# Low Impact Development and Green Infrastructure Guidance Manual

December 2014

## Contents

# Figures

# Tables

## 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 |
| COD | chemical oxygen demand |
| DO | dissolved oxygen |
| EPA | U.S. Environmental Protection Agency |
| ft | foot |
| GI | green infrastructure |
| HDPE | high-density polyethylene |
| HIE | heat island effect |
| hr | hour |
| $K_{sat}$ | saturated hydraulic conductivity |
| LID | low impact development |
| meq | milliequivalents |
| mm | millimeter |
| MS4s | municipal separate storm sewer systems |
| MSDS | material safety data sheets |
| NCSU-BAE | North Carolina State University Department of Biological and Agricultural Engineering |
| NPS | non-point source |
| 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

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

**Best Management Practices (BMP)**: Activities, practices or prohibitions of practices designed to prevent or reduce pollution.

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

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

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

**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 principal, 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 (EPA)'s Heat Island website.

**Level Spreader:** An outlet designed to convert concentrated runoff to sheet flow and disperse it uniformly across a slope 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, minimizing effective imperviousness to create functional and appealing site drainage that treat stormwater as a resource rather than a waste product.

**NPDES: National Pollutant Discharge Elimination System**; 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).

**Open Space:** Land set aside for public or private use within a development that is not built upon.

**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 gray water if available) while preserving tap water for indoor and drinking water needs.

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

**Site Fingerprinting:** Development approach that places development away from environmentally sensitive areas (wetlands, steep slopes, etc.), future open spaces, tree save areas, future restoration areas, and temporary and permanent vegetative forest buffer zones. Ground disturbance is confined to areas where structures, roads, and rights-of-way will exist after construction is complete.

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

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

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

*Sources*

RainScape Principles can be applied to a new or existing yard to create a beautiful and water efficient landscape AZ1539 February 2011 http://cals.arizona.edu/pubs/garden/az1539.pdf

Low Impact Development Center http://lowimpactdevelopment.org/school/glossary.html

# Preface

This manual is intended to be technical guidance 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. The sections of this manual are summarized as follows and shown in (Figure 1):

**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.

**Low Impact Development Principles:** The basic concepts of LID and 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 preservation of natural flow paths, where to locate structural practices in the watershed based on vegetation's water budget, 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 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 with an end result of an alternative site design which maintains the pre-hydrologic conditions of a site. Maintenance is integral to the long-term function of LID Practices.
- **Structural LID Practices**: This section provides guidance on the structural GI/LID Practices that can replace traditional stormwater infrastructure while achieving storage, infiltration and conveyance that mimics pre-development hydrology.
- **Common LID Components**: This section describes common drainage design features and how to incorporate them with LID 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
- 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 cfs/ac
- Appendix E: Simulating Offset of Water Demand from Varying Cistern Volumes
- Appendix F: AutoCASE™ Beta Testing Project
- Appendix G: Plant List
- Appendix H: Drawings

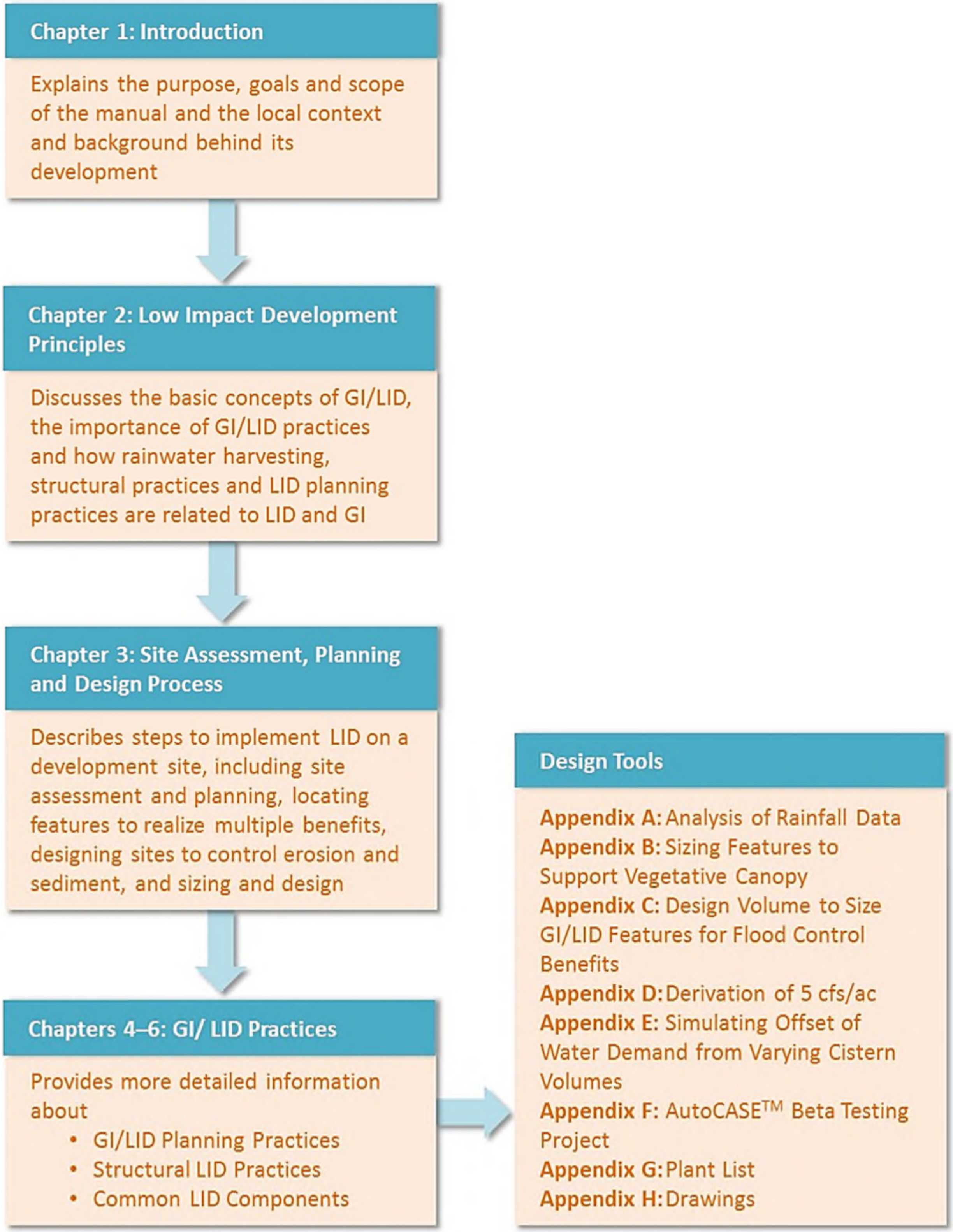



*Figure 1. Document organization.*

## 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 addressed 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 a Technical Assistance Grant to Pima County from the 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 grant, who provided oversight in collaboration with Christoper Kloss and Jamie Piziali.

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

**City of Tucson**
Irene Ogata
Beverly Hester
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
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) (GI/LID) Practices throughout Pima County. This manual provides supplemental guidance to the Pima County *Design Standards for Storm Water Detention and Retention* and the City of Tucson Water Harvesting Guidance Manual. The intended audience includes the professional community who design, build, and/or retrofit new developments and neighborhoods. In particular, the manual is intended to provide the following guidance:

1. Selecting appropriate GI/LID Practices;
2. Implementing multi-purpose GI/LID features during site layout;
3. Implementing treatment train approaches (series of GI/LID practices) to rainwater and stormwater management;
4. Designing and constructing these GI/LID Practices; and
5. Inspecting and maintaining procedures to ensure the GI/LID Practices continue to function as designed and provide the benefit expected.

## 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 at the lot and neighborhood scale result in the best opportunities. The benefits are enhanced because the percent of rainfall that can be harvested as stormwater is greatest at this scale and decreases as watershed size increases as illustrated by (Figure 2). This manual was developed to provide formal 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.

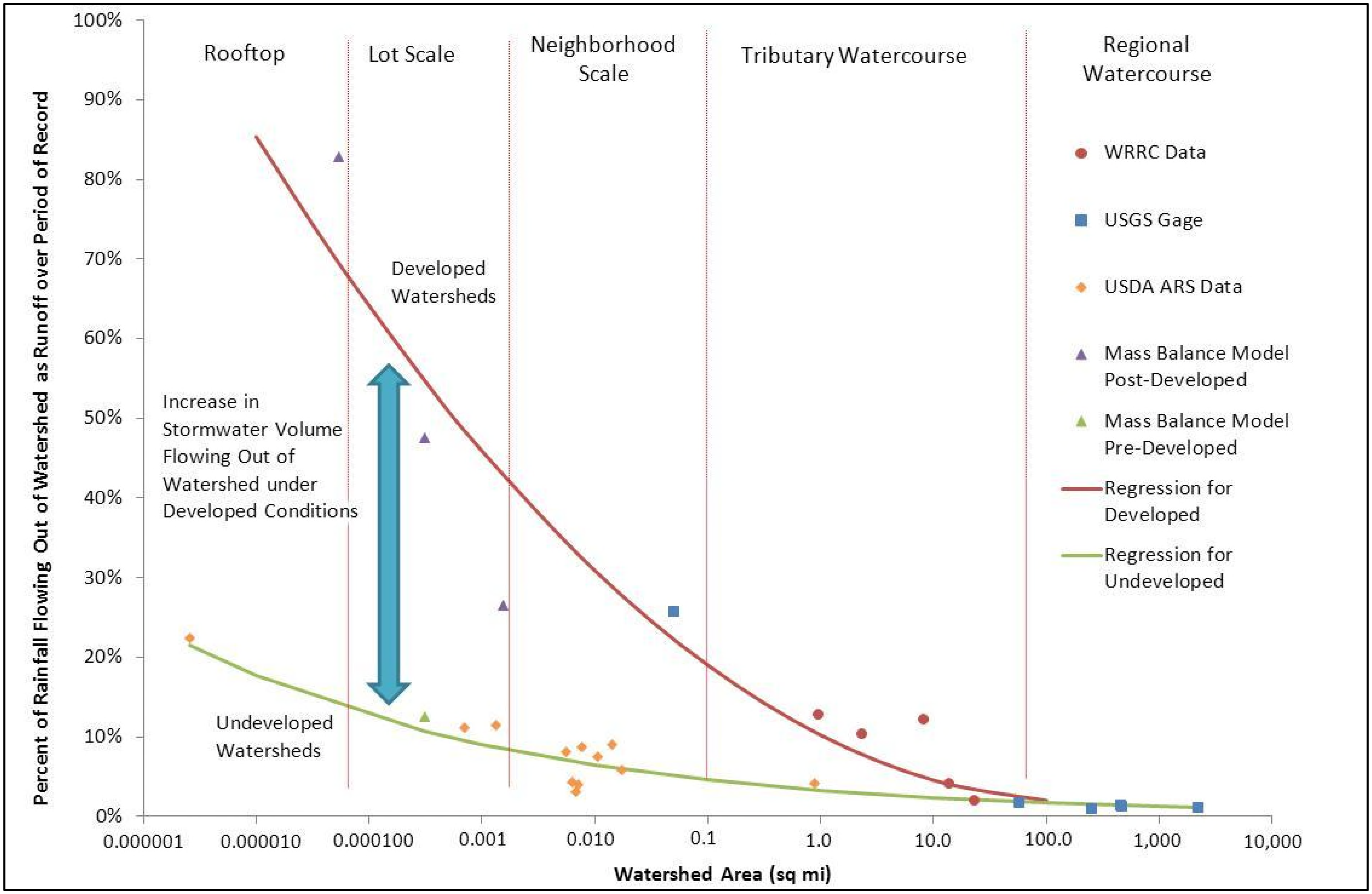



*Figure 2. The percent of rainfall flowing out of watersheds as runoff over the period of record for varying scales and development conditions.*

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, Pima County, 2009). In 2011, Arizona Department of Environmental Quality (ADEQ) issued individual Arizona Pollutant Discharge Elimination System (AZPDES) Municipal Separate Storm Sewer System permits to Pima County and the City of Tucson which required them to evaluate how incorporation of LID Practices into their respective planning and development processes can reduce pollutants in stormwater discharges. LID consists of 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. As a general principal, GI techniques 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 used together, they are often used synonymously or together and 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 manage water and water pollutants at, or near, the source and thereby 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. As described, 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 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. In addition to increasing and improving habitat availability for wildlife, these trees and other vegetation can also provide sound attenuation along major streets, provide a calming effect (reduced driving speeds) in residential streets, all of which enhances 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 GI/LID Practices during site design.
3. Design guidelines for locating and sizing structural GI/LID Practices.
4. Standard plan and/or cross-section views.
5. Standard details for the GI/LID Practice.
6. Design references.

The application of the manual's principals will be useful in assessing the applicability of LID and provide valuable information on field applications and design standards.

### 1.3.1 Project Scale

This manual is intended to cover 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 gray water practices, can be applied at the lot scale and are encouraged when in compliance with local regulations.

## 1.4 Integration with Other Efforts

This effort integrates with other current efforts as follows:

1. *The Stormwater Detention/Retention Manual*: The Detention/Retention Manual (http://webcms.pima.gov/cms/one.aspx?portalId=169&pageId=65527) is a regulatory document that describes which LID Practices have been accepted as practices having a quantifiable flood control benefit within Pima County. These practices can be used to reduce or off-set the requirement for on-site detention. Furthermore, it establishes standards regarding on-site retention and describes how stormwater harvesting basins must be constructed to meet this requirement.
2. Throughout Pima County and the City of Tucson, flood control measures must be implemented to mitigate the effect of increased impervious surfaces associated with development which increase runoff volumes. LID mitigates the impact of development by connecting impervious surfaces to porous 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 which are a non-life threatening nuisance, as well as peak flows that can cause flooding.

   The initial runoff in an event entrains contaminants and other materials. 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 capturing the first ½" of rainfall as a means to satisfy the flood retention requirements. This requirement will apply to new development and substantial redevelopment.
3. *A GI/LID Case Study Catalog:* Members of the community are collecting data on projects that use LID Practices already constructed. These will be compiled into a 'catalog' of projects that can be used to demonstrate the benefits of LID in our 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 development 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:* Directing stormwater runoff from roadways through GI prior to entering storm drains or natural drainage ways.
7. *Water Quality Regulations and Permits:* ADEQ stormwater quality regulations require Local municipal separate storm sewer systems (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, for Sections 303(d) and 404 of the Clean Water Act, site specific post-construction best management practice (BMP) for stormwater quality may be required to address stormwater discharges for construction operators. LID practices are a post construction BMP option to prevent erosion and provide vegetation cover. The designs and approaches in this LID Guidance Manual can be used in concert with the Arizona Department of Transportation (ADOT) Post Construction BMP Manual for Water Quality. The ADOT Manual was developed to provide options for ADOT's MS4 responsibilities and is referenced by other MS4s throughout the state. It provides information on specified ratings, appropriate applications, materials, design standards, design considerations, maintenance and schematics for the BMPs. The LID related BMPs addressed in this manual include: Roadway Drainage Conveyance to stormwater harvesting basins, Stormwater Quality and Treatment (bioretention, infiltration trenches, retention within stormwater harvesting basins, and vegetated swales).

Municipalities can implement 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 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. LID is also a measure MS4s can use to break down and sequester non-point source (NPS) stormwater pollutants and prevent their accumulation in downstream surface waters in order to meet stormwater quality standards.

The connection between LID and stormwater pollution preventions 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 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 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 can be used to gather ideas or new approaches to design and learn from previous projects. Lessons learned include what was successful and what could have been done differently.

# 2 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 less 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) then can be defined as systems and practices that preserve, enhance or recreate the natural functionality of an area being developed. GI/LID practices can 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 of a roof top. Stormwater is defined as precipitation that has landed on the ground, and will either infiltrate 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. 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 3) illustrates the integrated relationship between the above concepts. Key elements of GI/LID are described in (Figure 4).

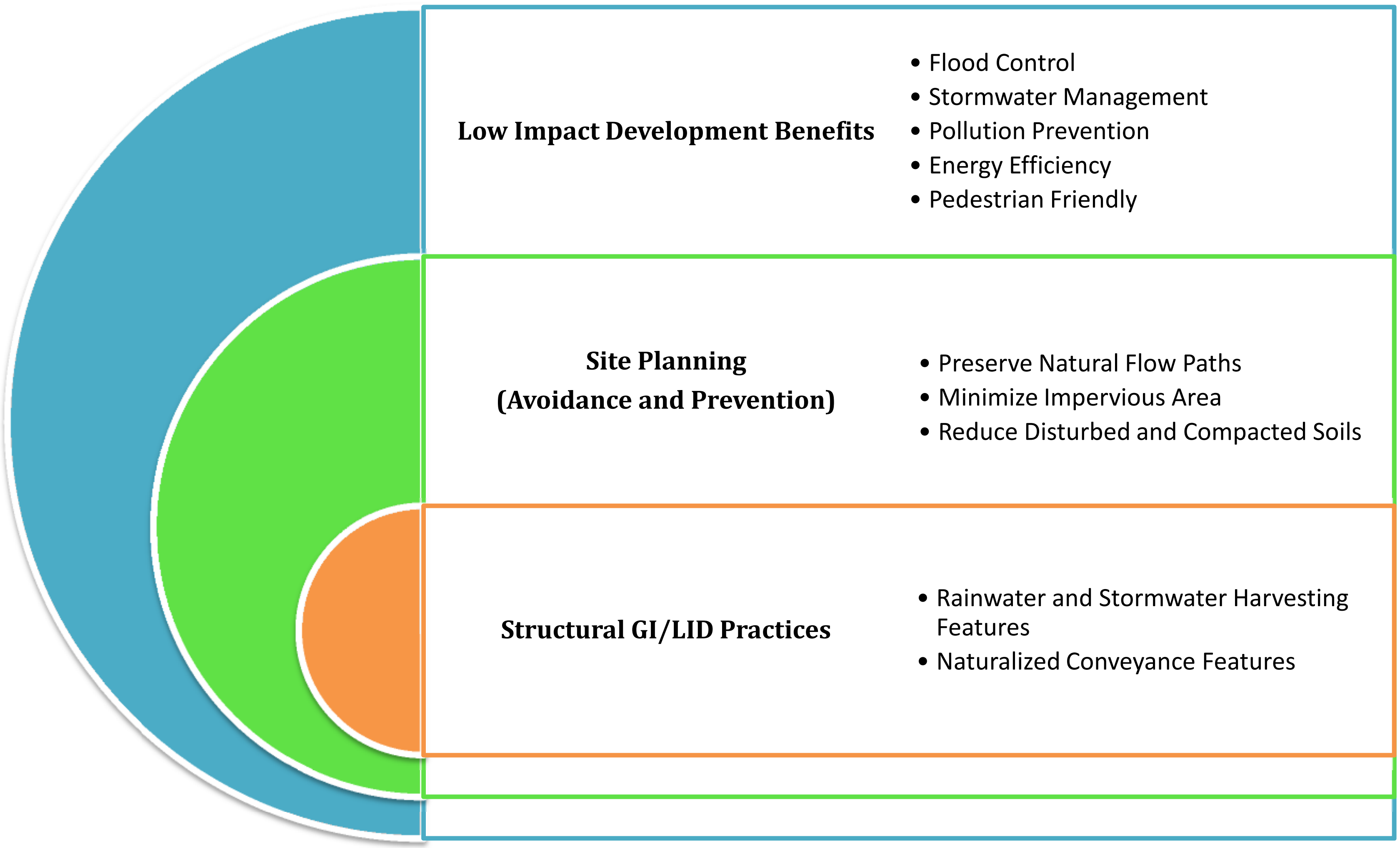



*Figure 3. Relation between LID strategies, LID planning control measures and structural GI/LID practices such as rainwater and stormwater harvesting.*


*Figure 4. Key elements of LID (Source: Low Impact Development Center).*

## 2.2 What are LID and GI?

The following descriptions and illustrations briefly describe LID planning and Structural GI/LID.

