subcategory range from Improved (i.e. slightly above industry standard) through Superior to Restorative (i.e. net positive impact). This recognizes that minimizing the negative impact of a project is beneficial, but reversing a trend to have the project make positive impacts is even better. Projects that receive certification through Envision™ can achieve different levels based on performance but perhaps more significantly Envision™ is intended as a tool to support planning and design processes by presenting:

- A transparent framework to compare options and make defensible choices;
- Guidance on best practices that are currently being used by owners and designers;
- Envision™ certification that can provide validation of claims of 'green' performance and associated reputational benefits; and
- An opportunity for owners to display innovation and leadership that will gain national recognition.

In order to accomplish these objectives Envision™ launched its points-based framework in 2012 but also needed to develop a companion economic tool that can be used to quantitatively assess the comparative costs and benefits of different design alternatives, for all dimensions of a project (i.e. economic, social, environmental). This is the role served by the closely related BCE and AutoCASE™.

Implementing the Envision Rating System in The Tucson Region

The work to develop the GI/LID Guidance Manual has occurred in the broader context of sustainability commitments and planning for Pima county and the City of Tucson. Tucson, Pima County and PAG have a well-established history of advancing sustainability values within local and regional policies and planning. This is nicely summarized by a statement from the Climate Change Committee of the City of Tucson contained within Plan Tucson (2013), the City's most recent general and sustainability plan: "A modern sustainability vision for Tucson is to be the world's leader and source of innovation for more efficient, more prosperous, and healthier desert living." Following voter ratification of Plan Tucson, the Office of Integrated Planning (OIP) was formed in November 2013 which updated and integrated the previous "Framework for Advancing Sustainability (2008)" throughout.

The Sonoran Desert Conservation Plan established sustainability principles that guide land use policies and infrastructure investments to direct sustainable growth and development. The Plan also provides infrastructure sustainability strategies and measurable implementation objectives. The Sustainable Action Plan for County Operations (2008) was intended to be "an adaptive plan that will be responsive to new ideas, technologies, partnerships, and shifts in available resources, with the goal of every new adaptation taking us down an even better and more sustainable path." Among its' features the plan includes goals, principles and an action plan for a number of infrastructure aspects including Water Conservation and Management, Waste Reduction, and Renewable Energy.

In 2010, both the City of Tucson Mayor and Council and the Pima County Board of Supervisors adopted the Phase 2 Water Study Report pursuant to the City/County Water and Wastewater Infrastructure, Supply and Planning Study (2008) which nicely encapsulated the region's perspective on sustainable infrastructure: "To achieve sustainability goals, changes to the existing infrastructure must begin by improving the efficiency and flexibility of the existing built environment, including roads, parks, public services water, wastewater and stormwater systems. In addition to considering the location and form of growth, integrated planning also needs to consider the efficient allocation, distribution and use of all available water resources including stormwater, effluent, reclaimed and potable water."

With these policies and commitments in mind, it is appropriate to consider the possible use of the Envision™ framework and rating system, described earlier in this document, to assess Local GI/LID practices. Beyond this, deploying Envision™ in the context of stormwater GI/LID could serve as a pioneering pilot sector from which to evaluate its' applicability across the spectrum of Tucson and Pima County infrastructure systems.

Without repeating the earlier general description of Envision™, there are a number of prospective uses and benefits to incorporating the framework into both stormwater GI/LID evaluations and planning. These elements are equally relevant to all civil infrastructure and perhaps most important to applying a consistent and transparent methodology to planning, design, options analysis, stakeholder engagement and defensible decision-making across an integrated infrastructure program.

Overall, Envision™ was developed to assist planners, engineers and ultimately project proponents, owners and stakeholders to understand and evaluate design options and make defensible choices through application of a simple, transparent and cost effective methodology. With this overarching intention, Envision™ intends to support an evolution from conventional design and efficiency of discreet projects to projects that meet rigorous performance expectations in accord with triple bottom line (economic, environmental and socio-cultural) objectives:

- durability;
- lifecycle efficiency and costing;
- whole system design;
- adaptive and resilient infrastructure components and integrated systems;
- close consideration of community needs, stakeholder engagement and broad partnerships;
- sustainable return on investment;
- affordability of operations and maintenance; and
- optimization of short and long range community benefits

The Envision™ framework accomplishes these objectives through reference to 55 assessment objectives (plus innovation objectives) across five overarching Credits (themes) – Quality of Life (Purpose, Community and Wellbeing), Leadership (Collaboration, Management and Planning), Resource Allocation (Materials, Energy and Water), Natural World (Siting, Land & Water and Biodiversity), and Climate (Emissions and Resilience). Each Credit is documented to include its intent, various levels of potential achievement, explanations on how to advance to higher achievement levels, criteria and documentation, sources and interrelationship with related Credits.

Envision™ is transparent to owners, design teams, community groups, environmentalists, constructors, regulators and policy makers. As a result it offers a mechanism for all of these stakeholders to discuss community priorities in civil infrastructure projects and the two pivotal related questions - “Are we doing the right project?" and “Are we doing the project right?" Use of Envision™, in either its full format assisted by a trained Envision™ Sustainability Professional (ENVSP), or by undertaking a preliminary assessment through application of the abbreviated Envision™ Checklist format provides the basis to:

- identify and understand options and tradeoffs
- engage stakeholders transparently - build public confidence

- consider sustainable implications in an organized fashion
- design to the Envision™ Framework

By incorporating the Envision™ Business Case Evaluator and/or the AutoCASE™ web-based analytic engine into the analysis it is now easily possible to meld the sustainability performance indicators of Envision™ (qualitative or quantitative) with sophisticated and flexible quantitative risk-based cost benefit analyses. Such analyses generate logical, defensible performance options, and ultimately a compelling case for optimization of sustainable infrastructure systems. Finally, the Envision™ framework, when applied either during planning or subsequently during construction or operations, presents a verifiable case for sustainable design and performance evaluation that is eligible for review by ISI and if deemed acceptable, for Envision™ Certification and Award (in four recognized levels). Such award would validate and recognize Tucson and/or Pima County for its leadership in sustainability and justify 'green' claims and commitments, with all attendant reputational benefits.

In the context of the current project, the AutoCASE™ business case analysis was applied to the GI/LID case examples. Since AutoCASE™ is mapped and synchronized to the Envision™ framework it has been easily possible to chart and produce risk-adjusted, dollar-based metrics for these infrastructure projects based on their costs, benefits, and sustainable design features. Although the scope of the project has not encompassed a formal Envision™ evaluation, the data and tools are now substantially in place to do so for one or both of the two beta test sites. Perhaps more importantly, the experience and foundation is now in place to apply Envision™ and AutoCASE™ as integrated tools on other and future Tucson or Pima County stormwater initiatives. It should be pointed out that Envision™ includes a specific Credit category (NW2.1) on Stormwater Management that is focused on LID measures (for which the GI/LID Manual will be an exceptional resource and source of validation and documentation). But greater value can be realized by application of the full suite of Envision™ Credits that are pertinent to the planning, design and sustainable performance of this and other infrastructure categories.

As stated earlier, Envision™ and the accompanying business case analysis takes a broad perspective that is relevant to all civil infrastructure both individually and as a set of interrelated systems. They look at the value to the community, government, and the environment providing the ammunition to make the case that these investments pay back in more than cash terms and the benefits have value to stakeholders and the community at large. In this way Envision™ is designed to do more than simply rate and rank projects in the built environment. It is designed as a template for planning, designing and constructing projects that contribute to the reduction of our environmental footprint while not diminishing our overall quality of life. At the same time, it helps engineers and other practitioners take into account the changes in operating conditions in ways that ensure the project will perform as specified over the entire design life. As such, Envision™ helps to create a new breed of sustainability public works staff and engineer/designers, people who have good knowledge of what it takes to design a project that truly contributes to sustainability and the ability to present these projects to decision makers and citizenry in logical, defensible fashion.

That these analyses can be integrated into well-established planning and procurement methods and accomplished at modest cost is rapidly contributing to the adoption of Envision™ across North America including jurisdictions such as New York City, Dallas, Milwaukee, Los Angeles County and Long Beach. Tucson and Pima County have taken this another step forward, having positioned themselves as pioneers in the application of AutoCASE™ as the further significant component of these evaluative processes. Therefore they are in a particularly advantageous position to establish clear leadership in the emergence of sensible sustainable infrastructure renewal that integrates sustainable and business case performance. A more complete discussion of the potential for this application with regard to stormwater GI/LID and/or infrastructure systems generally can be easily arranged.

Appendix VI: Annotated Bibliography

1.	University of Washington - Can Roadside Trees Screen Houses from Pollution?, November 21, 2013 • Pollution Reduction by Trees
2.	BelGard Hardscapes - Using Permeable Pavers in Northern Climates, December 23, 2013 • Total Suspended Solids (TSS) is removed through filtration as the stormwater passes through the aggregate layers.
3.	Interlocking Concrete Pavement Institute (ICPI) , Fact Sheet • Pollutant removal efficiencies percentages • In lieu of detention/retention ponds
4.	BelGard Hardscapes - Sustainable & Permeable Pavement Systems, 2011 • Improved water quality • Pollutant removal • Contributing to Leed Credits
5.	NYC Department of Transportation - The Economic Benefits of Sustainable Streets, 2012 • Very interesting before and after.
6.	ECONorthwest - The Economics of Low-Impact Development, November 2007 • LID Enhancements; Cost & Benefits; Cost Savings Attributed to Installing LID Stormwater Controls.
7.	American Rivers - Growing Green: How Green Infrastructure Can Improve Community Livability & Public Health, June 2012 • Urban Heat Island Effect • Green Space, Green Roof
8.	Effectiveness of Traffic Calming Countermeasures, 1998
9.	ENTRIX Inc. - City Of Portland's Green Infrastructure: Quantifying the Health, Energy, and Community Livability Benefits, February 16, 2010 • Summary of Benefits – Excellent!
10.	Institute for Sustainable Communities - Case Study: Philadelphia, PA Weathering the Storms, 2012 • Increased flooding risk due to urbanization; Reconnection to the watershed through Stormwater Management using GI Methods.
11.	Institute for Sustainable Communities - Promising Practices in Adaptive Urban Water Management, A Resource Guide for Local Leaders, Snapshot: Arizona, Case Study: Phoenix, AZ Taking the Heat, 2013 • Urban Heat Island effect (UHI) use cool roofs, shade tree programs

12.	City of Tucson - Downtown Comprehensive Street Tree Plan, May 2011 • Ex. Tree Summary, Tree Species & Characteristics; Water Use & Location, Tree Canopy Assessment, Air Pollution Removal, Ecosystem Service Values
13.	City of Tucson - Tucson, AZ, Urban Forest Effects and Values: Major Streets and Routes, Dec. 2010 • Ex. Tree Summary, Tree Species & Characteristics; Water Use & Location, Tree Canopy Assessment, Air Pollution Removal, Ecosystem Service Values.
14.	People for Bikes and Alliance for Biking and Walking - Protected Bike Lanes Mean Business, 2012
15.	DeepRoot - Practitioner's Checklist for Silva Cells Planting Factors (where to place Silva Cells)
16.	Environmental Science & Technology - Roadside Tree vs Indoor Concentrations of Traffic Derived Particulate Matter (PM), November 11, 2013
17.	EPA - The Economic Benefits of Green Infrastructure: A Case Study of Lancaster, PA , February 2014
18.	American Society of Civil Engineers - Bridging the Gap Between Climate Change Science and Civil Engineering Practice, August 30, 2013 • Incorporating Client Change Science into Engineering Practice • Water Resources – warming climate increases magnitude and frequency of floods and droughts which presents a challenge to traditional design and planning methods
19.	University of Arizona - Correlating vegetation, water use, and surface temperature in a semiarid city: A Multiscale Analysis of the Impacts of Irrigation by Single-Family Residences, 2012 • Urban Heat Islands (UHI) • Vegetation and water dynamics in Tucson Arizona • Very informative
20.	Interlocking Concrete Pavement Institute (ICPI) - Morton Arboretum PICP Parking Lot, A Case study, 2011 • Parking lot project using permeable interlocking concrete pavement
21.	ICPI - Permeable Interlocking Concrete Pavement, 2011 • A comparison guide
22.	BelGard Hardscapes – Case Study No.14, Paving Stones, 2013
23.	BelGard Hardscapes - Using permeable pavers in northern climates, December 23, 2013 • Common questions answered
24.	PCRFCD & Watershed Management Group - A Prototype Analysis for Determining the Stormwater Retention and Water Supply Benefits of Cisterns, Abstract • Retain rainwater so that water supply needs can be met with harvested rainwater
25.	Stantec Consulting Services - Green BMP Research Data, 2013 • Comparative costs; whole life costs
26.	Desert Southwest Community Tree Guide: Benefits, Costs, and Strategic Planting, July 2004 • Costs versus Benefits

27.	ENTRIX, Inc. - Portland's Green Infrastructure: Quantifying the Health, Energy, and Community Livability Benefits, February 16, 2010 • Grey to Green BMPs • Energy and Greenhouse Gases (savings benefits) • Community Benefits (benefits tables)
28.	Environmental Science & Technology - Impact of Roadside Tree Lines on Indoor Concentrations of Traffic-Derived Particular Matter (PM) – Abstract, 2013 • PM concentrations were measured within 8 homes before and after trees lined the street
29.	ECONorthwest - The Economics of Low-Impact Development: A Literature Review, November 2007 • Costs versus Economic Benefits • Limited information exists on the life-cycle costs, the economic benefits of LID beyond stormwater control and the economic impacts of installing LID in urban-redevelopment settings • Ecosystem services enhanced by LID • Tables of runoff storage comparison of LID versus conventional methods
30.	PCRFCD - Modeling Runoff Reduction from On-site Storage Design at the Lot Scale, May 2009 • Specific model developed to calculate the reduction in runoff from the water harvesting basin design relative to post-development conditions
31.	Tucson Water & PCRFCD - Water Use by Single-Family Residences in the Tucson Water Service Area in 2009 & 2010, April 2012
32.	City of Tucson & PCRFCD - City/County Stormwater Management Technical Paper, May 12, 2009
33.	Elsevier - Landscape and Urban Planning, February 2014 • Urban Heat Island – good information
34.	SFPUC - San Francisco Rainwater Harvesting, October 11, 2008
35.	PCRFCD & City of Tucson - Appendix A, Pima County and City of Tucson Stormwater Regulations, 2013
36.	NYC Department of Transportation - Press Releases, December 13, 2013 • The economic benefits of sustainable streets
37.	Sprinkle Consulting - The Influence of Lane Widths on Safety and Capacity: A Summary of the latest Findings
38.	Hartmut H. Topp - Traffic safety, usability and streetscape effects of new design principles for major roads, January 1990
39.	Center for Urban Horticulture, University of Washington - The Calming Effect of Green: Roadside Landscape and Driver Stress, August 2000
40.	Journal of Arboriculture, Kathleen L. Wolf - Freeway Roadside Management: The Urban Forest Beyond the White Line, May 2003

41.	Center for Urban Horticulture, University of Washington - The Freeway Roadside Environment: Testing Visual Quality at the Road Edge, August 2000
42.	University of Washington College of Forest Resources - Trees, Parking and Green Law: Legal Tools and Strategies for Sustainability (fact sheet), March 2004
43.	University of Washington College of Forest Resources - Trees, Parking and Green Law: Legal Tools and Strategies for Sustainability (report), February 2004 • Heat Island Effects • Vegetation Cooling Effects
44.	Arizona's Next Century: A Strategic Vision for Water Supply Sustainability, January 2014
45.	Tony Davis - Arizona's drinking water needs will force trade-offs, February 23, 2014
46.	Elsevier - Landscape improvement impacts on roadside safety in Texas, September 2005 • Relationship between landscaping and driver safety
47.	Road Directorate Ministry of Transport, Denmark - Beautiful Roads, 2002 • Road Architecture
48.	Oregon State University & University of Washington - Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response, May 7, 2007 • Climate and Heat Island Effects
49.	Landscape Architecture Magazine - The Intersection of Trees and Safety, May 2008
50.	URS & Forester University - Successful Green Infrastructure Program Drivers
51.	Arborist News, Kathleen L. Wolf - Roadside Urban Trees, Balancing Safety and Community Values, December 2006
52.	Wolf & Bratton - Urban Trees and Traffic Safety: Considering U.S. Roadside Policy and Crash Data, 2006
53.	Kathleen L. Wolf - Large Infrastructure & Urban Context, review of human-scale perception & response, 2006
54.	Eric Dunbar, Georgia Institute of Technology - Safe Streets, Livable Streets, 2005
55.	Mok, Landphair, & Naderi - Comparison of Safety Performance of Urban Streets Before and After Landscape Improvements April 30, 2003
56.	Oregon State University - Pedestrian Safety Impacts of Curb Extensions: A Case Study, July 2005 • While the intended purpose of curb extensions is for traffic calming; they may benefit pedestrian crossers
57.	Bratton & Wolf - Trees and Roadside Safety in US Urban Settings, 2005 • Improvement of roadway function while maintaining high levels of safety • Statistical modeling
58.	University of Washington College of Forest Resources - Trees in Urban Streetscapes: Research on Traffic Safety and Crash Risk, January 2005 • Environmental benefits: stormwater reduction, reduced urban heat island effects, lower levels of air pollution

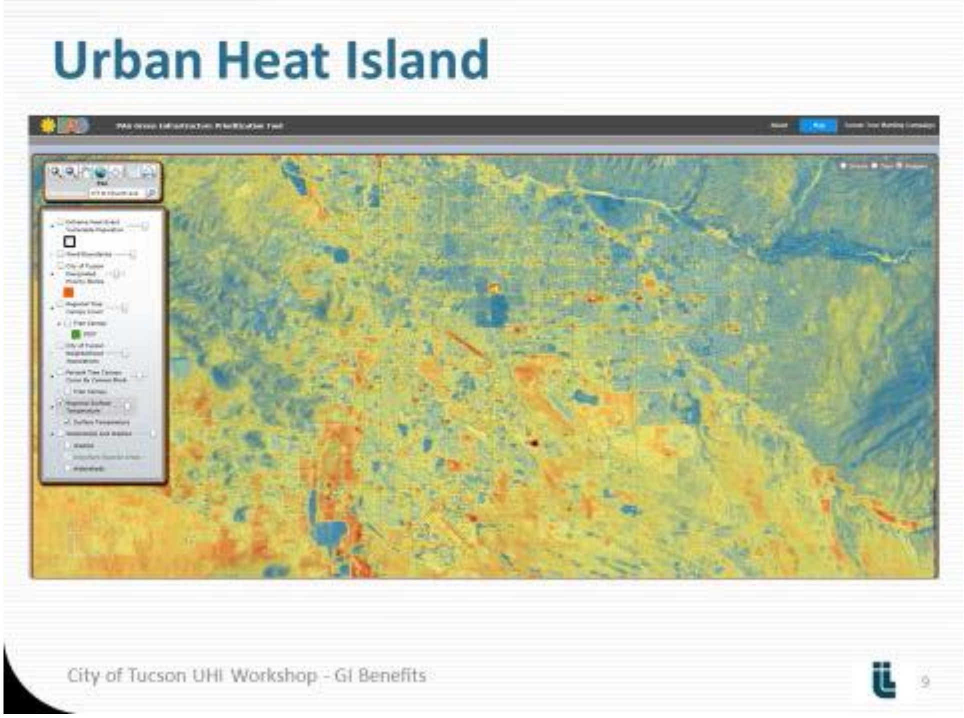
59.	University of California Transportation Center - The Effects of Transportation Corridors' Roadside Design Features on User Behavior and Safety, and their Contribution to Health, Environmental Quality, and Community Economic Vitality: A literature Review, November, 2008
60.	Washington State Department of Transportation - Evaluation of Long-Term Pavement Performance and Noise Characteristics of the Next Generation Concrete Surface: Final Report, January 2014
61	University of Arizona Water Resources Research Center - Tucson Conserve to Enhance (C2E) Evaluation Report, August 2013 • Unique local program to motivate water customers to conserve water by link their conservation efforts with local and regional environmental enhancement projects

Appendix VII: Heat Island Benefit Calculation

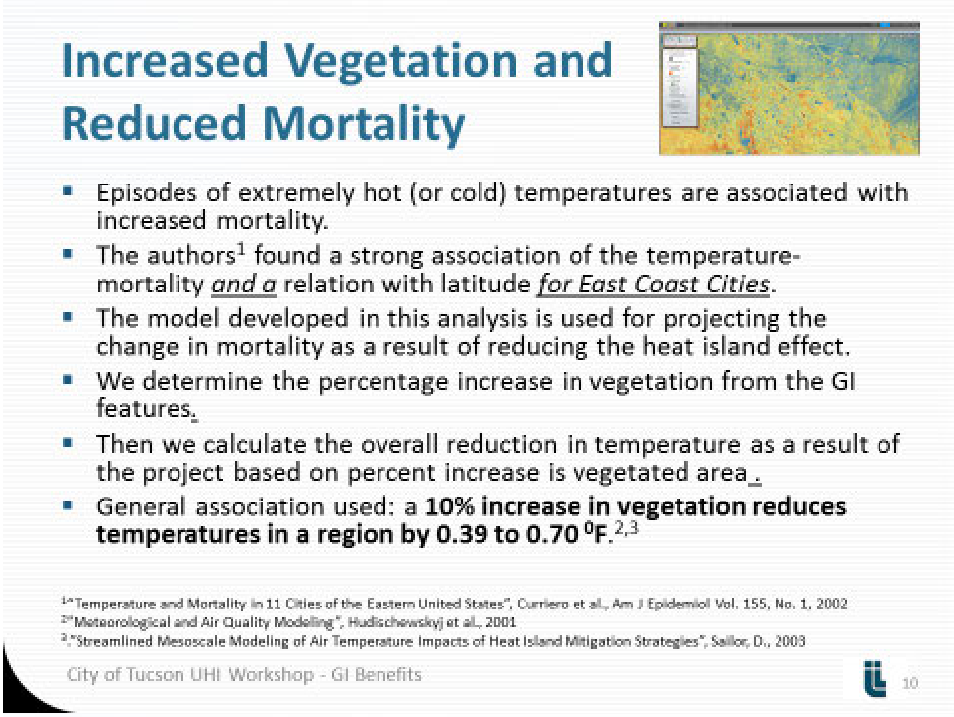
The following slides, taken from a presentation given by John Wise of Stantec to the 9th Annual Urban Heat Island Workshop on May 8th 2014. The full presentation is available from http://impactinfrastructurellc.com/blog/?p=663.

