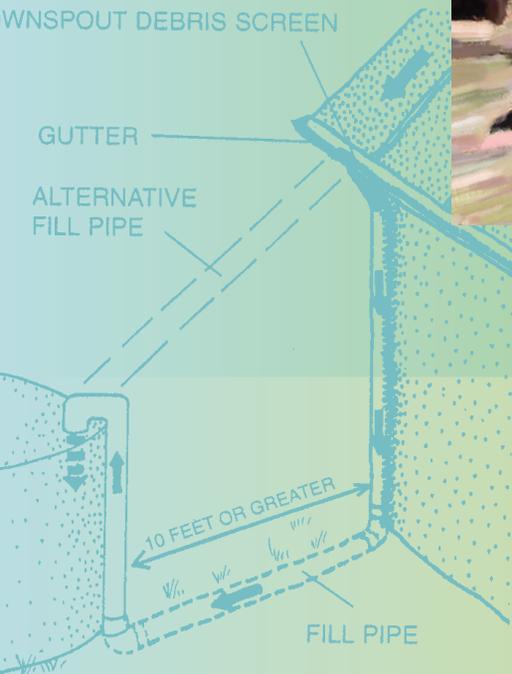


City of Tucson

Water Harvesting Guidance Manual



**CITY OF TUCSON
WATER HARVESTING GUIDANCE MANUAL**

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Ordinance Number 10210

*Edited and illustrated by
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Prepared for the
City of Tucson, Department of Transportation, Stormwater Management Section

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City of Tucson

WATER HARVESTING GUIDANCE MANUAL

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WATER HARVESTING GUIDANCE MANUAL

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SONORAN PERMACULTURE GUILD

Glossary

Note: The following definitions have been developed specifically for use within this manual and are not intended to be generalized to other uses.

Capillary rise. The tendency of water in soil to rise due to the strong attraction of water molecules to each other and to small pore spaces between soil particles.

Cistern. A water tank used to store harvested stormwater.

Contour line. A topographic contour line which is a line of equal elevation on a land surface.

Detention/retention basin. A structure that decreases flow from the site by temporarily holding stormwater runoff on the site.

Downslope. The portion of a slope that is downhill from a reference location. Water flows first to the reference location then proceeds downslope.

French drain. A gravel-filled trench that allows stormwater to quickly seep below land surface and ultimately into adjacent soil.

Gabions. A semipermeable barrier of rock or other material, which is usually encased in wire mesh. Gabions carefully placed in a small drainage slow, but do not stop, the flow of stormwater.

Infiltration. Movement of water from the surface to below ground through soil pore spaces.

Integrated design. A highly efficient site design that matches site needs with site products, and takes into account stormwater drainage, solar orientation, winds and many other factors. An integrated design saves resources while improving the function and sustainability of the site.

International Building Code, 2000. A set of specifications for construction adopted by the City of Tucson. Copies can be viewed for reference use at the City of Tucson, Development Services Department.

Microbasin. A small, relatively shallow basin used to capture, store and utilize stormwater.

Microclimate. Localized conditions of moisture, sun, wind, and other characteristics.

Overflow device. Component of a water harvesting structure that allows excess stormwater to flow out of the structure without damaging the structure.

Rainwater. Liquid precipitation falling from the sky before it has hit a solid surface.

Rock riprap. A rock layer that protects earthen surfaces from erosion.

Stormwater. Rainwater becomes stormwater once it has landed on a surface.

Stormwater Quality Storm (SQS). Commonly known as the “First Flush Storm,” the SQS is the rainfall depth that results in runoff that transports the majority of pollutants during a storm event.

Swale. A curvilinear depression in the land surface that collects stormwater. Generally has a mounded berm on the downslope side that assists in retaining stormwater.

Upslope. The portion of a slope that is uphill from a reference location.

Water harvesting. The process of intercepting stormwater from a surface such as a roof, parking area, or land surface, and putting it to beneficial use.

Watershed. A term commonly used to describe a catchment area within which all stormwater drains toward a common collection point. Used in this manual to describe those drainage areas affecting a particular site, which might include upslope areas draining toward the site or downslope areas receiving drainage from the site.

Xeriscape. Landscaping that saves water by using water conserving designs, drought tolerant plants, water harvesting techniques, reduced turf area, appropriate irrigation methods, soil improvements and mulching, and proper maintenance practices.

Introduction

WHAT IS WATER HARVESTING?

Water harvesting is the process of intercepting stormwater runoff from a surface (e.g. roof, parking area, land surface), and putting it to beneficial use. Intercepted stormwater can be collected, slowed down, and retained or routed through the site landscape using microbasins, swales and other water harvesting structures. Water harvesting reduces dependence on dwindling groundwater reserves and expensive Central Arizona Project (CAP) water. Capturing and using stormwater runoff also reduces site discharge and erosion, and the potential transport of stormwater pollutants.

HOW WILL WATER HARVESTING BENEFIT MY SITE?

Urban sites typically have a high ratio of impervious area (buildings and pavement) to pervious area (vegetated and bare soil areas). By harvesting and using stormwater you can:

- Increase water availability for on-site vegetation,
- Reduce on-site flooding and erosion,
- Reduce water bills and groundwater pumping, and
- Extend the life of landscaping (rainwater is usually low in salt content and relatively high in nitrogen).

In addition, you may be able to save money and increase usable land area by using stormwater harvesting techniques to reduce the City of Tucson retention/detention requirements for a site. As in many other large cities, developments in Tucson are accountable for the quality of the stormwater leaving their sites. Harvesting stormwater and vegetating stormwater collection areas can help improve stormwater quality by reducing particulates and pollutants in stormwater.

WHO SHOULD READ THIS MANUAL?

The Water Harvesting Guidance Manual was prepared for the City of Tucson to provide basic information and design ideas to developers, engineers, designers and contractors of commercial sites, public buildings, subdivisions and public rights-of-way. The City of Tucson Land Use Code includes requirements for water harvesting at these types of developments. The manual will also be useful for those interested in water harvesting on their existing or future home sites.

IS WATER HARVESTING GOING TO COST ME MORE?

Site development costs typically include design, grading, and landscaping. Long-term maintenance adds to these initial costs. Incorporating water harvesting into site development can save money by:

- Reducing the size of code-required detention/retention facilities,
- Saving the costs of structural stormwater quality controls,
- Combining detention/retention, landscape buffers and visual screens into single features,
- Reducing landscaping water bills, and
- Lowering energy requirements by shading buildings with vegetation watered with harvested stormwater.

Incorporating water harvesting concepts early into an integrated design for the site is key to reducing costs and maximizing long-term benefits.

WHAT IS A SITE WATERSHED?

The term watershed is commonly used to describe an area within which all stormwater drains toward a common collection point. The term watershed is used in this manual to describe drainage areas affecting your site, which might include upslope areas draining toward your site, drainage areas on your site, or downslope areas receiving drainage from your site.

HOW TO USE THIS MANUAL

This manual describes a process for evaluating site characteristics and developing integrated designs in which water harvesting enhances site efficiency, sustainability, and aesthetics. Water harvesting principles and techniques are described, followed by example designs for a subdivision, commercial site, public building and public rights-of-way. This manual is intended to provide general guidance; implementation will require site-specific modification, sizing, and engineering. Illustrations indicate relative size and order of magnitude, not specific scale. **Note: Every site is unique; adapt the information in this manual to specific conditions at your site. Prior to installation, obtain all permits and have the site Blue Staked (1-800-782-5348) to locate underground utilities.** Appendices have been included to address City of Tucson Code requirements (Appendix A), engineering considerations (Appendix B), water harvesting calculations (Appendix C), landscaping considerations (Appendix D), mosquito considerations (Appendix E), example water harvesting sites (Appendix F), and related resources and contact information (Appendix G).

Water Harvesting Principles

START MANAGING WATER AT THE TOP OF THE WATERSHED

- Determine the site watershed, including offsite watersheds that contribute stormwater runoff to, or receive stormwater runoff from, your site.
- By managing small volumes of water at the top and throughout the watershed, the need to manage a large volume of stormwater at the bottom of the watershed is decreased.
- Encourage upslope neighbors to conduct water harvesting on their sites, and/or capture and use this stormwater runoff as it enters your site.

CREATE MULTIPLE SMALL WATERSHEDS

- Evaluate existing topography using a detailed site contour map and site visits.
- Divide the site into small watersheds based on existing topography, or based on grading and reshaping as necessary, to maximize stormwater harvesting.

COLLECT, SLOW AND INFILTRATE THE WATER

- Slow and spread stormwater flow to reduce its erosive nature, allow sediments to drop out, and allow more water to infiltrate into soils.
- Expose stormwater to as much soil surface area as possible within the confines of the water harvesting structure to increase infiltration into the soil; the least expensive place to store water is in the soil.
- Stormwater should be stored in the soil at locations where it can support plant growth but not damage facility foundations. The International Building Code (IBC) recommends a minimum of 10 feet between building foundations and ponding water or infiltration areas [2000 IBC section 1803.3]. Consultation with a soil professional is recommended when planning water harvesting near a structure.
- As more stormwater infiltrates into the soil, less stormwater has to be managed as surface runoff.

PREPARE FOR OVERFLOW

- Water harvesting structures need to allow excess stormwater to overflow safely to other locations where it will be used beneficially.
- Overflow devices (tank overflow pipes, spillways, etc.) should be sized to safely handle large rainfall events. Convey overflow discharge to safe locations to avoid contributing to erosion.
- Overflow devices should be checked and maintained regularly.