### 2.2.1 LID Site Planning—Avoidance and Prevention

| Feature | Name | 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 makes use of existing resources such as stormwater flow paths and vegetation which maximizes infiltration of storm flow.<br>Directs stormwater to the site's pervious areas, natural areas, natural flow paths, floodplain and riparian areas. Approach reduces use of impervious conveyance structures (storm drains, concrete channels, etc.) |
|  | Conserve Natural Areas and Protecting Natural Flow Paths | Uses natural drainage features to reduce or eliminate the need for structural drainage systems.<br>Sets aside sensitive areas that otherwise would be negatively impacted. Attenuates impacts of increased stormwater by capturing and infiltrating water.<br>Provides passive recreation opportunities that can Increase adjacent property values.<br>Conforms to Sonoran Desert Conservation Plan. |

| Feature | Name | Purpose |
|---|---|---|
|  | 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 |

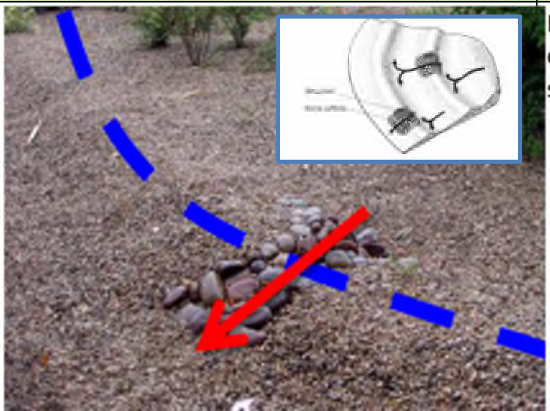
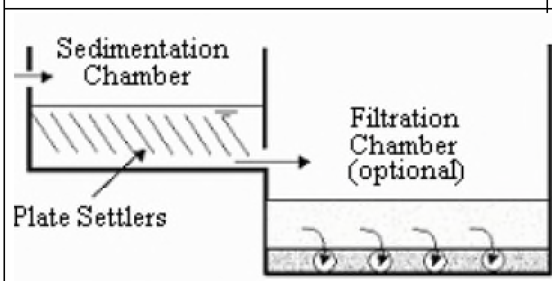
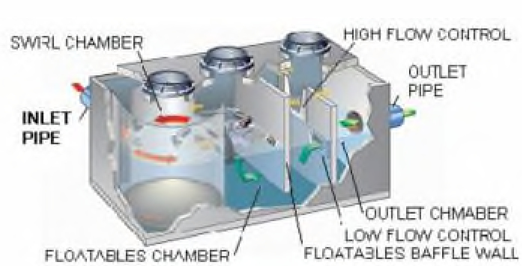
### 2.2.2 Structural GI/LID Practices—Mitigating Impact and Retrofitting

| Feature | Name | Purpose |
|---|---|---|
|  | 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. |
|  | Bioretention Basin | A depressed area with a constructed soil media that captures stormwater and may also contain underdrains to enhance infiltration. |

| Feature | Name | Purpose |
|---|---|---|
|  | | |
|  | 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 rigged to supply irrigation to the site by a simple hose bib or a complex automatic pumping and perforated polyvinyl chloride (PVC) piping system. |

| Feature | Name | Purpose |
|---|---|---|
|  | 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 | 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.<br>Inlet/Outlet Protection such as a rock 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. |
| <br> | Pretreatment Devices | Often a chambered device that filters stormwater prior to introduction to a downstream cleaner water source. These devices include sand filters as well as many proprietary elements. |

## 2.3 Why Use 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, Arizona, rainwater and stormwater are valuable resources that have many beneficial uses, but have historically been disposed of as a nuisance and a hazard. The concept of GI/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, reduces the amount of runoff exiting the development, and improves runoff quality by providing greater areas for infiltration, evapotranspiration, and sediment deposition. When applied appropriately, the LID site layout concepts minimize the number of GI/LID Practices required to restore discharge rates and volumes, and maximize the effectiveness of these structural GI/LID 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 following 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, and 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 practices seek 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 ($K_{sat}$) compared to the adjacent undeveloped watershed when measured by tension infiltrometer at spatially varying points (Figure 5, Kennedy 2007). The geometric mean of the $K_{sat}$ of the undeveloped grassland watershed was 6.1 mm (millimeter)/hour (hr) and for the newly developed soils it was 2.2 mm/hr (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 reduce the impacts of the developed area and preserve areas of undisturbed soils allowing for higher rates of infiltration.

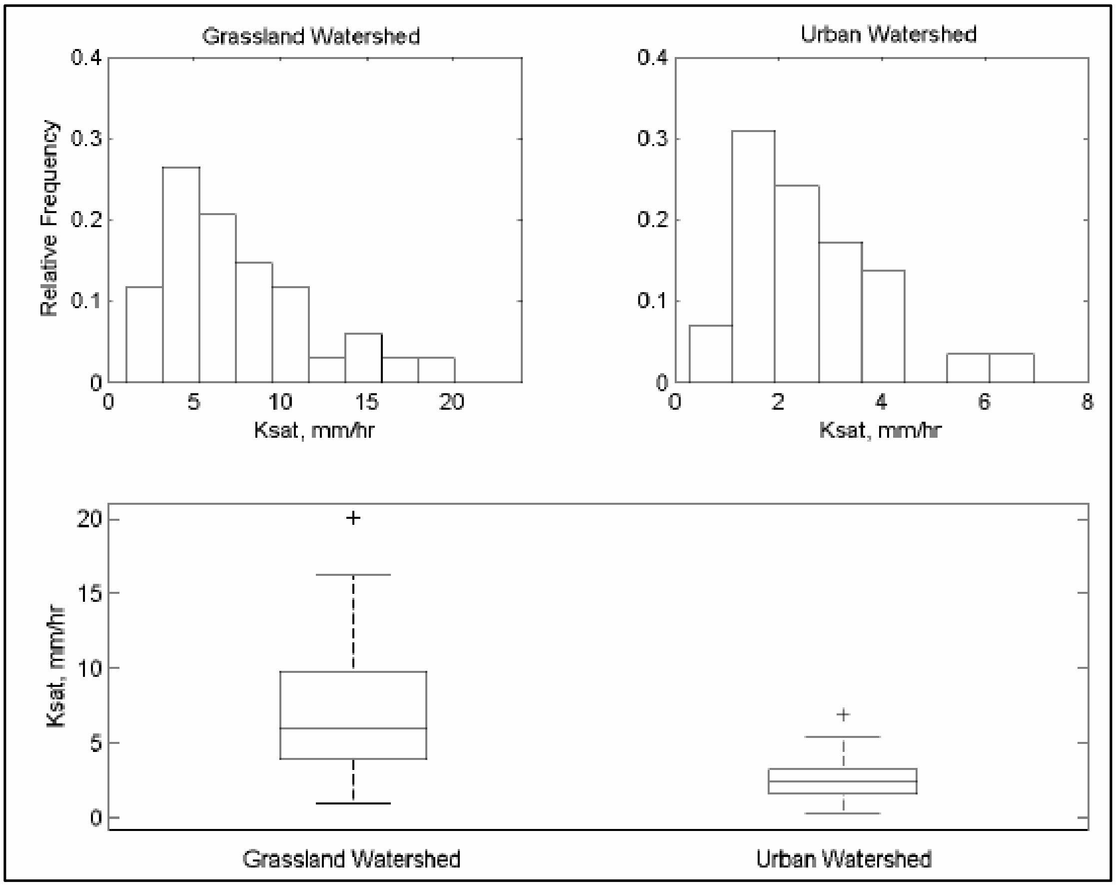



*Figure 5. $K_{sat}$ data measured by tension infiltrometer at spatially varying points within the undisturbed and developed watersheds at Sierra Vista, Arizona (Kennedy 2007).*

### 2.3.3 LID Reduces Pollutants in Stormwater

Water quality improvement occurs with reduced runoff, filtering solids and adsorbing dissolved constituents, and decomposing nutrients. When runoff is reduced, the flow rate is slower resulting in less downstream erosion. Structures filter suspended materials. A study in Davis, California, assessed the change in runoff and water quality characteristics between a control site which 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 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).

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 an LID practice where natural processes (Chapin, et al, 2002) can improve the water quality Figure 6). Natural processes that can improve stormwater quality include the following:

1. Interception (portion of rainfall lands on plants, dissipates the impact and accumulation of the rainfall; therefore reduces runoff)
2. Infiltration (rainfall passes into soil; 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 plant’s leaves; therefore cannot increase runoff)
5. Evaporation (stormwater is retained in crevices or swales on the land, is evaporated to the atmosphere; therefore cannot become runoff)
6. Sedimentation (stormwater is slowed by rough terrain or swales, allowing settling of clay, silt, sand and gravel to swale bottom by gravity; therefore prevents 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; therefore prevents floatables from being transport 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 are enhanced due to increased interface increased exposure time with stormwater and development of a soil micro-climate. These include: adsorption (adhesion of ion or molecules to oppositely charged soil particles); chelation (process where organic acids combine with metallic ions making them soluble and mobile); ion exchange (exchange of ions between water and a media); organic complexing (synthesis of organic compounds with other organic or inorganic compounds); therefore cleansing the stormwater as it is absorbed into the soil.
10. Microbial decomposition is also improved (conversion of dead organic matter into $CO_2$ and inorganic nutrients through leaching, fragmentation and chemical alteration by soil, animals, bacteria and fungi)

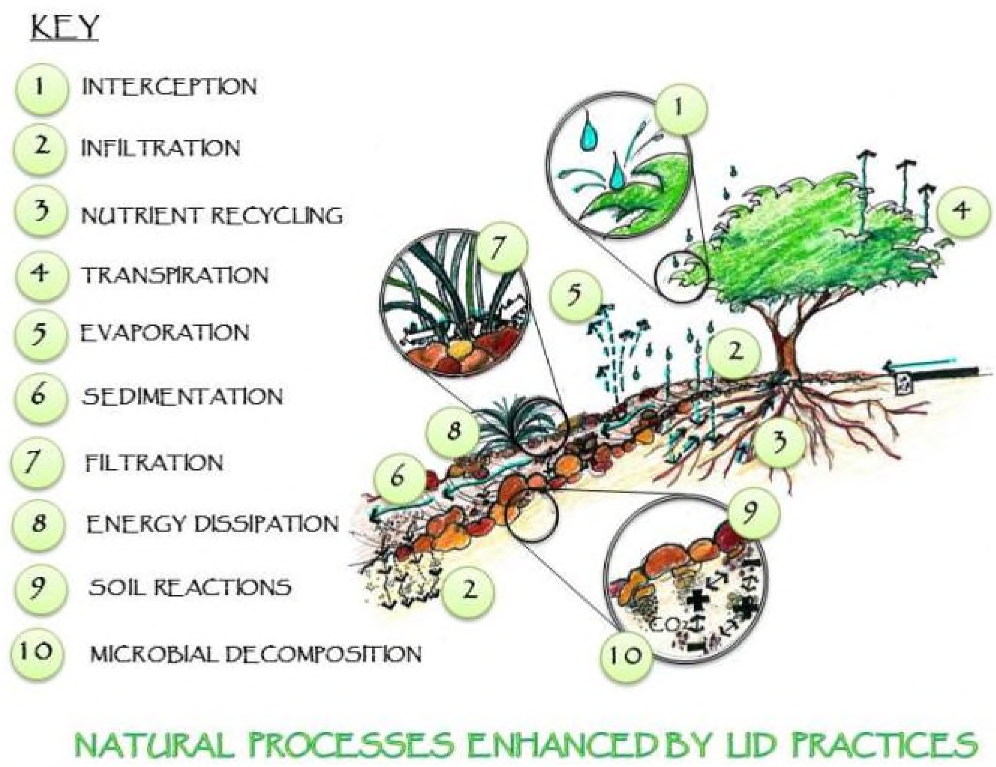



*Figure 6. Natural chemical and biological transformations in LID.*

Interception, transpiration, evaporation and infiltration reduce the amount of runoff which in turn slows the surface reducing the potential for erosion. Nutrient cycling and soil reactions improve the 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

#### 2.3.4.1 GI/LID Supports Vegetative Growth

##### Native Plant Materials

GI/ LID practices promote sustainability of plant materials 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 all plant materials. GI/ LID practices further encourage sustainable design by promoting locally native, or plant species with characteristics compatible to local conditions. By definition, these plant materials 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. A list of native and desert-adapted plant materials is found in **Appendix G.**

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. Their tolerance to standing in water accumulated 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. The plant list in Appendix G provides guidance on plants capable of survival in a variety of situations.

#### 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 all 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 and mitigate perceived negative visual impacts. 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. Maintaining the bufferyard is less of a financial burden when the water cost is reduced.

#### 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 used 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 a home, but a popular trend is gardens that support an adjacent restaurant. 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. Cistern storage would provide a longer-term sustainable water source.

### 2.3.4.2 GI/LID Can Provide Passive Recreation and Improved Aesthetics, Safety, and Economic Benefits

#### Recreation and Aesthetics

LID Practices can provide substantial benefits to a residential subdivision. Integration of these practices into the design process automatically increases the amount of undisturbed natural area and its proximity to proposed homes. A home in the context of a more natural setting will always have a greater aesthetic value. These natural landscapes already support native plants which will thrive due to redirection of stormwater resources. 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 walking, bird watching or viewing sunsets, to name a few. Such activities increase family and social networks and create the kind of neighborhood that continually grows in value.

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 greener, high-rise apartment buildings 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 LID 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. 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 more efficiently should be incorporated into new development.

Reduced crime is another beneficial side effect of 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 provides several examples of increased property values associated with natural areas and GI.

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

| Source | Percent increase in Property Value | Notes |
|---|---|---|
| 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. |
| Shultz and Schmitz (2008) | 0.7 to 2.7% | Referred to effect of clustered open spaces, greenways and similar practices in Omaha, NE. |
| Wachter and Wong (2006) | 2% | Estimated the effect of tree plantings on property values for select neighborhoods in Philadelphia. |
| Anderson and Cordell (1988) | 3.5 to 4.5% | Estimated value of trees on residential property (differences between houses with five or more front yard trees and those that have fewer), Athens-Clarke County (GA). |
| 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 |
| Espey and Owasu-Edusei (2001) | 11% | Refers to small, attractive parks with playgrounds within 600 feet of houses |
| Pincetl et al. (2003) | 1.5% | Refers to the effect of an 11% increase in the amount of greenery (equivalent to a one-third ac garden or park) within a radius of 200 to 500 feet from the house |
| 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 |

Figure 7 summarizes the multiple benefits of LID Planning Practices, while Figure 8 summarizes the multiple benefits derived from structural GI/LID Practices.

| GI/LID Non-Structural Practices \ Benefits | REDUCES STORMWATER 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 | Yes | Yes | Yes | Yes | Yes | Yes |
| DISCONNECT AND MINIMIZE IMPERVIOUS AREAS | In Some Cases | Yes | In Some Cases | No | No | No |
| MINIMIZE DISTURBED AREAS AND SOIL COMPACTION | Yes | Yes | In Some Cases | In Some Cases | In Some Cases | In Some Cases |
| RESTORE DISTURBED NATURAL AREAS | Yes | Yes | Yes | Yes | Yes | Yes |

*Ordinance No. 2010 FC5 Title 16 Chapter 16.30

Yes — In Some Cases — No

*Figure 7. Benefits of GI/LID planning practices.*

| GI/LID Practices \ Benefits | REDUCES STORM-WATER RUNOFF | | INCREASES AVAILABLE WATER SUPPLY | | IMPROVES COMMUNITY LIVABILITY | | | |
|---|---|---|---|---|---|---|---|---|
| | 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 HARVEST-ING BASINS | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes |
| SWALES | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes |
| BIORETENTION SYSTEMS | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes |
| INFILTRATION TRENCHES | Yes | Yes | In Some Cases | No | In Some Cases | In Some Cases | In Some Cases | In Some Cases |
| DRY WELLS | Yes | Yes | No | No | No | No | No | No |
| CISTERNS | In Some Cases | In Some Cases | Yes | Yes | No | In Some Cases | No | No |
| PERVEOUS PAVEMENT | Yes | Yes | No | No | In Some Cases | No | In Some Cases | No |

Yes In Some Cases No

*Figure 8. Benefits of structural GI/LID practices.*

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# 3 Site Assessment, Planning, and Design Process

## 3.1 Site Assessment and Hydrology

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/LID 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 tools are provided in the manual. The guidance provided here is non-regulatory.

A LID planning site design preserves existing flow paths through the site and minimizes the disturbed area. Structural 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. 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.

## 3.2 Site Planning

The placement of development within regulatory floodplains, riparian habitat and the 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 (natural resource). 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; to provide a natural buffer from neighboring properties; to provide a recreational amenity.

Once the site layout is determined, consideration of the type and location of structural GI/LID Practices is necessary. These practices should augment/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 LID Practices as described in Section 2.3, "Why Use 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. Location of Impervious Site Features

On larger commercial sites and multiple family residential sites, the strategic location of impervious surfaces and the pervious areas can optimize the 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 amenity 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 tenuous the path, the greater the infiltration to the vegetation root zone, and the less potable water required. 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 potential patrons of commercial sites.

### 3.3.2 Shade to Mitigate HIE

Shade-providing trees should be considered when selecting vegetation for LID Practices. LID Practices should be located close to impervious areas such as buildings, sidewalks and parking lots to reduce the heat absorbed by and radiated from impervious surfaces when shade can be provided.

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 water quality should be identified when designing an LID site. These 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 and/or infiltration 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 by designing 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 LID 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 an LID practice should be covered with rock mulch, or rip rap 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 LID Practices. Rock mulch should be ½” or greater crushed gravel and should be screened and washed to remove fines.

At the transition from impervious areas draining to pervious areas, a 1–2 foot (ft) 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 such as 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 ft/second (s). 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 retention LID Practices at the end of conveyance features should be designed to collect sediment entrained in runoff. This can be accomplished by designing sediment traps at the inlets of stormwater harvesting basins. Sediment traps facilitate maintenance of LID retention features and can prevent the need for major maintenance by preserving infiltration properties of LID 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 during the months of July, August, and 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; there is also a selection of native- adapted plants that may be considered as listed 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 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. Approximately 85% of all events are less than 0.5 inch (Figure 9). 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 *Design Standards for Storm Water Detention and Retention*).