Benefit Calculation - Example

URBAN HEAT ISLAND AND MORTALITY



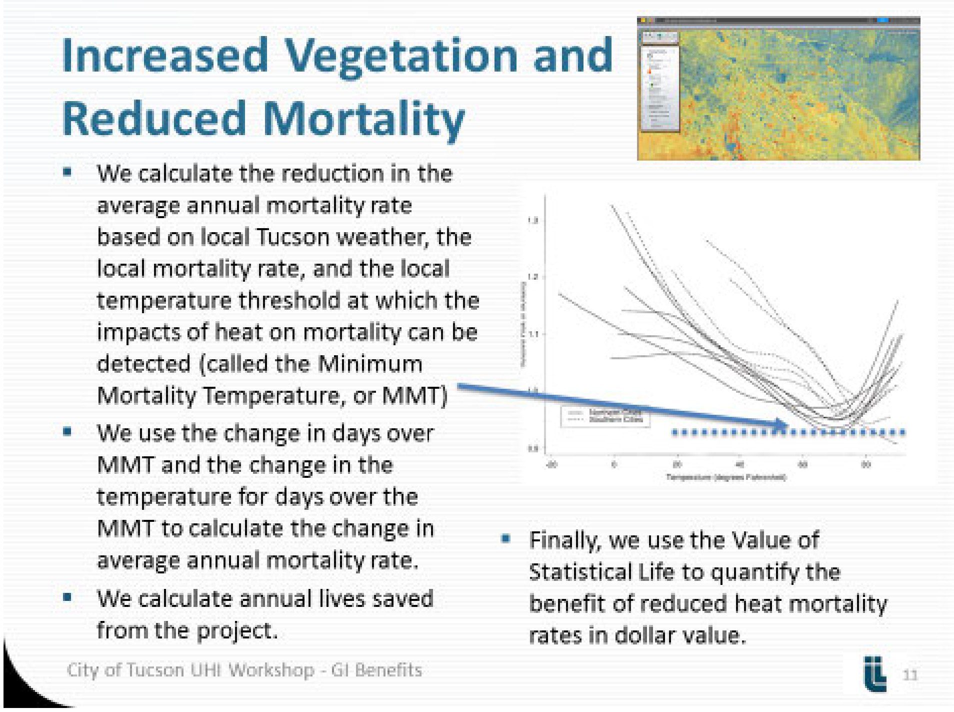
Urban Heat Island



Increased Vegetation and Reduced Mortality

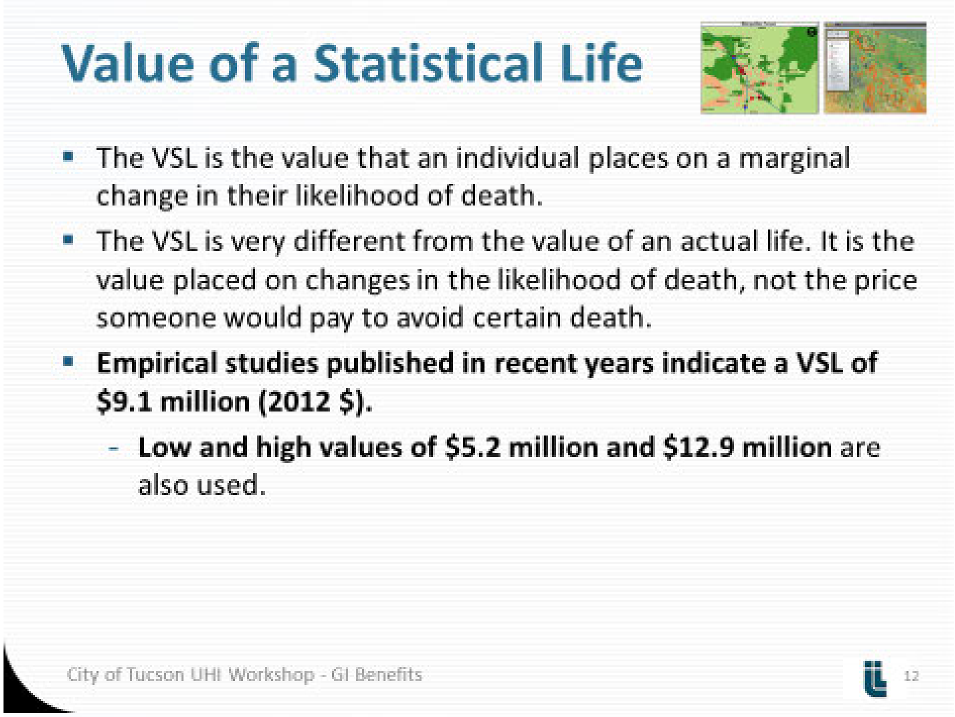
- Episodes of extremely hot (or cold) temperatures are associated with increased mortality.
- The authors[1] found a strong association of the temperature-mortality *and a* relation with latitude *for East Coast Cities*.
- The model developed in this analysis is used for projecting the change in mortality as a result of reducing the heat island effect.
- We determine the percentage increase in vegetation from the GI features.
- Then we calculate the overall reduction in temperature as a result of the project based on percent increase is vegetated area .
- General association used: a **10% increase in vegetation reduces temperatures in a region by 0.39 to 0.70 ^{0}F.**[2,3]

[1] "Temperature and Mortality in 11 Cities of the Eastern United States", Curriero et al., Am J Epidemiol Vol. 155, No. 1, 2002
[2] "Meteorological and Air Quality Modeling", Hudischewskyj et al., 2001
[3] ."Streamlined Mesoscale Modeling of Air Temperature Impacts of Heat Island Mitigation Strategies", Sailor, D., 2003



Increased Vegetation and Reduced Mortality

- We calculate the reduction in the average annual mortality rate based on local Tucson weather, the local mortality rate, and the local temperature threshold at which the impacts of heat on mortality can be detected (called the Minimum Mortality Temperature, or MMT)
- We use the change in days over MMT and the change in the temperature for days over the MMT to calculate the change in average annual mortality rate.
- We calculate annual lives saved from the project.
- Finally, we use the Value of Statistical Life to quantify the benefit of reduced heat mortality rates in dollar value.

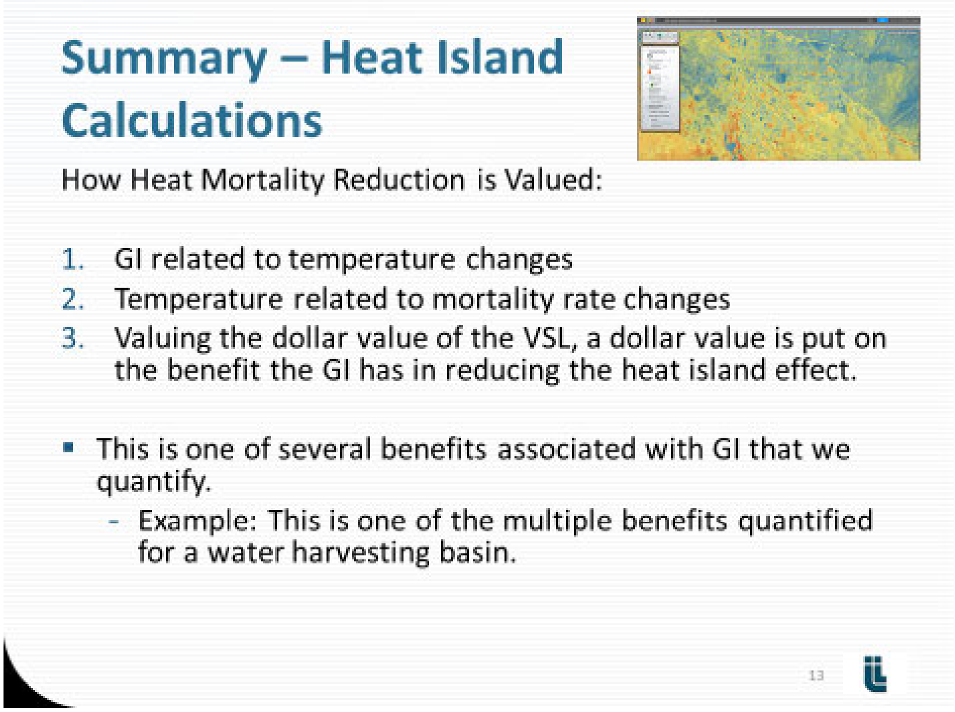


Value of a Statistical Life

- The VSL is the value that an individual places on a marginal change in their likelihood of death.
- The VSL is very different from the value of an actual life. It is the value placed on changes in the likelihood of death, not the price someone would pay to avoid certain death.
- **Empirical studies published in recent years indicate a VSL of $9.1 million (2012 $).**
  - **Low and high values of $5.2 million and $12.9 million** are also used.

City of Tucson UHI Workshop - GI Benefits

12



Summary – Heat Island Calculations

How Heat Mortality Reduction is Valued:

1. GI related to temperature changes
2. Temperature related to mortality rate changes
3. Valuing the dollar value of the VSL, a dollar value is put on the benefit the GI has in reducing the heat island effect.

- This is one of several benefits associated with GI that we quantify.
  - Example: This is one of the multiple benefits quantified for a water harvesting basin.

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Use of the Value of Statistical Life (VSL) Approach for Valuing Heat Mortality Risk

To the extent possible, Impact Infrastructure (II LLC) has followed EPA guidance for valuation of risk in AutoCASE. The EPA itself has not opined on the appropriateness of valuing the reduced risk associated with lower temperatures that come from using GI/LID. However, recent guidance indicates that Value of a Statistical Life (VSL) is the preferred methodology for valuing similar risk. According to the EPA, VSL is: "..how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by environmental pollution."
http://yosemite.epa.gov/ee/epa/eed.nsf/pages/MortalityRiskValuation.html

In their *Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants* (June 2014 http://www.epa.gov/ttn/ecas/regdata/RIAs/111dproposalRIAfinal0602.pdf), EPA reported the opinion from the Science Advisory Board Environmental Economics Advisory Committee for calculating estimates of the mortality risk benefits of their regulation air pollution health co-benefits of their proposed carbon regulation (i.e. the economic value of reductions in ambient concentrations of air pollution that lower the risk of future adverse health effects by a small amount for a large population). They stated that the VSL approach "..provides the most reasonable single estimate of an individual's willingness to trade off money for reductions in mortality risk. The VSL approach is a summary measure for the value of small changes in mortality risk experienced by a large number of people. " (quote from http://www.epa.gov/ttn/ecas/regdata/RIAs/111dproposalRIAfinal0602.pdf with the reference given is to: http://yosemite.epa.gov/sab%5CSABPRODUCT.NSF/0/34D7008FAD7FA8AD8525750400712AEB/$File/White+Paper+(Dec.+2010).pdf).

Impact Infrastructure has presented the valuation of heat mortality risk methodology to the EPA and had follow-up discussions with a couple of economists at the National Center for Environmental Economics in the US Environmental Protection Agency. These economists told II LLC that the method used in the AutoCASE model, while not endorsed, will be listed as a resource on the EPA website for people to evaluate GI/LID features. In our opinion, the EPA uses the same approach as II LLC for valuation of changes in risks that may cause deaths (see below) and they certainly do identify that GI/LID can reduce the risks of deaths (http://www.epa.gov/heatislands/impacts/index.htm, http://www.epa.gov/heatisland/resources/pdf/BasicsCompendium.pdf and http://www.epa.gov/heatisland/about/pdf/EHEguide_final.pdf) .

II LLC has determined that the approach EPA has used to assess acceptable levels of contaminant clean-up solutions for Superfund cannot be easily adapted to heat mortality valuation in AutoCASE. This 'Minimum Acceptable Risk' approach sets performance objectives, so all clean up solutions for a Superfund site meet a combined mortality risk of one death in one million from ingestion, inhalation, dermal contact etc.. This approach would require us to define a minimum or acceptable reduction in heat mortality risk for stormwater infrastructure. In essence the value of this acceptable reduction is a policy decision, and there are currently no national standards for heat mortality that would allow us to pursue valuation using this approach.

Tucson and Pima could mandate an acceptable risk for heat mortality, which would then eliminate the valuation of how much people are willing to pay for reduced heat mortality from the AutoCASE assessment. However II LLC's intent is to make the decision-making process easier so that trade-offs and subjective weights (e.g. one in a million risk) do not have to be applied to trade off one risk with another. If the region regulated minimum mortality risk reductions the difference in benefits between competing technologies would be zero and they would be evaluated on their costs and other benefit categories. The AutoCASE methodology and data would stay the same but mortality benefit would be zero.

While there may be situations where EPA continues to use this Minimum Acceptable Risk approach, their guidelines for Cost-Benefit Analysis (http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/guidelines.html) and in particular Appendix B on Mortality Risk Valuation Reductions (http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0568-22.pdf/$file/EE-0568-22.pdf) published in 2010 suggest they have adopted the VSL approach (and expecting to continue to use it although they are looking at refining it to communicate the concept more effectively).

It is important to recognize that VSL is way to recognize a societal rather than an individual benefit. VSL is " the willingness to pay for small risk reductions across large numbers of people, but it has led to confusion because many have interpreted it as referring to the loss of identified lives" (http://www.sra.org/sites/default/files/u32/EPA-SAB_2011-VSL_Review.pdf). Therefore, our study does not place a dollar value on individual lives. Rather, when conducting a benefit-cost analysis of GI/LID practices we use estimates of how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by the heat island effect (see for example http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/mortalityriskvaluation.html). It may be more appropriate to replace the "heat island mortality benefit" term with "value of mortality risk" (proposed but not yet adopted by the EPA - "guidance on mortality risk valuation is a multi-step process ...this may take some time to complete") or a term like "value of risk reduction" to better "communicate the notion that value is derived from reducing risks rather than the risks themselves" (http://www.sra.org/sites/default/files/u32/EPA-SAB_2011-VSL_Review.pdf).

A complicating factor is that people may value heat related mortality risk mitigation differently than traffic accident risk, cancer risk or some other risk. Context-specific and aged-related risk is something that, while an area for research, the EPA has not endorsed.

Mortality rates could be included in benefit calculations such as flood risk reduction as well. However, AutoCASE does not currently use mortality rates as a factor in flood risk because the most common and best documented risk from flooding is property damage rather than mortality. The costs associated with flood risk are derived from historical property damage costs (both residential and commercial) due to flood events over a 50 year period, broken down by state. To be completely thorough, AutoCASE should also be counting mortality rates associated with flood events, as well as impacts on the environment and economic activity. For most costs and benefits, II LLC took the approach of quantifying the most commonly, best documented, and quantified aspect of a cost and benefit. We used mortality rates and the VSL in the heat mortality benefit and traffic calming benefits as the most immediate, documented, and defensible benefit.

PLANT LIST

Low Impact Development / Green Infrastructure

The following pages contain a collection of plants that are most suited to the hot dry conditions of the desert southwest. Many other plants imported from all over the world can survive here, but they often require diligent attention as well as unreasonable amounts of water. The purpose of the Low Impact Development and Green Infrastructure Guidance Manual is to learn to live within the available resources of our desert southwest climate. Our most precious resource is water; therefore plants that require the least are the most preferred.

Although many of the plants listed here can survive on minimal water, or endure drought conditions, typically they will look better and bloom more profusely with a rainy year. When there is a year of abundant rainfall, these plants will look their best. If the year leans toward a drier average rainfall, then the supplemental water that LID Planning and Structural Practices provide may be the difference between the plant's survival and its demise.

The survival capabilities of these plants are dependent on many conditions: prevailing winds, sun exposure, soil type and quality, duration of extreme cold or heat, adjacent surfaces or structures, etc.. One plant may not do well in cold seasons, but when placed against a west or south facing wall, it will perform year-round. Another plant may like wet conditions, but if the soil doesn't drain well, and the wet condition lasts too long, that plant may not survive. Sometimes a simple adjustment to a current condition will permit the plant to thrive in your landscape.

Although some native plants look good or are evergreen year round, many plants in this region have a dormant season. For some plants, looking poorly doesn't last too long and occurs during the heat of the summer; for others it falls in the chill of winter. Once the dormancy is over, the plant may need to be cut back to prepare for the growth season.

Before selecting specific plants, evaluate your site's conditions. Use the references provided to get further details and compatibility for the unique conditions of your site. Talk to local nurseries that have a history of providing plants that work in harmony with our local conditions.