MULCH TO REDUCE EVAPORATION

- Mulching soil by adding a thick layer of organic or inorganic material reduces evaporation of water from, and retains moisture in, the soil to support plants. Mulch to an appropriate thickness (3" to 4" is usually sufficient) for the vegetation types present. Avoid mulching against tree trunks.
- Organic mulches include bark, leaves, straw, and other plant materials that decompose over time to create healthier, more porous soils. Organic mulches can float on water, so water harvesting basins should be large enough to contain floating mulch. Vegetation will help immobilize mulch.
- Inorganic mulches include rock, gravel, decorative rock (not decomposed granite), and other materials that do not inhibit infiltration into the soil.

PUT HARVESTED WATER TO BENEFICIAL USE

- Think about all the ways you use water at your site, and consider how harvested stormwater can be used to meet these needs.
- Harvested stormwater is much lower in salts and higher in nitrogen than groundwater, which benefits plants.
- Stormwater stored in well-mulched soil supports plants during and after the rainy season. Stormwater stored in tanks is typically available beyond the rainy season.

ADJUST AND MAINTAIN YOUR SYSTEMS AS NEEDED

- Inspect water harvesting systems periodically, especially after big rainstorms, and adjust as needed to address basin or overflow sizing, erosion, or mosquito breeding issues.
- Water harvesting basins might need to be expanded as plants mature.
- Some systems will need more ongoing maintenance than others; all systems should be carefully designed to be as low-maintenance as possible.

— Water Harvesting Design Process: Integrated Site Design —

INTRODUCTION

Integrated site design matches the needs of a site (e.g. water, energy, aesthetics) with the products of a site (e.g. stormwater runoff, shade from buildings, vegetation) to create an efficient design that saves resources (e.g. energy, water) while improving the function and sustainability of the site. An integrated design is based on detailed site analysis.

STEP 1:

ADOPT AN INTEGRATED DESIGN PROCESS

- An integrated design process must be based on a multidisciplinary approach. Members of the design team can include the developer, architect, engineer/hydrologist, landscape architect, contractor, land use planner and others.
- Hold a predesign meeting with the entire team to address water harvesting potential.
- Throughout the design process, it is important to keep focused on integrating various technical perspectives and to pursue opportunities to achieve multiple benefits.

STEP 2:

ANALYZE SITE CHARACTERISTICS AND CONDITIONS

- Inventory site characteristics including topography, geology, native plants, soils, views, site history, pollution history, etc.
- Obtain a detailed contour map of the site.
- Map the site's watersheds (stormwater drainage pattern) on the contour map and determine stormwater flow rates.
- On the contour map plot other conditions that affect the site including warm and cool microclimates, seasonal winds, noise, light pollution, traffic patterns, wildlife corridors, human pathways, etc.
- Evaluate adjacent land uses for their impact on the site, and evaluate the site's impact on them.

STEP 3:

IDENTIFY THE POTENTIAL TO USE HARVESTED WATER AND OTHER SITE RESOURCES

- Determine how harvested stormwater and other resources can improve efficiency, comfort, open-space buffering and aesthetics of the site.
- Determine how harvested stormwater and other resources can reduce water consumption, energy requirements, landscape maintenance and other needs.
- Determine how each site element can serve multiple functions (e.g. above-ground water tanks could provide stored water, shade and noise abatement).

STEP 4:

DEVELOP AN INTEGRATED DESIGN FOR THE SITE

- Evaluate maps and potential uses prepared in Step 2 and Step 3 to determine which characteristics are useful (e.g. stormwater) and which are not useful (e.g. noise).
- Design water harvesting, landscapes, buildings, roads, parking lots, sidewalks to use desirable elements (e.g. stormwater, winter sun, views) and to deflect unwanted elements (e.g. harsh winds, noise, summer sun).
- Design water harvesting approaches to supplement landscape irrigation, reduce stormwater discharge, and downsize detention/retention facilities.
- Design landscapes to use harvested water, to cool buildings, shade parking lots, provide visual screens and improve aesthetics.
- Develop an integrated design for the site that incorporates these considerations and incorporates the multidisciplinary approach.

STEP 5:

PREPARE DETAILED DESIGNS

- Use the final integrated design as the basis for preparing detailed plans for site layout, grading, drainage, architecture and landscaping.
- Check detailed plans for consistency with the integrated design.

Water Harvesting Techniques: Microbasins

Goal

Collect stormwater in localized basins served by small watersheds.

Appropriate siting, water volume and slope

Microbasins are appropriate for use on gently sloped or nearly flat land with low volumes of runoff water such as along sidewalks, in landscaped areas, in parking lot planters, etc. Microbasins can be used in areas with more concentrated runoff if they are arrayed in a series with spillways in between. **Microbasins are generally not suitable in washes or other locations with heavy stormwater flow. Every site is unique; the appropriate scale of any water harvesting technique needs to be determined based on site-specific conditions. Consult a professional when in doubt.**

Construction

Dig out a shallow basin, putting the extra dirt downhill and on the sides of the basin to create a thick, crescent-shaped, gently-sloped berm. Compact the berm to keep it from eroding. Berms can be covered with riprap or ground cover vegetation to protect them from the impact of rain and overflow erosion. The upslope side of microbasins should be open to intercept water. The bottom of the basin can be flat to spread the water evenly, or gently concave to focus water where desired. It may be necessary to construct depressed, rock-lined spillways on some microbasins to manage overflow. **Do not** compact the bottom of the basin since this would inhibit water infiltration. Microbasins should be vegetated and mulched to encourage rapid infiltration of stormwater.

Vegetation

Plants will prefer the sides or bottoms of microbasins depending on their tolerance for temporary inundation. Plant seedlings rather than seeds in microbasins since temporary inundation can drown sprouting seeds. Basins are also useful for retaining supplemental irrigation water. Mulch the basins to reduce evaporation losses. Avoid mulching against tree trunks.

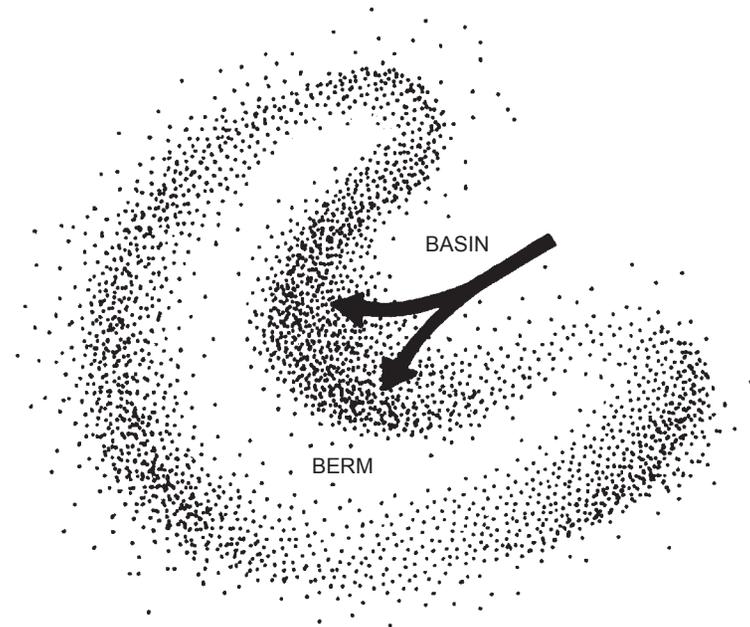
Maintenance

After heavy rainfall, check microbasins for evidence of overflow. If needed, build a shallow spillway on the berm to control the outlet of future large flows from the microbasin. A well-mulched and planted microbasin receiving water from a small localized watershed generally does not over-

flow. Microbasins **must** be designed and maintained to infiltrate stormwater completely within 12 hours to avoid mosquito problems (Appendix E).

Variations

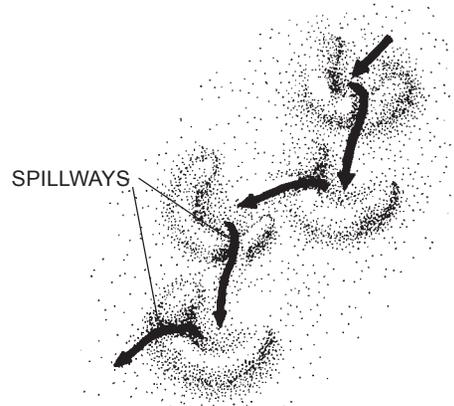
Several variations of microbasins are shown on the following page. Microbasins can be constructed in a range of sizes to support single or multiple plants with different water needs. All variations **must** be designed and maintained to infiltrate stormwater completely within 12 hours to avoid mosquito problems.



Water Harvesting Techniques: Microbasins

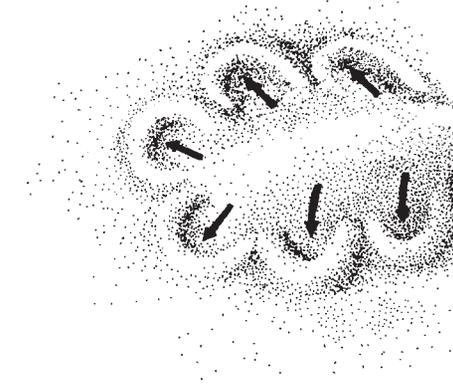
A. Microbasins in a series.

Offset the spillways on microbasins to create a longer water flow path to encourage more infiltration into the soil. These are appropriate for moderate flows. May need more erosion control measures for overflow areas.