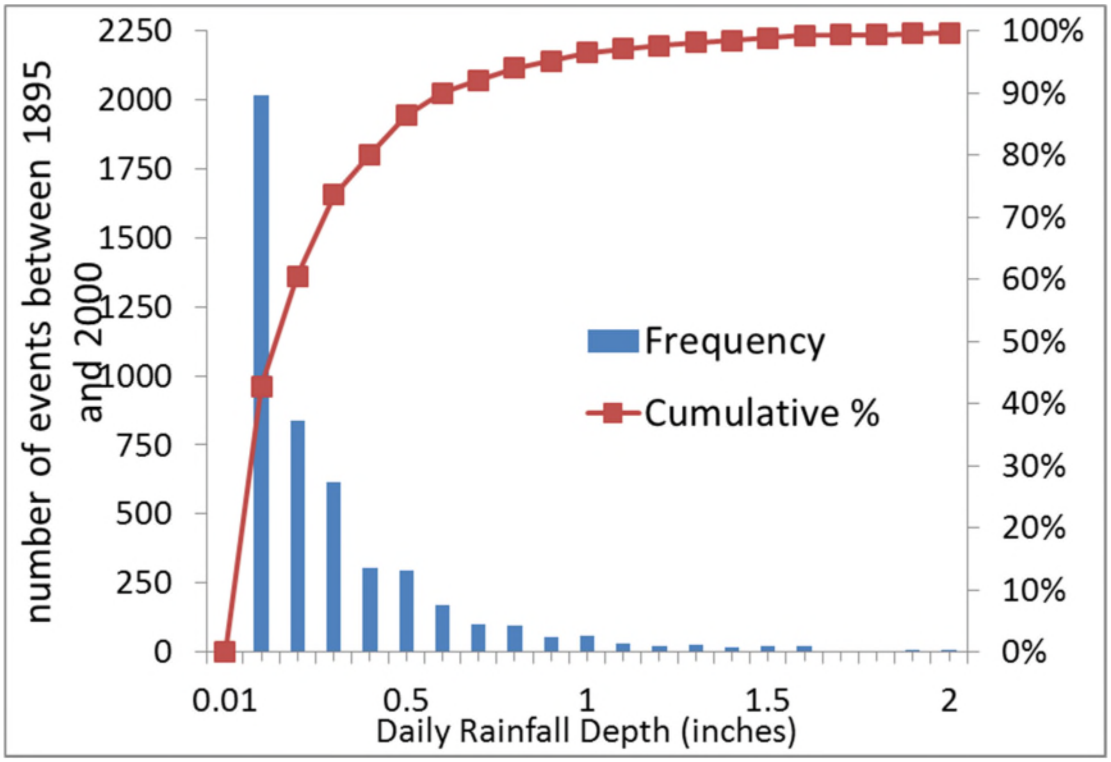


*Figure 9. Distribution of rainfall events measured at the University of Arizona between 1895 and 2000.*

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 cost-effectively. Figure 10 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.

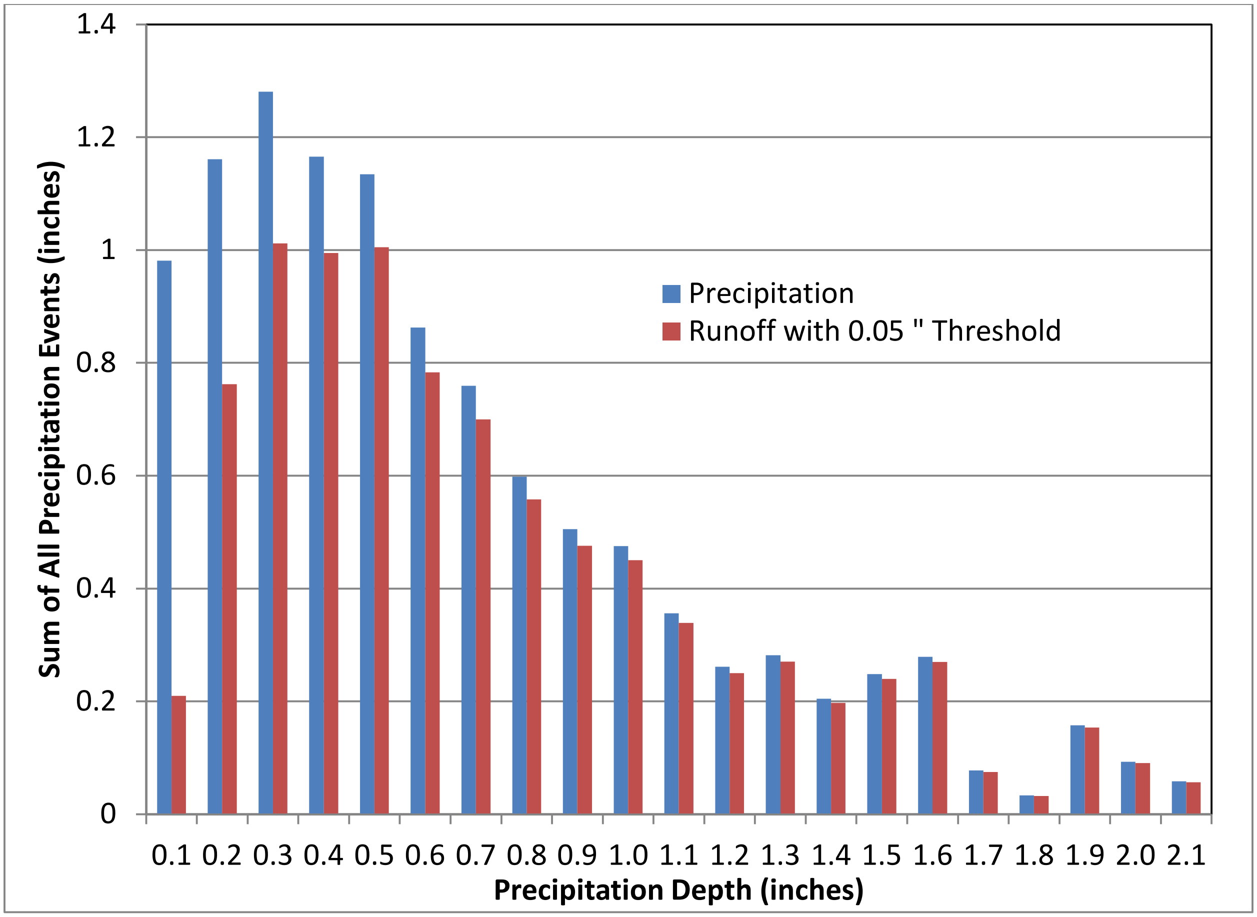


*Figure 10. Average annual precipitation and runoff from an impervious surface (based on 1895–2000 daily precipitation at University of Arizona).*

The figure illustrates that very small events, such as those less than 0.1-inch depths, 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 inches 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 11. 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 (yr)] flood event). Therefore, the analysis of rainfall indicates that features should be designed to accommodate rainfall events between 0.5 inches 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 the peak rainfall volumes are described in Appendix C.

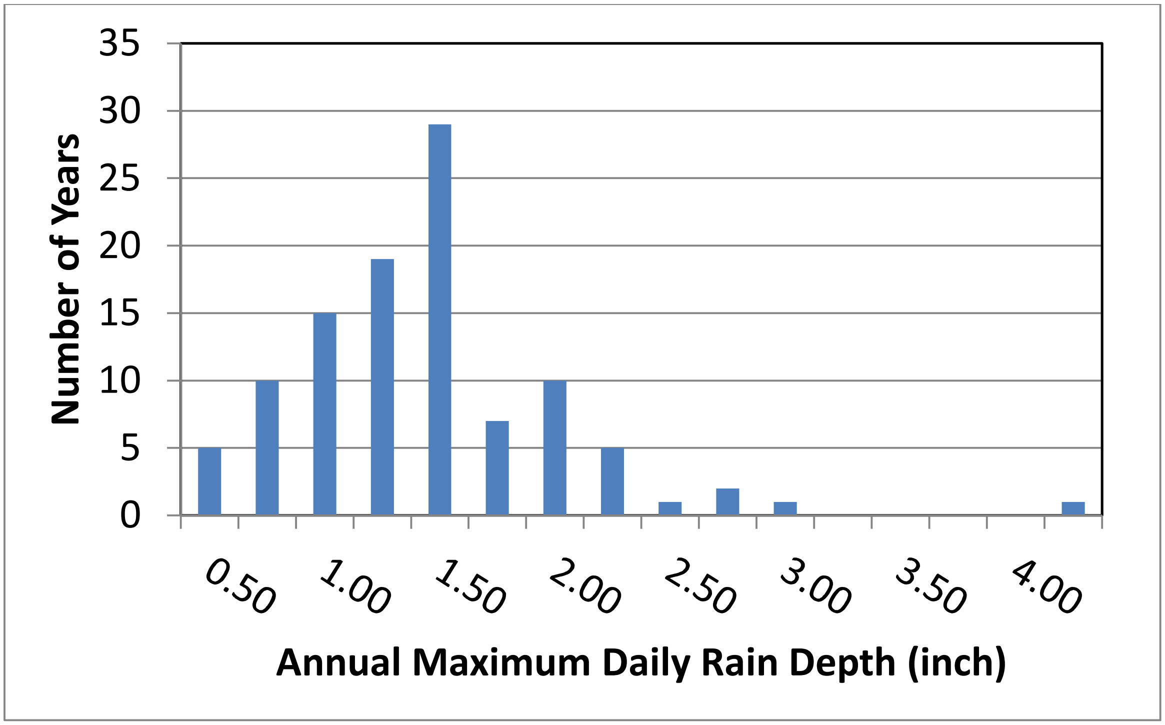


*Figure 11. The annual maximum daily rainfall depths in the University of Arizona data.*

However in some cases the features may need to be sized for a regulatory requirement. In other cases, the LID 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 a LID Practice. 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-hr 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 ac (acre) of impervious surface can be assumed to be 5 cubic feet per second (cfs). The derivation of this 5 cfs/ac 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-yr, 1-hr 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 to estimate a reduced peak discharge rate that can be used 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 LID 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 goals of LID Site Planning Practices emphasize avoidance and prevention. The focus is to minimize the initial generation of excess stormwater runoff. The entire site must be evaluated with these practices in mind before site design begins. The primary goals of LID Site Planning Practices include:

- Conserve Natural Areas and Protect Natural flow Paths (Analysis)
- Disconnect and Minimize Impervious Areas (Design)
- Minimize Disturbed Areas and Soil Compaction (Construction)
- Restore Disturbed Natural Areas (Restoration)
- 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.

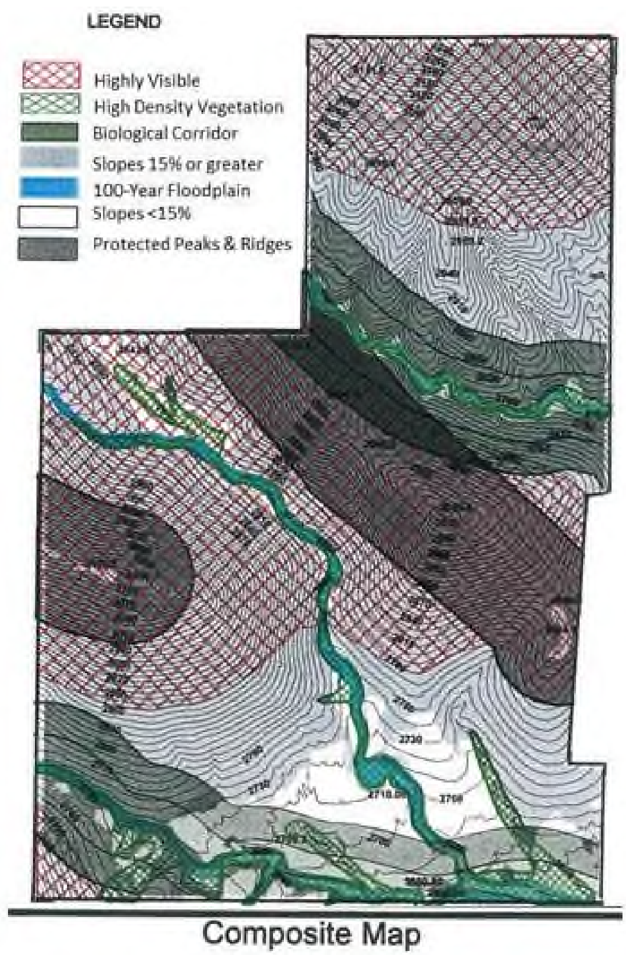



*Figure 12. Sample site analysis.*

### 4.1.1 Site Analysis

The first step of the design process is a thorough, comprehensive site analysis which should include 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 12) of critical natural features will reveal opportunities and constraints of the site; these may include contiguous unique natural areas, as well as areas that require the least effort to develop. No two sites are the same; 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 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 sub watershed 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 floodplain within or adjacent to the limits of the site are identified.

If possible, at this point in the planning process, opportunities to integrate desirable LID Practices into other community design objectives can be identified. At a minimum, the general influences from the surrounding conditions should be incorporated into the subject site.

### 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 set back 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 to not 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 now be expanded. In addition: drainage flows are minimized by accessing the newly created more permeable paved or landscape 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 LID Practices. Structural Practices are even more efficient when included in the design phase, rather than as a retrofit option. Proper location of Structural GI/ LID practices further influences how much stormwater is allowed to infiltrate and create benefits before it exits the site.

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. As these practices become more prevalent, and their value is more clearly perceived, they will become second hand to the design community.

### 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-ac park with access to a local wash which 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 which had provided support to the environmental assets of our 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 which promote wildlife survival, as well as amenity path systems and linear parks which 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. This is better described in Section 4.1.7 Considerations during Construction.

In contrast, by transforming these natural corridors into rigid concrete-lined channels, 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 allows the use of gravity flow to direct captured stormwater runoff to landscape areas which receive a direct benefit. 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 allows sediment a chance to drop out of the flow and gives stormwater time to infiltrate, decreasing the 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 LID Practices. These 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. See section 4.5 Restore Disturbed Natural Areas.

### 4.1.5 Unique Opportunities

Some sites undergoing design have natural areas that were disturbed previous to the current development. Disturbed areas should be included in the original site analysis and targeted for as much of the new development footprint impact as possible. These sites often offer unique opportunities for restoration, whether to complete a broken link to an otherwise undisrupted wildlife corridor/ riparian area on adjacent properties; or create a path for flows that previously backed up and flooded homes, allowing the stormwater to continue on its natural course. This 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 acquisition. There is often a high percentage of impermeable area due to the inclusion of utilities and drainage, plus necessary accommodation for pedestrian and bicycle uses. But opportunities still exist for LID Site Planning Practices. Some rights of way (ROW) 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 retro-fit 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 right-of-way, drainage can be slowed with curvilinear rocked and vegetated swales. These swales can intermittently direct flow to nearby natural riparian areas or 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, costly stormwater inlets, channels, and culverts can be significantly reduced.

### 4.1.6 Benefits from Using LID Site Planning Practices

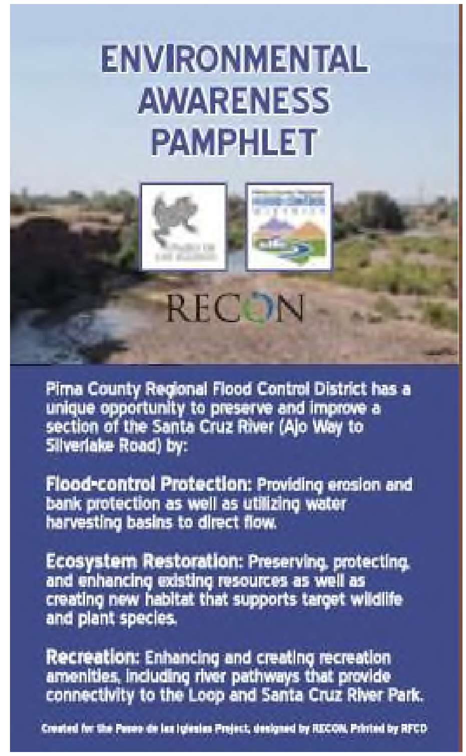
LID Planning practices are so tightly interwoven that the implementation of one practice often simultaneously produces the goals of a different practice, resulting in similar or the same benefits. This applies especially to larger sites that typically have more site features available to work with. See the individual practices where they are listed 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. The 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. Soils in the swales improve allowing better filtration and the net flow off-site is reduced. The development benefits from the act of setting aside the natural area: the net increase in site temperatures is decreased. By receiving supplemental water, the vegetation in the natural area flourishes and the wildlife benefits. Infiltration 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 principal 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; 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 due to increased sequestration of carbon dioxide in soils and plant biomass, therefore mitigating climate warming.

- Reduces the HIE by reducing or removing pavement and preserving and/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

A pre-construction meeting should be conducted with local neighbors, community officials, contractors and subcontractors. The goal 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 13).

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

### 4.2.1 General Description

| 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 |

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.

Natural areas and flow paths are often include riparian areas which have soils with some of the highest infiltration rates, and characteristically have established stands of native vegetation. They typically have a meandering character which delays the speed of flow, further increasing infiltration. Traditionally, post-construction flows quickly accumulate off hard surfaces and 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 the stormwater impacts. This type of flow management can reduce or eliminate the need for costly flow structures. This ultimately results in minimized stormwater runoff and reduction of the associated pollutants.

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 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 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). 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 which:

- Slow runoff flows
- Decrease 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 which 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 carbon dioxide 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

- 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; some hold critical environmental value; some improve the hydrology of the site design; some improve the value of the overall design due to aesthetics or recreational value. Once natural areas of greatest importance are identified, those areas can be designated for set-aside; thereby defining the remaining area to be suited for development.

The Copper Creek subdivision, located on Tucson's northwest side, was designed before GI/LID principals were household terms. Figure 14 illustrates how the original 1987 Concept Plan exhibits numerous characteristics that reflect current GI/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.