GI/ LID
RECOMMENDED PLANTS

		Plant Type						Water Usage once Established				Special Use/Restrictions	Benefits				
BOTANICAL NAME	COMMON NAME	Tree	Shrub	Succulent	Forb/ Herb	Vine	Grass	None	Minimal	Moderate	Drought Resistant	NOTES	Wildlife Plant	Native Pollinators	Songbirds/ Native Birds	Cover	Medicinal or Food
Abutilon palmeri	Indian Mallow		X					X	X		X	full sun, 2,000-4,500', survives extreme drought once established; butterfly larval lost, attracts bees, to 6' tall, reflected heat	X				
Acacia angustissima	Prairie Acacia		X		X				X	X		sun/partial shade, 2,000-6,000'; butterfly larval source, attracts bees, attractive clumping shrub	X	X	X	X	
Acacia constricta	White Thorn Acacia											See Vachella constricta					
Acacia greggii	Catclaw Acacia	X	X		X			X	X		X	prefers washes; full sun, 2,000-5,000'; hardy plant, butterfly larval plant, great pollinator nectar source; traditional medicinal and food source	X	X	X	X	X
Acourtia wrightii	Brownfoot				X			X	X			partial shade, 2,000-4,500', typically found along washes under native trees; pink flowers bloom January to June, attract butterflies		X			
Agave deserti simplex	Desert Agave			X				X			X	full sun, 2,500-4,000'; good choice for residential, 1-3 feet at maturity; Tight rosette	X	X	X		
Agave murpheyi	Murphey's Agave			X					X	X		sun/partial shade, 1,500-3,000', matures faster and blooms earlier than other agaves, produces bulbils; traditional Native American food/fiber plant; Pinal and Maricopa County native, deer resistant	X	X	X		X
Agave palmeri	Palmer Agave			X				X				sun/partial shade, 3,000-6,000'; pollinator plant, esp. bats, hummingbirds; flower attracts birds; signals end of plant's life		X	X		
Agave toumeyana	Toumey Agave			X				X				sun, 2,000-5,000', clumping, forming colonies to 6-10 ft in time; Maricopa and Pinal County native; attracts hummingbirds	X	X			
Aloysia gratissima	Fragrant Bee Bush		X					X			X	sun/partial shade, 3,500-5,500'; Santa Cruz county native; extremely drought tolerant once established, cold hardy, fragrant flowers, great nectar plant, attracts small butterflies and goldfinches	X	X	X	X	
Aloysia wrightii	Origanillo		X					X				sun/partial shade, 2;500-5,000'; fragrant foliage, great nectar source for pollinators, attracts small butterflies and goldfinches	X	X	X	X	
Ambrosia deltoidea	Triangle leaf bursage		X					X	X			prefers full sun, 1,000-3,000'; hardy once established, stabilizes soil, nurse plant for young cacti	X				
Amoreuxia palmatifida	Desert Sunrise				X				X	X		sun/partial shade, 3,500-5,500'; large orange/red flowers, tuberous perennial; traditional food source, entire plant is edible					X
Amorpha fruticosa	False Indigo		X						X	X		sun/partial shade, 3,000-6,000', typically found along streams and canyons; dark purple/orange flowers; butterfly larval source, nectar for butterflies and bees	X	X		X	
Anemone tuberosa	Desert Anemone				X			X	X			sun/partial shade, 2,600-8,200', spring blooming perennial wildflower, well-drained soils; may be hard to find	X				
Anisacanthus thurberi	Desert Honeysuckle		X						X			sun/partial shade, 2,500-5,500', typically found along washes; hummingbird pollinated, butterfly larval source	X	X	X	X	
Aristida purpurea	Purple Threeawn						X		X		X	full sun, 1,000-5,000', well-drained soil; re-seeds quickly; flower spikes have beautiful purple hue			X	X	
Aristolochia watsonii	Desert Pipevine					X			X			partial shade, 2,000-5,000', foliage has purplish color; larval source for Pipevine Swallowtail Butterfly	X	X	X		
Asclepias linaria	Pineleaf Milkweed				X					X		sun/partial shade, 3,000-5,600', well-drained soils; inflated fruits, dense shrub; attracts bees, Monarchs, Queen butterfly larval source		X			
Asclepias subulata	Desert Milkweed				X			X			X	full sun, 0-2,500', hardy evergreen, well-drained soils; poisonous, used for many ailments; butterfly nectar source and host for Queens and Monarchs, attracts aphids	X	X			X
Atriplex canescens	Four-wing saltbush		X					X			X	full sun, 2,000-8,000', hardy evergreen shrub; valuable pollinator plant, provides good cover and nesting sites	X		X	X	
Baileya multiradiata	Desert Marigold				X			X	X		X	full sun, 2,000-5,000'; short-lived perennial, prolific re-seeder; attracts butterflies	X	X	X	X	
Bebbia juncea	Sweetbush		X					X	X		X	sun/partial shade, 2,000-5,000', well-drained soils, hardy; flowers have a sweet scent that attracts butterflies and other insects, butterfly larval source	X	X	X	X	
Berberis haematocarpa	Red barberry		X					X	X			sun/partial shade, 3,000-5,000', drought tolerant hardy evergreen; fragrant yellow flowers in spring followed by red berries favored by birds; traditional medicinal and food source	X	X	X	X	X
Brickellia californica	California bricklebush		X					X	X			sun/partial shade, typically found along washes, 2,000-6,000'; medicinal uses			X	X	X
Bouteloua curtipendula	Sideoats grama						X	X				full sun, 300-8,200', warm season perennial bunchgrass; important forage for grazers, butterfly larval source	X	X	X	X	
Bouvardia glaberrima	Firecracker Bush		X						X	X		sun/partial shade, 3,500-6,000'; hummingbird pollinated, moth larval source	X	X	X		
Buddleja marrubiifolia	Woolly Butterfly Bush		X					X	X		X	sun/partial shade, hardy plant; attracts butterflies; TX native		X	X		
Caesalpinia mexicana	Mexican Yellowbird	X	X		X			X	X			sun/partial shade, MX native; host for Curve-Winged Metalmark caterpillars, attracts native birds, butterflies and bees		X	X		
Caesalpinia pulcherrima	Mexican Redbird of Paradise		X					X	X		X	sun, Sonora, MX native; hummingbirds love beautiful red/orange flower, freezes back every winter, but returns with fast growth		X			
Calliandra californica	Baja Fairy Duster		X						X			sun/partial shade, Baja native; showier than native fairy duster, frost sensitive; attracts hummingbirds and butterflies	X	X	X	X	
Calliandra eriophylla	Native Fairy Duster		X					X	X			sun/partial shade, 1,000-5,000'; hardy plant that's easy to establish; hummingbird pollinated, butterfly larval source	X	X	X	X	
Calylophus hartwegii	Yellow Evening Primrose				X				X	X		prefers partial shade and well drained soils, 2,500-4,500'; large showy flowers throughout the warm season; sphinx moth larval source	X	X			
Capsicum annuum	Chiltepin				X				X	X		annual/perennial herb, sun/partial shade/shade, native hot pepper; seeds available from Native Seed Search	X		X		X

GI/ LID
RECOMMENDED PLANTS

		Plant Type						Water Usage once Established				Special Use/Restrictions	Benefits				
BOTANICAL NAME	COMMON NAME	Tree	Shrub	Succulent	Forb/ Herb	Vine	Grass	None	Minimal	Moderate	Drought Resistant	NOTES	Wildlife Plant	Native Pollinators	Songbirds/ Native Birds	Cover	Medicinal or Food
Celtis pallida	Desert Hackberry		X					X	X			sun/partial shade, 1,500-3,500'; semi-evergreen shrub, lives 90+ years, provides erosion control; edible berries attract many wildlife species, butterfly larval source	X	X	X	X	X
Celtis reticulata	Desert Hackberry	X						X	X		X	sun/partial shade, 1,500-3,500'; edible berries attract many wildlife species, butterfly larval source- Emperor butterfly caterpillars feed on the leaves; important bird tree	X	X	X	X	X
Cercocarpus montanus	Mountain Mahogany		X			X			X	X		sun/partial shade, 4,500-7,000'; prefers well-drained, coarse, poorly developed soils, great form and seeds; traditional medicinal uses	X			X	X
Chilopsis linearis	Desert Willow	X						X	X		X	sun/partial shade, 1,500-5,000', deciduous; attracts hummingbirds, birds and bees, moth larval source; traditional medicinal uses; wood: baskets & bowls	X	X	X	X	X
Cirsium arizonicum	Arizona Thistle								X	X		sun/partial shade, 4,000-8,000'; butterfly larval source, flowers attract hummingbirds; flowers late Spring/Summer, reseeds	X	X	X		
Clematis drummondii	Old Man's Beard					X			X	X		partial shade, 1,000-4,000'; prolific bloomer, Fatal Metalmark butterfly larval source	X	X	X	X	
Cleome isomeris	Bladder Bush		X					X	X			spring blooming evergreen shrub, prefers full sun and well-drained soils; Pinal Co. native; attracts native bees; traditional food source, may be hard to find	X	X		X	
Condalia warnockii var. kearneyar	Kearney's snakewood		X					X	X			full sun, 1,600-5,000'; edible black berries, low growing spiny bush attracts wildlife	X		X	X	
Concolulus equitans	Silver Morning Glory				X	X			X	X		sun/partial shade, 3,000-5,000'; forms small tuber, prolific bloomer, reseeds easily		X			
Conoclinium greggii	Butterfly mist				X				X	X		sun/partial shade, 3,500-5,000'; Nectar source for butterflies and other pollinators; Cochise Co. native	X	X	X	X	
Cordia parviflora	Littleleaf Cordia		X					X	X		X	full sun, MX native; takes reflective heat; drought tolerant		X			
Coursetia glandulosa	Baby Bonnets		X					X	X			sun/partial shade, 2,000-4,000'; pink and yellow pea like flowers in warm season; butterfly larval source	X	X		X	
Crossosoma bigelovii	Rhyolite Bush		X					X	X			sun/partial shade, 2,000-5,500', well-drained soils; hardy once established, spring blooming shrub; may be hard to find	X	X	X	X	
Cylindropuntia acanthocarpa	Buckhorn Cholla		X	X				X				sun/partial shade, 500-3,500'; edible fruits used by wildlife, well-protected nesting site; red to brownish yellow flowers attract native bees; traditional food source	X	X	X	X	X
Cylindropuntia bigelovii	Teddybear cholla		X	X				X				full sun, 100' to 2,000'; densely covered with spines; greenish yellow flower; attracts birds and pollinators, well-protected nesting site; makes a good barrier, traditional food source	X	X	X	X	X
Cylindropuntia fulgida	Chain-fruit cholla		X	X				X				full sun, 1,000-4,000'; 1-inch pink flower from June to August; attracts birds and pollinators, good nesting habitat. During droughts, animals like the bighorn sheep rely on the juicy fruit for food and water.	X	X	X	X	
Cylindropuntia leptocaulis	Christmas cactus		X	X				X				sun/partial shade, 1,000-5,000'; smaller branched cactus, red fruits mature in the winter, nesting sites, traditional medicinal and food source	X	X	X	X	X
Cylindropuntia spinosior	Cane cholla		X	X				X				full sun, 1,000-6,000'; attracts birds and pollinators, good habitat; ripe yellow fruits are edible, traditional food source; skeleton often used for decorative canes or lamp bases	X	X	X	X	X
Cylindropuntia versicolor	Staghorn cholla		X	X				X				full sun, 2,000-3,000', well-drained soils; buds and fruit traditional food source	X	X	X	X	X
Dalea formosa	Feather Dalea		X					X	X		X	sun/partial shade, 2,000-6,500', well-drained soils, butterfly larval source, attracts bees/nectar insects, rabbits, deer; traditional medicinal uses	X	X		X	X
Dalea frutescens	Black Dalea		X					X	X		X	sun/partial shade, TX/Chihuahuan desert native; butterfly larval source, attracts Southern Dogface; pleasant citrus odor, fall bloomer		X			
Dalea greggii	Trailing Indigo Bush				X			X	X		X	sun, TX/ Chihuahuan desert native; butterfly larval source, attracts Southern Dogface; provides erosion control	X	X	X	X	
Dalea pulchra	Indigo Bush		X					X	X			sun/partial shade, 2,500-5,000', well-drained soils; butterfly larval source	X	X	X	X	
Dasylirion acrotriche	Green Desert Spoon		X					X	X		X	sun, frost hardy to 20 F, Chihuahuan Desert/MX native; striking accent, well-drained soil				X	
Dasylirion longissimum	Smooth Leaf Desert Spoon		X					X	X		X	sun/partial shade, MX native; striking accent, no spines				X	
Dasylirion wheeleri	Desert Spoon, Sotol		X					X	X		X	sun/partial shade, 4,000-6,000'; striking accent, well-drained soil; native bees use flower stalks for nests; traditional medicinal, food and fiber source, used to make "sotol" beverage	X	X			X
Datura wrightii	Sacred Datura				X			X	X			sun/partial shade, 1,000-6,000'; sphinx moth larval source, blooms in response to monsoon rains, winter dormant, huge fragrant white flower attracts bees and hawk moths; all parts poisonous- use gloves; traditional cultural & medicinal value	X	X	X	X	X
Dodonaea viscosa	Hop Bush		X					X	X		X	sun/partial shade, 2,000-4,500'; grows quickly, evergreen screen	X	X	X	X	
Encelia farinosa	Brittlebush		X					X	X			full sun, 1,000-3,000'; desert tortoises eat flowers, prolific seed producer; attracts House finches, quail; many traditional uses; erosion control	X	X	X	X	X
Epilobium canum ssp.latifolium	Hummingbird Trumpet				X				X	X		sun/partial shade, 3,000-7,000'; flowers bloom in the Fall, attracting late season butterflies, especially Whites and Sulphurs (Family Pieridae), moth larval source, attracts hummingbirds	X	X			
Ericameria laricifolia	Turpentine bush		X					X	X		X	sun/partial shade, 3,000-7,000'; evergreen shrub flowers late fall, good late season nectar source, attracts bees		X			

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RECOMMENDED PLANTS

		Plant Type						Water Usage once Established				Special Use/Restrictions	Benefits				
BOTANICAL NAME	COMMON NAME	Tree	Shrub	Succulent	Forb/ Herb	Vine	Grass	None	Minimal	Moderate	Drought Resistant	NOTES	Wildlife Plant	Native Pollinators	Songbirds/ Native Birds	Cover	Medicinal or Food
Eriogonum fasciculatum	Flattop Buckwheat		X					X	X		X	sun/partial shade, 2,000-6,000'; well-drained soils, dense blue-green foliage; food source for deer and desert tortoise, butterfly larval source	X	X	X	X	
Eriogonum wrightii	Wright Buckwheat		X					X	X		X	sun/partial shade, 3,000-7,000'; late summer bloomer attracts bees and butterflies, esp. Veined Blue; traditional medicinal uses		X			X
Erysimum capitatum	Western Wallflower				X				X	X		short lived perennial spring wildflower prefers full sun and well drained soils; reseeds; attract butterflies like Western Tiger Swallowtail; may be hard to find	X	X	X		
Erythrina flabelliformis	Southwest Coral Bean		X						X	X		sun/partial shade, 3,500-5,500'; deciduous perennial shrub; all parts of plant poisonous; hummingbird pollinated	X				
Eschscholzia californica ssp. Mexicana	Mexican Gold Poppy				X			X				full sun, 1,000-4,500'; annual wildflower germinates w/ good winter rains, by Summer self sows into large colonies; attracts bees; poisonous		X			
Euphorbia antisyphilitica	Candelilla				X				X		X	sun/partial shade, 100-3,800', Baja/TX native; wax used for candles, soap, polish; traditional medicinal use					X
Euphorbia rigida	Gopher Plant				X			X			X	sun/partial shade, well-drained soil, hardy to 20 F; although it has no wildlife value, it is deer resistant and provides a strong accent; South African/Mediterranean native					
Eysenhardtia orthocarpa	Kidneywood	X			X				X	X		sun/partial shade, 3,500-5,500'; butterfly larval source; traditional medicinal uses	X	X		X	X
Eysenhardtia texana	Texas Kidneywood		X						X	X		sun/partial shade, TX native; cold hardy, butterfly larval source, fragrant blooms, browsed by deer	X	X		X	
Fallugia paradoxa	Apache Plume		X						X	X		sun/partial shade, 3,500-6,000'; white flowers and pink plumed seeds	X	X	X	X	
Fendlera rupicola	Cliff Fendlerbush		X					X	X			deciduous to semi-evergreen white blooming shrub, 3,000-7,000', well-drained soil; may be hard to find; traditional medicinal uses	X	X	X	X	X
Ferocactus wislizeni	Fishook Barrel cactus		X					X				full sun, 1,000-5,600'; flowers attract native bees, fruits seeds eaten by a variety of wildlife including both mammals and birds; traditional food use (beverage)	X	X	X		X
Fouquieria splendens	Ocotillo		X					X				full sun, well-drained soils, 2,000-5,000'; drought deciduous; hummingbird pollinated, moth larval source; traditional native food source	X	X	X		X
Galactia wrightii	Wright's milkpea					X			X	X		sun/partial shade, 3,000-6,000'; afternoon pink blooming twining vine attracts butterflies, butterfly larval source	X	X	X		
Gaura lindheimeri 'Siskiyou Pink'	Pink Gaura				X				X	X		sun/partial shade, Chihuahuan desert native; attracts butterflies and hummingbirds; deer resistant		X		X	
Gaura lindheimeri 'Whirling Butterflies'	White Gaura				X				X	X		sun/partial shade, Chihuahuan desert native; attracts butterflies and hummingbirds; deer resistant		X		X	
Glandularia gooddingii	Goodding's Verbena				X			X	X			sun/partial shade, 2,000-5,000'; short-lived perennial, re-seeds after Winter; heat hardy; attracts butterflies, moths and bees	X	X	X	X	
Glandularia pulchella	Rock Verbena				X				X		X	sun/partial shade, hardy to 20 F, well-drained soils; attracts bees; reseeds; South American native	X	X	X	X	
Glandularia rigida	Sandpaper Verbena				X				X		X	Full sun, hardy to 0 F, resprouts from rhizomes after Winter, well-drained soils; South American native	X	X	X	X	
Gossypium thurberi	Arizona Wild Cotton		X						X	X		sun/partial shade, 2,500-5,000'; deciduous, blooms August-October, leaves turn bright red in the fall; attracts cardinals and Pyrrhuloxia, host plant and larval food for the splendid royal moth; may be hard to find; traditional use as a fiber source	X	X	X		X
Guardiola platyphylla	Guardiola				X				X	X		sun/partial shade, prefers partial shade, 3,000-5,500'; reseeds, attracts butterflies	X	X	X	X	
Haplophyton crooksii	Hierba de la Cucaracha		X						X	X		sun/partial shade, 2,000-4,500'; hardy yellow flowered subshrub, summer/fall bloomer, well-drained soils, hates wet feet	X				
Helianthus annuus	Common Sunflower				X			X	X		X	annual forb occurring at elevations <7,000', attracts Northern Cardinal, other birds, butterflies and bees; edible seed, traditional food use	X	X	X		X
Hesperaloe parviflora	Red hesperaloe		X					X	X		X	0-2,000', MX native, well-drained soils, slow to moderate growth; attracts hummingbirds; of all Hesperaloe, this one has greatest value to wildlife			X		
Hesperaloe sp	Hesperaloe		X					X	X		X	various sizes and bloom colors, strong accent, flowers attract hummingbirds			X		
Hibiscus cardiophyllus	Heartleaf Hibiscus		X						X		X	full sun, TX/Chihuahuan desert native; hardy plant, blooms brilliant red 2" flowers in summer	X	X	X		
Hibiscus coulteri	Desert Rosemallow		X					X	X		X	sun/partial shade, 2,000-4,500'; warm season yellow w/ red or purple base flowers; attracts bees, rabbit & deer; reseeds	X	X			
Hibiscus denudatus	Rock hibiscus		X							X		full sun, 1,000-4,000'; hardy plant, well-drained soils, lavender/red flowers in spring/fall, does not like inundation	X				
Hyptis emoryi	Desert Lavender		X					X	X		X	sun/partial shade, 1,000-3,500'; good nectar source for pollinators, attracts hummingbirds, frost damage in cold years; traditional medicinal uses	X	X	X	X	X
Indigofera sphaerocarpa	Indigobush		X						X	X		sun/partial shade; 3,500-7,000'; butterfly larval source, fast growing		X			
Janusia gracilis	Slender janusia					X			X			sun/partial shade, 1,000-5,000'; hardy plant with bright yellow flowers followed by red winged fruit; desert tortoise food	X	X			
Jatropha cardiophylla	Limberbush		X					X	X			full sun, 1,000-3,500'; leaves out after rain, no leaves other times of the year; tropical looking during the monsoon; traditionally used to make baskets	X				X