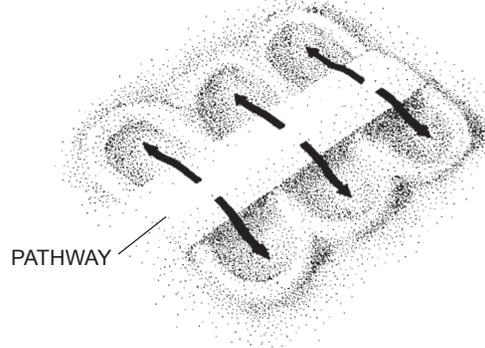
B. Microbasins on-contour.

Arrange microbasins to intercept water running off a ridge. Microbasins will follow the shape of the contour line around a ridge with the upslope ends of basins at the same elevation.



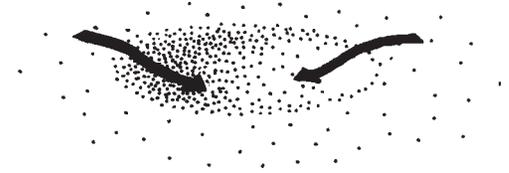
C. Build microbasins in association with pathways, driveways, etc.

Raise pathways and other hard surfaces relative to microbasins so the surfaces drain toward basins and water does not pool where people walk or drive. Avoid a steep drop off at the pathway edge.



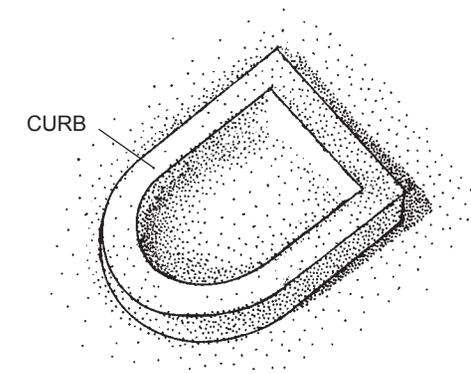
D. Localized depressions.

Construct gentle localized depressions without constructing associated berms.



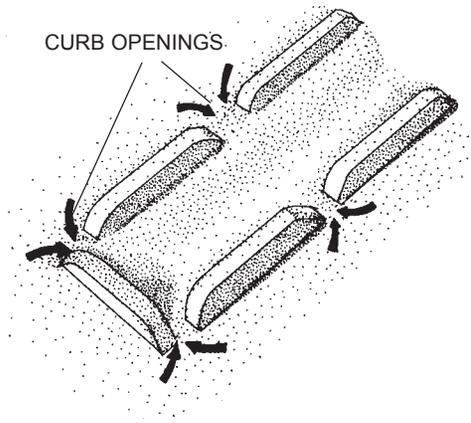
E. Lower soil level inside curbed areas.

Use a concrete header as the berm for a microbasin and lower the soil level inside the header. This allows retention of all the rainwater that falls into the basin, though it does not intercept additional stormwater flowing in the area. This is a good way to retrofit existing parking lot planting areas. If multiple plants are present, multiple internal basins can be shaped to further focus the water.



F. Direct parking lot runoff toward microbasins.

Slope parking lot surfaces to direct stormwater runoff toward depressed microbasins positioned so that trees planted in them will shade cars and people. Use curb-stop sections or formed curb with curb openings to stop car tires, while allowing water to flow into the microbasin planting areas.



Water Harvesting Techniques: Swales On-Contour

Goal

Intercept small to moderate volumes of shallow, slow-moving stormwater (sheet flow) with swales and associated berms constructed on-contour.

Appropriate siting, water volume and slope

On-contour swales can be used in small- to moderate-sized watershed areas with gentle slopes such as parks, large landscape area, open spaces, etc. On-contour swales should not be constructed within a drainage channel, and should be at least 10 feet from any building foundation (2000 IBC Section 1803.3). Position swales carefully since water will pond in the swale to a line approximately level with the top of the spillway. **Every site is unique; the appropriate scale of any water harvesting technique should be determined based on site-specific conditions. Consult a professional when in doubt.**

Construction

Determine the overall storage volume needed for the water harvesting swale based on the watershed area above the swale and the slope at the swale location. Dig a curvilinear swale (depression) parallel with the land contour (any line of equal elevation), and place excavated dirt on the downhill side to create a berm. Smooth the swale and berm and compact the berm only. The berm should be wide and strong and can be covered with riprap or ground cover vegetation to reduce erosion. The top of the berm should generally be level, with the exception of a depressed spillway area. The spillway will be the low point in the berm, and should be lined with rock to reduce erosion. The bottom of the swale is lower than the berm and spillway so stormwater is stored within the swale. Multiple swales catching stormwater runoff at multiple locations in the watershed are preferable to a single large swale.

Carefully design and construct spillways to handle large flows without damaging the structure. Large spillways should be depressed in the center to avoid the tendency of water to scour around the outside edges of the spillway. Extend the rock downslope of the spillway to create an apron or splash pad to absorb the impact of overflow water. The bottom of swales can be uneven (but lower than the spillway) to allow existing plants to be left in place. Swales should be planted and mulched to assist rapid infiltration of water and minimize evaporation. Swales **must** be designed to infiltrate stormwater completely within 12 hours to avoid mosquito problems (Appendix E).

Vegetation

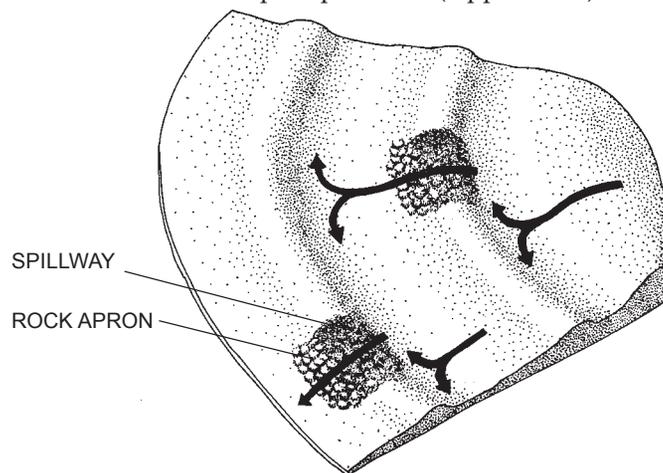
Native and other drought-tolerant plant species are appropriate for planting in or near these water harvesting structures. Extensive roots will help stabilize the structure, as will the self-mulching tendency of dense vegetation (leaf drop accumulation creating a mulch layer). Position plants to take advantage of water but avoid placing plants where they block spillways or would be damaged by large flows. Smaller plants with shallow roots should be planted in the bottom or sides of the swale close to higher soil moisture areas. Trees can be planted in the swale, on the berm, or immediately downslope of the berm, since tree roots will seek moist soils. Mulch the plantings. Supplemental irrigation might be needed to establish vegetation. Once established, low water use plants typically do not need irrigation, except during extended dry periods.

Maintenance

Check swales and spillways after heavy rainfall for overflow of the berm, erosion of the spillway, and to see if water remains in the swale for more than 12 hours. Adjust spillway or swale configuration accordingly. Sediment can accumulate in the bottom of swales reducing storage volume and infiltration rate. Break up the bottom of the swale, add mulch or increase plantings to aid infiltration rate. If needed, remove built-up sediment to re-establish storage volume and infiltration rate.

Variations

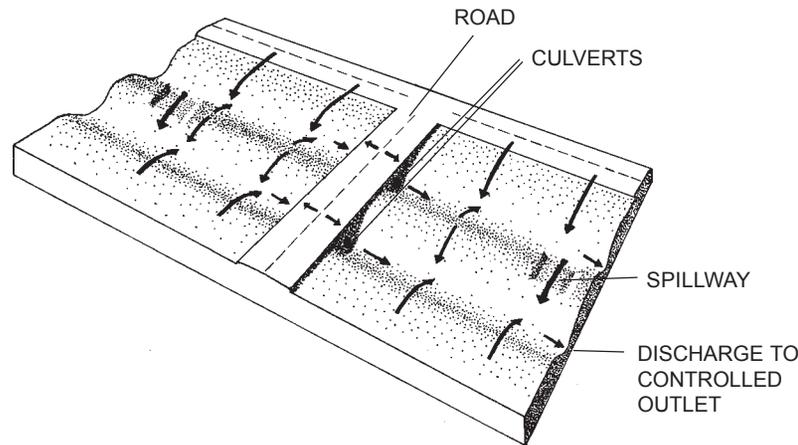
Variations of on-contour swales are shown on the following page. All variations **must** be designed and maintained to infiltrate stormwater completely within 12 hours to avoid mosquito problems (Appendix E).



Water Harvesting Techniques: Swales On-Contour

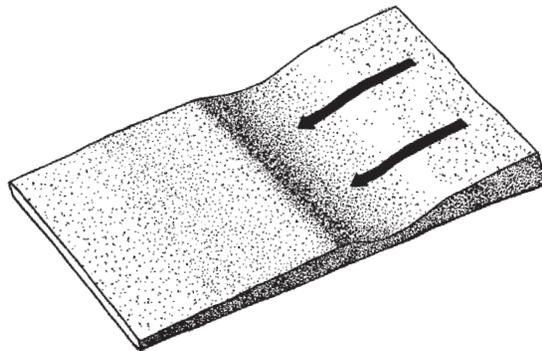
A. Large-scale parallel on-contour swales.

Install parallel on-contour swales to act as a retention/detention feature. The first swale intercepts the water and retains it for use. The second swale intercepts overflow stormwater from the first swale, and can be built to transmit excess stormwater offsite if necessary. Plant both swales with vegetation to utilize the stored water and act as landscape buffers. Roads, sidewalks and paths can be built in conjunction with these structures.