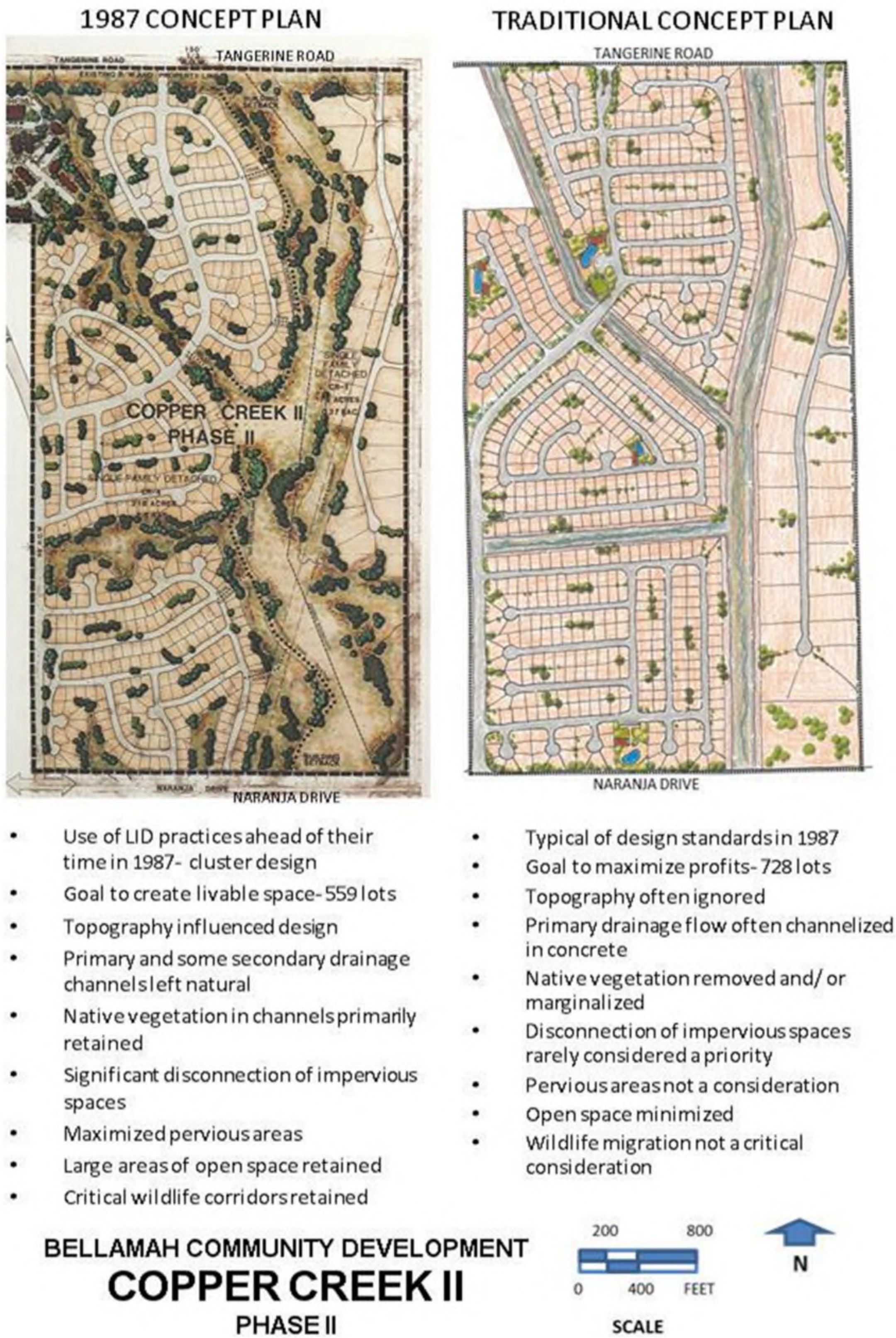



*Figure 14. Copper Creek subdivision early GI/LID design compared to 1980's traditional engineered design.*

Figure 15is a comparison of the original undisturbed site to a current aerial with the platted subdivision over-laid. The 2012 aerial clearly exhibits substantial canopy growth in drainage areas that had been left natural.


*Figure 15. 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, 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.

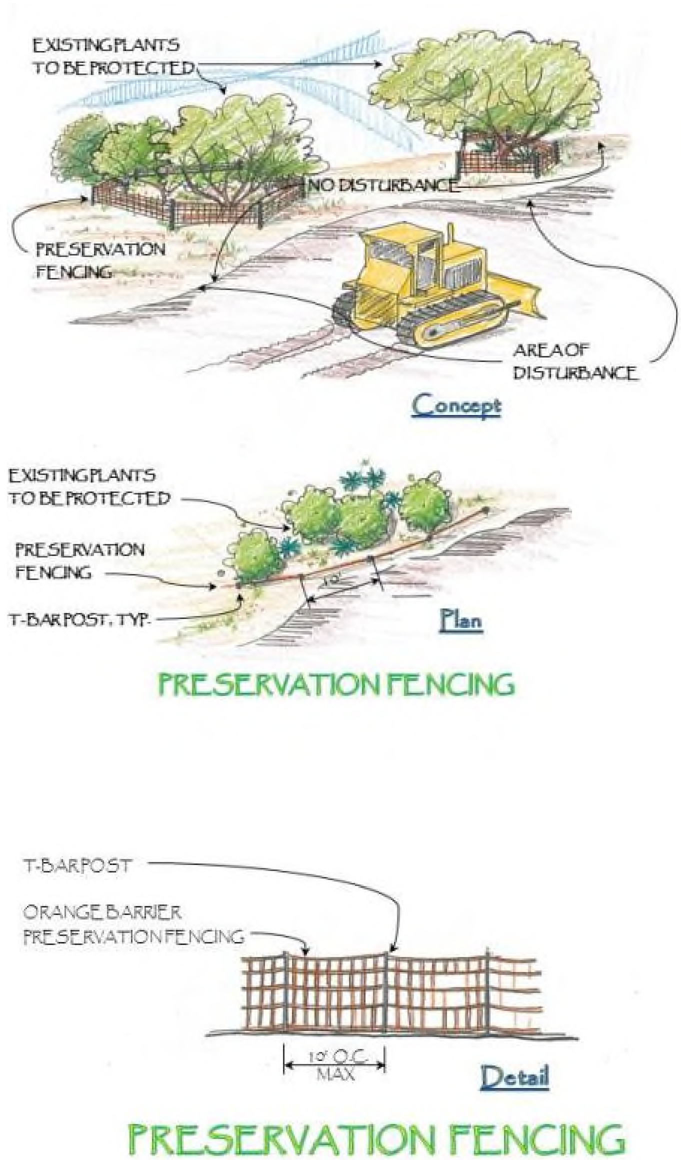



*Figure 16. Detail of barrier fencing used to preserve existing vegetation.*

In general, along much of this same boundary, the plans should identify preservation fencing (Figure 17 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.

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.

Excavate only what is absolutely necessary to meet engineering requirements. Do not store excavated material in sensitive areas. Excavated material can be used in other areas of the site to improve seeding success. Conduct onsite monitoring during construction to ensure sensitive natural areas are protected as planned. Conduct post-construction monitoring to ensure sensitive natural areas that were impacted by construction receive restoration.

If vegetation within the natural area is damaged or removed during construction, replace 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 use hydroseed and mulch blankets immediately after site disturbance. Refer to Section 4.5 Restore Disturbed Natural Areas.

### 4.2.8 Consideration 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 LID Practices

- All structural LID Practices
- Disconnection 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:

- Incorporate pervious areas into site design
- Disconnect downspout flows from impervious areas; direct them to discharge into pervious areas (Figure 18)
- Narrow residential roads and consider alternative street designs (Figure 19)

- Alternative driveway and parking lot designs
- Utilization of porous materials (Figure 19)
- Sidewalk reduction or alternative designs and materials
- Consider clustered development and larger natural open spaces

*Figure 18. Downspout flow disconnected from impervious drive surfaces; directed to a pervious area.*

*Figure 19. Left: LID street design (Seattle Public Utilities), right: permeable parking lot (Reid Park Zoo).*

### 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 which includes roadways, sidewalks, parking, and driveways. Minimizing impervious surfaces includes the reduction in the building footprint. 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/ GI Planning Practices.

Alternative layouts for neighborhood design will reduce the overall impervious area but also can decrease development costs (i.e., cut and fill, pavement area, drainage conveyance structures etc.). For example, by replacing curbs and gutters with a roadside swale, the impervious surface and associated runoff volume and rate is reduced. Not only is the capital cost of curbs and gutter eliminated, but so will the cost of drainage structures. 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 which 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 LID 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

- Reduces runoff volume and peak rate
- Reduces both construction and maintenance costs
- Can be used with multiple 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 access shallow groundwater tables and more importantly our deeper aquifers

### 4.3.4 Limitations

- 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

- Directs flows into pervious areas
- Combine numerous Structural and Planning Practices to create a tenuous treatment train
- Limit the contributing rooftop area to a maximum flow per downspout
- Minimizes 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 (i.e., roads, sidewalks, driveways, etc.) 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/drainage courses promotes LID Site Planning Principal: Conserving Natural Areas and Protecting Natural Flow Paths. These concepts are illustrated in (Figure 20).

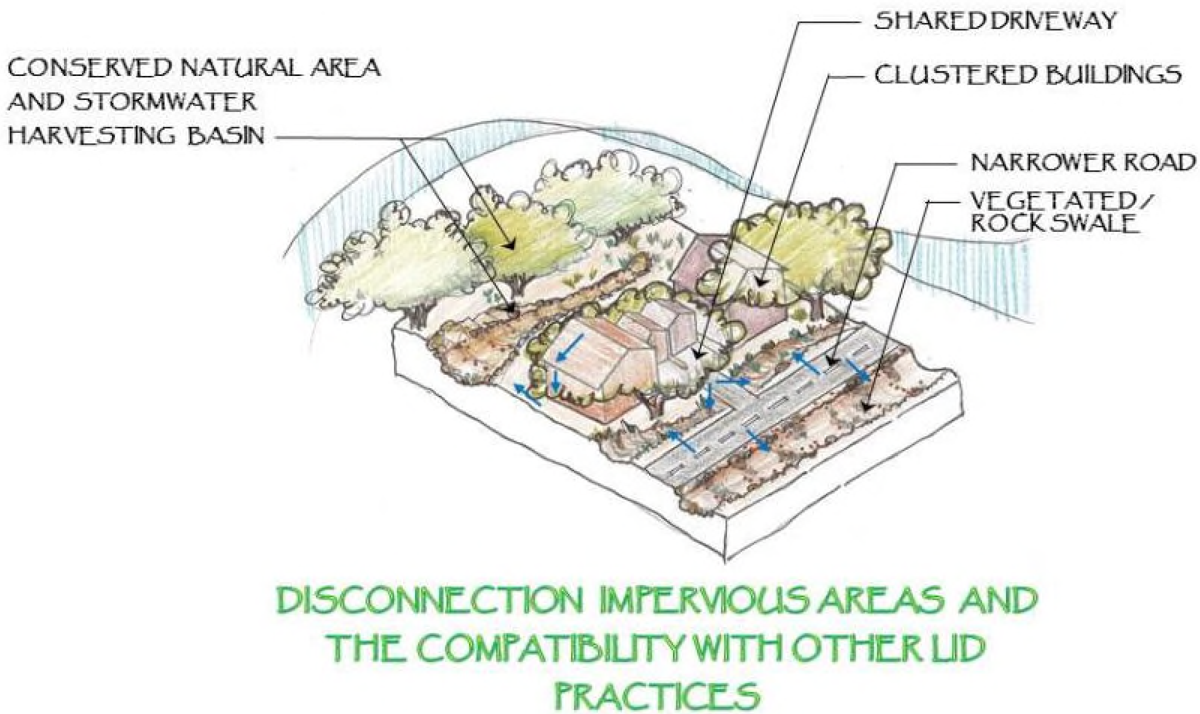



*Figure 20. Use of disconnection of impervious areas with other LID practices.*

Paved areas can be sloped towards vegetated areas where the width of the 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. 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 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 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 area can also provide time for infiltration and should also reduce flow velocity to protect the soil structure. 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; function of 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 right-of-way 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 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 providing pedestrian safety. A network of traffic circles, chicanes, center islands, and speed humps, when combined with structural LID Practices (bio retention, water harvesting basins, etc.) 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 LID Site Practices and 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, 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 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 reduction 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 to 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 for 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 Consideration 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 Consideration during Maintenance

When disconnecting stormwater from impervious surfaces 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/LID practice, such as bioretention or vegetated swales, the specific guidance for that feature shall 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 shall 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 LID Practices

- Conserving Natural Areas and Protecting Flow Paths
- Minimize Disturbance and Compaction
- Alternative Site Design; Cluster Development
- Landscape Buffers and Swales
- Pervious Surfaces

## 4.4 Minimize Disturbed Areas and Soil Compaction (Construction)

| 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 | ◒ |

### 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.

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, 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, and
- 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 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 has limited application, although may be feasible depending on the site conditions.

As site area decreases and density and intensity of development increases, this GI/LID Site Practice requires more innovative and new products developed to address urban density preferences are difficult to apply successfully.

### 4.4.3 Advantages

- 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

- 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
- 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, etc.) 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/LID 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 identified areas such as soil improvement.

**Identify soils**: Soils with high infiltration capacity can be identified with available soils maps and the GI/LID 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, 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 **s**oil 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 Consideration during Construction

Management of soil protection during construction activities will only be effective if it is carefully implemented and monitored are 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, etc. 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, etc. 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 only be allowed 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 Consideration 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 or landscaped areas that continue to 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. Combine these LID Site Practices serve to protect natural sensitive areas and the resources they produce by reducing site grading and maintenance required for long-term operation of a development.

- 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

| 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 | ● |

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.

### 4.5.2 Applicability

Restoring sensitive natural areas is applicable to all types of land development projects; whether a residential subdivision, an office park, a commercial, industrial or institutional uses. 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 a retro fit, it is recommended to require restoration of disturbed natural areas when applicable.

### 4.5.3 Advantages

- 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

- 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, and
- 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 its 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/LID Practices. These features will divert stormwater, allow the 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 from 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, such as 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 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 DriWater. Whichever method is selected, encourage root establishment 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 who are willing to provide instruction on how to control noxious and/or invasive plants.

### 4.5.6 Considerations during Design and Construction

- 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., 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 shall 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. See Code 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

- 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, May, June, as well as July, August and September if monsoon rains are brief or spotty). Replace DriWater Gel Pacs 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 Liquid Fence;

- 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 LID Practices

- 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 21). 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, 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 LID Practices.

### 4.6.2 Comparison of an LID Site Plan to a Conventional Site Plan on the Same Site


*Figure 21. Drainage paths at a traditional site versus at an LID site that uses natural open space for drainage.*

### 4.6.3 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 Elements** | | |
|---|---|---|
| Site Area Classification | Section 4.2 | Conserve Natural Areas and Protect Natural Flow Paths |
| Optimize the Site Layout | Section 4.2<br>Section 4.3 | Conserve Natural Areas and Protect Natural Flow Paths<br>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) |

#### 4.6.3.1 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.

#### 4.6.3.2 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 façade 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***; EPA, 1983; ADEQ 2013). These pollutants dissolve in stormwater or are carried downstream where it 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 removing 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).

*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 pollutants with non-toxic chemicals,
- Store and use pollutants indoors or in shelters,
- Contain pollutants exposed to rainfall or stormwater, and
- 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 pollutants out of the natural environment. Outdoor structures providing secondary containment include 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 Sections 5 and 6. Manufactured devices can support LID/GI designs and remove pollutants through sedimentation, precipitation, hydrodynamic separation, filtration, ion exchange, oxidation, and nitrification-denitrification.

*Table 3. Pollutants in stormwater, from Davis and McCuen (2006).*

| 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<br>• Released by tire wear<br>• Brake pads<br>• 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 |
| Nitrogen compounds | • Excess residential, agricultural, and commercial fertilizer use<br>• Animal wastes<br>• Plant decay<br>• Atmospheric deposition | Turf grass; Non-native ornamental landscapes | Highly managed landscapes in both residential and commercial developments |
| Phosphorus | • Excess fertilizer use<br>• Decaying vegetation, such as lawn clippings and leaves<br>• Animal waste | Maintained commercial and residential landscapes Golf courses | Highly managed landscapes in both residential and commercial developments |
| Oxygen demanding substances | • Natural origin<br>• 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 & agricultural areas |
| | • Polycyclic aromatic hydrocarbons | Motor vehicle fuel leakage and spillage Asphalt pavement Asphalt roof runoff | Roads & parking lots. Runoff from buildings with asphalt roofing materials (shingles, membrane, other types) |
| | • Solvents | Industrial, commercial and residential cleaners, degreasers and lubricants | |

### 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. Replacement examples include 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

- 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. 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 and 3.6.

*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.

*Store and use Pollutants Indoors or in Shelters*

Structures providing shelter from the elements can be customized to the needs. 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.

*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 include the following:

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

These structures are designed to hold liquids. 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 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 (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

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)

Pesticides are used as a last resort after using the other methods. 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). When these 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).

Integrated pest management reduces the amount of pesticides in the environment preserving beneficial insects, including bees, and minimizing the amount entering the hydrologic cycle.

#### 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, and
- 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

Build structures providing the 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 22).

### 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.


*Figure 22. Pet waste station with baggies and garbage can mounted on a post.*

### 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, and
- 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 23). 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-engineered for non-toxic chemicals, and
- Low level berm of concrete or asphalt to keep run-on out of the enclosure

*Figure 23. 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 24) 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 24. 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 25). 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 25. Containment structure for vehicle washing set in gravel.*

### Fueling Areas

Fueling areas can be designed with the following:

- Paved with Portland cement concrete or equivalent smooth impervious surface,
- Sloped to a trench and drain; add 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 25 and Figure 26).
- Low concrete berm around fuel dispensing area to keep fuel spills within bermed area and use dry cleanup methods, 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 26. 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 ft (0.3 meter), whichever is greater;
- Equal to or greater than the area within the fuel dispensing area's grade break; and

- Designed to drain the water from roof to an LID feature.

### Design Loading Docks to Reduce Pollution Contribution

Loading docks areas (Figure 27) can be designed with the following:

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

*Figure 27. Designs for loading docks and ramps.*

## 4.7.6.4 Treat Stormwater Using Green Infrastructure 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 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, and
- 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 (Reference, searching for the source).

#### 4.7.7 Considerations during Maintenance

LID 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 and prunings can be added to a compost. As these systems have ponded water, there is a potential for breeding vectors, such as mosquitoes, and requires maintenance.

For the manufactured devices, follow the maintenance instructions. The materials will also need to be properly disposed 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 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/LID Practices

## 5.1 Introduction

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

### 5.1.1 Selecting Structural LID Practices

Selection of appropriate Structural LID Practices depends on site-specific conditions and design intent; Figure 7 and Figure 8 listed the general benefits and functions of each practices and can be used as a guide for selecting. When multiple design goals cannot be efficiently achieved with one type of Structural LID Practice, multiple LID Practices can be combined in series to form a *treatment train*. Examples of effective treatment trains are shown in Figure 28 (presented in the order that runoff encounters the Structural LID 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 series, while performance of the second practice is much lower (because it is inefficient to remove pollutants from runoff that is already "clean").