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RECOMMENDED PLANTS

		Plant Type						Water Usage once Established				Special Use/Restrictions	Benefits				
BOTANICAL NAME	COMMON NAME	Tree	Shrub	Succulent	Forb/ Herb	Vine	Grass	None	Minimal	Moderate	Drought Resistant	NOTES	Wildlife Plant	Native Pollinators	Songbirds/ Native Birds	Cover	Medicinal or Food
Justicia californica	Chuparosa		X						X		X	sun/partial shade, 1,000-2,500'; cold and drought deciduous, sprawling, open form; needs warm microclimate, sometimes blooms during winter, hummingbird pollinated		X	X		
Justicia candicans	Red Justicia		X						X	X		sun/partial shade, 1,500-3,500'; attracts hummingbirds and butterflies; needs warm microclimate		X			
Justicia spicigera	Mexican Honeysuckle		X						X	X		partial shade/shade, MX native; evergreen plant flowers year-round; needs warm microclimate; hummingbird pollinated		X			
Keckiella cordifolia	Heartleaf Keckiella		X						X	X		partial shade, So. CA native below 4000'; hummingbird pollinated					
Koeberlinia spinosa	Allthorn		X					X	X			full sun, 2,500-5,000'; hardy plant, black berries provide food for wildlife; creates a good plant barrier	X		X	X	
Lantana montevidensis	Trailing Lantana				X					X		full sun, hardy to 20 F with full recovery, South America native; attracts hummingbirds, butterflies and bees		X	X		
Larrea tridentata	Creosote Bush		X					X	X		X	full sun, 1,000-4,500'; evergreen shrub that blooms multiple times throughout the year; extremely long-lived, attracts small mammals; traditional medicinal plant	X		X	X	X
Leucaena retusa	Littleleaf leadtree	X	X					X	X		X	TX native; perennial evergreen tree, well-drained soils; open form good for light shade, winter sun; patio; browsed by deer, provides good cover	X	X		X	
Leucophyllum frutescens	Texas Ranger		X					X	X		X	full sun, TX/MX native, 1,000'-4,500'; cold hardy to 0 degrees; evergreen, lavender/purple flowers; silver to deep green leaves; tough, well-drained soils	X	X	X	X	
Leucophyllum laevigatum	Chihuahuan sage		X					X	X		X	full sun, MX native, 4,000-7,800'; cold hardy evergreen, lavender/purple flowers; silver to deep green leaves; tough, needs good drainage	X	X	X	X	
Lobelia laxiflora	Sierra Madre Lobelia		X		X				X	X	X	partial shade, 3,000-5,000'; hardier than L. cardinalis; red/orange flowers Spring thru Fall; attracts hummingbirds; okay with wet soil; spreads; poisonous		X			
Lonicera albiflora	White Honeysuckle					X			X	X		partial shade, 3,500-5,500'; large woody perennial vine; moth pollinated, attracts hummingbirds, produces berries	X	X	X	X	
Lotus rigidus	Shrubby deervetch				X			X	X		X	<5,000'; found along washes and disturbed areas; hardy; attracts native bees		X		X	
Lycium species	All Native Wolfberries		X					X	X		X	most species produce edible fruits; good wildlife plant, nectar for butterflies; Variety parishii may be hard to find	X	X	X	X	
Lysiloma watsonii	Feather Tree	X	X						X	X	X	full sun/partial shade, 2,800-4,000'; small thornless tree, frost sensitive above 3,000'; benefits Large Orange Sulphur butterfly & preying mantis		X			
Macrosiphonia brachysiphon	Rock Trumpet				X				X	X		sun/partial shade, 3,500-5,500'; rhizomatous perennial with perfumed white flower, prefers limestone; moth pollinated	X	X			
Malvaviscus arboreus var. drumn	Wax mallow		X							X		fast growing perennial to 6'; attractive to bees; deer-resistant; prefers some shade, TX and southeast U.S. native	X	X	X		
Matelea arizonica	Arizona milkvine					X		X	X			full sun/partial shade, 3,000-4,500'; perennial vine, butterfly larval source, attracts snout butterflies when in bloom	X	X			
Maurandya antirrhiniflora	Snapdragon Vine					X		X	X			partial shade, 1,500-6,000'; hummingbird pollinated; larval food for Common Buckeye; often reseeds	X	X		X	
Melampodium leucanthum	Blackfoot daisy				X			X				full sun/partial shade, 2,000-5,000', well-drained soils, hardy plant typically grows on limestone; attracts bees and butterflies	X	X	X	X	
Menodora scabra	Rough Menodora				X			X	X			sun/partial shade, 2,000-4,500'; hardy plant, cannot withstand long periods of inundation, but reseeds	X		X		
Mirabilis longiflora	Sweet four o'clock				X				X	X		partial shade, 4,000-8,000'; forms underground tuber, fragrant flowers bloom during summer evenings, attracting moths and providing a larval source; deer resistant	X	X		X	
Mirabilis multiflora	Desert four o'clock				X				X	X		sun/partial shade, 3,000-6,000'; forms underground tuber, magenta flowered groundcover; moth larval source, deer & rabbit resistant; historic medicinal value and dye	X	X			X
Muhlenbergia capillaris	Regal Mist						X		X		X	provides seed, cover and nesting materials; attracts lady bugs; high tolerance for salinity; TX native	X		X	X	
Muhlenbergia porteri	Bush muhly						X	X	X			full sun, 2,000-6,000'; hardy grass with purplish flowers, frequently grows under shrubs. Good forage for deer, desert tortoise and other wildlife	X			X	
Muhlenbergia rigens	Deer Grass						X		X	X		full sun/partial shade, 2,500-7,500'; good forage for wildlife, provides seed, cover and nesting materials	X	X	X	X	
Muhlenbergia rigida	Dwarf Deergrass						X	X	X			4,000-7,200'; smaller grass; handles all conditions, prefers well-drained soils		X	X	X	
Oenothera caespitosa	Tufted Evening Primrose				X				X			sun/partial shade, 4,000-7,500', well-drained soils; large white flowers, good rabbit and javalina food, sphinx moth larval and nectar source, can reseed	X	X	X		
Olneya tesota	Desert Ironwood	X						X	X			sun/partial shade, 1,000-2,500', well-drained soils; a favorite native shade tree, long lived, slow growing, traditional food source	X	X	X	X	X
Opuntia basilaris	Beavertail Prickly Pear		X	X				X				sun/partial shade, sea level to 6,000'; low but spreading to 3'; edible fruits consumed by wildlife; flowers attract native bees; traditional food source	X	X	X	X	X
Opuntia ficus-indica	Indian Fig		X	X	X			X				grows to 12' or more, striking accent; sun/partial shade, 2,000-5,000'; most tender of local species; edible fruit or "tuna" harvested by humans and consumed by wildlife; pads or nopales eaten as a vegetable; flowers attract native bees; traditional food source	X	X	X	X	X

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RECOMMENDED PLANTS

		Plant Type						Water Usage once Established				Special Use/Restrictions	Benefits				
BOTANICAL NAME	**COMMON NAME**	**Tree**	**Shrub**	**Succulent**	**Forb/ Herb**	**Vine**	**Grass**	**None**	**Minimal**	**Moderate**	**Drought Resistant**	**NOTES**	**Wildlife Plant**	**Native Pollinators**	**Songbirds/ Native Birds**	**Cover**	**Medicinal or Food**
Opuntia phaecantha	Prickly Pear		X					X				sun/partial shade, 2,000-5,000'; edible fruits used by wildlife; flowers attract native bees; larval host for Yucca giant skipper butterfly; fruit a traditional food source for jelly and teas, pads served as "napolitos" in restaurants.	X	X	X	X	X
Opuntia violacea santa-rita	Santa Rita Prickly Pear		X	X				X				sun/partial shade, 2,000-4,000'; the purple pads become more pronounced in winter or drought; edible fruits used by wildlife, flowers attract native bees; traditional food source	X	X	X	X	X
Parkinsonia florida	Blue Palo Verde	X						X	X		X	sun/partial shade, 500-4,000'; fast growing, typically found along washes; Desert Tortoise eats dropped flowers; attracts Verdins & Orioles, provides nesting bird habitat; traditional food source. Note: at this time the Blue Palo Verde is not recommended due to the continuing infestation with Witch's Broom which stunts the branch formation. Check current status before choosing this plant.	X	X	X	X	X
Parkinsonia x 'Desert Museum'	Desert Museum Palo Verde	X						X	X			hybrid between P. aculeate, P. microphyllum, and P. florida; prolific bloomer; thornless			X		
Parthenium incanum	Mariola		X						X			small silver shrub, very rabbit resistant, full/partial sun, 2,000-5,000', Evergreen, great smell to the foliage, flowers are said to be fragrant at night	X		X	X	
Passiflora arizonica	Arizona Passion Vine					X					X	3,000' to 6,000'. Beautiful 2" diameter "exotic" flower blooms in the late afternoon, closing at midnight, with a strong fragrance. Hairy leaves. P. arida is also a native but slightly different look, blooming early morning and closing by noon.		X	X		
Passiflora mexicana	Mexican Passion Vine					X						most common Passion Vine. Beautiful "exotic" flower and smooth, hairless leaves. Must have damp, shady environment. Flower scent may not be pleasing to some.		X	X		
Pedilanthus macrocarpus	Lady's Slipper		X						X		X	full sun, 0-1,500', frost hardy to 30 F so best in warm location; bold accent, tubular, vertical stems curling at tops, Baja native, evergreen, great container plant or in ground in warm spot, showy flowers that hummingbirds love		X			
Penstemon barbatus	Scarlet Bugler				X				X	X		sun/partial shade, 4,500-8,000'; late bloomer, blooms in April in Tucson, hummingbird pollinated, can reseed	X	X	X		
Penstemon palmeri	Palmer's Penstemon				X				X	X		sun/partial shade, 3,500-6,500', northern AZ native; large showy flowers, hummingbird plant	X	X	X		
Penstemon parryi	Parry's Penstemon				X				X	X		sun/partial shade, 2,000-5,000'; white 'Snowy' tolerates inundation; early bloomer, easy to grow, hummingbird pollinated, can reseed	X	X	X		
Penstemon pseudospectabilis	Canyon Penstemon				X				X	X		sun/partial shade, 3,000-6,000'; blooms later into Fall, hummingbird pollinated	X	X	X		
Penstemon superbus	Superb Penstemon				X				X	X		sun/partial shade, 3,500-5,500', Cochise & Graham Co. native; late bloomer, striking when in bloom, forms large clump, hummingbird pollinated	X	X	X		
Phaseolus acutifolius	Wild Tepary Bean					X			X	X		wild tepary bean, really good rabbit food, butterflies; container stock may be hard to find but seeds are readily available from Native Seed Search	X	X	X		
Pithecellobium mexicanum	Mexican Ebony	X						X	X			MX native; grows in arroyos, desert slopes and valley floors- prefers well-drained soils; tolerant to 18°			X		
Proboscidea altheafolia	Wild Devil's Claw				X			X	X			sun/partial shade, 1,000-3,500'; bees pollinate; bright yellow flowers; "claw" fibers used in traditional basket weaving and currently in many art venues; seed, fruit edible	X	X			X
Prosopis glandulosa	Honey Mesquite	X						X	X		X	eastern and western AZ native, attracts native pollinators and mammals but does hybridize with local native mesquites; beautiful weeping form; traditional medicinal uses	X	X	X	X	X
Prosopis pubescens	Screwbean Mesquite	X								X	X	sun/partial shade, 1,000-4,000', prefers well-drained soil but will tolerate inundation; seedpods are traditional native food; wood versatile, requires occasional supplemental irrigation for best appearance but tolerates drought as well	X		X	X	X
Prosopis velutina	Velvet Mesquite	X						X	X		X	sun/partial shade, 1,000-6,000'; tough native tree that easily hybridizes with other mesquites- if true native is desired, contact Native Seed Search; seedpods are traditional native food; butterfly larval source	X	X	X	X	X
Psilotrophe cooperi	Paperflower		X						X		X	full sun/partial shade; 2,000-5,000', well-drained soils- will not tolerate inundation; very aromatic yellow flowers dry papery tan, hardy plant; attracts pollinators	X	X	X	X	
Purshia Mexicana	Cliff Rose		X						X		X	hosts Desert Elfin butterfly; bees and flies consume nectar; forage for small and large wildlife; very aromatic; well-drained soil; traditional medicinal and functional uses	X	X			X
Quercus turbinella	Scrub Oak		X						X	X		sun/partial shade, 3,500-7,000', evergreen native oak provides shelter and nesting for birds, acorns for wildlife: bluish tinted leaves	X	X	X		
Rhus microphylla	Littleleaf Sumac	X	X						X	X		partial shade, 3,500-6,000', deciduous shrub; edible berries loved by birds and wildlife, attracts native bees	X	X	X	X	
Rhus trilobata	Squawbush		X						X	X		sun/partial shade, 2,500-7,000'; deciduous shrub w/ edible berries, fragrant leaves, flowers smell like chocolate	X		X	X	X
Ruellia californica	Baja Ruellia		X						X	X	X	also attractive to bees, butterflies and birds; blooms year round		X	X		
Ruellia nudiflora	Wild Petunia		X						X	X		partial sun or shade, 2,000-4,000', Large flowers, spreads readily from seed, butterfly nectar and larval source		X			

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RECOMMENDED PLANTS

		Plant Type						Water Usage once Established				Special Use/Restrictions	Benefits				
BOTANICAL NAME	COMMON NAME	Tree	Shrub	Succulent	Forb/ Herb	Vine	Grass	None	Minimal	Moderate	Drought Resistant	NOTES	Wildlife Plant	Native Pollinators	Songbirds/ Native Birds	Cover	Medicinal or Food
Ruellia peninsularis	Desert Ruellia		X					X	X		X	prefers well-drained soil; accepts some shade, Baja MX native; full sun, cold hardy to about 25 degrees		X			
Sapindus saponaria	Western Soapberry	X							X	X		medium deciduous shade tree; variety Drummondii may be hard to find	X			X	
Salvia chamaedryoides	Mexican Blue Sage		X						X	X	X	prefers well-drained soils, sun/partial shade, higher elevation Chihuahuan native; attracts hummingbirds; evergreen, easy to grow		X	X		
Salvia clevelandii	Chaparral Sage		X						X		X	sun/partial shade, well-drained soils; so. CA/Baja native, cold hardy to 4,500'; attracts bees and hummingbirds		X	X		
Salvia greggii	Autumn Sage		X						X	X		sun/partial shade, 2,200-8,000'; blooms Spring and Fall; TX and N. MX native; cold hardy to about 0 F; attracts bees and hummingbirds, deer resistant		X	X		
Salvia leucantha	Mexican Bush Sage		X						X	X		sun/partial shade, sensory velvety flower and wooly leaf; heavy soils ok; Sphinx Moth; bees; MX native; dies back in winter, but can be planted up to 4000'		X	X		
Salvia nemorosa 'May Night"	Meadow Sage		X						X		X	durable; adapted to varied soils and exposures; attracts hummingbirds, bees and butterflies; deer and rabbit resistant		X	X		
Sambucus nigra ssp. cerulea	Blue Elderberry		X						X	X		1,000-4,000'; blue or purple berries edible; traditional medicinal value; tolerates wet soil	X	X	X	X	X
Senna covesii	Desert Senna		X					X				full sun, 1,000-3,500' short-lived perennial, well-drained soils; larval food for sulfur butterflies; reseeds readily	X	X	X	X	
Senna wislizenii	Shrubby Senna		X					X	X			full sun/partial shade, 3,000-5,000'; larval food for sulfur butterflies; Cochise Co. native; attractive shrub	X	X		X	
Simmondsia chinensis	Jojoba		X					X	X		X	sun/partial shade, 1,000-5,000'; slow growing evergreen shrub, female plants produce nuts; traditional medicinal uses	X		X	X	X
Solidago wrightii	Wright's Goldenrod				X				X	X		partial shade, 3,000-8,000'; reseeds, attracts butterflies and bees for nectar; forms a patch, attractive foliage	X	X	X	X	
Sophora secundiflora	Texas Mountain Laurel	X	X					X	X		X	full sun, 1,000-5,000', native to TX, NM, northern MX; evergreen, slow growing, extremely fragrant flowers in spring; deer resistant; possible medicinal uses					X
Sphaeralcea ambigua	Globemallow		X					X	X			sun/partial shade, 1,000-3,500'; short-lived perennial, reseeds readily, butterfly larval source, attracts native bees	X	X	X	X	
Tecoma stans	Trumpet Bush		X						X	X		sun/partial shade, 3,000-5,500'; freezes to ground in cold winters but easily resprouts; great moth larval source, hummingbirds love; large showy flowers during warm weather	X			X	
Thymophylla pentachaeta	Dogweed				X			X	X			sun/partial shade, 2,000-5,000'; butterfly larval source, reseeds easily, good nectar source, blooms a lot, weedy but easily controlled	X	X	X		
Tiquilia greggii	Plume Tequilia		X					X	X		X	full sun and well-drained soils; nectar for insects; Chihuahua desert native	X	X	X		
Tradescantia occidentalis	Western Spiderwort				X				X	X		partial shade, 4,000-8,000'; grasslike plant with attractive purple flowers	X	X			
Trixis californica	Trixis		X					X	X			partial shade, 2,000-4,000'; covered with yellow flower heads in spring; typically found under native trees and along washes, good nectar source	X	X	X	X	
Vachella constricta	White Thorn Acacia		X		X				X			full sun, 2,500-5,000', prefers well-drained soil, hardy plant; traditional medicinal and food source; butterfly larval source, attracts bees	X	X	X	X	X
Vauquelinia californica	Arizona Rosewood		X					X	X			full sun, 2,500-5,000'; small white flowers, evergreen, slow growing, great screen plant or hedge	X			X	
Yucca elata	Soaptree Yucca		X					X	X			full sun, 1,500-6,000'; butterfly larval source, pollinated by yucca moth, edible flowers	X	X	X		X
Zauschneria californica	Hummingbird Trumpet		X						X	X		sun/partial shade, 3,000-7,000'; showy flowers bloom in the Fall, attracting late season butterflies, especially Whites and Sulphurs (Family Pieridae), moth larval source, attracts hummingbirds	X	X	X	X	
Zinnia acerosa	Desert Zinnia		X		X			X				2,000-5,000', small evergreen shrub; seeds/flowers attract insects	X	X	X	X	
Zinnia grandiflora	Prairie Zinnia				X			X	X			full sun, 4,000-6,500'; wonderful ever blooming groundcover; Cochise and Santa Cruz County native	X	X	X	X	
Ziziphus obtusifolia	Graythorn		X					X	X			1,000-5,000'; deciduous evergreen shrub, well-drained soils; Birds love purple berries, moth larval source; traditional medicinal and food source	X	X	X	X	X

REFERENCES

The following sources provided information for the GI/ LID Plant List.
These sources can provide additional tips on appropriate selection and placement of the recommended plant materials.

Sources:

Arizona Native Plant Society (ANPS). Desert Bird Gardening. Tucson, AZ: ANPS with Tucson Audubon Society, 1997.

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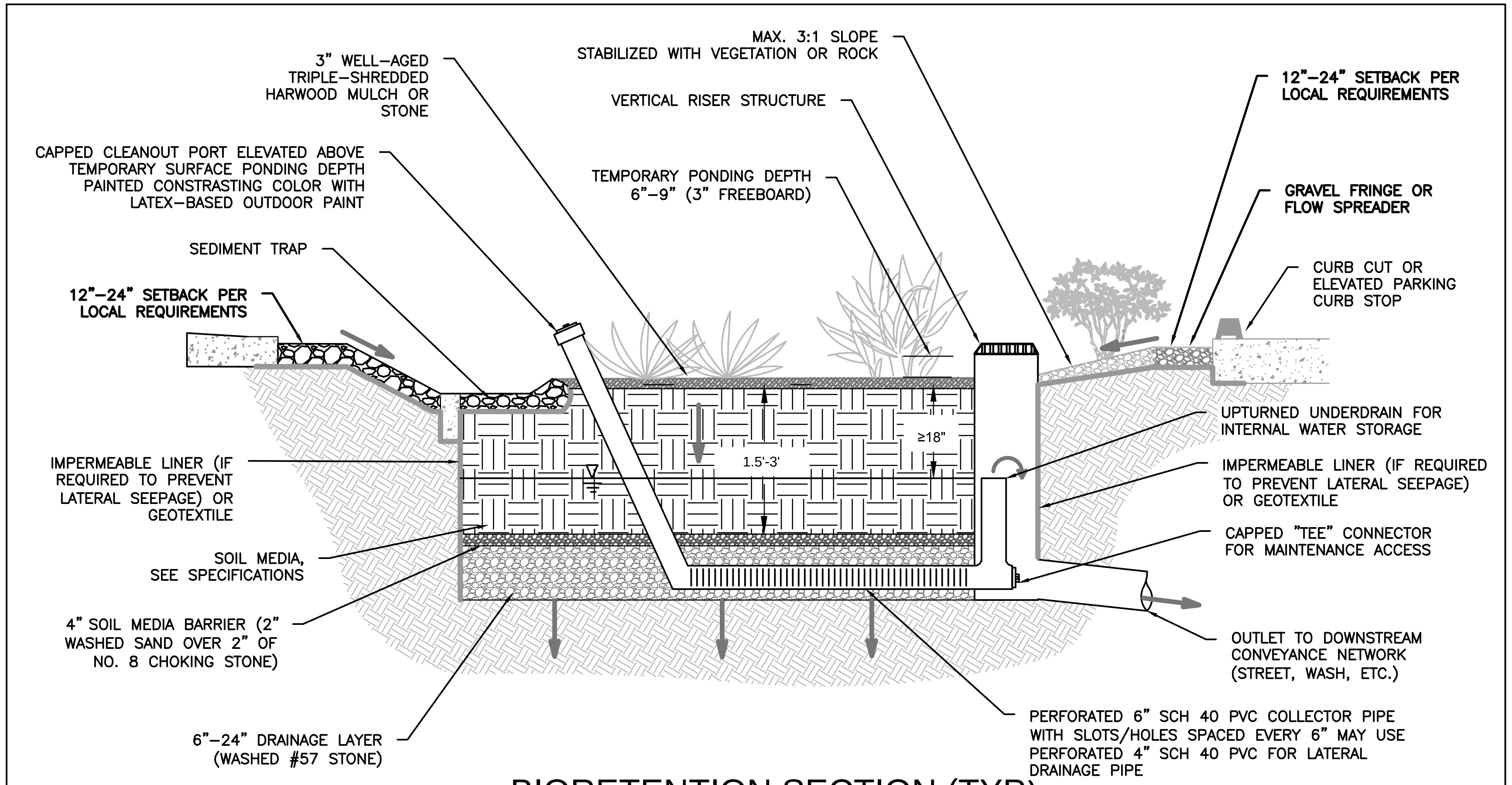
Mielke, Judy. Native Plants for Southwestern Landscapes. Austin, TX: University of Texas Press, 1995.

Pima County Regional Flood Control District. "Regulated Riparian Habitat Mitigation Standards and Implementation Guidelines", November 2011, Pima County, AZ.