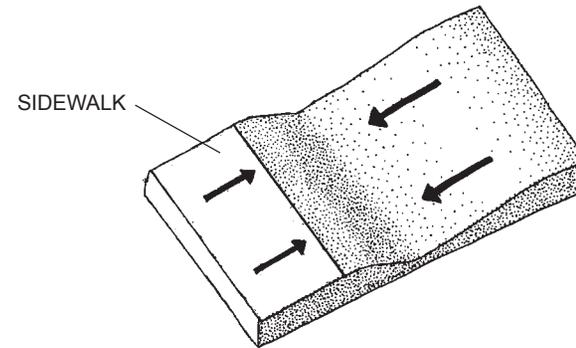
B. Swales without associated berms.

Create wide, gentle linear depressions on-contour to collect stormwater without constructing associated downslope berms. This results in less volume of storage, but is a less noticeable structure.



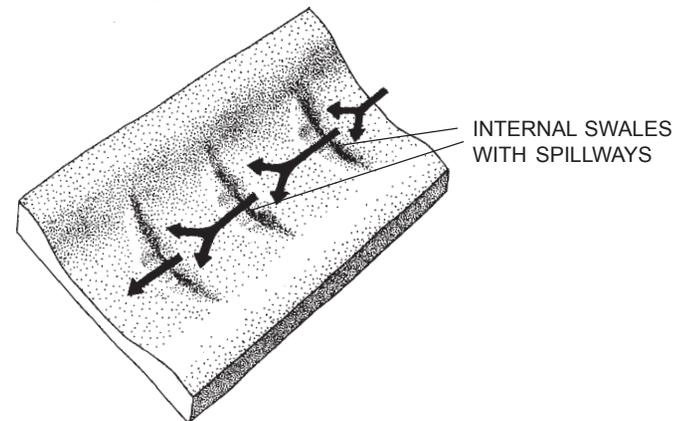
C. Use roads, sidewalks and paths as berms for adjacent swales.

Raised roads, sidewalks and paths constructed on-contour can act as berms to retain water in upslope swales. Direct a portion of the paved surface runoff toward the upslope swale. Earth along the edge of paved surface is vulnerable to erosion and might need erosion controls. Use caution where infiltration into the subsurface could saturate a compacted road base. Provide a gentle slope between a sidewalk and adjacent basin to avoid creating a tripping hazard.



D. Swales as microbasins.

Build swales and berms along contour lines within the confines of a gently-sloped drainageway. Include overflow spillways to allow excess stormwater to flow downslope.



Water Harvesting Techniques: Swales Off-Contour

Goal

An off-contour swale is constructed at a slight angle from the contour line. As shown in the illustration, the swales and berms are aligned slightly off parallel with the contour lines. Off-contour swales convey stormwater **slowly** downslope in a controlled manner to maximize infiltration, support vegetation, control erosion, reduce stormwater flow velocity, and eventually discharge any excess stormwater to a safe location.

Appropriate siting, water volume and slope

Off-contour swales and berms can be used in moderate-sized watersheds in areas with gentle slopes such as parks, large landscaped areas, open spaces, etc. They are not designed for use within a drainage channel. Large off-contour swales should be at least 10 feet from any building foundation (2000 IBC, Section 1803.3). **Every site is unique; the appropriate scale of any water harvesting technique should be determined based on site-specific conditions. Consult a professional when in doubt.**

Construction

Off-contour swale construction methods are similar to those for on-contour swales, as detailed on page 6. Very slight drops in the slope of the off-contour swale will convey water **slowly** downslope without causing erosion. Additional basins can be constructed inside larger swales to further reduce flow rate and retain more water in the soils. The final destination of the water should be a multipurpose detention basin area or other area where the stormwater can be put to beneficial use and/or discharge safely. Minimize erosion by using rock riprap on any steep banks. Spillways might be needed if the swales serve relatively large watershed areas.

Vegetation

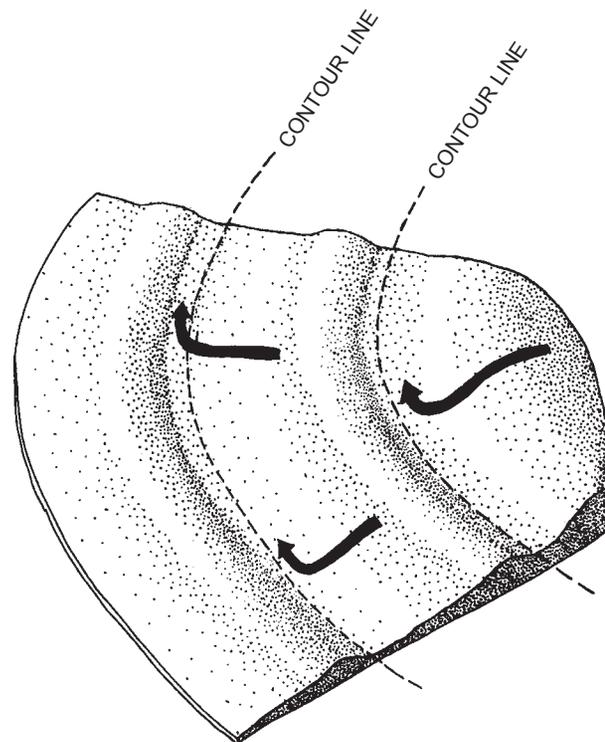
Drought-tolerant native trees and shrubs and other drought tolerant species are appropriate for planting in or near these structures. The root systems will help stabilize the structure, as will the self-mulching tendency of dense vegetation. Arrange plants to take advantage of water availability and avoid planting near spillways where plants might be damaged by large flows.

Maintenance

Inspect the structure after large rainfall events for erosion, inadequate sizing of spillways, and other deficiencies. Correct any deficiencies and continue to inspect and maintain the swale following major events. Swales **must** be designed and maintained to infiltrate stormwater completely within 12 hours to avoid mosquito problems (Appendix E).

Variations

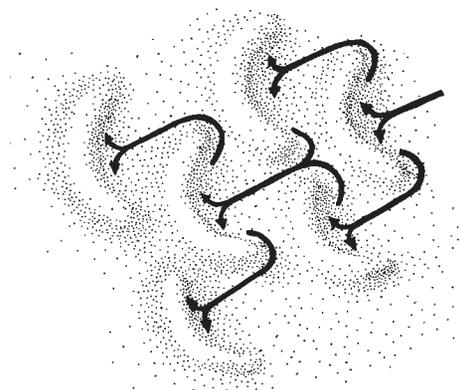
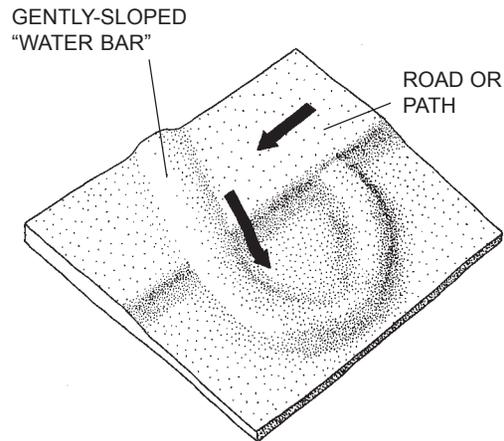
Several variations of off-contour swales are shown on the next page. An additional variation is to create a wide, gently sloped drainage swale perpendicular to the land contour to move water gently downslope. Use appropriate plantings to stabilize soil in the gentle drainage swale. Swales can also be arranged to direct stormwater slowly downslope in a switch-back pattern. All variations **must** be designed and maintained to infiltrate stormwater completely within 12 hours to avoid mosquito problems.



Water Harvesting Techniques: Swales Off-Contour

A. Pocket swales.

Where roads and paths slope downhill, install a “water bar” (a very gently sloped berm) across the travel surface to intercept stormwater that might cause erosion. The water bar should be constructed slightly off-contour to direct water toward an adjacent depression. Extend the water bar to create a hook-shaped berm enclosing a basin next to the path. If the watershed area is relatively large, an overflow spillway can be constructed in the hooked portion of the berm to route excess water away from the path. Make sure the water bar is very gently rounded to avoid creating a tripping hazard on pathways. Avoid a steep drop off at the pathway edge.

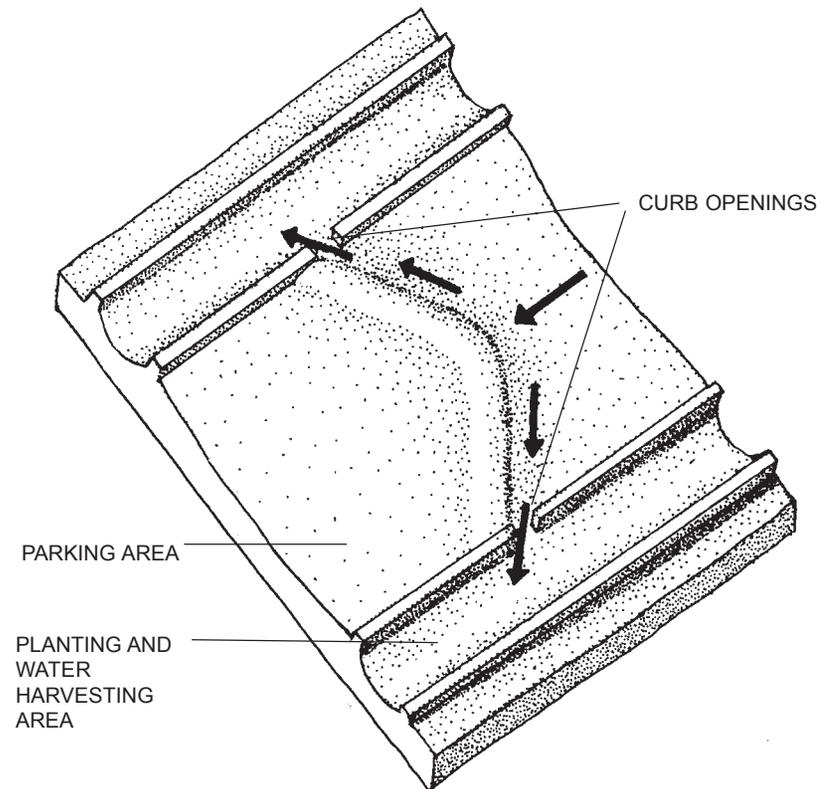


B. Boomerang swales.

Endpoints of these arc-shaped swales point uphill, and are the low points of the berm. After a swale fills, overflow occurs at one or both end points. Protect end points from erosion using rip rap or other erosion-control approach. Boomerang swales can be installed individually or in a series.