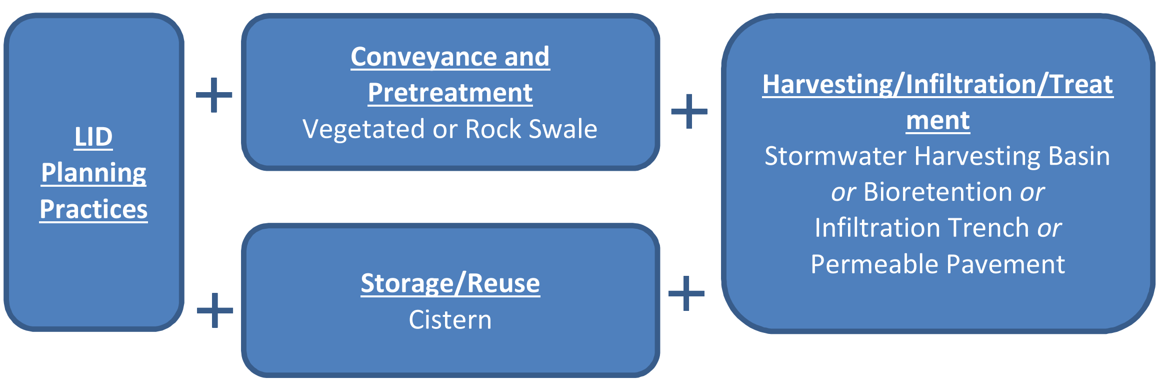
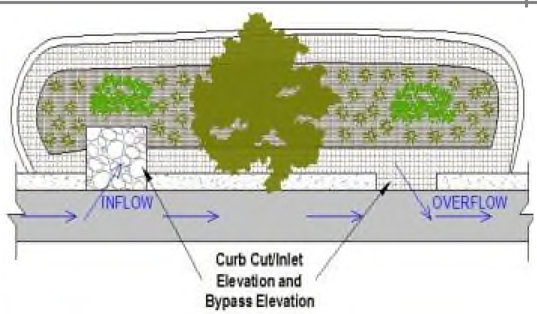
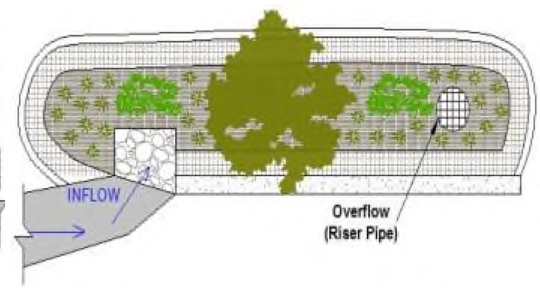



*Figure 28. Example combinations of LID practices with complementary design goals.*

### 5.1.2 On-line versus Off-line Configuration

Most Structural LID 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 LID Practice presented in the following subsections.

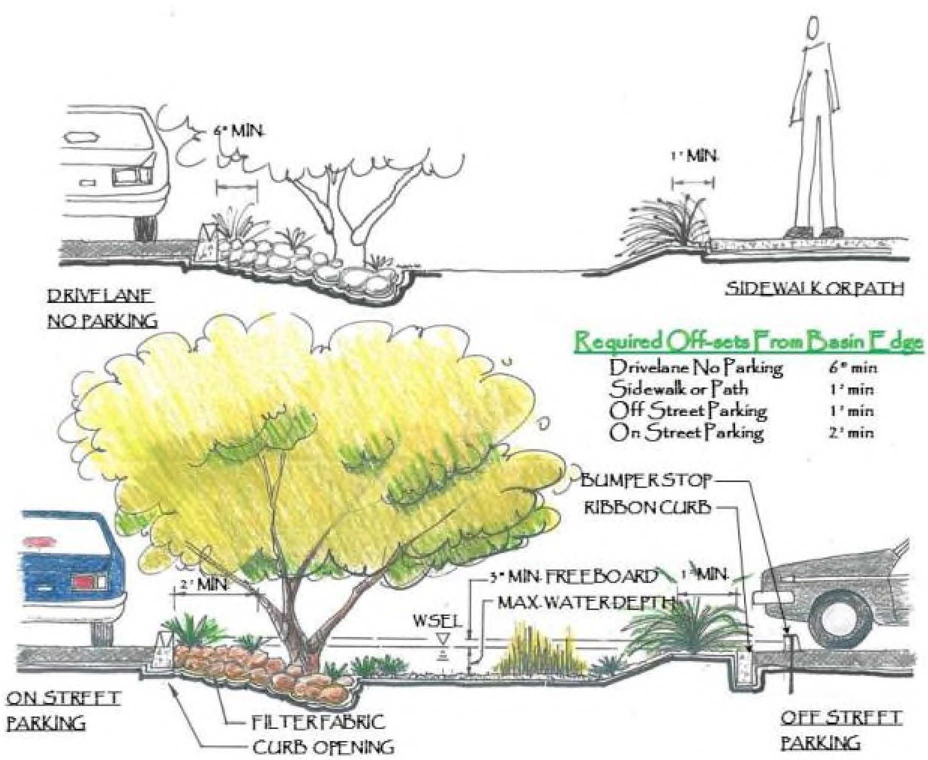
*Table 4. Comparison of off-line versus on-line configurations.*

| | **Off-line Practice** | **On-line Practice** |
|---|---|---|
| **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 |
| **Advantages** | The Structural LID Practice is protected from erosion or excessive sediment deposition that may be experienced during high flow events. Typically require less 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

| 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 | ● |

Stormwater harvesting basins (Figure 29) are shallow earthen depressions that collect stormwater runoff and infiltrate into native soils to support planted native vegetation, 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.




STORMWATER HARVESTING BASIN

### 5.2.1 Applicable Sites

Stormwater harvesting basins (Figure 30) are appropriate within any landscaped area supporting native vegetation that will benefit from a supplemental supply of water while reducing stormwater volume leaving the site. Stormwater harvesting basins next to impervious areas such as parking lots or rooftops or along roadways with curb openings provide cost-effective landscaped features.

*Figure 30. Example stormwater harvesting basin (source: Grant McCormick).*

### 5.2.2 Advantages

- Stormwater harvesting basins can retain large amounts of stormwater that can 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 which can provide multi-use benefits such as habitat, aesthetics, credit towards landscaping requirements, educational opportunities, and shade.
- Stormwater harvesting basins tend to be cheaper 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

Below are 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 31.

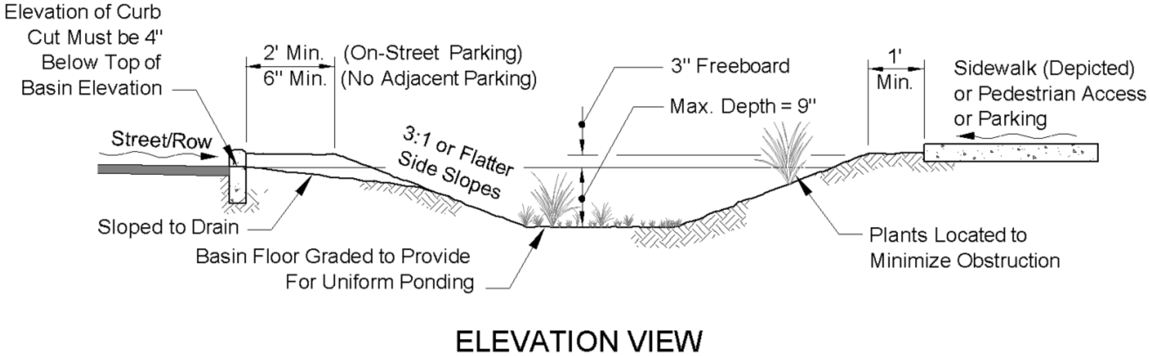



*Figure 31. Roadside stormwater harvesting basin cross-section.*

Source: Draft Design Standards for Storm Water Detention and Retention for Pima County

### 5.2.4.2 Sediment Trap

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 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. Rip-rap 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 which safely directs stormwater to the next LID practice or to a watercourse should be designed for any stormwater harvesting basin. The most appropriate overflow for a stormwater harvesting basin is a 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 LID 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, treat the subgrade using the methods described in Section 6.10 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 hrs 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 and Section 6.13.

#### 5.2.4.7 Gravel Drainage Layer

There are generally no gravel drainage layers in stormwater harvesting basins. See Bioretention 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 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 inches of runoff for an impervious watershed) as described in Section 3.5.

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 Stormwater Detention Retention Manual and is approved by the Floodplain Administrator.

### 5.2.6 Consideration 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 Consideration 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 |

City of Santa Barbara, 2008

### 5.2.8 Alternative LID Practices

- Bioretention systems
- Infiltration Trench
- Permeable Pavements
- Dry well

### 5.2.9 Compatibility with Other 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

| 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 | ● |

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 33 and Figure 34). 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 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 allowing 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.

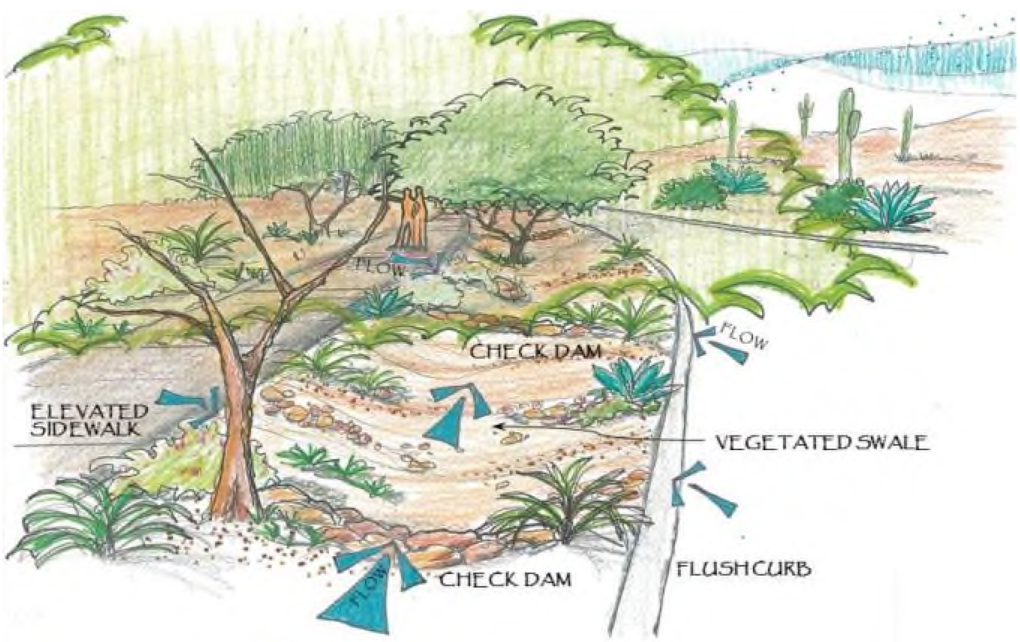



*Figure 33. Elements of a vegetated swale.*

*Figure 34. Xeriscape swale.*

An effective swale achieves relatively uniform ponding over the bottom area and prolongs the flow path travel time (Figure 35). 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.

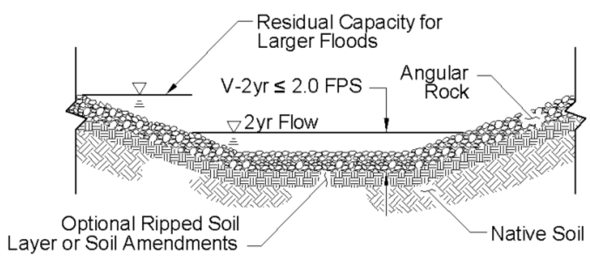



*Figure 35. Cross-section of a vegetated or rock swale.*

### 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. When 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 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 can replace curbs, gutters, and storm drain systems. Whenever possible, inflow should be directed towards the upstream end of the swale, but 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 (i.e., flow splitter) to divert flows off line to a water harvesting basin or other Structural LID 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, 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

Because swales transport water at a slower rate than lined channels, 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 up 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 should be reinforced if high flows are predicted.

***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 Bioretention).

### 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 one- (1) –ft level shelf may be provided if the practice is located adjacent to sidewalks or parking areas, but is not required. To minimize the formation of meandering flow paths and incision, bottom widths should generally be no wider than eight (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 nine (9) inches and velocity in the swale should not exceed 2 ft/s, although a maximum velocity of 1 ft/s 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 ft per second. This maximum water quality design flow velocity promotes settling and keeps vegetation upright.

This 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 ft.*

b. Increasing channel roughness by adding roughness elements such as obstructions and vegetation. These can be estimated using methods described in Phillips & 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 “Flow Spreaders” below) 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 Consideration during Construction

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 avoid operating 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 Consideration during Maintenance

Inspect vegetated swales for erosion or damage to vegetation after every storm greater than 0.5" 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 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 hrs 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 hrs of the end of the storm. Till the swale if compaction or clogging occurs. The perforated underdrain pipe, if present, should be cleaned if necessary.

Vegetation should be healthy and dense enough to provide filtering while protecting underlying soils from erosion:

- Vegetation, large shrubs or trees that interfere with landscape swale operation should be pruned.
- Dead vegetation should be removed if greater than 10% of area coverage 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), noxious or nuisance weeds, should all be removed.

A summary of the routine and major maintenance activities 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 |
| | Trash and debris removal |
| | Cleaning of underdrain (where applicable) and/or unclogging 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 |
| | Photographs taken before and after maintenance is encouraged |
| 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 LID Practices

Swales can be used in connection with:

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

| 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 | ● |

## 5.4 Bioretention Systems

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 inches to 36 inches, and the sub-base drainage layer is typically in the range of 6 inches to 24 inches of washed, coarse aggregate (although depths should be customized to suit design goals – see 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 36 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** |

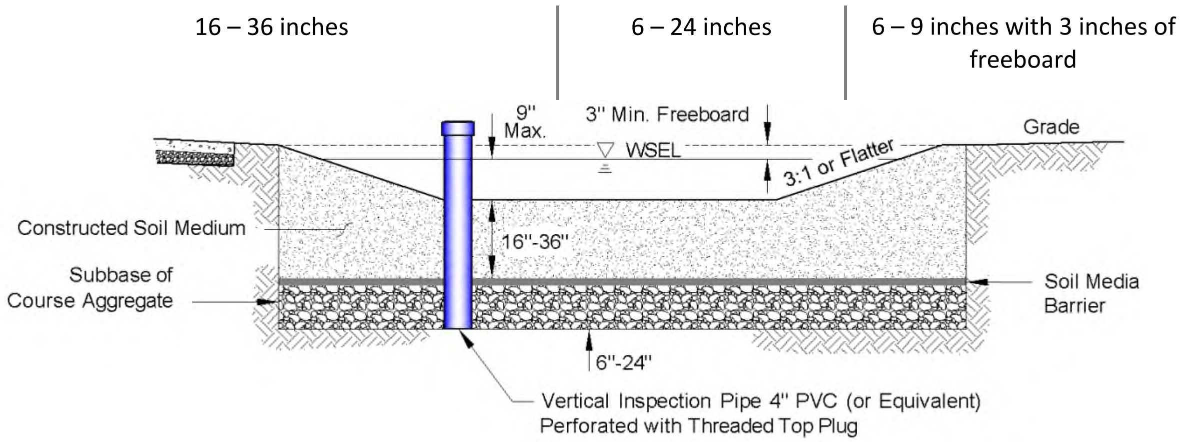



*Figure 36. Cross-section of a bioretention system.*

### 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 37).

### 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 that can 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 provide multi-use benefits such as habitat, aesthetics, credit towards landscaping requirements, educational opportunities, and shade.

*Figure 37. Example bioretention system.*

### 5.4.3 Limitations

- Bioretention systems are generally more expensive than other practices such as stormwater harvesting basins
- Bioretention systems allow a greater infiltration of stormwater and therefore larger setbacks may apply from pavement or foundations unless cutoff walls are installed

### 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 rip-rapped side slope or a concrete cut-off wall at the edge of a parking lot (Figure 39). 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 LID 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 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 that 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 39). This design configuration ensures greater retention while still allowing for drainage of excess runoff volume.

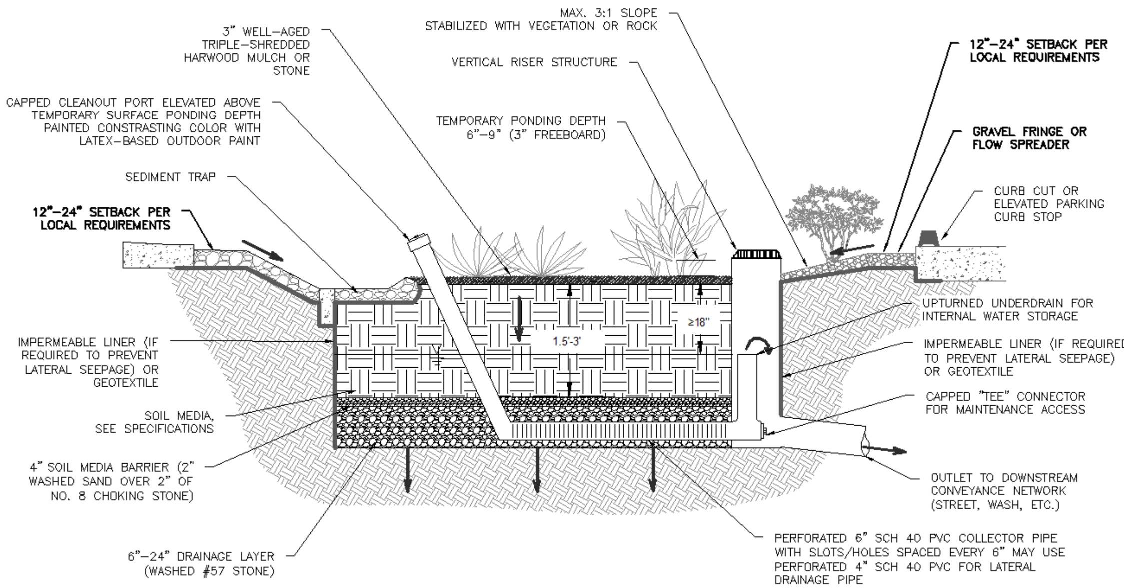



*Figure 39. Example bioretention system detail.*

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 ASTM (American Society for Testing and Materials) 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 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, clog resistant drainage, and 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 six inches of drain rock. Drain rock should form an envelope of at least 1 ft around the sides and top of the underdrain and should be comprised of washed ASTM No. 57 stone or similar alternative that has been washed to remove all fines. See Gravel Drainage Layer 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 length of the system (a maximum spacing of 50 ft 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 ft 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, **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 | Minimum 32 part per million (ppm) (NOTE: magnesium sulfate can be added to increase Mg) |
| • Phosphorus (Phosphate $–P_20_5$) | Not to exceed 15 ppm |
| • Potassium ($K_20$) | 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 g of dry soil |

Source: 04 CA Southern California

### 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 is generally not recommended because filter fabric is prone to clogging over time, may prevent percolation into the subsoil, or 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 hrs.

As described in Section 3.5, 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 LID 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 Storm Water Detention and Retention and is approved by the Floodplain Administrator.