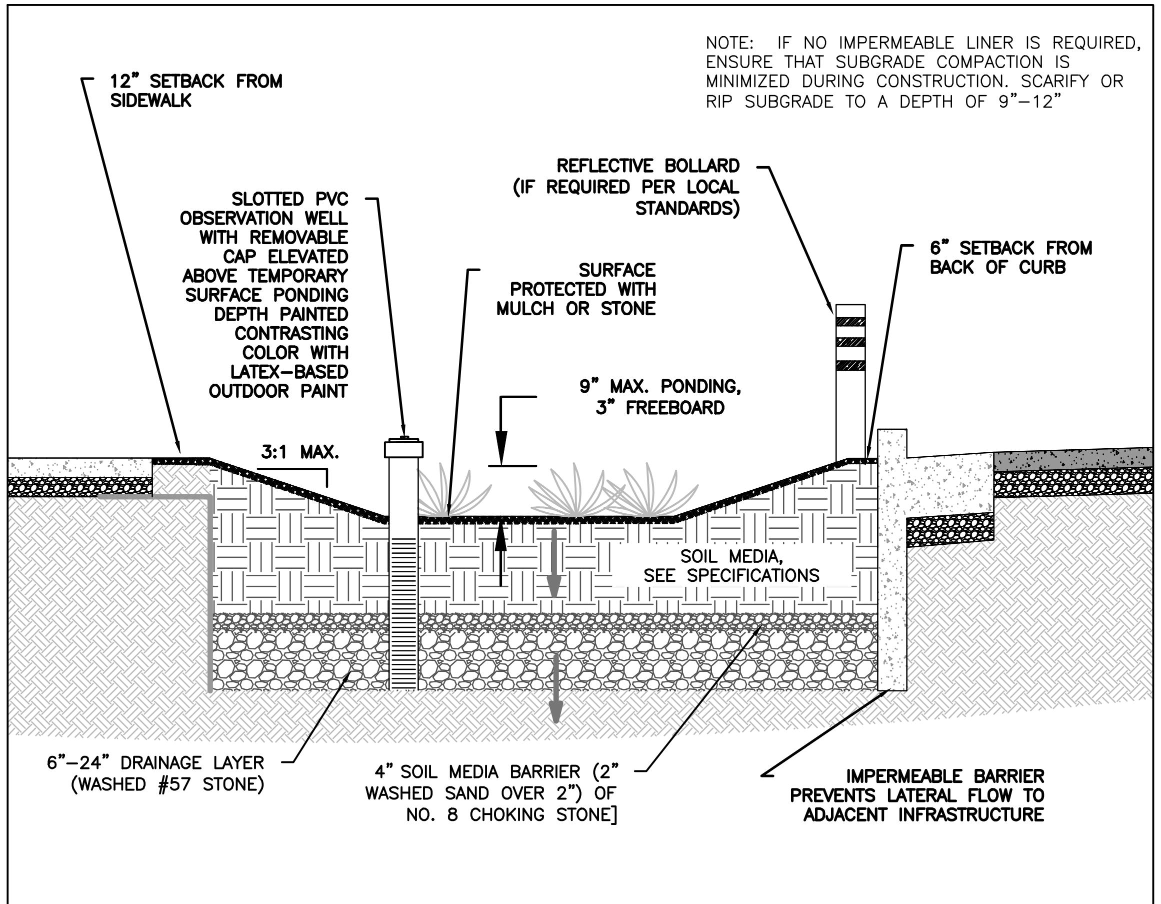
http://rfcd.pima.gov/wrd/riparian/guidelines/pdfs/onsite-guidelines.pdf	Pima County Regional Flood Control District. "Regulated Riparian Habitat Mitigation Standards and Implementation Guidelines"
http://www.fireflyforest.com	Southeastern Arizona Wildflowers and the Plants of the Sonoran Desert
http://swbiodiversity.org/seinet	Southwest Environmental Information Network
http://www.desertsurvivors.org/Nursery/Plant_DB/PlantList.html	Desert Survivors Plant List
http://borderlandsrestoration.org/info-news/field-guide/plants-of-borderland/	Borderlands Restoration Plant Guide
http://www.efloras.org	Flora of North America
htt/://canotia.org	Canotia Journal
http;//www.tucsonaudubon.org	Plant list for native Sonoran Desert habitat
http://www.azgfd.gov/pdfs/w_c/landscaping/PlanningHabitat.pdf	Plant list for wildlife
http://www.herb.umd.umich.edu	Native American Ethnobotany (University of Michigan - Dearborn)
http://en.wikipedia.org	Wikipedia
http://ag.arizona.edu/pima/gardening/aridplants	Master Gardeners of the University of Arizona Pima County Cooperative Extension
http://aggie-horticulture.tamu.edu	Texas Native Plants
http://davesgarden.com. Plant Files.	Dave's Garden
http://www.desertusa.com	Desert USA
http://jan.uss.nau.edu/~plants	NAU
http://museum2.utep.edu/chih/chihdes.htm	Chihuahuan Desert Plants
http://www.perennials.com	Plant Profiles
http://www.wildflower.org	Lady Bird Johnson Wildflower Center



NOTE: IF NO IMPERMEABLE LINER IS REQUIRED, ENSURE THAT SUBGRADE COMPACTION IS MINIMIZED DURING CONSTRUCTION. SCARIFY OR RIP SUBGRADE TO A DEPTH OF 9"–12"

A BIORETENTION SECTION (TYP)

WITH UNDERDRAIN - NOT TO SCALE



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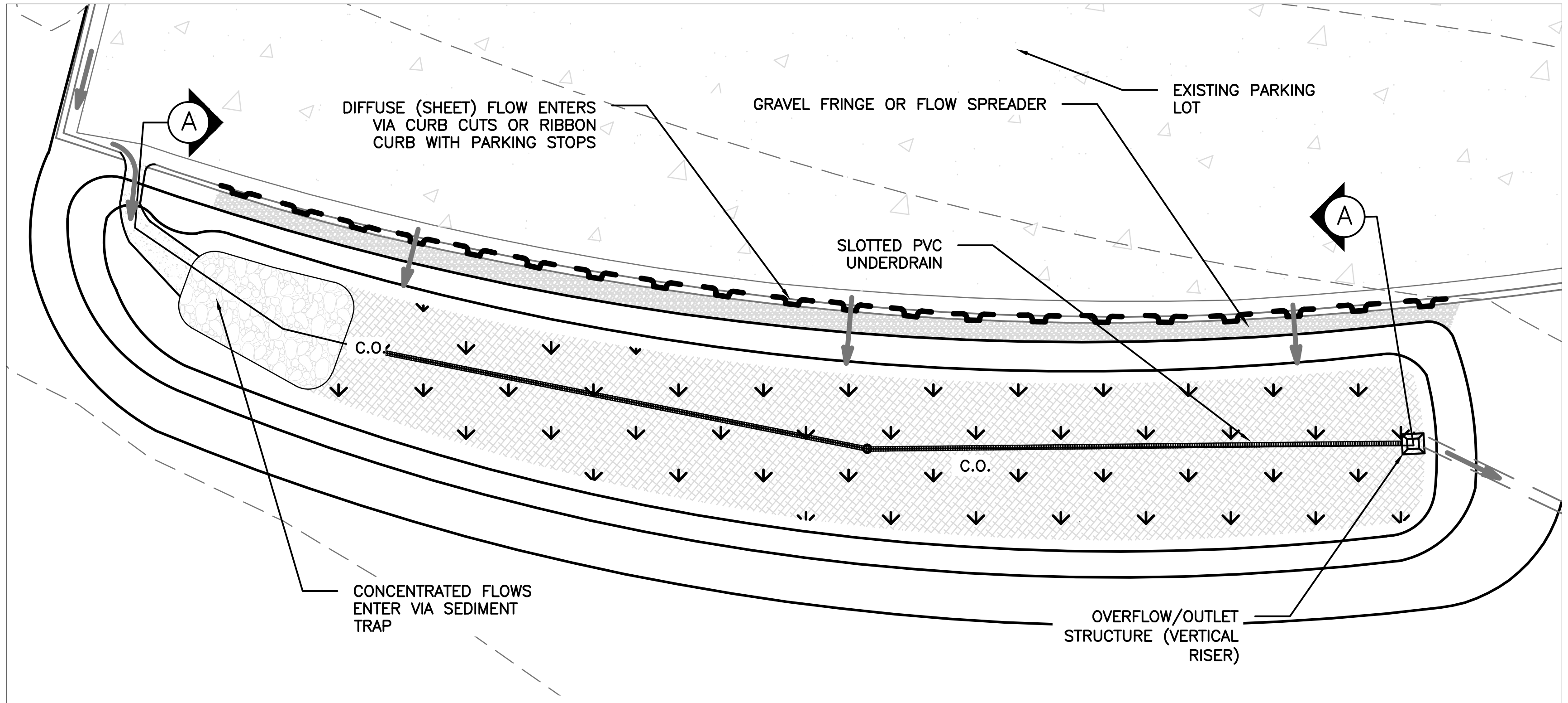
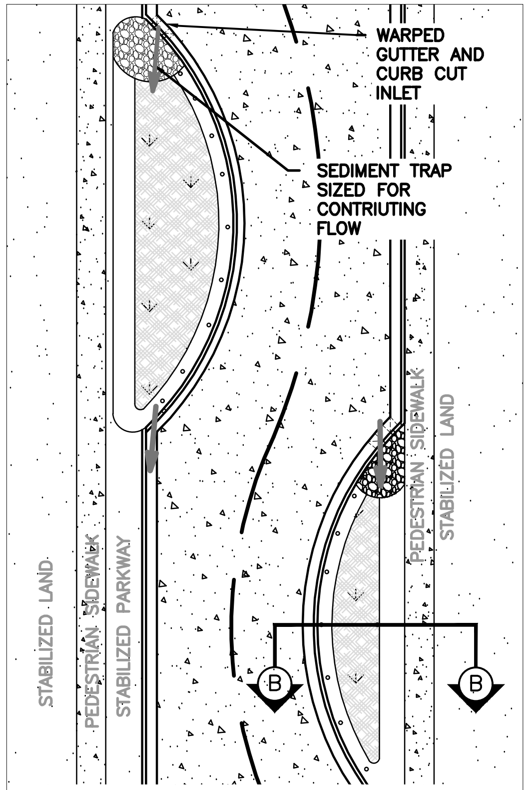
B TYPICAL BIORETENTION CHICANE SECTION

NO UNDERDRAIN - NOT TO SCALE



BIORETENTION PLAN - EXAMPLE ONLY

NOT TO SCALE - EXAMPLE ONLY



BIORETENTION CHICANE

NOT TO SCALE - EXAMPLE ONLY

NOTE: BIORETENTION IS INTENDED TO TEMPORARILY POND WATER ON THE SURFACE. VERIFY VIA SURVEY THAT SPECIFIED TEMPORARY SURFACE PONDING VOLUME IS PROVIDED.

CITY OF TUCSON FOUNDED 1775

PIMA COUNTY

ENGINEERING DESIGN TEMPLATE

PIMA COUNTY

BIORETENTION

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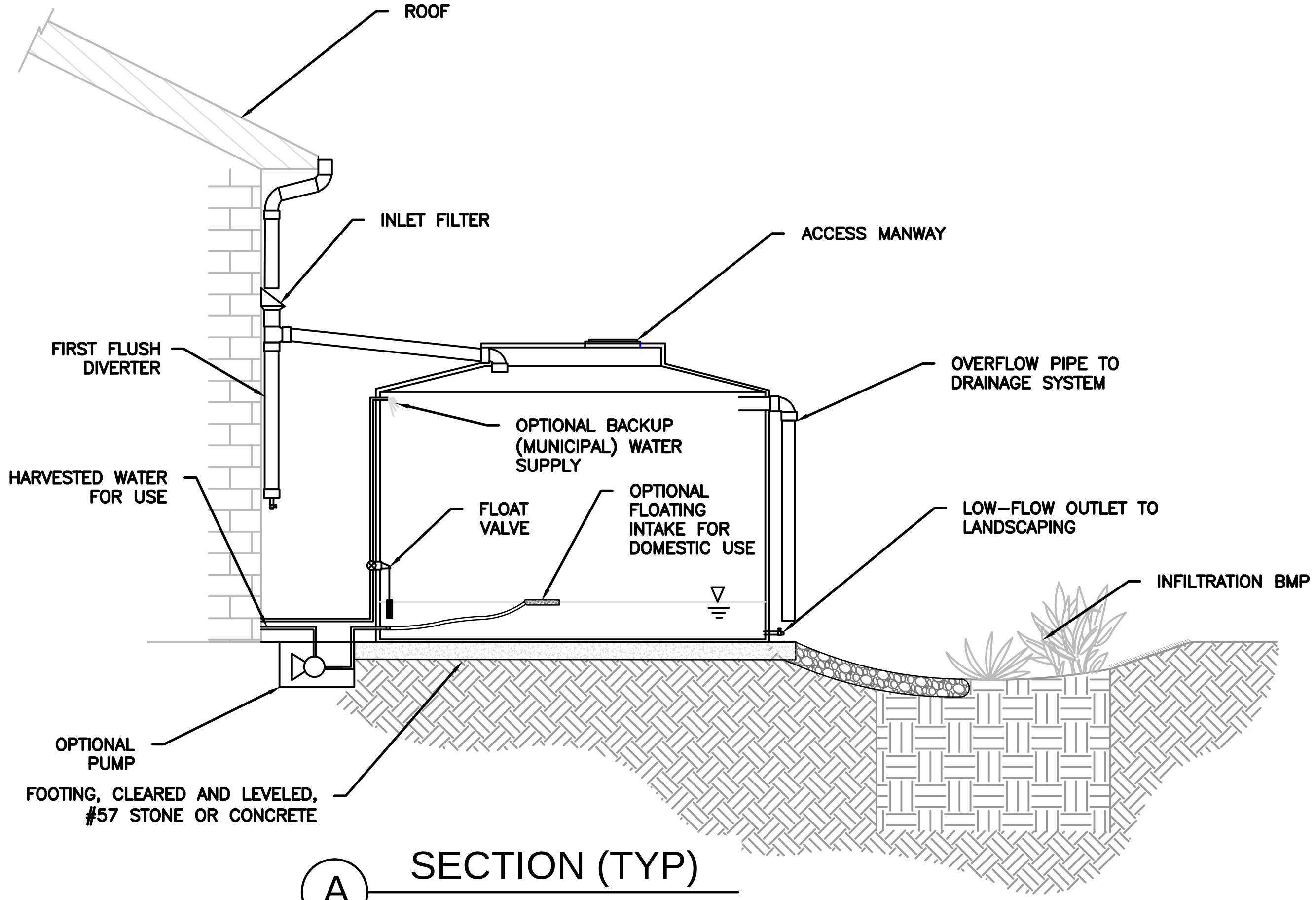

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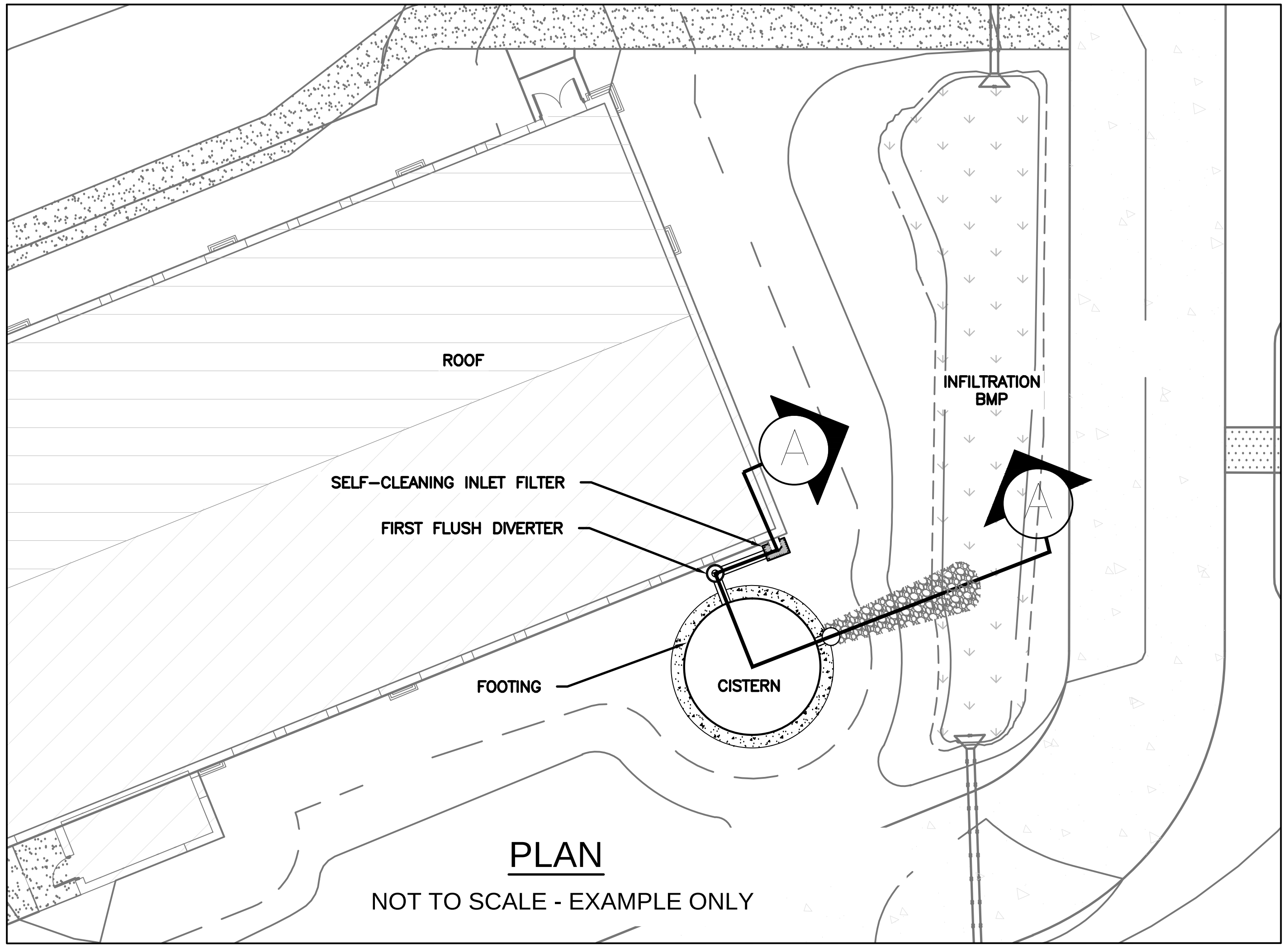

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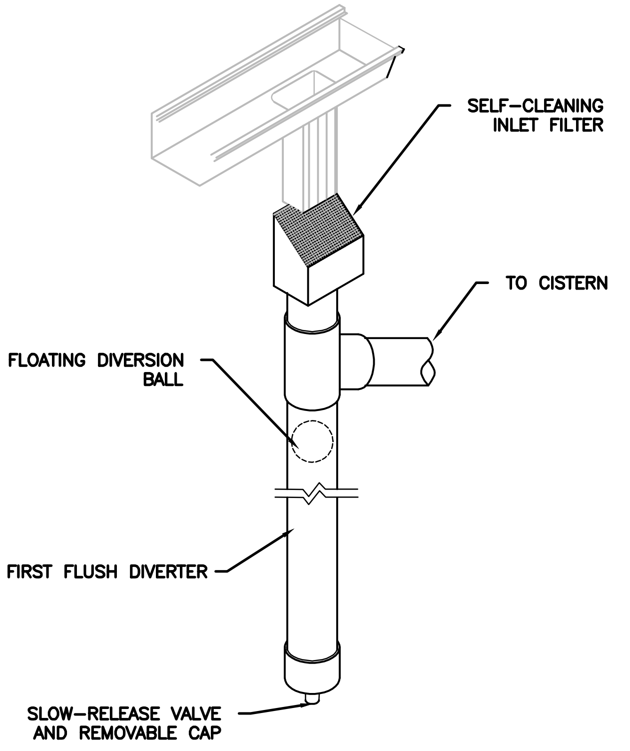

PRETREATMENT DETAIL (TYP)

NOTES: CAUTIONARY SIGNAGE AND LOCKING FEATURES

CLEAR AND OBVIOUS SIGNAGE SHOULD BE PROVIDED WHEREVER HARVESTED RAINWATER IS USED. SIGNS SHOULD READ: "CAUTION: NON-POTABLE WATER, DO NOT DRINK" OR SIMILAR IN ENGLISH AND SPANISH. AREAS WHERE SIGNAGE IS RECOMMENDED INCLUDE ENTRANCES TO ROOMS (INCLUDING MECHANICAL ROOMS) WHERE HARVESTED WATER IS PIPED OR USED, IRRIGATION AND AUTOMOBILE WASHING HOSES, LOW-FLOW OUTLET ORIFICES, TOILET TANKS THAT USE HARVESTED WATER FOR FLUSHING, AND ANY SPIGOTS, DRAWDOWN PIPES, OR ACCESS HATCHES.