C. Parking lot berms.

Parking lots are typically sloped to funnel stormwater runoff down the middle of the travel lane. Instead, gently crown the parking lot to direct stormwater toward adjacent depressed planting/water harvesting areas. To retrofit an existing parking lot, construct asphalt berms (speed humps) in the parking lot to intercept water and direct it into adjacent depressed planting areas (see figure below). Add appropriately sized curb openings to allow runoff water to enter the planting areas.



Water Harvesting Techniques: French Drains

Goal

French drains are rock-filled trenches that are designed to encourage rapid stormwater infiltration through the sides, ends and bottom of the trench where soil and water meet.

Appropriate siting, water volume and slope

Because they are filled with rock, French drains hold only about one-third of the water that an open trench would hold. French drains can intercept low to moderate flows depending on their size. French drains are typically used on flat to moderate slopes. French drains should receive runoff water only from watershed areas that are relatively free of sediment like parking lots, rooftops, sidewalks, or areas stabilized with vegetation. French drains should not be built in a watercourse, where silt could quickly clog the pore spaces. French drains are useful for intercepting water in areas where a level surface is needed. French drains could be used on steeper slopes where water harvesting basins would have only small storage volumes.

The use of French drains in required pedestrian or vehicular use areas will require approval by a City of Tucson Development Services Department official. French drains are not typically designed to stand up to the weight of vehicular traffic. As with other water harvesting structures, French drains should be placed at least 10 feet away from building foundations (2000 IBC, Section 1803.3). **Be sure water harvesting efforts do not generate unstable slopes. Consult a soils engineer when designing water harvesting structures for any slopes that may not be completely stable. Every site is unique; the appropriate scale of any water harvesting technique should be determined based on site-specific conditions. Consult a professional when in doubt.**

Construction

Dig a trench and fill it with gravel or cobbles to a level even with land surface. Rounded rock provides larger pore space between rocks resulting in more storage volume than angular rock. French drains can be built on-contour to intercept water, or across contour to intercept and transmit water slowly downslope without erosion. To reduce clogging of gravel pore spaces in areas where the runoff carries sediment, place filter fabric around and on top of the French drain, or construct a shallow basin upslope of the French drain to intercept stormwater and allow sediment to settle out be-

fore stormwater enters the French drain. Ground cover plants can be used to stabilize soils in upslope locations to reduce sediment transport to the French drain.

Vegetation

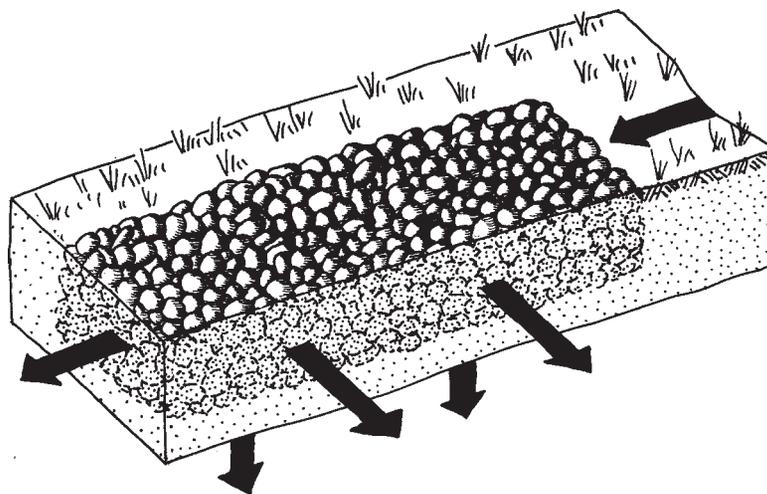
Shrubs and trees can be planted along the sides or at the terminus of the French drain. Avoid potential clogging of the French drain from accumulated leaf litter by using good maintenance practices.

Maintenance

Keep French drains free of surface debris and sediment buildup to keep pore spaces open. French drains **must** be designed and maintained to infiltrate stormwater completely below the top surface of the French drain within 12 hours to avoid mosquito problems (Appendix E).

Variations

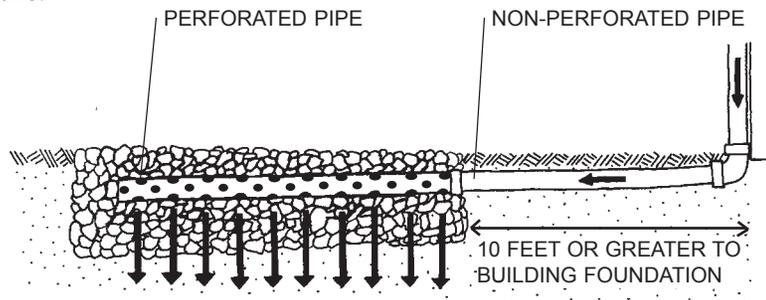
Several variations of French drains are shown on the next page. An additional variation is to create a large expanse of “porous” pavement to allow water to infiltrate directly into parking areas and pathways. The use of “porous” pavement may require approval by a City of Tucson Development Services Department official. All variations **must** be designed and maintained to infiltrate stormwater completely below the ground level surface of the French drain within 12 hours to avoid mosquito problems.



Water Harvesting Techniques: French Drains

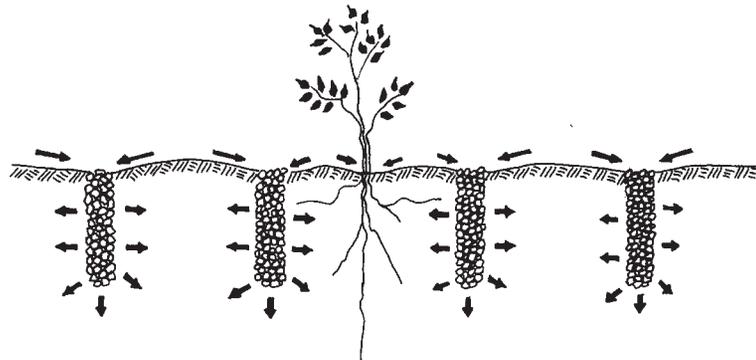
A. Direct stormwater to a French drain using subsurface pipe.

Install non-perforated pipe from the point of origin of water to the edge of the French drain. Switch to perforated pipe within the French drain to allow water to enter the drain and infiltrate into the soil. When pipe is used inside the drain, the pipe will not usually withstand heavy loading. French drains should be placed at least 10 feet away from building foundations.



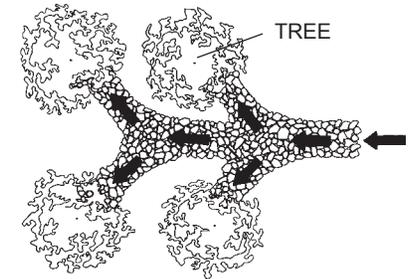
B. Construct vertical gravel columns or "curtains."

Stormwater can be directed quickly into the ground around tree roots by excavating columns or "curtains" around the perimeter of the tree and backfilling these with gravel. Over time the tree roots will find the water provided by the wider-spaced curtains. These structures will fill with silt over time, but will continue to provide better infiltration than without the drain. If this style of French drain is constructed around an existing tree, locate the columns outside the perimeter of the drip line of the tree to avoid damaging growing roots.



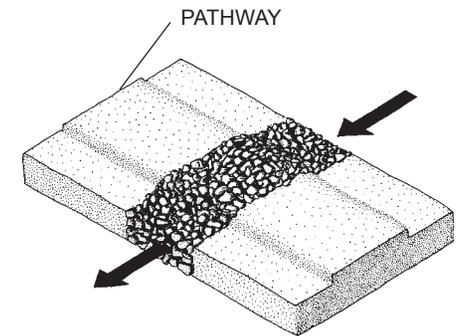
C. Branch the French drain.

The bottom of the French drain trench can be sloped to direct water toward a specific point, and can have multiple branches to direct water to different planting areas.



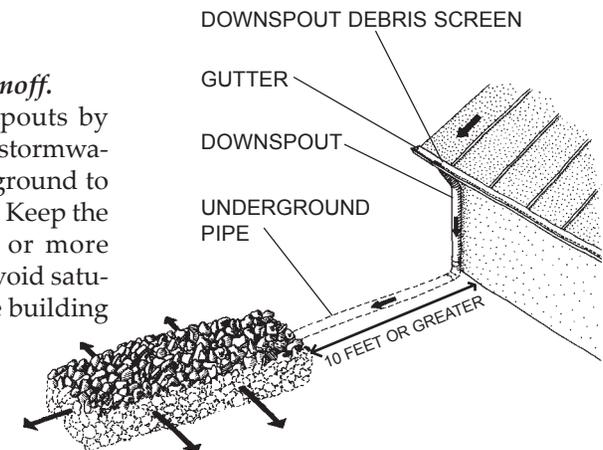
D. French drains and pathways.