The bioretention system should be sized using the design stormwater volume ($V_{design}$, Section 3.5) with the limiting infiltration rate, k (in/hr), depth of soil medium, d (ft), the porosity of the soil medium, n, the allowable ponding depth, p (ft), 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 hrs) 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 (ft3)

k = effective infiltration rate (in/hr)

$d_s$ = depth of the soil medium (ft)

$n_s$ = porosity of the soil medium (dimensionless)

$d_g$ = depth of the gravel layer (ft)

$n_g$ = porosity of the gravel layer (dimensionless)

p = allowable ponding depth (ft)

$d_{in}$ = depth of infiltration (ft) calculated as

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

k = effective infiltration rate of the subsoil (in/hr)

3 hrs = 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 Consideration during Construction

Fence off bioretention system construction area 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 that it 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.

When gravel drainage layer and soil medium have been placed, no compaction should occur to the soil medium from construction equipment.

#### 5.4.6.1 *Consideration 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.

### 5.4.7 Alternative LID Practices

- Stormwater Harvesting Basin
- Infiltration Trench
- Dry well

### 5.4.8 Compatibility with Other LID Practices

Bioretention systems can be used in connection with:

- Swales
- Overflow from cisterns
- LID Site Planning Practices (i.e., 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 |

City of Santa Barbara, 2008

## 5.5 Infiltration Trenches

| 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 | ◒ |

An infiltration trench (Figure 40) 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 or may not 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 such as filter strips in order to prevent clogging of infiltration trenches by sediment over time.

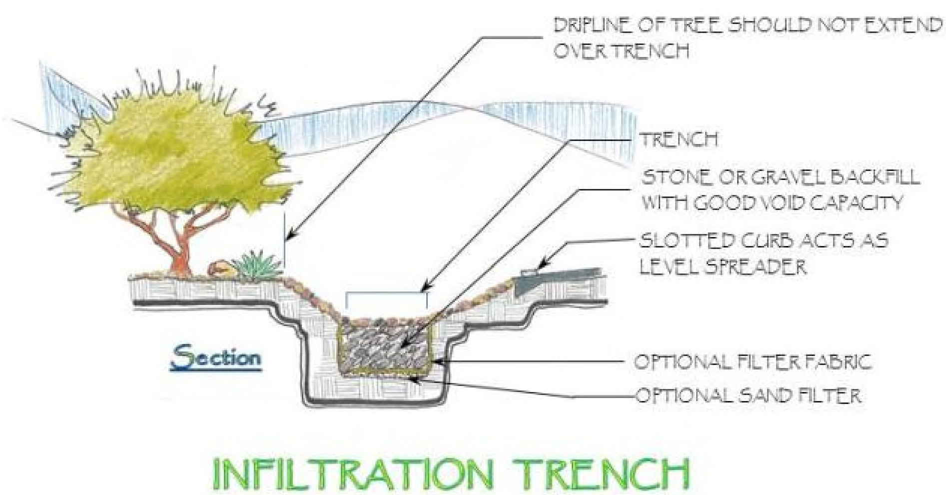



*Figure 40. Example infiltration trench design with xeriscape filter strip.*

### 5.5.1 Applicable Sites

Infiltration trenches (Figure 41) 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 LID practices.

*Figure 41. Infiltration trench (Source Laura Mielcarek).*

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/hr (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 ft (State of Michigan, 2008) from the bottom of the infiltration trench. 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 ac.

### 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 ft 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 ft deep and a minimum width of 1 ft.

#### 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 area surrounding 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 a sediment trap. 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 may have a longitudinal slope of up to 3% (City of Santa Barbara, 2008) to facilitate drainage at an overflow.

#### 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 (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 ft 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. See Bioretention 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 for additional information on vegetation.

### 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 hrs) 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 (ft3) |
| $d_g$ | = | depth of the rock, stone or gravel layer (ft) |
| $n_g$ | = | porosity of the rock, stone or gravel layer (dimensionless) |
| p | = | allowable ponding depth (ft) |
| $d_{in}$ | = | 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 (in/hr) |
| 3 hrs | = | assumed storm duration and approximate time of runoff |

### 5.5.6 Consideration 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 Consideration 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 Stormwater Harvesting Basins and Bioretention for recommended maintenance activities and frequencies.

### 5.5.8 Alternative LID Practices

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

### 5.5.9 Compatibility with Other LID Practices

Infiltration Trenches can be used in connection with:

- Swales
- Overflow from cisterns
- LID planning BMPs (i.e., Disconnected Downspouts)
- Soil Amendments
- Vegetation
- Curb openings

## 5.6 Cisterns

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 () 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 Pima County Stormwater Manual due to the variation in water level and stormwater retention volume available in cisterns at any given time.

### 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 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.

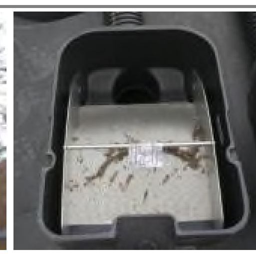
A pump will be necessary for any water use applications requiring high pressure.

Backflow preventers are required if rainwater supply will be pressurized and if any of the pipes will be connected to the municipal water supply.

*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 varies 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 |

*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 LID practice (such as a 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 Detention/Retention Manual does not currently allow cisterns as an option to satisfy water quality and flood control requirements.

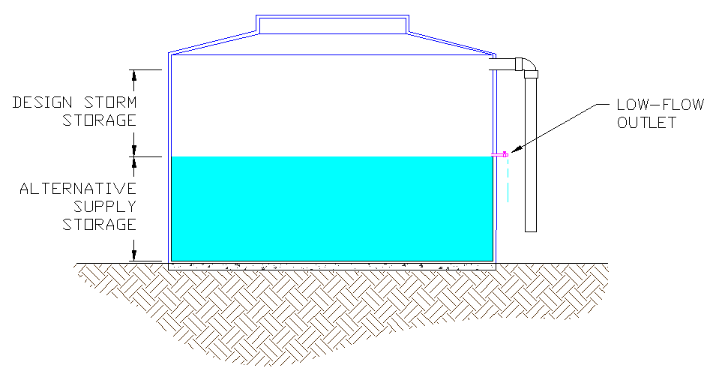
### 5.6.1.1 Designed Overflows

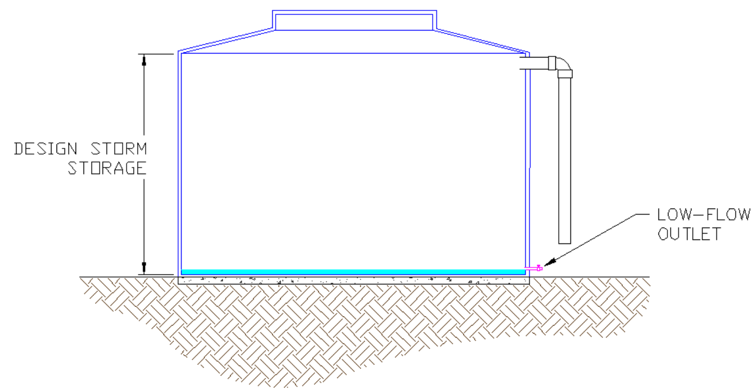
Cisterns must have an overflow pipe to divert excess stormwater to another location, preferably a vegetated area or another GI/LID feature, when the cistern reaches capacity. It is recommended that metal cisterns have the overflow pipe placed up through the location of where the concrete pad will be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

### 5.6.1.2 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 greywater 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. |  |

| Alternative Water Demand | Typical Uses | Outlet Location | Example Profile |
|---|---|---|---|
| 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 are certain locations, such as schools and public parks. 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, and 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 (gal), which should be rounded to the nearest tank volume

Z = cistern volume / roof area ($ft^3/ft^2$) (recommended value is 0.20 ft)

A = roof area draining to the cistern ($ft^2$)

Our analysis shows that Z = 0.2 ft (1500 gal of storage per 1000 $ft^2$ 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 ft 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 1000 $ft^2$ of draining roof area (Z = 0.05 ft) can provide from 2600 to 3300 gallons of offset in annual potable water demand per 1000 $ft^2$ 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 ft (3000 gal storage per 1000 sq-ft) is likely to be limited by rainfall and unlikely to provide additional benefit for the increased volume and cost, so we consider 3000 gal of storage to 1000 $ft^2$ 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.

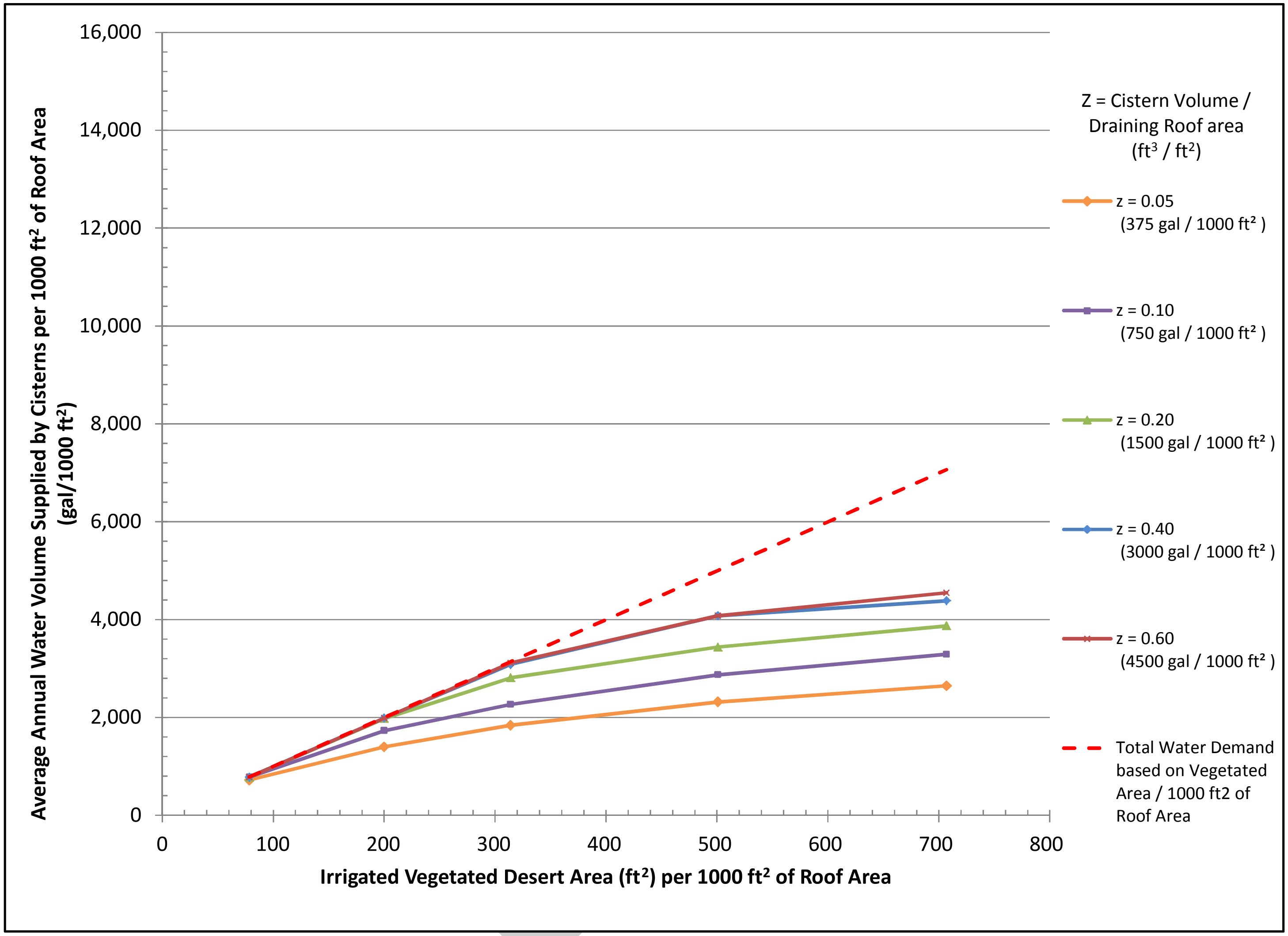



*Figure 43. Offset in annual irrigation water demand by vegetated desert area relative to draining roof area.*

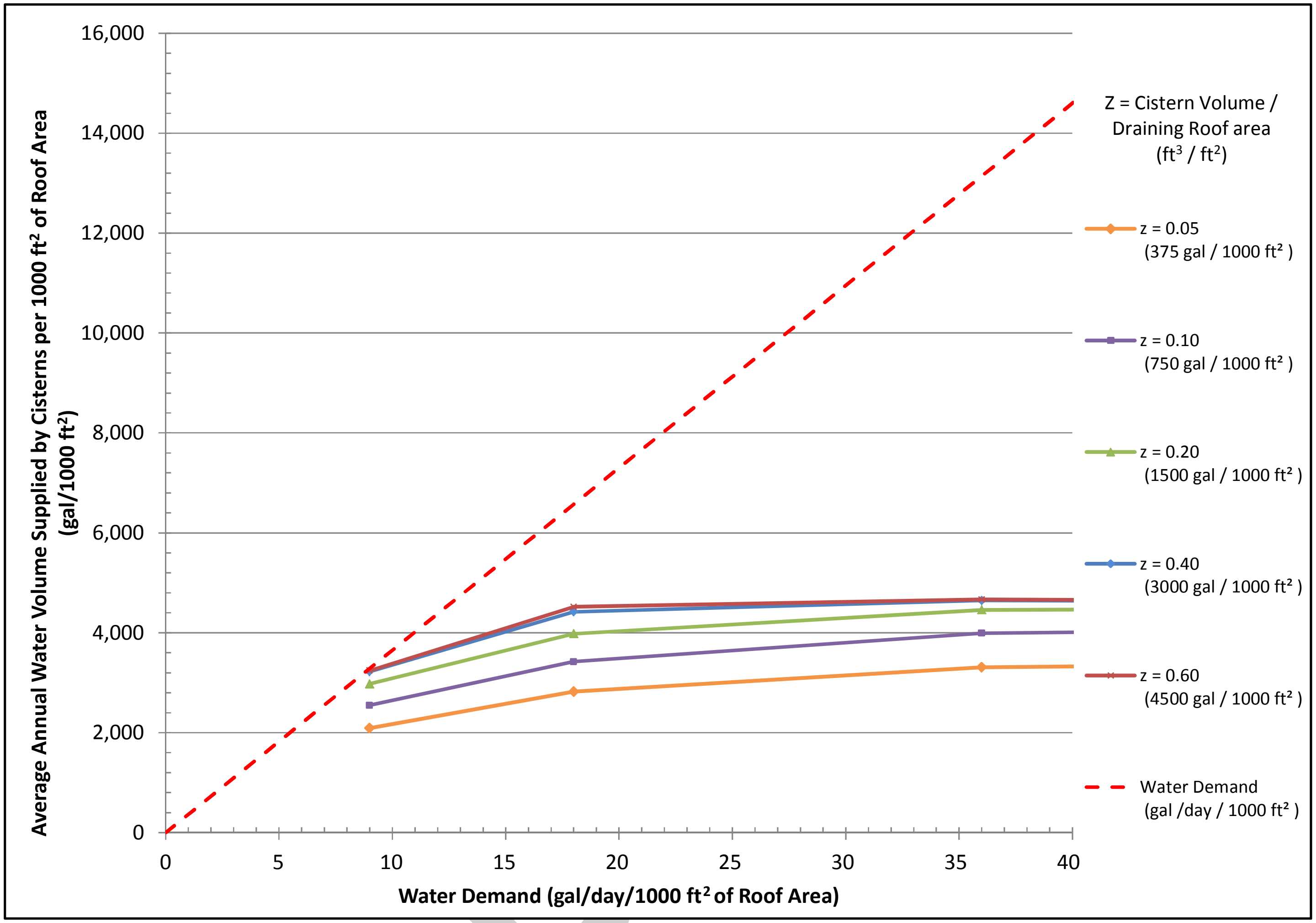



*Figure 44. The average annual offset in constant daily water demand such as indoor use that can be supplied by cisterns at varying levels of water use.*

### 5.6.3 Consideration during Construction

A level pad of compacted ASTM No. 57 stone, or comparable aggregate, is typically sufficient to support cisterns under 5000 gallons. Cisterns larger than 5000 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.

### 5.6.4 Consideration 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 hrs. |
| Major Maintenance | Repair any damage to cistern structure. |

### 5.6.5 Alternate LID Practices

- Stormwater Harvesting Basins
- Bioretention Basins
- Infiltration Trenches
- Dry Wells

### 5.6.6 Compatibility with Other LID Practices

Cisterns can be installed in series with:

- Stormwater Harvesting Basins
- Swales
- Bioretention Systems

- Infiltration Trenches
- Permeable Pavements
- LID Planning BMPs (i.e., 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/LID 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, so 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.

Suitable for:

- Parking Lots
- Driveways
- Storage Yards
- Maintenance Roads

Benefits

- Low Cost

An example porous gravel installation and typical detail (Urban Drainage and Flood Control District) are provided in Figure 45.

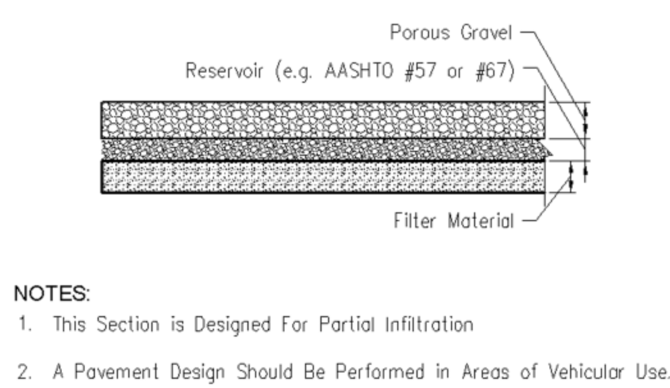



*Figure 45. Example porous gravel installation (left). Typical permeable pavement detail (right).*

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, (like Gravelpave) 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.

#### 5.7.3.2 *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 46). 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.

Benefits

- Concrete pavers can be removed and replaced for maintenance of underlying utilities.
- Concrete pavers 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.

An example PICP installation and typical detail (Urban Drainage and Flood Control District) are provided in Figure 46.

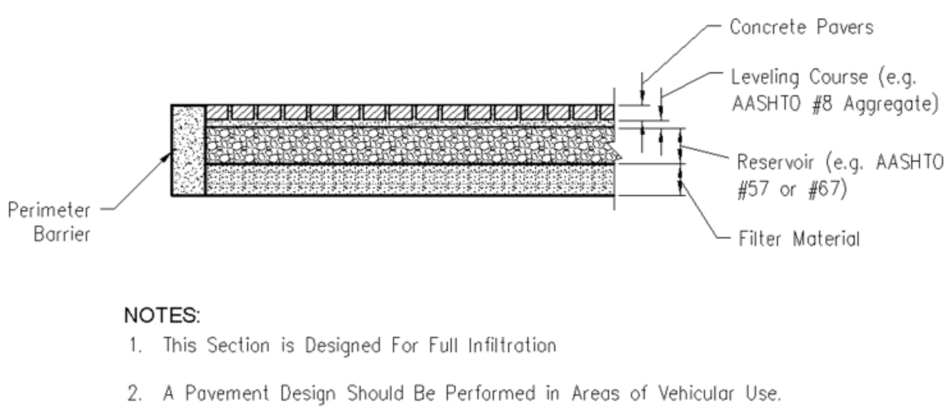



*Figure 46. Example PICP installation (left). Typical PICP detail (right).*

Limitations

- Costs can be greater than concrete or asphalt.