ALL VALVES (EXCEPT FIXTURE SUPPLY CONTROL VALVES) SHOULD BE EQUIPPED WITH LOCKING FEATURES.

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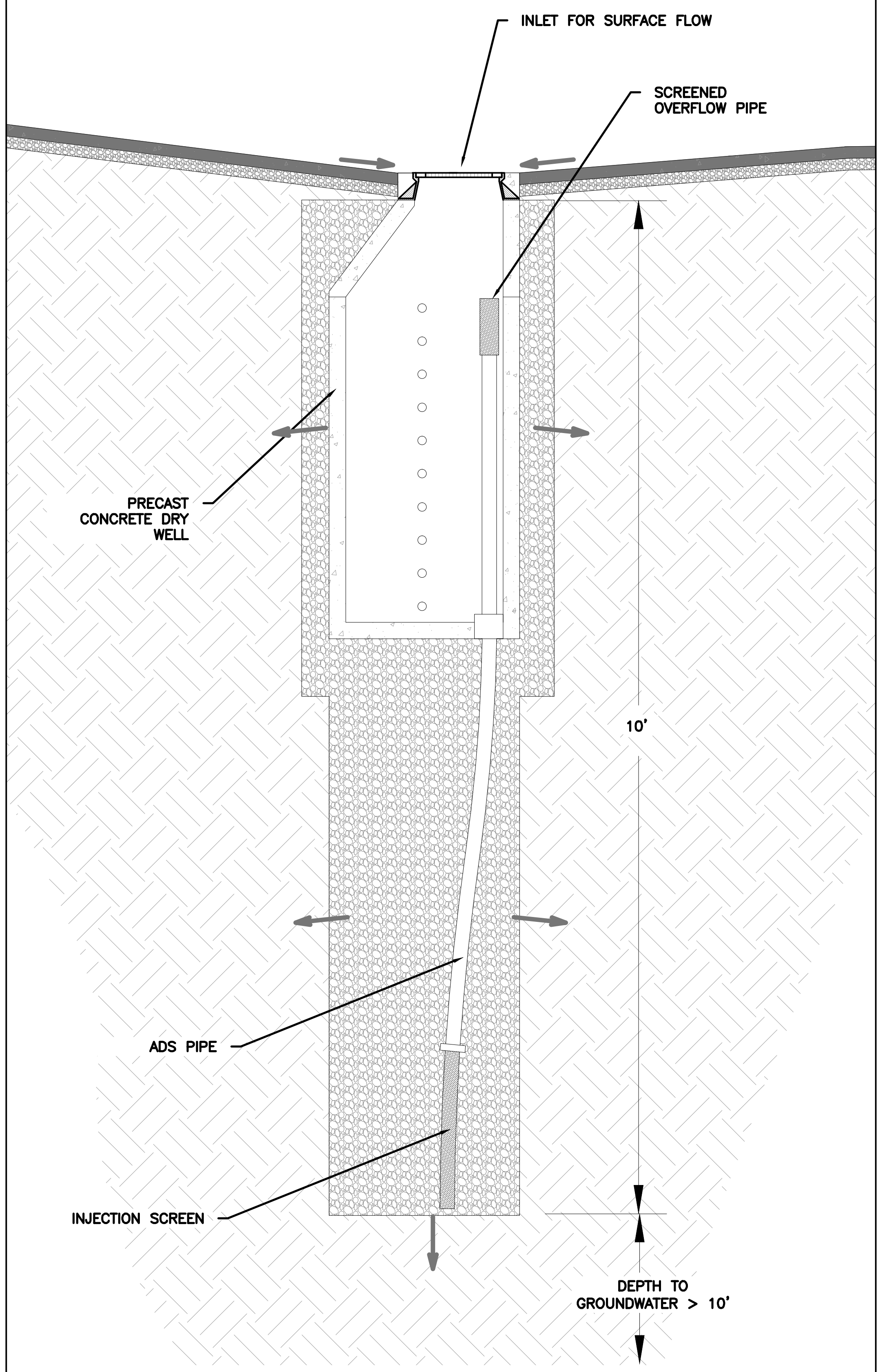
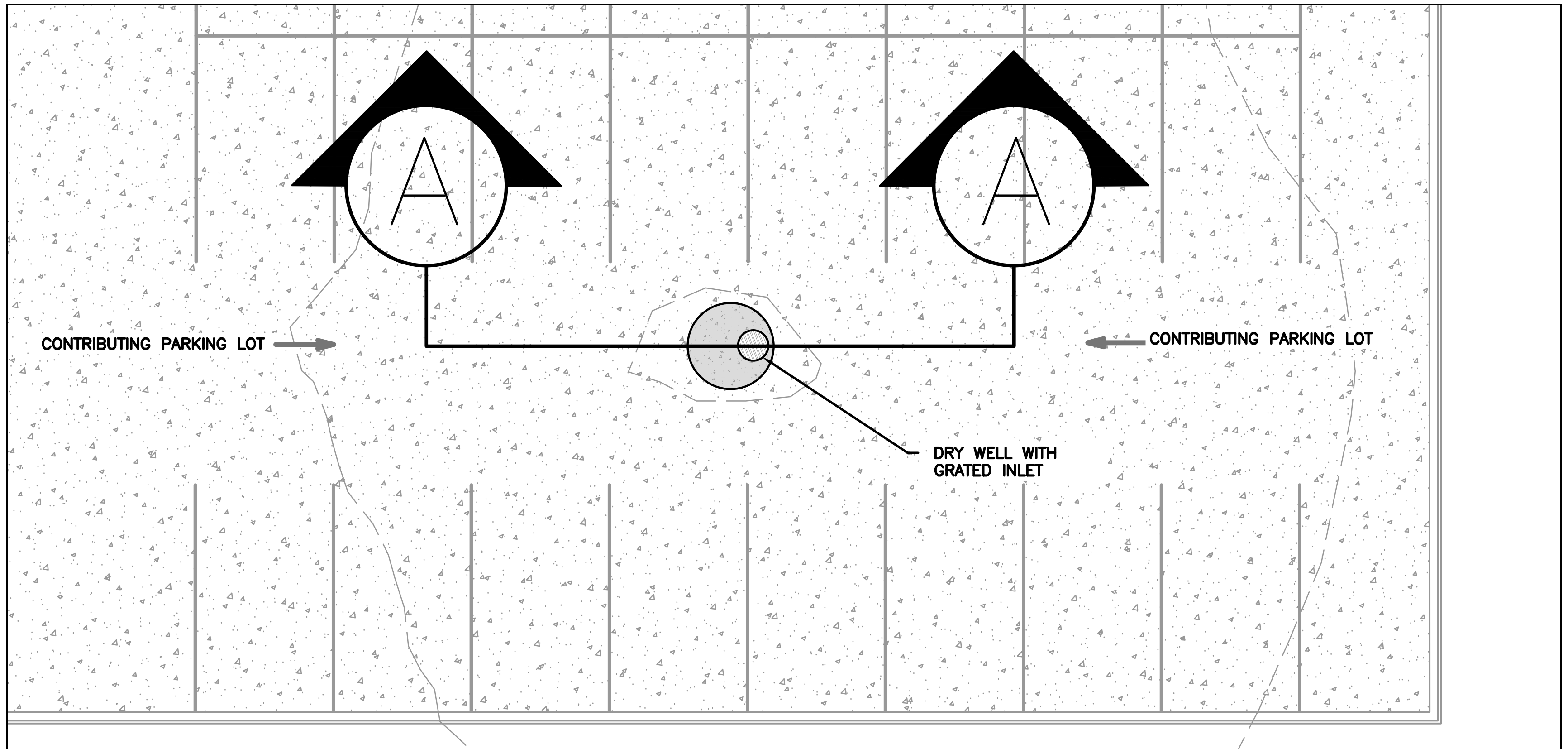


A DRY WELL CROSS SECTION (TYP)

NOT TO SCALE



DRY WELL PLAN (TYP)

NOTE:
DRY WELLS MAY BE CLASSIFIED AS A CLASS V DRAINAGE WELL AND MUST BE PERMITTED/REGISTERED ACCORDINGLY. USE OF DRY WELLS IS RESTRICTED TO SITUATIONS PERMITTED BY THE STANDARDS FOR STORMWATER DETENTION AND RETENTION FOR PIMA COUNTY

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ENGINEERING DESIGN TEMPLATE

PIMA COUNTY

DRY WELL

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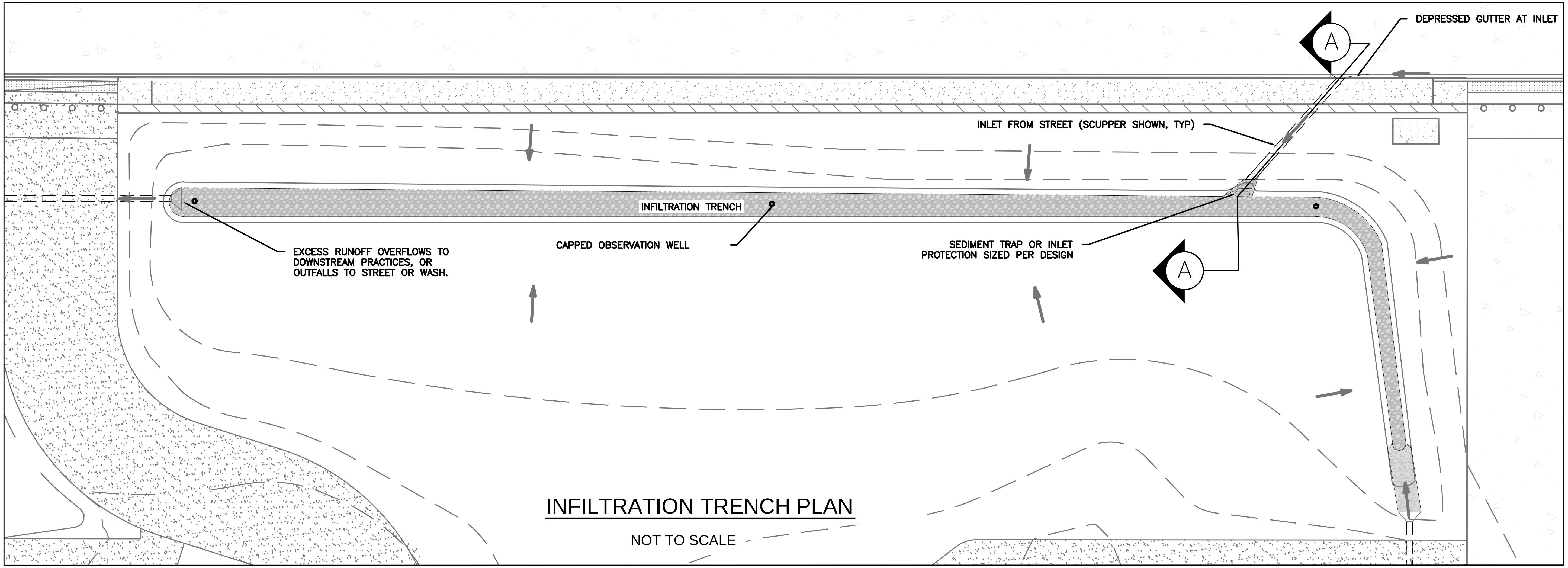
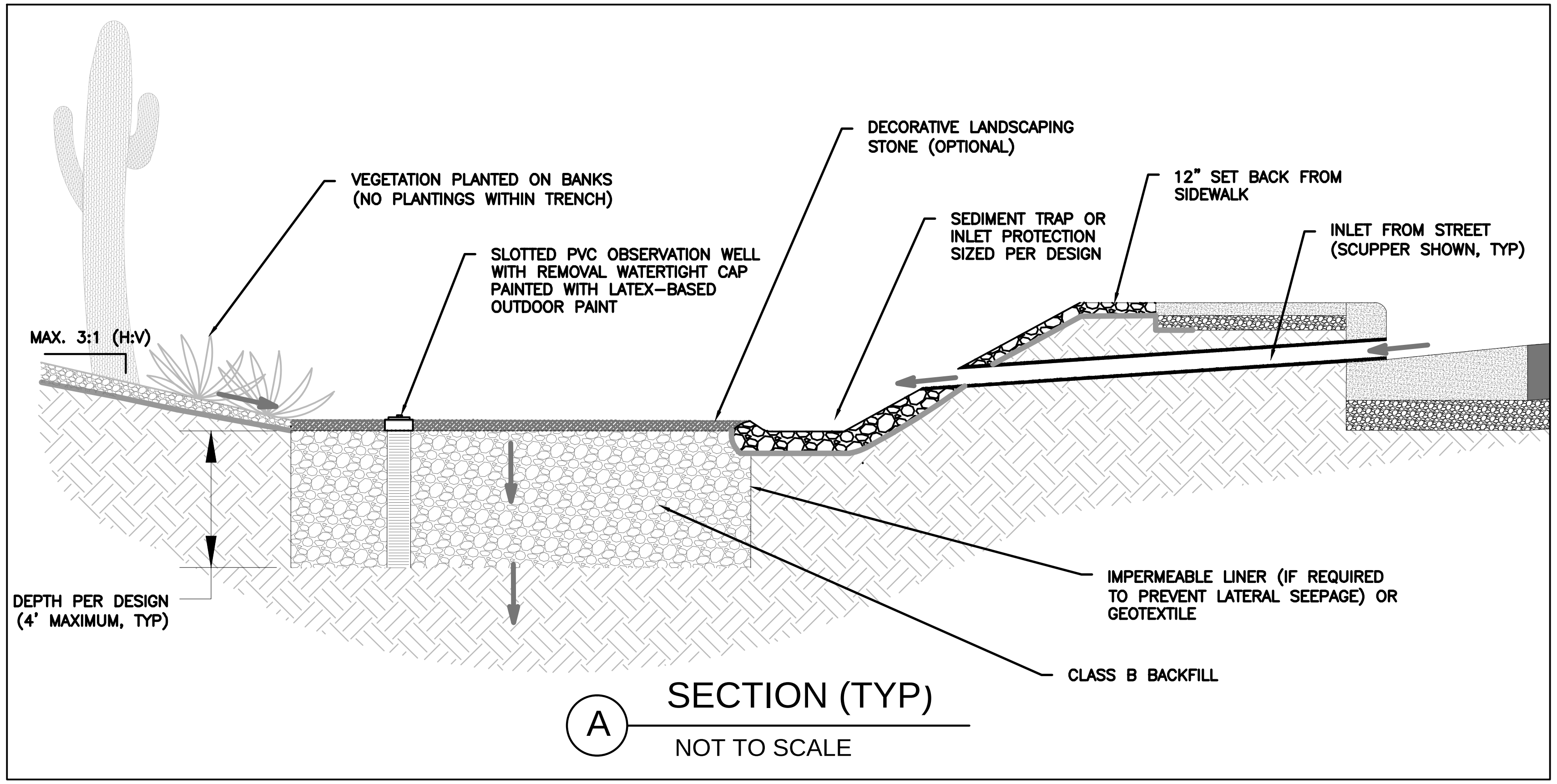


INFILTRATION TRENCH PLAN

NOT TO SCALE



A

SECTION (TYP)

NOT TO SCALE

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CITY OF TUCSON FOUNDED 1775

PIMA COUNTY

ENGINEERING DESIGN TEMPLATE

PIMA COUNTY

INFILTRATION TRENCH

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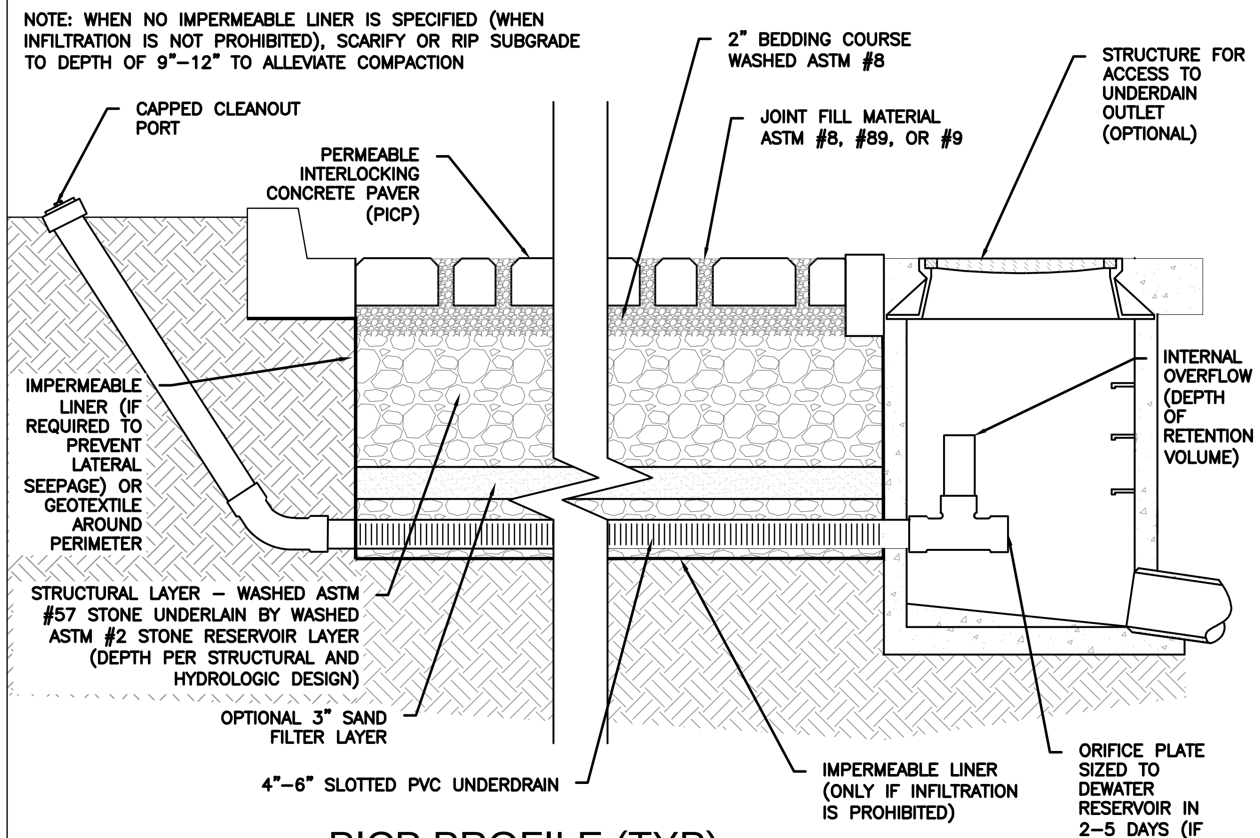

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PICP PROFILE (TYP)

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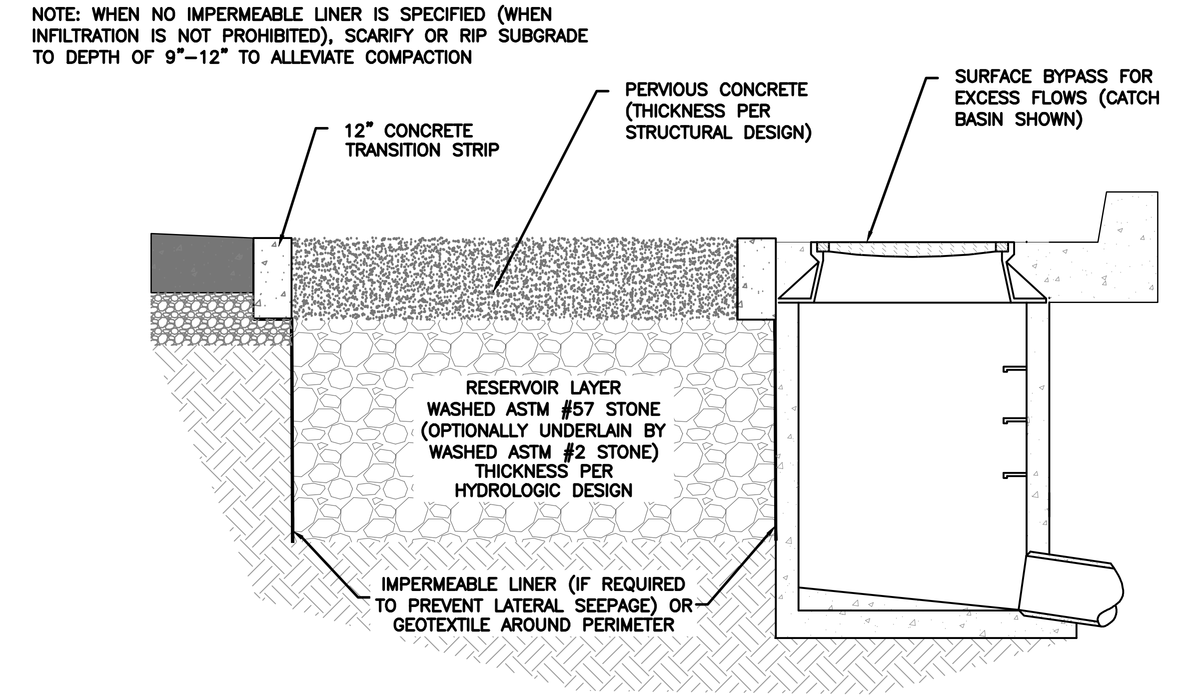