Build French drains in association with paths to keep the walking surface relatively level while safely moving stormwater toward nearby vegetation. The surface must be stable in the pathway area to avoid tripping hazards. Use of French drains in association with paths will require approval by a City of Tucson Development Services Department official.



E. Intercept rooftop runoff.

Extend gutter downspouts by using a pipe to convey stormwater over or under the ground to a nearby French drain. Keep the French drain 10 feet or more from the building to avoid saturating the soil near the building foundation.



Water Harvesting Techniques: Gabions

Goal

Construct a semipermeable barrier or grade control structure to slow, but not stop, the flow of stormwater in a small watercourse to help prevent or repair upstream erosion, trap rich detritus, and allow stormwater to infiltrate into the channel sediments and adjacent soils.

Appropriate siting, water volume and slope

Gabions are appropriate for use in small watercourses. Gabions should be located within a straight reach of the watercourse, *not* on a curve nor immediately after a curve. Do not build a gabion taller than 3 feet; instead, work upstream to construct more frequent, smaller gabions. Gabions should be located along washes with firm or rocky banks and shallow to moderate slopes. Sandy banks generally are not structurally strong enough to anchor gabions. A poorly designed or poorly constructed gabion can do more harm than good by diverting water towards the bank, or failing in a large flow, so proceed carefully with this technique and **consult a qualified professional**. **Every site is unique; the appropriate scale of any water harvesting technique should be determined based on site-specific conditions. Consult a professional when in doubt.**

Note: For purposes of constructing a gabion, a small watercourse has a watershed of less than 4 acres in size, and/or has a 100-year flow rate of less than 20 cubic feet per second (cfs). Construction in a wash involves complex factors that can become a liability, therefore a qualified design professional should be consulted. For development in areas where 100-year flow rates are 100 cubic feet second (cfs) or more, a Floodplain Use Permit and a design by a registered Professional Engineer are required. Obtain all necessary permits prior to the start of construction. Consult the U.S. Army Corps of Engineers to determine if a Clean Water Act Section 404 permit is needed. Consult the Arizona Department of Water Resources to determine if existing surface water rights would preclude gabion use on your site.

Construction

Construct gabions perpendicular to a watercourse channel so stormwater flows straight into the gabion rather than at an angle. Excavate a trench perpendicular to the channel and “key” it 12 to 18 inches or more into both banks and 12 to 18 inches deep into the streambed to hold the gabion firmly in place. Place the excavated dirt upstream (do not dam the wash) so it will begin the process of filling in the gabion. In the bottom of the trench place a length of wire mesh that has enough length to fold over the top and com-

pletely enclose the rock that will fill the gabion. Two- by four-inch galvanized steel fencing with wrapped joints serves as a good wire mesh. Fencing made with welded joints might not hold up to the stresses over time. Carefully place 6- to 12-inch angular rocks into the wire mesh framework to create a stable rock structure. Angular rock locks together creating a more stable structure than rounded rock. Wrap the wire mesh over the top of the rock structure and secure the wire mesh snugly to completely enclose the structure.

The top surface of a gabion should be sloped so it is higher at the wash banks and lower at the center of the wash. The lowered center portion focuses overflow water in the center of the channel. Construct a rock apron on the downstream side of the gabion. The apron thickness should be twice the diameter of the rock used to fill it. Construct the apron across the entire width of the gabion to absorb the energy of overflow water. The apron should extend downstream of the gabion a distance of at least two or three times the height of the gabion. Completely enclose the rock apron with wire mesh. Attach the apron to the gabion. Tie the upper and lower wire mesh layers of the apron together in several places to keep the rocks from shifting. Prefabricated gabion baskets are available. A gabion-like structure can be built with tightly placed rocks without a wire framework. However, these must be carefully designed to not be damaged by flowing water forces.

Vegetation

Silt and organic material are trapped upstream of the gabion. Water slowed by the gabion will infiltrate into the stream bed and banks creating a moist, fertile microclimate for existing and newly planted vegetation.

Maintenance

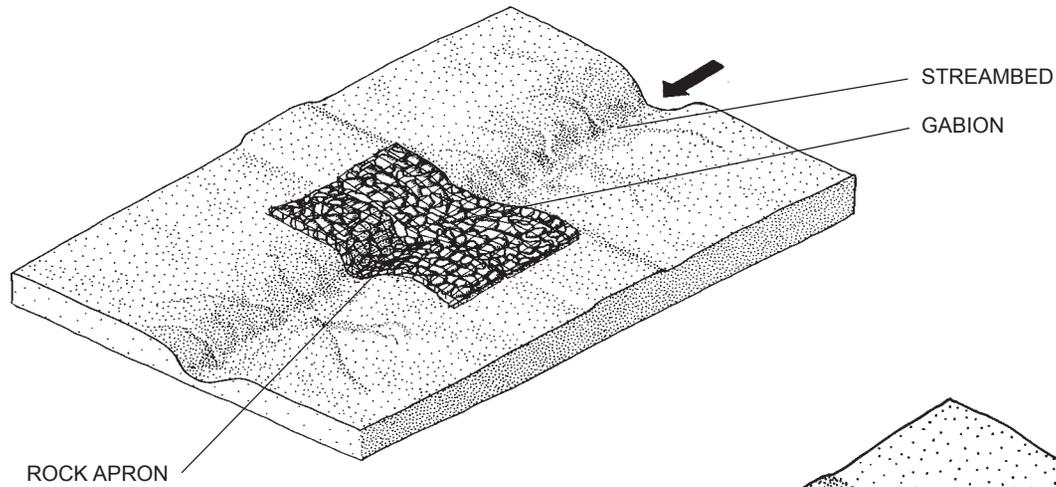
Inspect gabions following major runoff events. Adjust apron size, gabion width, and gabion height as needed based on its performance. Watch for stormwater flowing under or around the structure, and correct as needed. Gabions **must** be designed and maintained to infiltrate stormwater completely within 12 hours to avoid mosquito problems (Appendix E).

Variations

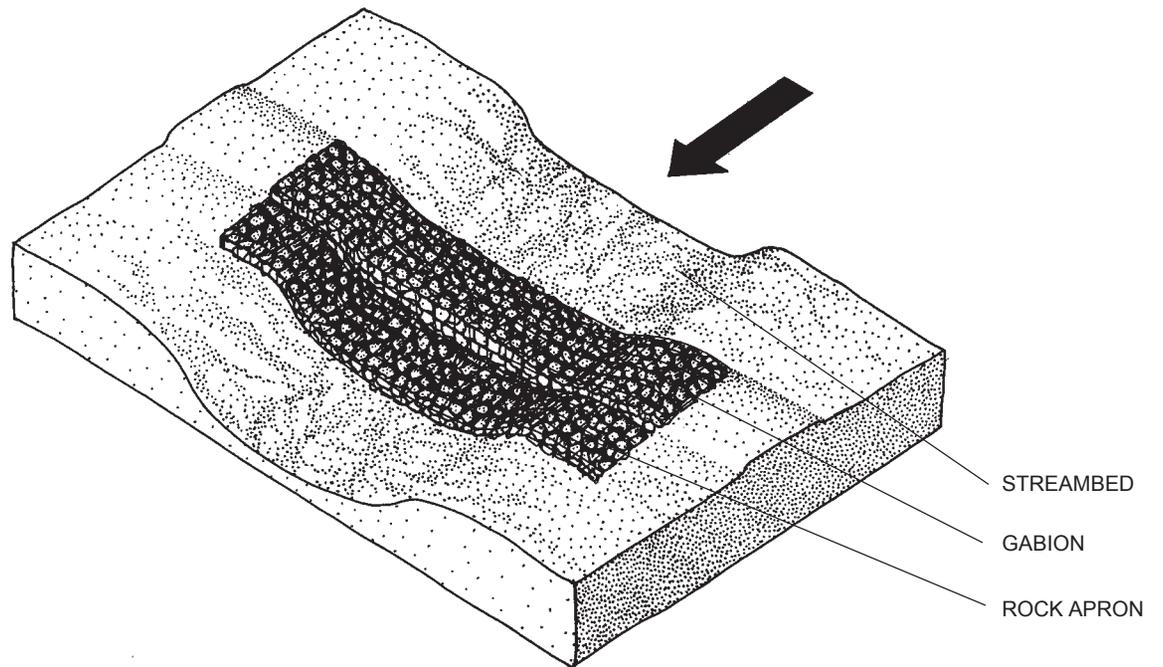
Gabions can vary in size and location. If the top of a gabion also serves as a crossing points over a wash, additional surfacing materials might be needed for safe pedestrian or equestrian uses. Consult City of Tucson Development Service Department officials and design professionals to ensure that gabions meet all safety and construction standards.

Water Harvesting Techniques: Gabions

GABION IN NARROW STREAMBED



GABION IN WIDE STREAMBED



Water Harvesting Techniques: Water Tanks

Goal

Store rooftop runoff for use at a later time.

Appropriate siting, water volume and slope

Water tanks (sometimes called cisterns) come in all shapes, materials and sizes. Determine appropriate tank volume based on roof area, rainfall, downspout location, available space, water uses and site-specific conditions. Tanks need to be placed on level pads in areas not vulnerable to settling, erosion or slope failure. Tanks should be located at least 10 feet from a building to avoid foundation damage in case the tank leaks. In addition to storing water, tanks can serve multiple functions such as shading, providing visual screens, and moderating hot and cold temperature extremes. The higher on the site above-ground tanks are located, the more gravity-feed pressure will be available. Water can be distributed by gravity flow or by a booster pump via hoses, irrigation systems, channels, or perforated pipes.