#### 5.7.3.3 *Pervious Concrete*

Pervious concrete is a surface that allows water to infiltrate, because it is designed without the fines used in most concrete aggregate 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.

Benefits

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

An example pervious concrete installation and typical detail (Urban Drainage and Flood Control District) are provided in Figure 47.

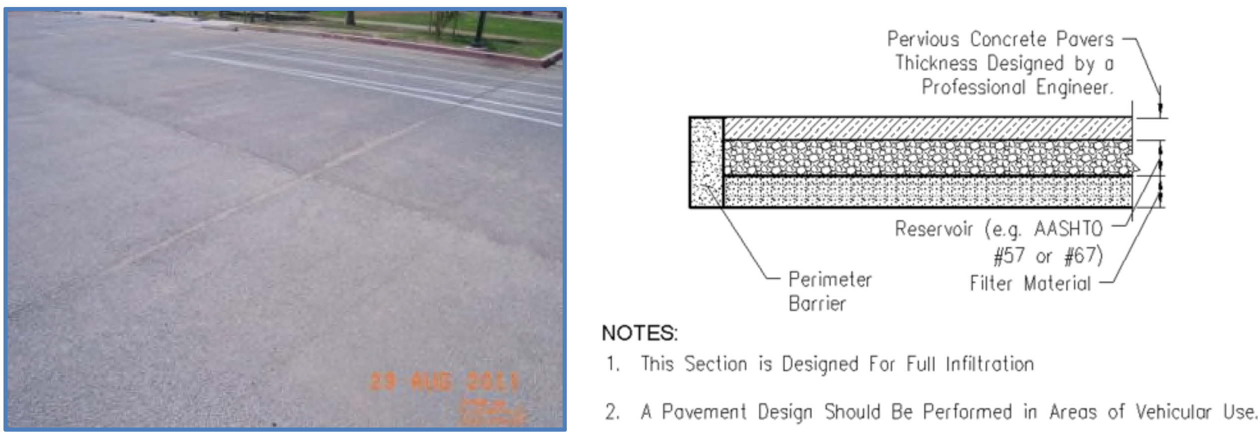



*Figure 47. Example pervious concrete installation (left). Typical pervious concrete detail (right).*

Limitations

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

#### 5.7.3.4 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 is still 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 Minimizing and Mitigating Soil Compaction).

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

*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 48, Configuration 1) are designed to infiltrate the full design volume (recommended to be 0.5" to 1.5" rainfall event as described in Section 3.5). 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, as shown in Figure 48, Configuration 2, or can be placed at the subgrade to allow for complete drainage (Figure 48, 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 48, Configuration 4), a liner and underdrain system is 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 Bioretention. 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 ½ft/100-ft of pipe for 6" pipe, and 1ft/100-ft for 4" pipe (1/8"/1-ft), which will assure a flow velocity of 2ft/s. 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 up an envelope of stone around the pipe.

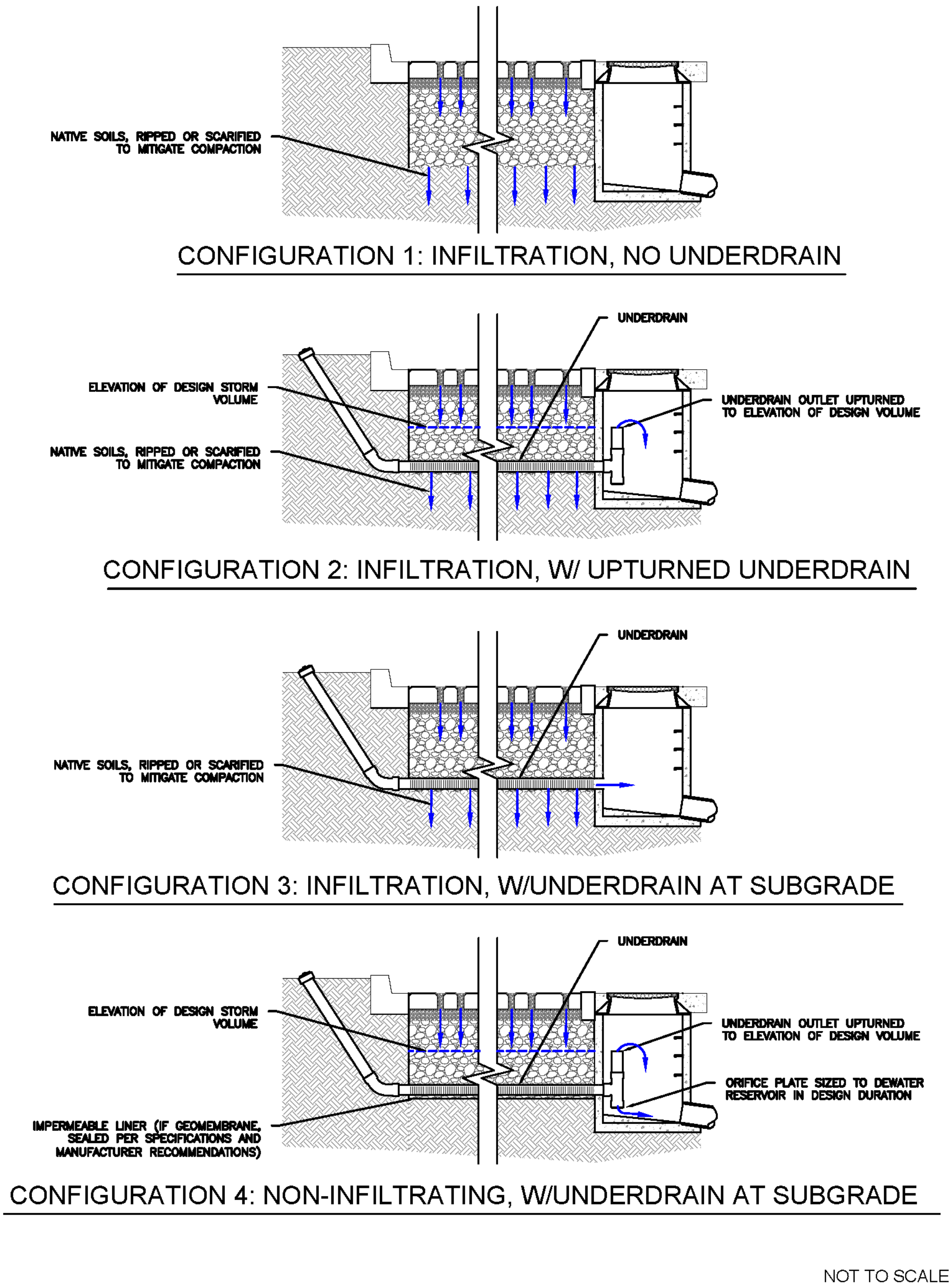



*Figure 48. Various configurations for infiltrating and non-infiltrating permeable pavement.*

#### 5.7.3.5 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 49.

*Figure 49. Concrete transition strip examples.*

#### 5.7.3.6 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.

#### 5.7.3.7 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 LID for stormwater management. Identifying permeable pavement as such will also reduce the likelihood that permeable systems will be unknowingly replaced/repaved with impermeable 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, this should be at least 0.5” rainfall event, however, in many cases, the 1.5” 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 $ft^3$. 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 (ft)

$V_{design}$ – design volume ($ft^3$)

A – Area of pervious pavement ($ft^2$)

$\eta$ - porosity of the gravel layer (unitless)

AASHTO #57 or #67 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 do 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:

1. 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.
2. Regularly (e.g., monthly for a few months after initial installation, then quarterly) inspect pavement for pools of standing water after rain events, this could indicate surface clogging.
3. 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,
4. Inspect for vegetation growth on pavement and remove when present.
5. Inspect for missing sand/gravel in spaces between pavers and replace as needed.
6. 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 are vehicle tracks and utility maintenance.
7. Spot clogging of porous concrete may be remedied by drilling 0.5” holes every few feet in the concrete.
8. Interlocking pavers that are damaged can be replaced.
9. Maintain landscaped areas; reseed bare areas.

### 5.7.7 Alternate LID Practices

- Stormwater Harvesting Basins
- Bioretention Basins
- Infiltration Trenches
- Dry Wells

### 5.7.8 Compatibility with Other LID Practices

- Stormwater Harvesting Basins
- Bioretention Basins
- Xeriscaped Swales

| 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 | ○ |

## 5.8 Dry Wells

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 that stormwater entering a dry well may remain in the unsaturated zone where it is typically too deep for many plants to access. As such, they are typically a last resort.

Dry wells can only receive stormwater without pollutants and must be registered with the ADEQ. If there is potential for pollutants, the owner may also be required to obtain an aquifer protection permit from the 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 such as 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 cfs per well nor more than 0.5 cfs. (Design Standards for Stormwater Detention and Retention for Pima County) 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 shall 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. (Design Standards for Stormwater Detention and Retention for Pima County). 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, which 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 (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 and more information can be found here: http://water.epa.gov/type/groundwater/uic/class5/types_stormwater.cfm. The ADEQ also maintains requirements for dry wells which can be viewed at: 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 50) 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 for additional information on vegetation.

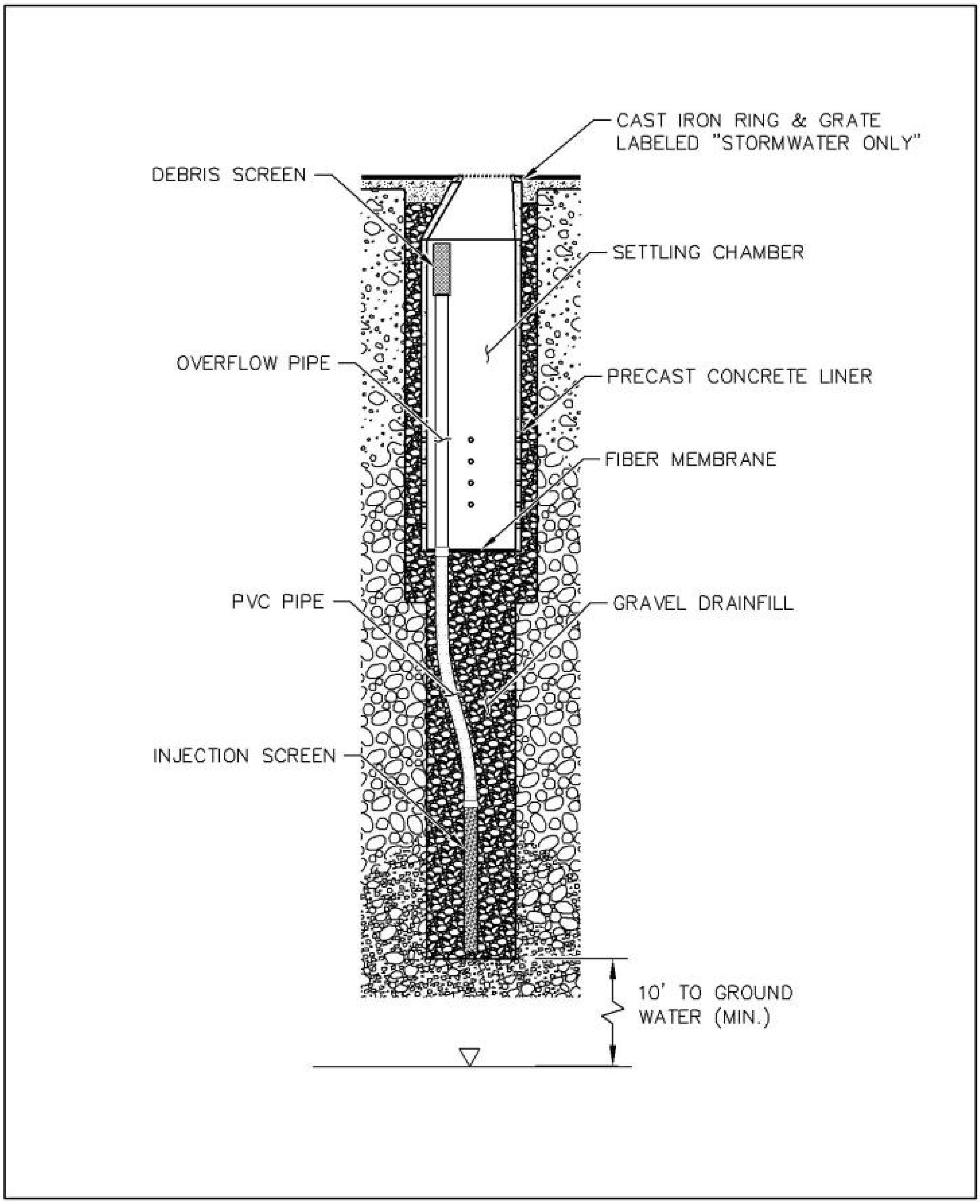



*Figure 50. Example dry well design from the Draft Design for Storm Water Detention and Retention for Pima County.*

### 5.8.5 Consideration 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 Consideration 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 LID Practices

- Stormwater Harvesting Basins
- Bioretention Basins
- Infiltration Trenches
- Cisterns
- Permeable Pavements

### 5.8.8 Compatibility with other LID Practices

- Permeable Pavement
- Cisterns

## 5.9 Sources, Citations and Additional Resources

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# 6 Common LID Components

## 6.1 Introduction

Many of the LID Practices include common elements that support the implementation of these other practices. For this reason, these common elements are listed below rather than restated in each of the other LID 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 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 2 samples or 1 sample per 50,000 square feet of structural LID 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 51 (curb cuts), Figure 52 (curb cores), and Figure 53(curb slots).

**Curb Cuts**

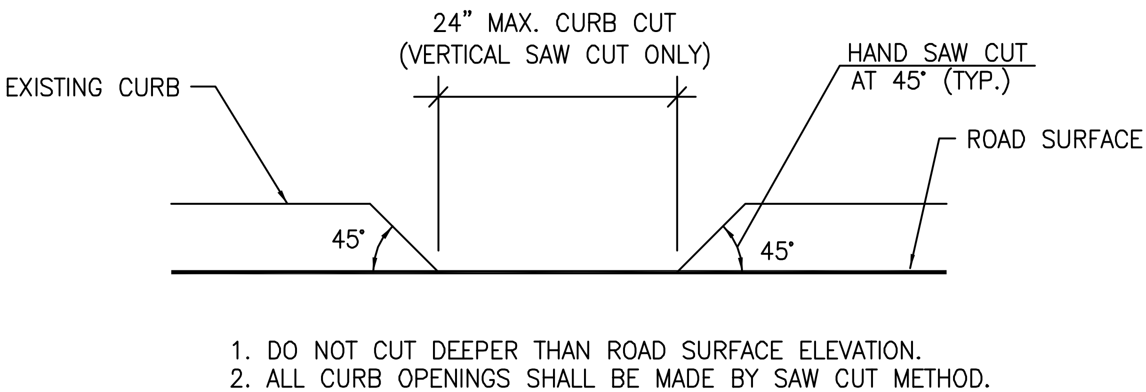



*Figure 51. Example curb cut and standard curb cut drawing.*

### Curb Cores

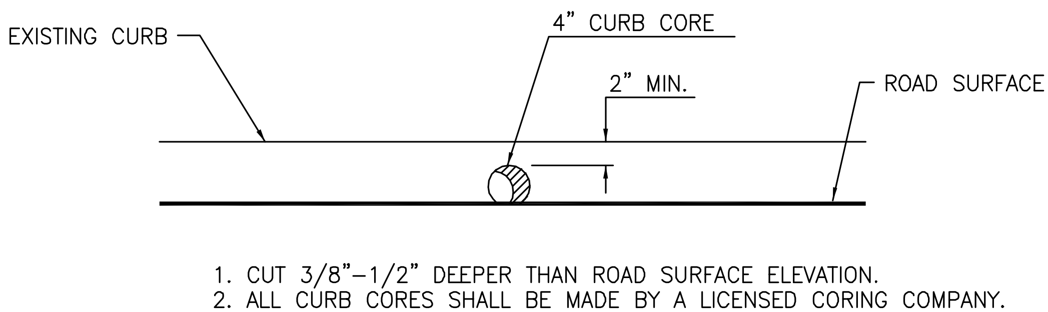



*Figure 52. Example curb core and standard curb core drawing.*

### Curb Slots

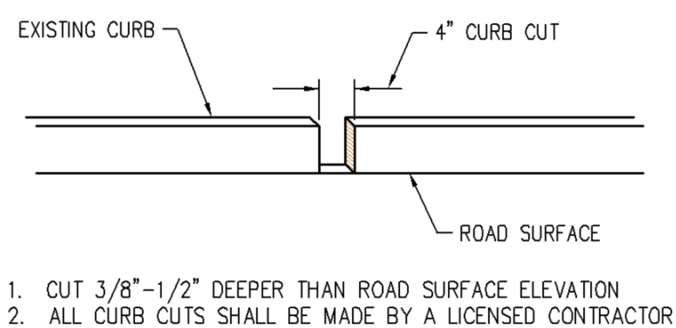



Figure 53. Example curb slot and standard curb slot drawing.
Source: City of Tucson Green Streets Suggested Technical Best Practices

## 6.4 Overflows and Outlets

There are several types of outlets that facilitate Structural GI/LID Practices. The overflow/outlets described here are commonly used for stormwater harvesting basins, but can be used with other structural practices such as swales or infiltration trenches.

Outlets shall 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:

1. An outlet that also functions as an inlet,
2. An outlet connected to a storm drain,
3. An outlet to street, and
4. An outlet that connects other structural GI/LID practices.

**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 54). Appropriate inlet protection and sediment traps as discussed in Section 6.5 will prevent erosion and transportation of sediment from the basin into the street when the feature drains.

*Figure 54. The inlet to this stormwater harvesting basin also functions as an outlet.*

**Outlet connected to a storm drain**. An outlet that is directly connected to a storm drain system as shown in (Figure 55), are systems that typically are 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.