B

PERVOIUS CONCRETE SECTION (TYP)

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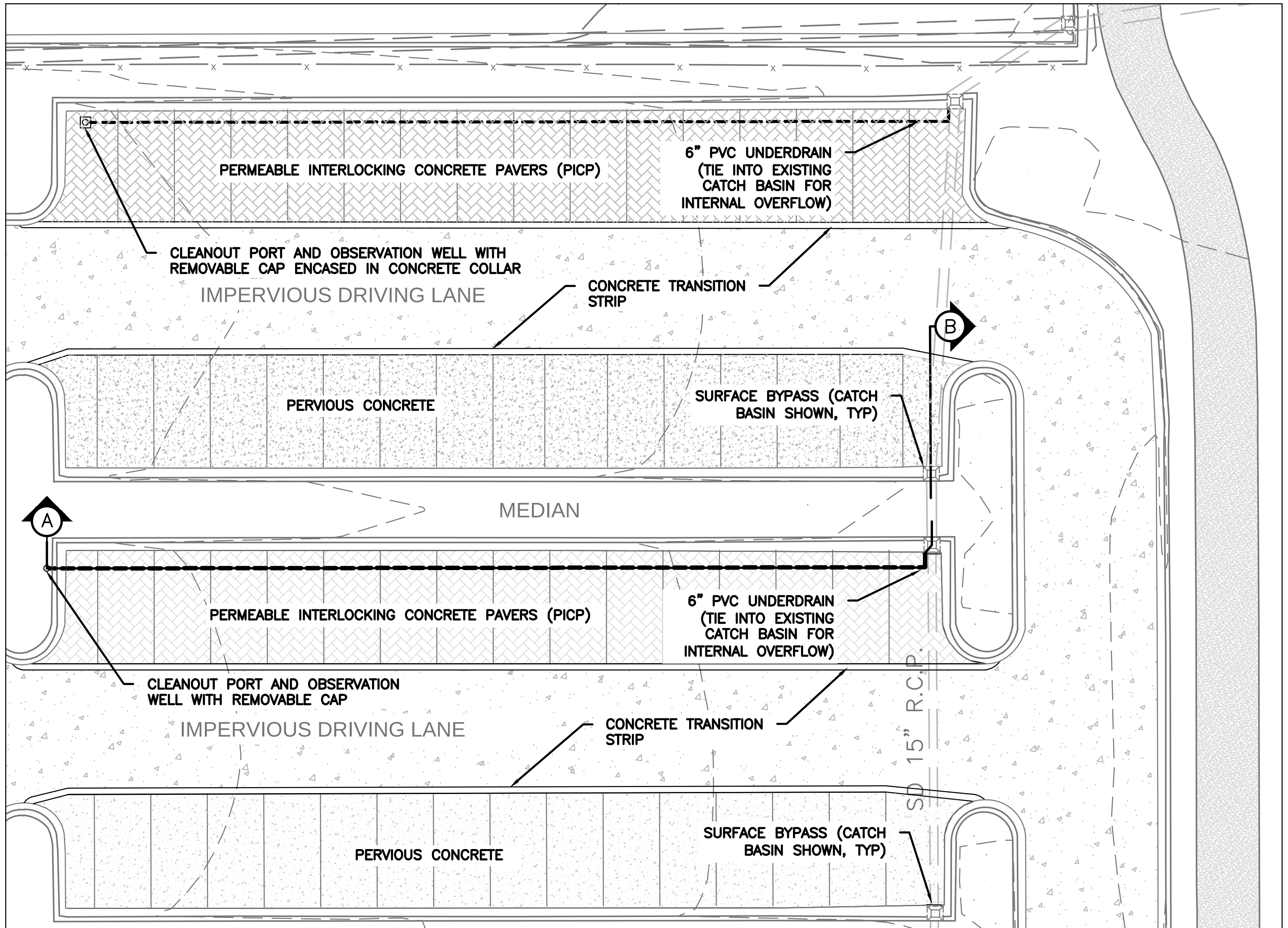

PLAN

NOTES:

INTERNAL OVERFLOW SHOULD BE PROVIDED FOR PERMEABLE INTERLOCKING CONCRETE PAVERS TO PREVENT DISLODGING AND TRANSPORT OF JOINT FILL MATERIAL BY UPWELLING WATER. PERVIOUS CONCRETE MAY BYPASS AT THE SURFACE WHEN FULL.

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ENGINEERING DESIGN TEMPLATE

PIMA COUNTY

PERMEABLE PAVEMENT

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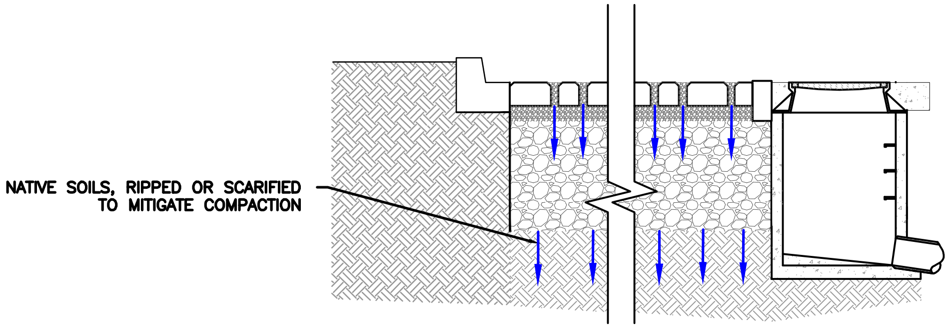
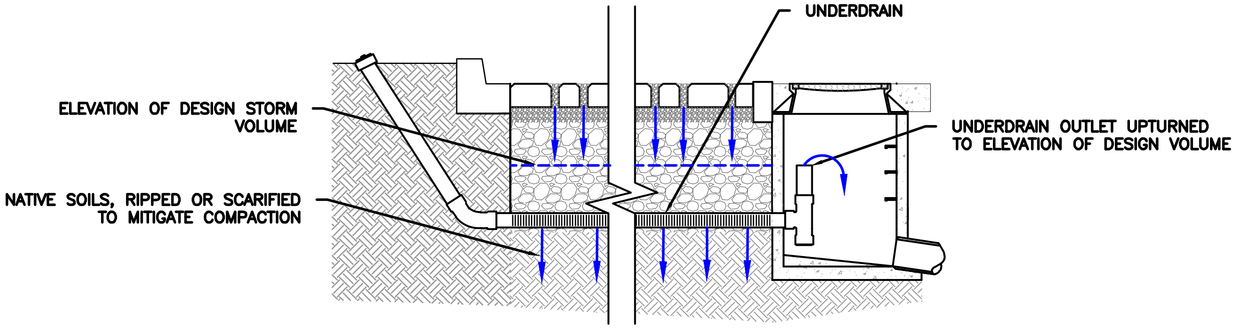
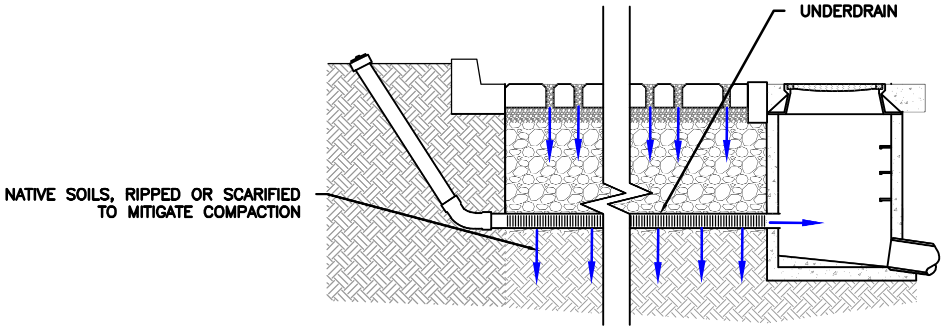


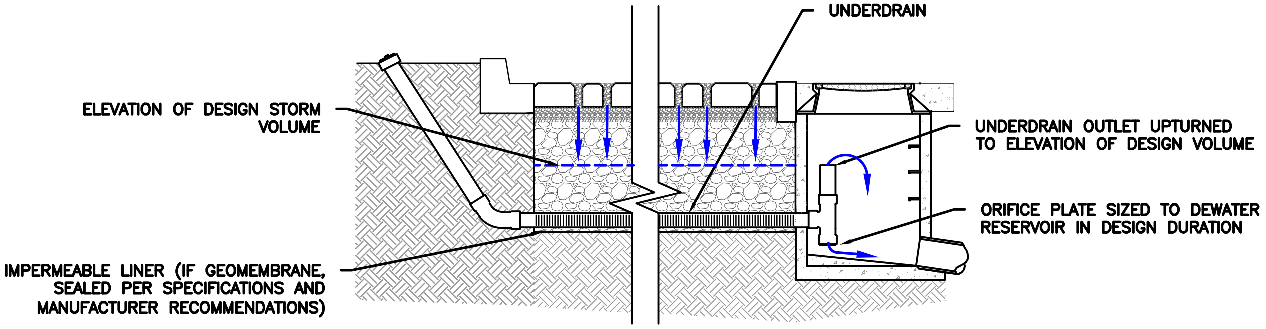
CONFIGURATION 1: INFILTRATION, NO UNDERDRAIN



CONFIGURATION 2: INFILTRATION, W/ UPTURNED UNDERDRAIN



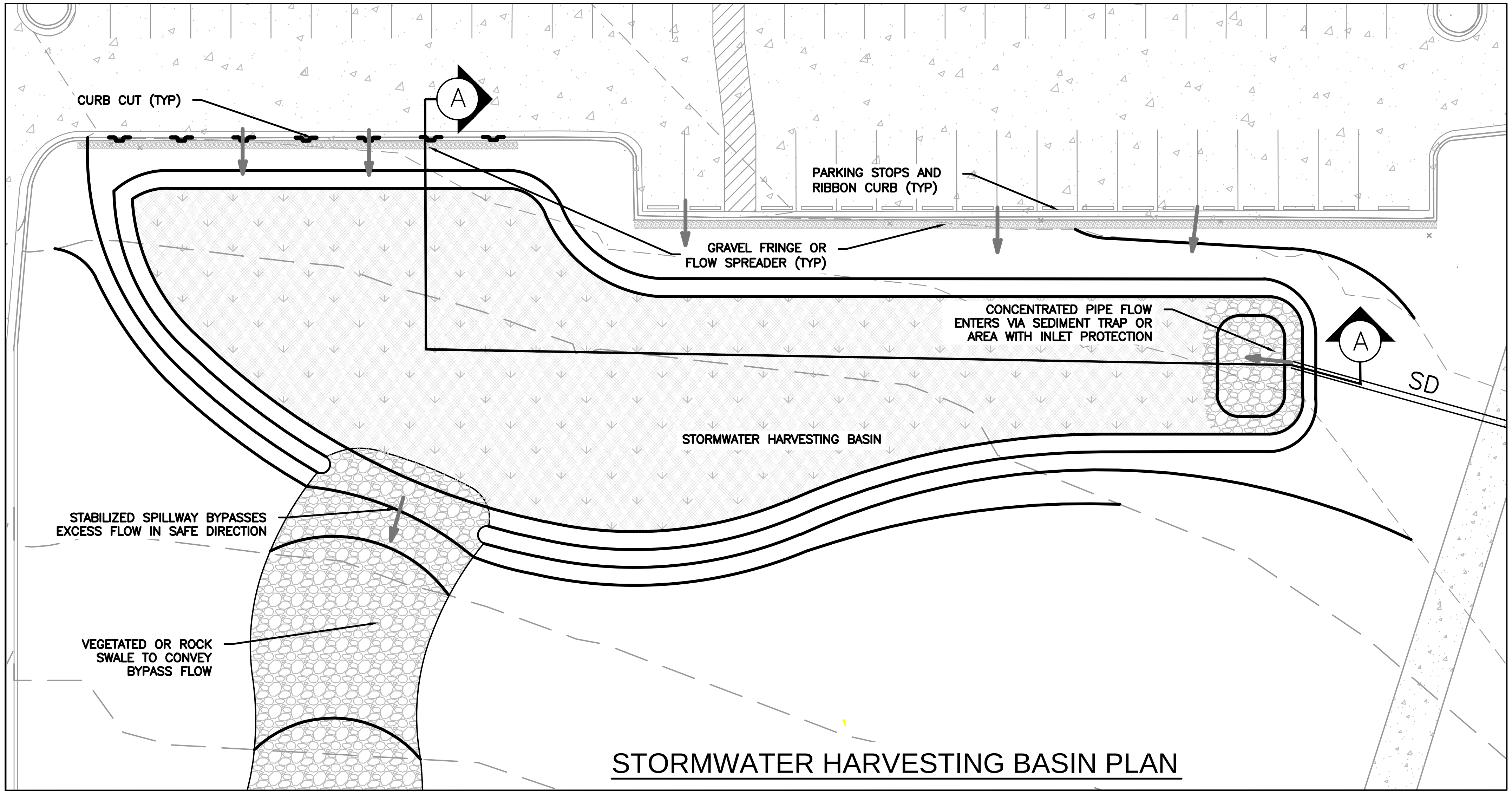
CONFIGURATION 3: INFILTRATION, W/UNDERDRAIN AT SUBGRADE



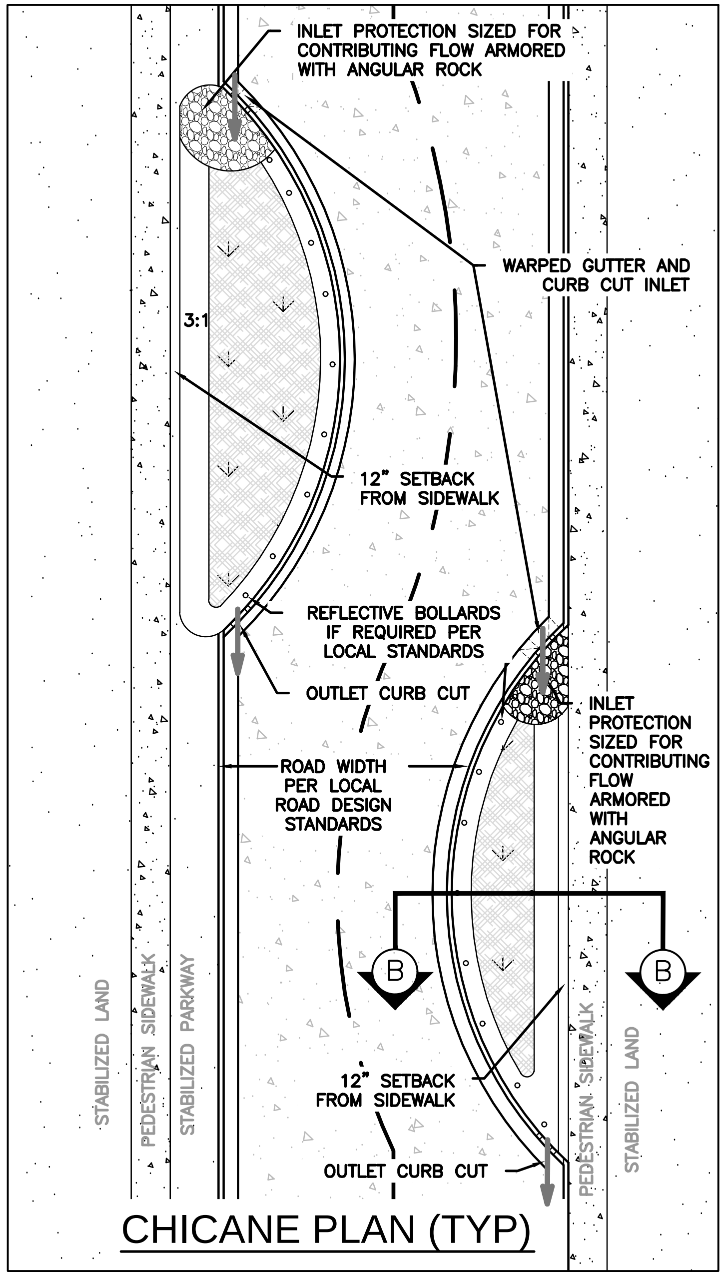
CONFIGURATION 4: NON-INFILTRATING, W/UNDERDRAIN AT SUBGRADE

NOT TO SCALE

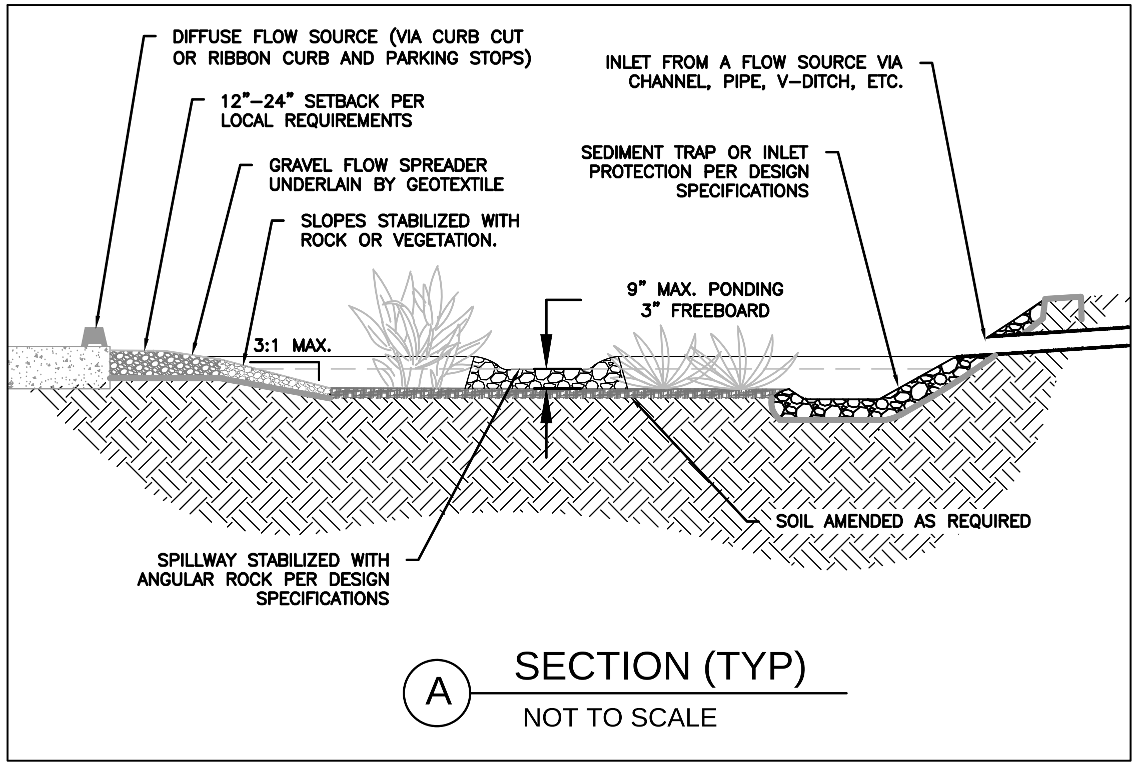
12/2014



STORMWATER HARVESTING BASIN PLAN



CHICANE PLAN (TYP)