Construction

Prefabricated tanks of plastic, metal, or concrete can be purchased and installed professionally. Securely cap tanks with opaque material to prevent evaporation, mosquito breeding, and algae growth. Lock all caps and entry ports for safety. The interior of tanks should be accessible for periodic inspection and maintenance. Downspouts, inlets and outlets **must** be screened to keep mosquitoes (Appendix E), animals and debris out of the tank. Gutters must be cleaned regularly. Position outlet pipes several inches above the bottom of the tank to allow sediment to settle in the bottom. All tanks need an overflow pipe of equal or greater capacity than the fill pipe.

Overflow pipes should be able to operate passively (i.e. not dependent on a pump). Route overflow water into a water harvesting basin, adjacent tank, French drain, or other useful location away from buildings. Water in above-ground tanks can be delivered by gravity flow alone to low-pressure uses nearby. Below-ground tanks save land area, but require substantially more construction. A booster pump can be added to hook tanks into an irrigation system. Tank water should be filtered as it enters irrigation lines to keep debris from plugging the irrigation system. Calculations for sizing tanks are shown in Appendix C and discussed in some references listed in Appendix G.

Vegetation

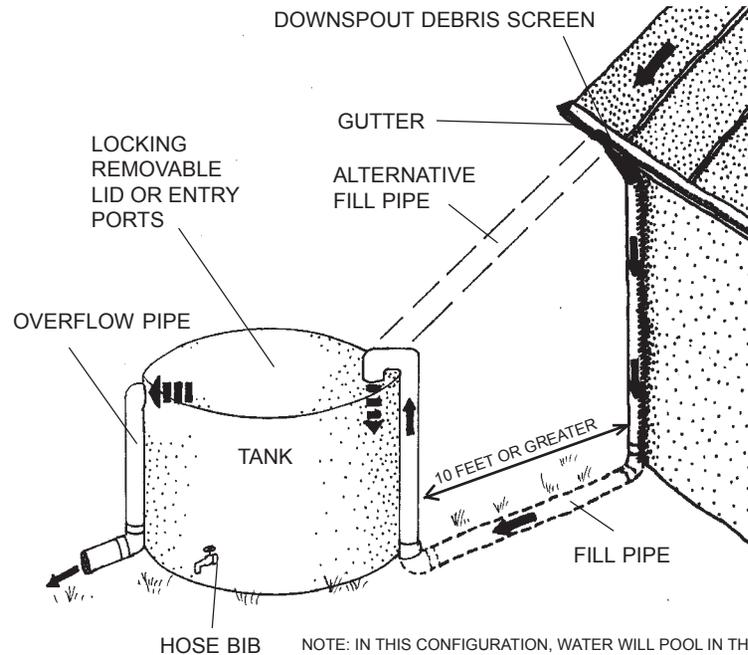
Areas around above-ground tanks can provide beneficial microclimates for heat- and cold-sensitive plants. Avoid placing plants with intrusive roots around below-ground tanks. Vegetation can be used to visually screen above-ground tanks to improve site aesthetics.

Maintenance

Periodically inspect all screens, gutters and tanks to remove accumulated debris. Check tanks following major rainfall events to verify that overflow system is working correctly. Periodically inspect and maintain the interior of tanks.

Variations

Tanks can be constructed individually or in a series with the overflow from one tank filling the adjoining tank, or connected at the bottom to maintain the same water level in all tanks.



NOTE: IN THIS CONFIGURATION, WATER WILL POOL IN THE U-SHAPED FILL PIPE AND WILL BACKUP IN THE DOWN-SPOUT TO A HEIGHT EQUAL TO THE HEIGHT OF WATER IN THE TANK. INSTALL WATER-TIGHT SEALS TO PREVENT LEAKS.

Water Harvesting Technique: Mulch

Goal

Optimize water harvesting by reducing evaporation from soils.

Appropriate siting, water volume and slope

Rainfall in Tucson averages around 11 inches per year, but evaporation of standing water averages around 78 inches per year. Solar energy quickly evaporates soil water brought to the surface by capillary rise. Placing mulch over bare soils in water harvesting depressions will reduce moisture loss from the soil leaving soil moisture available for use by plants. Use organic mulches in relatively low flow areas where mulch will not be washed away. Use inorganic mulches in areas where higher velocity flow might occur.

Construction

All water harvesting swales and basins should be mulched to substantially reduce water loss through evaporation. Organic mulches include composted bark, wood chips, leaves, twigs, straw, and grass clippings. Living understory and ground cover plants also have a mulching effect. Chipped, composted vegetation cleared during construction is a good source of mulch. Organic mulch should be applied in a layer from 3 to 4 inches deep. Organic mulch has a tendency to float, so make sure basins are deep enough to retain mulch during heavy rainfall events.

Inorganic mulches include rock, gravel, cobbles, decorative rock (not decomposed granite) and other hard materials. Do not use mulches that contain fine-grained particles that can clog soil pore spaces and seriously inhibit infiltration. Use a sufficient depth of inorganic mulch (2 - 3 inches or more) to reduce evaporation and help prevent erosion from berms and steeper slopes. Supplement cobble-size mulches with smaller diameter gravel or small-grained organic mulch to fill in crevices and prevent erosion between the cobbles. The top layer of inorganic mulch will become hot in summer and might damage heat sensitive plants. A canopy of established plants can provide shade to reduce inorganic mulch temperature during the hot summer days.

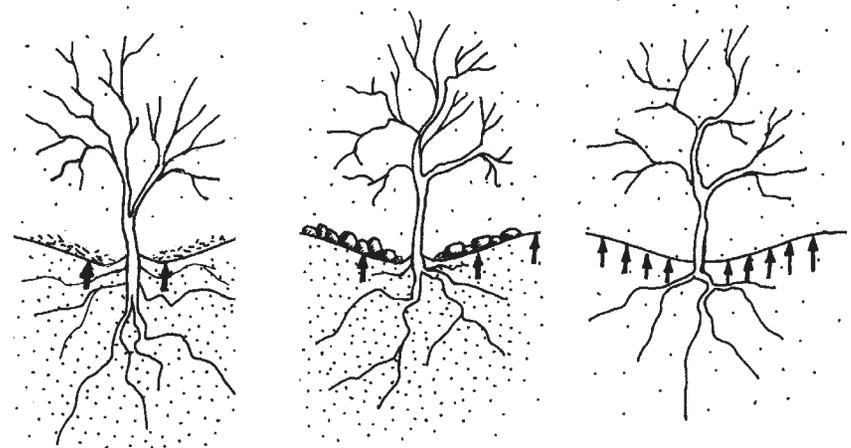
When placing organic or inorganic mulch, leave several inches of open space between the mulch and the base of plants. A small earthen mound at the base of plants will protect plants from contact with mulch.

Vegetation

Plant seedlings in water harvesting basins since seeds usually will not germinate under deep mulch. Allow seeds, leaves and twigs that drop off plants to accumulate to supplement the mulch layer.

Maintenance

Organic mulch breaks down with time forming rich soil, and should be replenished as needed. With time, seeds, leaves and twigs dropping from plants in the basins will create a renewable mulch layer (self mulching). Additional mulch can be added if the level of self-mulching is not sufficient. Both inorganic and organic mulch should be periodically maintained to keep soils covered.