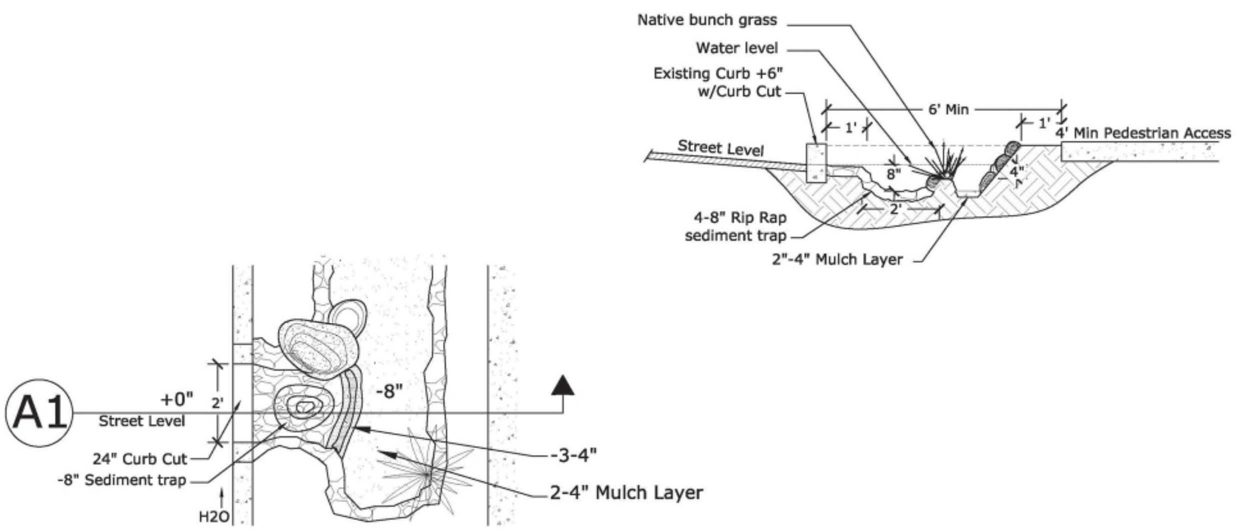
*Figure 55. An outlet connected directly to a storm drain at the downstream end of a stormwater harvesting basin.*

**Outlet to 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 to not locate an outlet where flow will be directed over decomposed granite or other erodible pedestrian pathway.

*Figure 56. 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 LID 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 57 and Figure 58) also provide inlet protection and have the added benefit of helping maintain the long term functionality of structural LID 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**

*Figure 57. Sediment trap details.*

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

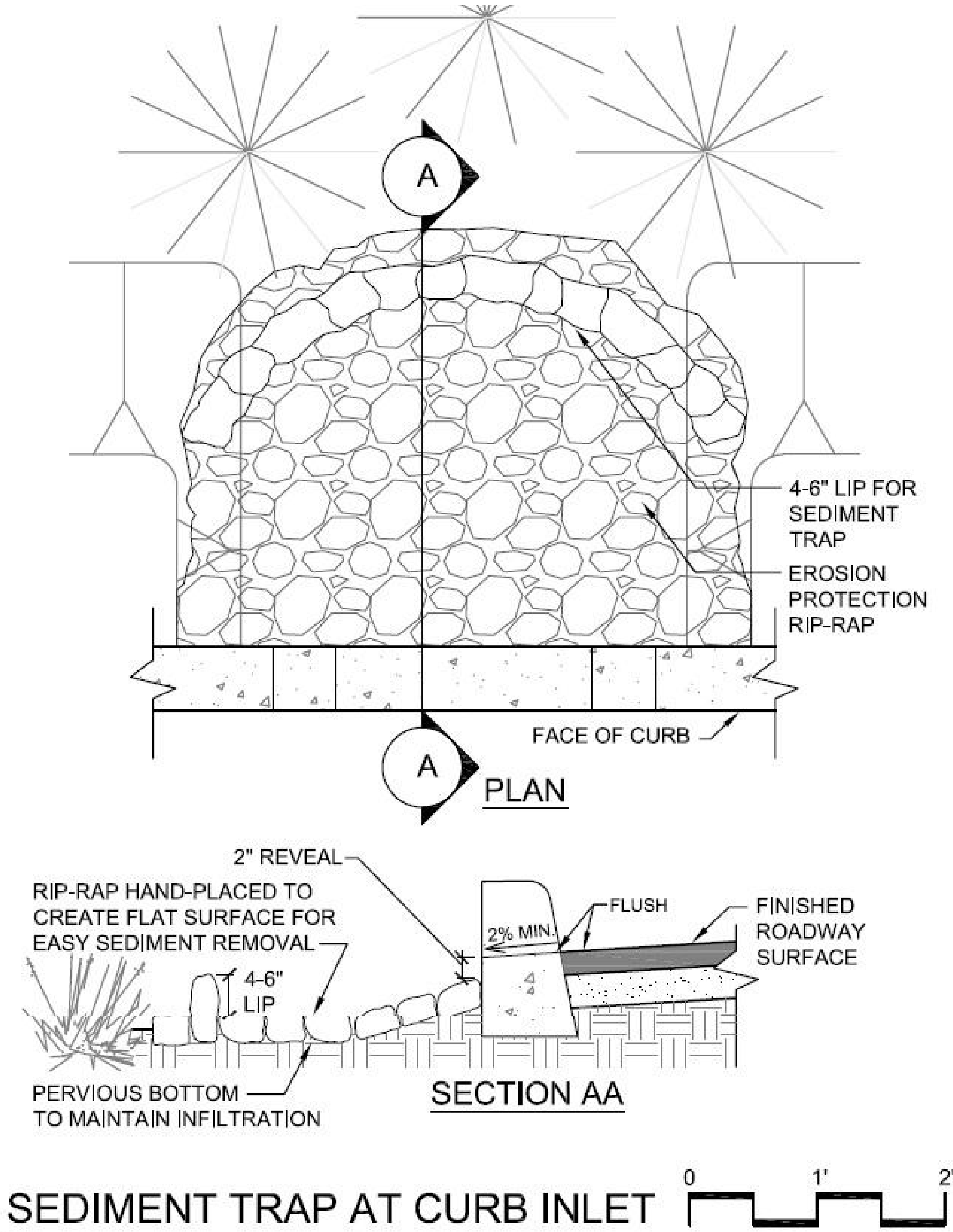



*Figure 58. Plan and cross-section views of a sediment trap at a curb inlet.*

Source: City of Tucson Green Streets Suggested Technical Best Practices

## 6.6 Flow Spreaders

1. 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 59 shows details for an inlet flow spreader, check dam and flow spreader combination, and V-notched flow spreader.

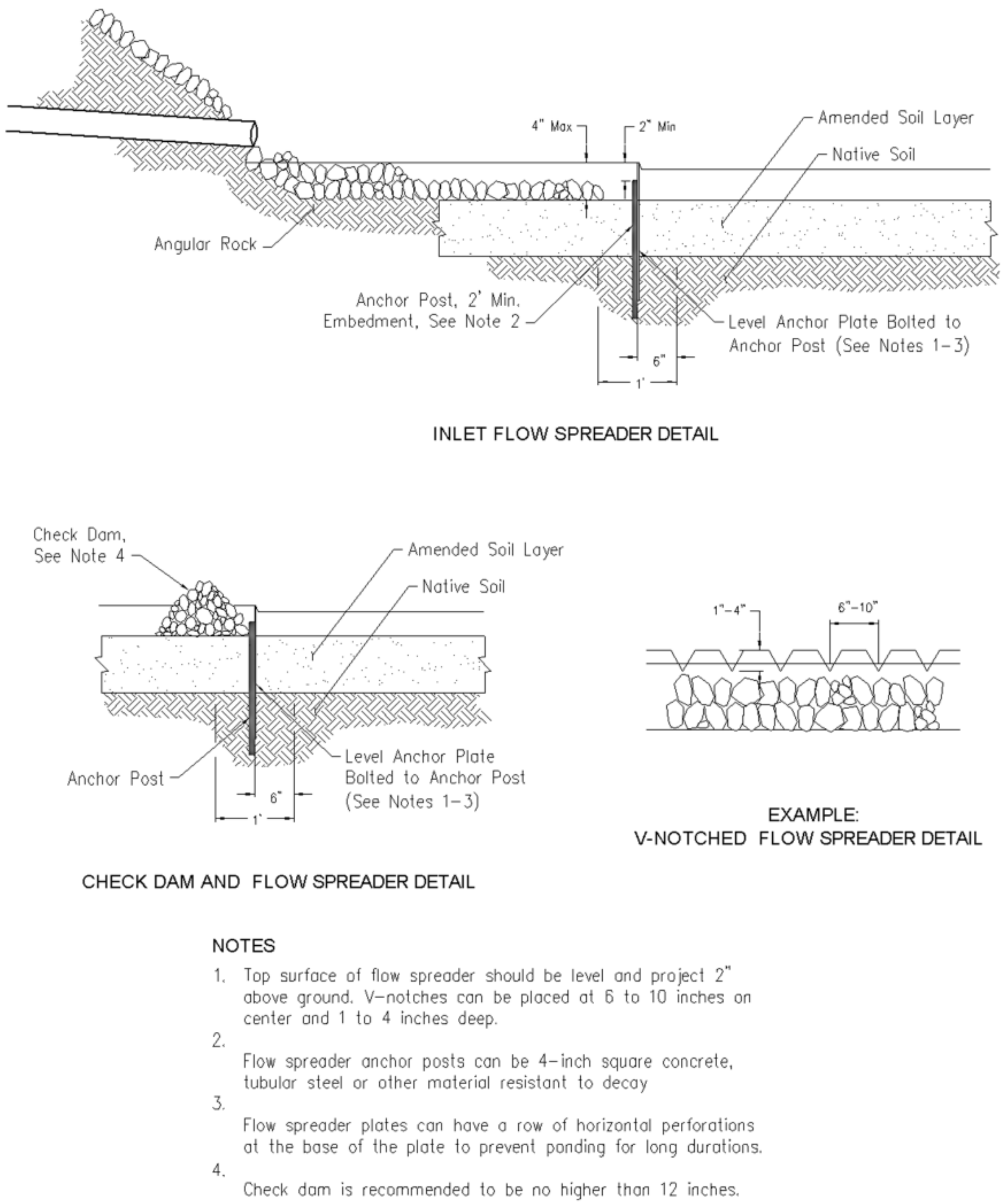



*Figure 59. Inlet flow spreader, check dam and flow spreader combination, and V-notched flow spreader detail.*

2. 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).
3. 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-hr storm event (on-line swales) or the maximum flow that will enter an off-line swale.

4. Flow spreader plates should be securely fixed in place.
5. 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 60). 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" | 100 |
| 15" | 75 |
| 9" | 50 |
| 4" | 10 |

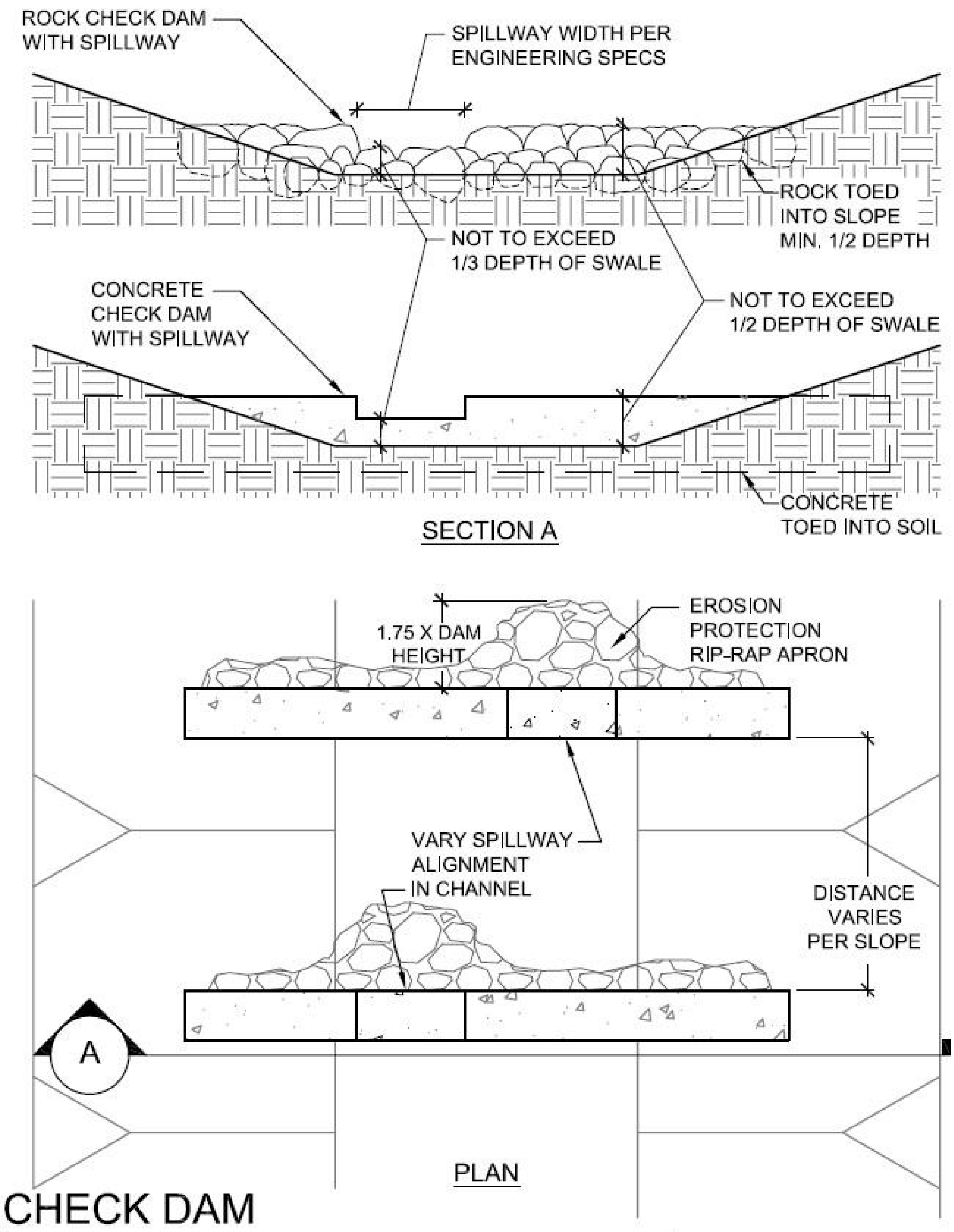



*Figure 60. Check dam details.*

Source: Watershed Management Group

## 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 3H:1V on the upstream side and 4H:1V on the downstream. However, in very cohesive clayey soils, it may be possible to construct up to 2H:1V. 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 LID 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 ($CaSO_4$ $2H_2O$) to improve permeability. Use of gypsum in soils with good structure and where low infiltration is due to other factors will not improve the soil permeability.

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 and 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 and 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” | \$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” (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” (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” | Reduced evaporation and increases water retention properties of soil |

Source: 01 Santa Barbara

## 6.10 Hydraulic Restriction Layers

Lateral and vertical seepage can cause adverse impacts when structural LID 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. Geomembranes 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 LID 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 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 ft below ground surface, where 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 LID structural practices. The designer should be cognizant of these potential conflicts in the early stages of planning in 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 LID structural 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 LID structural 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 LID in Transportation Systems

- Street configurations, topography, soil conditions, and space availability are some of the factors that will influence the design of the LID 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, increasing evapotranspiration, and may increase 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.
- **Recycled rubber sidewalks** are used as an alternative to cracked sidewalks and also help to infiltrate runoff.
- 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 Silva Cells™ 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.
- **Utility** right of ways 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 right of ways 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 LID 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 61; 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-ft-wide by 1-ft-deep on 6-ft centers and filled with a 0.5-inch layer of washed sand, then topped off with pea gravel (Tyner et al. 2009).

*Figure 61. For infiltrating practices, mitigate subsoil compaction by ripping grade to a depth of 12 inches.*

Source: NCSU-BAE

## 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.

### 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. DriWater, or another slow water release product, are typically placed in the planting hole when using tall pots, and can also be used with tree pots. (Additional information and source needed) 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 DriWater typically narrows the plant palette to the hardiest of site-specific native species, and substantially increases the labor costs for installation as well as first-year maintenance due to the requirement to refill the DriWater cartons. This cost increase can be balanced if only DriWater is 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 DriWater in areas of lower active public use and less visibility such as areas of restoration. DriWater is 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, A*cacia 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 Consideration 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 DriWater systems are used, they will require the dedicated replacement of DriWater cartridges to keep plants healthy. The hardiest plants such as agave, typically receive three DriWater 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. Commercial application or other highly visible-use and activity areas have not been fully evaluated; this practice is currently used predominately in restoration and park projects with large areas of open space.

## 6.15 Tree Canopy

Trees provide many benefits toward LID practices. They intercept rainfall with their canopies, diminishing the full impact of rainfall as I hits the earth. The canopy also holds droplets with surface tension, allowing time for evaporation. They 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 be occurring
- Do not compact soils in areas to be planted
- Roughen surface to improve seed establishment and moisture retention
- Use mulch to increase water retention, improve soil stability
- Provide erosion matting or soil stabilizers on steep slopes to prevent erosion, a critical negative issue.

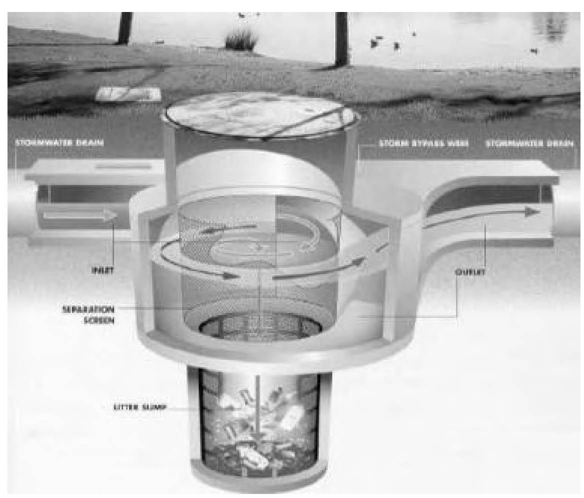
## 6.16 Pretreatment Devices

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 use will improve water quality on its own.

In order to address these concerns, a number of devices have been developed which 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




These devices allow stormwater to pass through filter media which 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.

Filter types:

- 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 63) 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 63. Bag or sock type inserts.*

- Basket type inserts (Figure 64) 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.

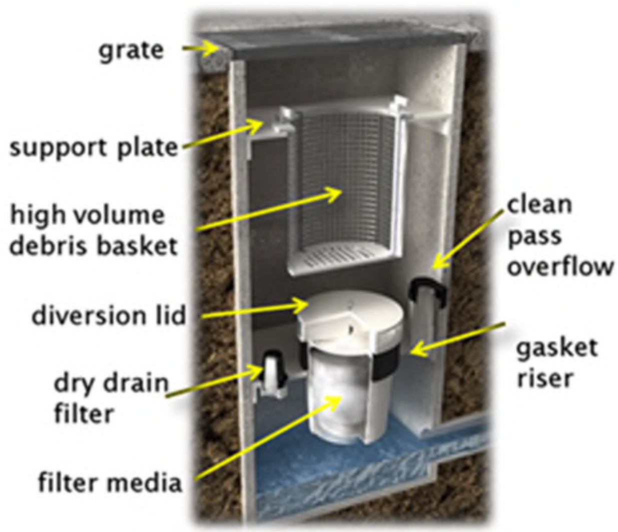



*Figure 64. Basket type insert.*

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.

*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

These devices can be used to capture oil, grease, and floatables, although they are predominantly used is remove coarse sediment from water column by enhancing the rate of sediment settling through the circular motion of the stormwater in the chamber. 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.

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 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 list of acceptable proprietary products, there 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

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# 7 Appendices