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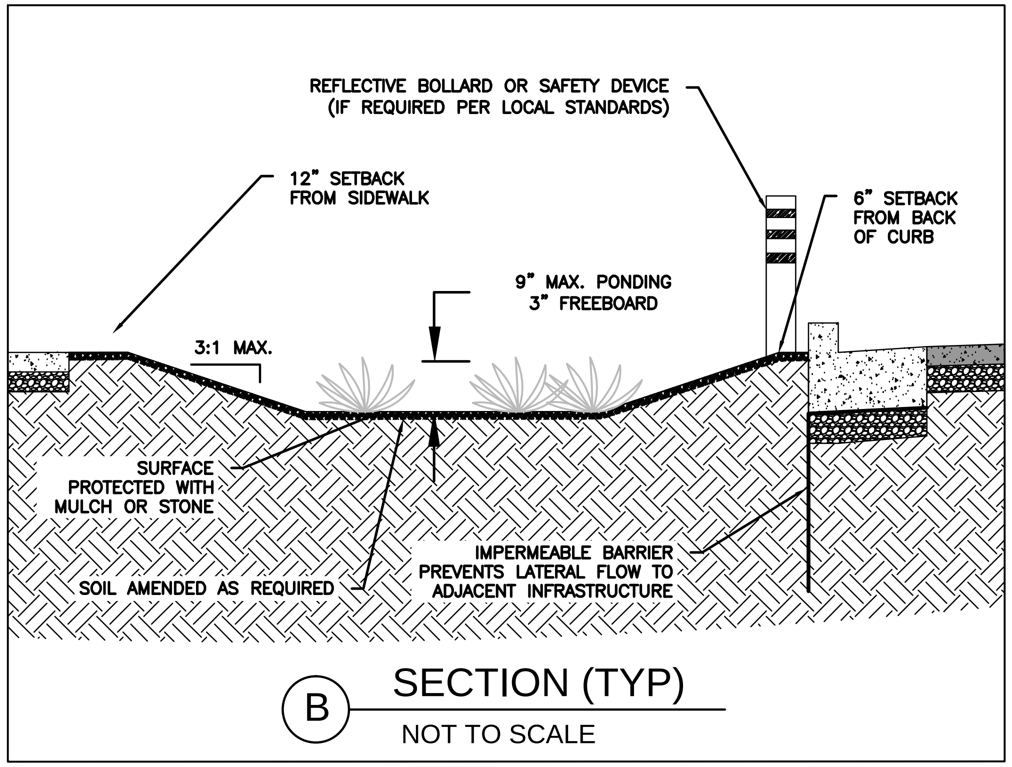

B SECTION (TYP)

NOT TO SCALE

CITY OF TUCSON

PIMA COUNTY

ENGINEERING DESIGN TEMPLATE

PIMA COUNTY

STORMWATER HARVESTING BASIN

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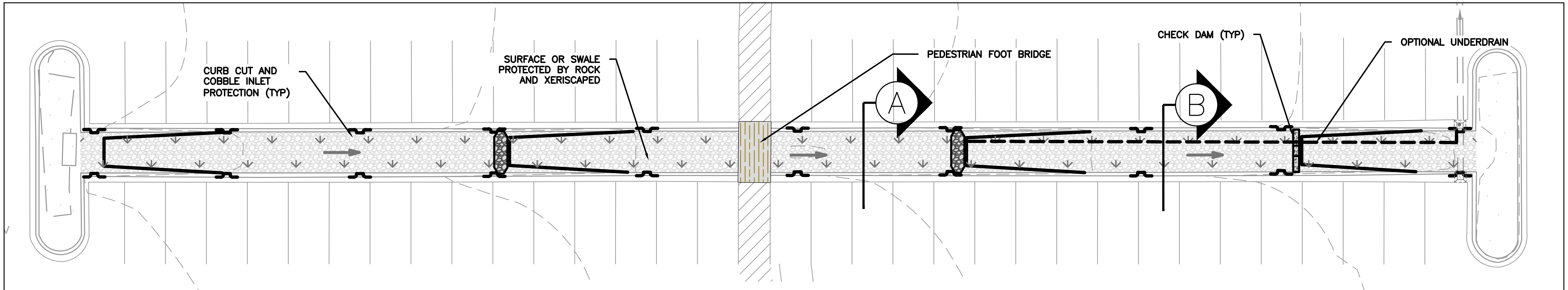
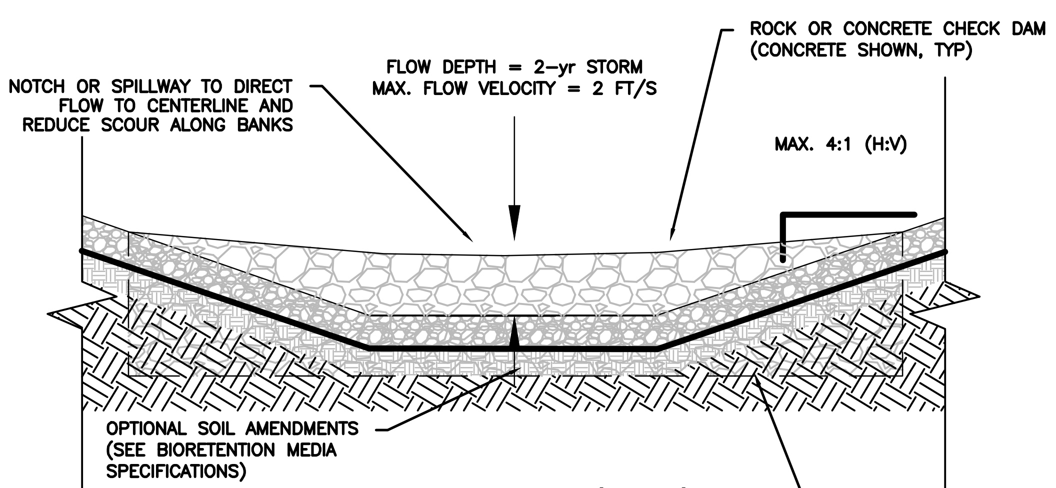


VEGETATED OR ROCK SWALE PLAN



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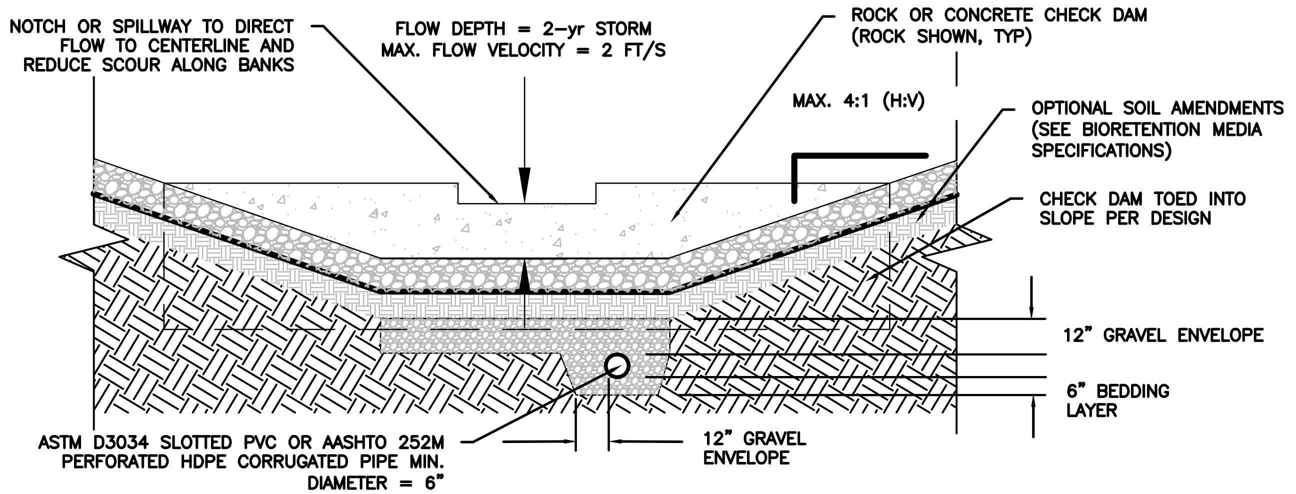

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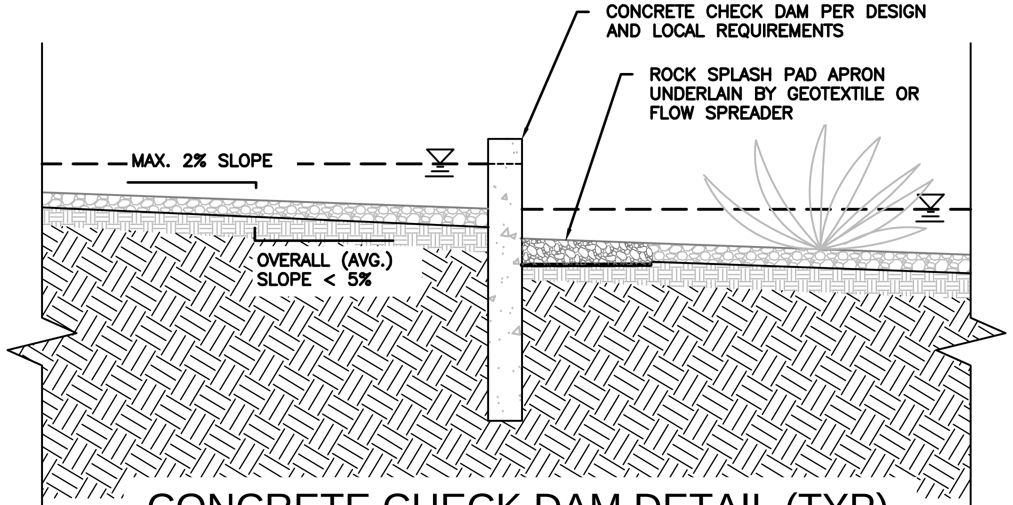

CONCRETE CHECK DAM DETAIL (TYP)

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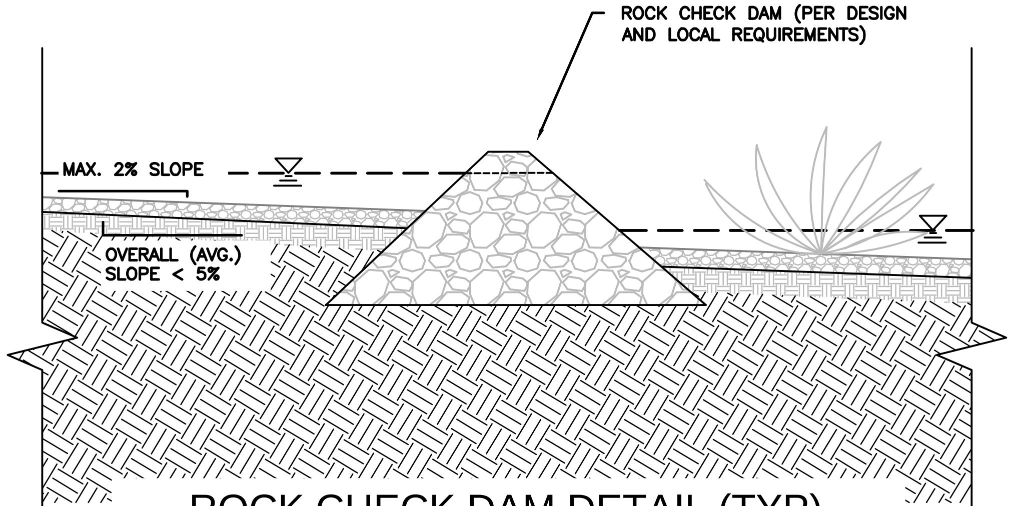

ROCK CHECK DAM DETAIL (TYP)

NOT TO SCALE

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PIMA COUNTY

ENGINEERING DESIGN TEMPLATE

PIMA COUNTY

VEGETATED OR ROCK SWALE

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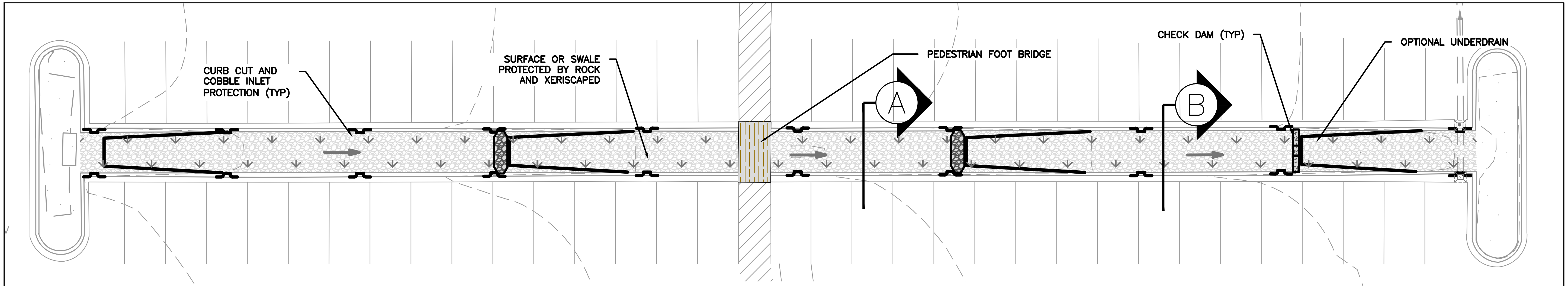
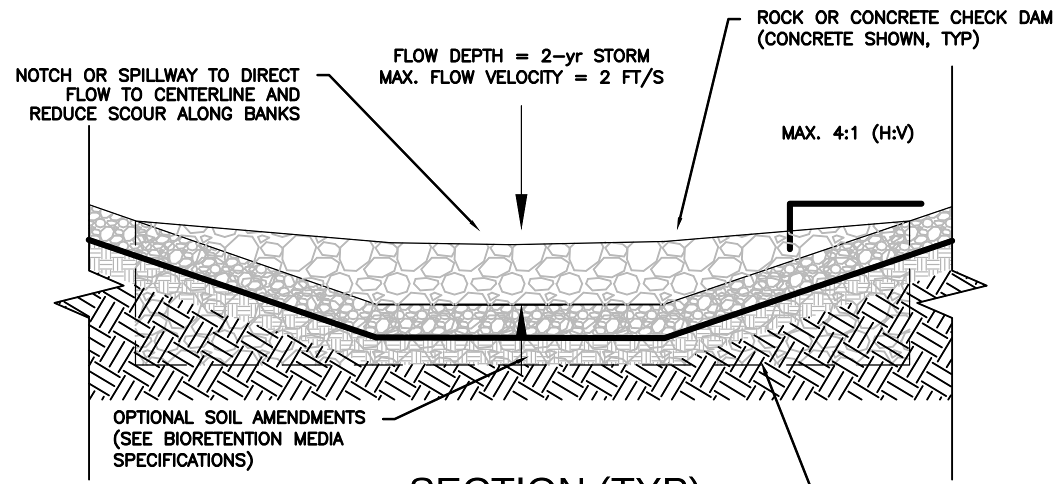


VEGETATED OR ROCK SWALE PLAN



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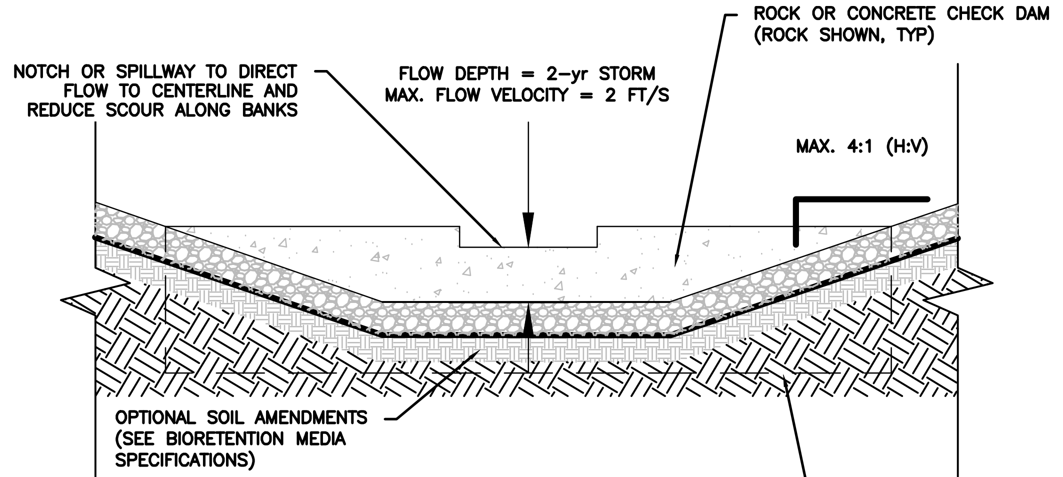
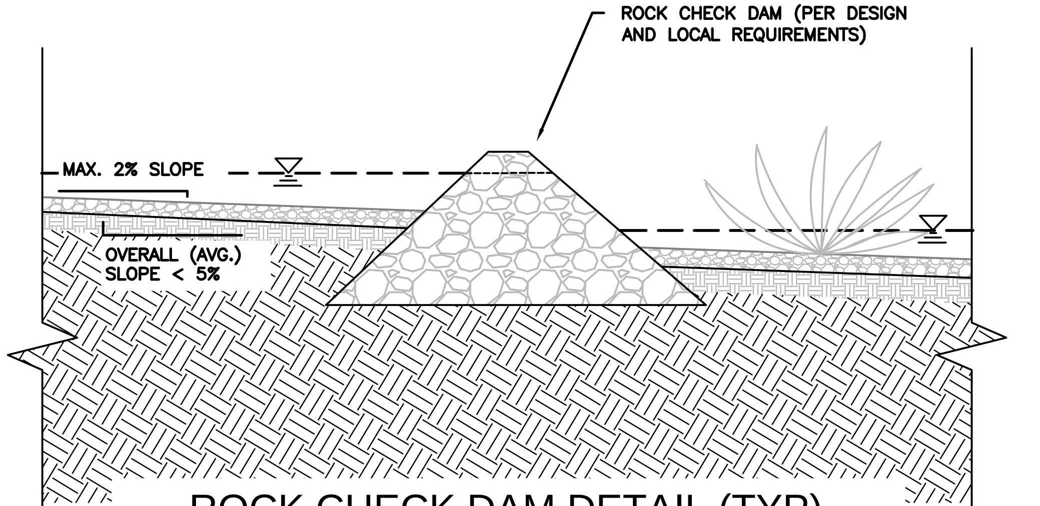


B SECTION (TYP)

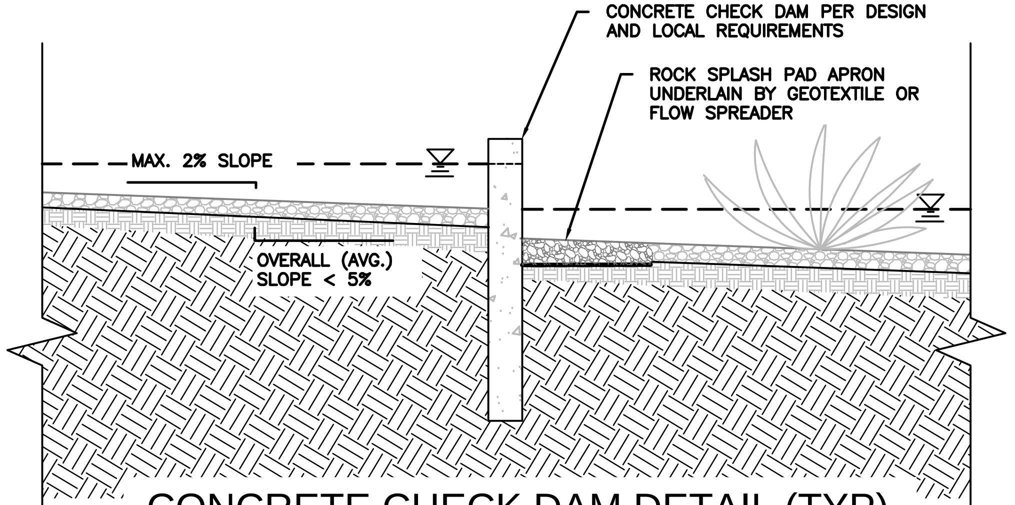
NOT TO SCALE

NOTE: STORMWATER HARVESTING VIA INFILTRATION SHOULD BE ENCOURAGED BY MINIMIZING AND MITIGATING COMPACTION OF SUBSOILS WHERE SUITABLE. CONCRETE CHECK DAMS SHOULD ONLY BE USED IF SOILS WILL DEWATER IMPOUNDED RUNOFF IN A SUFFICIENT DURATION (PER LOCAL REQUIREMENTS), OTHERWISE A NON-CLOGGING WEEP HOLE OR OTHER DEWATERING MECHANISM SHOULD BE PROVIDED.



ROCK CHECK DAM DETAIL (TYP)

NOT TO SCALE



CONCRETE CHECK DAM DETAIL (TYP)

NOT TO SCALE

CITY OF TUCSON

PIMA COUNTY

ENGINEERING DESIGN TEMPLATE

PIMA COUNTY

VEGETATED OR ROCK SWALE

DISCLAIMER: THESE TEMPLATES ARE INTENDED TO REPRESENT TYPICAL DETAILS. EACH DETAIL WILL REQUIRE REVISIONS TO MEET SPECIFIC SITE CONFIGURATIONS AND CONSTRAINTS BEFORE INCORPORATION INTO DESIGN PLANS.

DRWN. BY:Tt(BJW)	DATE: 12/2014	REVISED:____	SHEET NO.: 1 OF 1