ORGANIC MULCH
LOW EVAPORATION
HIGH SOIL MOISTURE

INORGANIC MULCH
LOW EVAPORATION
HIGH SOIL MOISTURE

NO MULCH
HIGH EVAPORATION
LOW SOIL MOISTURE

Water Harvesting Techniques Information Sheet

Goals for Techniques	Appropriate Locations	Variations	General Notes	Maintenance and Inspection Notes	Construction Techniques
MICROBASINS					
Captures surface water from very small catchment areas and infiltrates it into the soil	Gentle to nearly flat sloped land. Very small to small catchment areas (10s to 100s of square feet)	- in a series	1, 2, 3, 4, 6	7, 8, 10	13 and/or 14
		- on-contour	1, 2, 3, 4, 6	7, 8, 10	13 and/or 14
		- w/pathway/driveway	1, 2, 3, 4, 6	7, 8, 10	13, 14 and/or 19
		- local depression	1, 2, 3, 4, 6	7, 8, 10	13 and/or 14
		- inside curbed areas	1, 2, 3, 4, 6	7, 8, 10	13, 14, 16 and/or 17
		- in a parking lot	1, 2, 3, 4, 6	7, 8, 10	14, 15, 16 and/or 17
SWALES ON-CONTOUR					
Captures surface water from small to moderate catchment areas and infiltrates it into the soil.	Small to moderate sized catchment areas with gentle slopes. Large scale use should be based on engineered designs.	- large scale	1, 2, 3, 4, 6	7, 8, 10	13, 14, 15, 16, 17, and/or 19
		- without berms	1, 2, 3, 4, 6	7, 8, 10	13, 14, 15, 17, and/or 19
		- adjacent to paths	1, 2, 3, 4, 6	7, 8, 10	13, 14, 15, and/or 19
		- internal microbasins	1, 2, 3, 4, 6	7, 8, 10	13, 14, 15, and/or 19
SWALES OFF-CONTOUR					
Captures surface water from small to moderate catchment areas and slowly conveys it downgradient while it infiltrates into the soil.	Small to moderate sized catchment areas with gentle slopes. Large scale use should be based on engineered designs.	- pocket swales	1, 2, 3, 4, 6	7, 8, 10	13, 14 and/or 19
		- boomerang swales	1, 2, 3, 4, 6	7, 8, 10	13, 14, 15, 16, and/or 19
		- parking lot berms	1, 2, 3, 4, 6	7, 8, 10	14, 15, 16, 17, and/or 19
FRENCH DRAINS					
Captures surface water and rapidly conveys it underground in a subsurface trench. Maximize infiltration while minimizing evaporation.	Very small to small catchment areas. Flat to moderate sloped land. Avoid use in areas where sediment will clog pores in the French drain.	- subsurface pipe	1, 2, 3, 4, 6	7, 9, 10	13, 14, and/or 16
		- as "curtains"	1, 2, 3, 4, 6	7, 9, 10	13, 14, and/or 16
		- branched	1, 2, 3, 4, 6	7, 9, 10	13, 14, and/or 16
		- across pathways	1, 2, 3, 4, 6	7, 9, 10	13, 14, 16 and/or 19
		- for roof drainage	1, 2, 3, 4, 6	7, 9, 10	13, 14, and/or 16
		- general surface flow	1, 2, 3, 4, 6	7, 9, 10	13, 14, and/or 16
GABIONS					
Slow surface water flow in very small drainages, capture detritus and sediment from water to fill in erosion cuts upstream of the gabion.	Very small drainages with stable banks. Put in straight reaches of the drainage, not on curves.	- Wire basket wrapped around rocks	1, 2, 3, 4, 5, 6	7, 8	13, 14, 15, 16, 17, 18 and/or 19
		- Loose rock gabions	1, 2, 3, 4, 5, 6	7, 8	13, 14, 15, 16, 18 and/or 19
WATER TANKS/CISTERNS					
Stores harvested water for later use.	Above-ground tanks placed high in the landscape afford more head for gravity feed. Water stored in both above- and below-ground tanks can be accessed via small pumps.	- Above-ground tanks	1, 2, 3, 6	7, 12	13, 14, 16, 17, 18, and/or 19
		- Below-ground tanks	1, 2, 3, 6	7, 12	13, 14, 15, 16, 17, 18, and/or 19
MULCH					
Aids water infiltration into soils, retards evaporation. Enriches soil nutrients, suppresses weed growth, helps reduce pollutants. Keeps soil temperature lower in summer and warmer in winter.	Basins, swales and other water harvesting depressions. Place mulch 3 - 4 inches deep. Replenish as needed.	- organic	--	7, 11	13 and/or 14
		- inorganic	--	7, 11	13 and/or 14

Water Harvesting Techniques Information Sheet

General Notes	Maintenance and Inspection Notes
1. All of the water harvesting techniques are scaleable from home site designs to large scale applications. Larger projects will involve more complex designs and construction. If you are unsure how to proceed, hiring a professional is strongly advised. Hiring a professional for large applications may be required.	7. Proper monitoring and maintenance is important for any system to work appropriately and efficiently. Each configuration will perform differently. After the system has stabilized, inspection and maintenance might be needed several times a year and/or after heavy rainfall events.
2. Always design for overflow. Create overflow spillways as needed to focus overflow in preselected locations. Protect water harvesting structures from overflow erosion, and direct overflow to locations that will not be damaged by and will benefit from additional water, such as other water harvesting areas.	8. Ponding should not last more than 12 hours to avoid mosquito breeding (Appendix E). Long-term standing water can damage vegetation. Soil types percolate at different rates. Soils in Tucson generally percolate about 1/2 to 1 inch of water per hour. Test soil and modify design as needed.
3. Section 1803.3 of the 2000 International Building Code recommends keeping standing/ponding water at least 10 feet from structure foundations. A soils professional should be consulted for poor soil conditions or for ponding closer than 10 feet.	9. French drains are most effective when they are kept free of sediment. Filter fabrics and/or sediment traps might be needed to keep sediment out of the drain. The rocks in French drains might settle over time. Refill and relevel as needed.
4. When placing berms, depressions and gabions, be sure to configure them to eliminate/minimize tripping hazards. Trees should be placed 15 to 20 feet from structures to allow for full growth.	10. Water harvesting structures placed on steeper, soil covered slopes tend to fill with sediment and overflow more frequently than swales on flatter slopes. More frequent inspection/maintenance might be needed.
5. Use caution in designing, placing and constructing gabions. Do not obstruct or divert stream flows. An engineered design might be needed. Development in a wash may require a Floodplain Use Permit from the City, and/or a Clean Water Act Section 404 permit from the US Army Corps of Engineers. Check with the City Development Services Department for official City requirements. Check with the Arizona Department of Water Resources to determine if there are any surface water right issues in the stream.	11. Mulches are important to keeping harvested water in the soil due to the high evaporation rate in Tucson. Choose organic or inorganic mulch based on location, need for soil enrichment, and availability of materials. Do not place mulch against trunks of shrubs and trees. Wash fine sediments off decomposed granite if it is to be used for mulch. Organic mulches are light weight and can float away in heavy water flows. Organic mulches decompose and might need to be replenished.
6. For larger projects, check with City of Tucson Development Services Department officials regarding grading permits (50 cubic yards of fill from any source) and/or stormwater pollution prevention plan requirements (1-acre or more of disturbance). Both permits will require a registered professional to design and seal the plans.	12. Inspect water tanks periodically to insure proper functioning. Screen inlet and outlet pipes to keep the system closed to mosquitoes (Appendix E). Cap and lock tanks for safety. Caps should have access ports for interior inspection and maintenance. Clean gutters, inflow and outflow pipes as needed.
Construction Techniques	
13. Hand tools, light earth work	
14. Small machine earthwork	
15. Heavy machine earthwork	
16. Construction materials needed	
17. Plans by a registered professional may be required	
18. Prefabricated materials available	
19. Check with City of Tucson Development Services Department official	

Design Examples: Subdivision

BACKGROUND FOR SUBDIVISION EXAMPLE

A subdivision is planned as an infill development in an urban area. Water harvesting will be practiced at the subdivision level and will be encouraged at the household level.

STEP 1: ASSEMBLE THE SITE TEAM

- Team members include the developer, civil engineer, building architect, landscape architect, construction foreman, and one volunteer future resident (if available).
- The member chosen to be team leader should have knowledge of subdivision-wide drainage and lot design to accomplish water harvesting.

STEP 2: MAP RESOURCE FLOWS & PHYSICAL ELEMENTS

- The site contour map indicates that drainage flows from east to west on moderate slopes. Drainage is generally in the form of sheet flow, with no significant offsite contribution to drainage.
- Site conditions: The site is somewhat rocky and covered with sparse vegetation. Geology and soils are suitable for building.
- Flows and elements: The moderate west-facing slope increases summer heating. Harsh prevailing winds come from the southwest. Water pools at low points on the west side. There is noise from an arterial street along the south side of the site.

STEP 3: IDENTIFY POTENTIAL FOR RESOURCE USE

- Stormwater harvested from roads and lots and infiltrated into soils will reduce stormwater runoff and support vegetation onsite.
- Vegetation removed during construction will be chipped and composted onsite for use as mulch in water harvesting structures.
- New predominantly native, drought-tolerant vegetation will provide shade for passive cooling, comfort, aesthetics, visual screening, child play areas, and urban wildlife habitat.
- On-site rocks and cobbles will be collected during construction and used to build gabions, to armor spillways, and as inorganic mulch.
- Water harvesting at residences will help support vegetation used to provide shade and windbreaks. Tanks could be built at private residences and the community building to store additional runoff water.
- Existing vegetation will be preserved in place whenever possible.

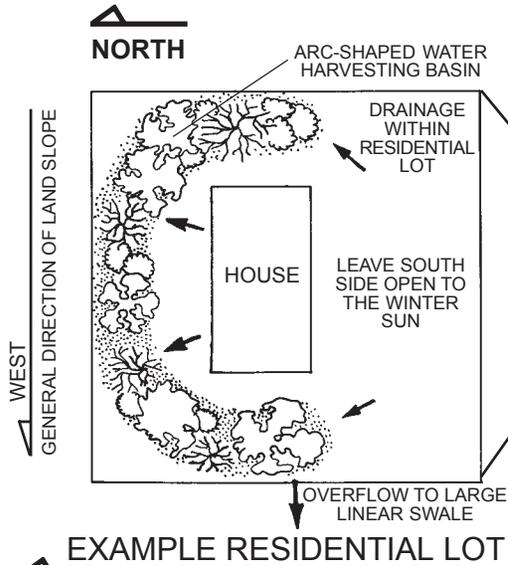
STEP 4: DEVELOP AN INTEGRATED SITE CONCEPT DESIGN

- Construct large linear on-contour and off-contour swales around the site and between rows of houses to intercept stormwater runoff. Construct path systems in association with the swales. These swales will slow stormwater, support plantings that screen noise, provide recreational areas, and provide urban wildlife habitat.
- Use onsite rock to build gabions, and line the sides and spillways of water harvesting features to reduce erosion and reduce evaporation.
- Crown roadways, construct curb cuts, and scupper and grade the parkway to direct runoff water towards the large swales.
- Grade individual lots to create arc-shaped basins along the west, north and east sides of the lots. These will collect runoff water to support trees that provide windbreaks, shade and other purposes. Orient the longest axis of the house toward the south to intercept warm winter sun. Install window overhangs to provide shade in summer.
- Provide the installation of gutters, downspouts and covered household tanks as options on model/house plans. Specify roof surfaces such as tile and metal that are long lasting and shed relatively pollutant-free stormwater.
- Prepare information for home owners on the purpose, potential uses and maintenance of pre-graded, yard-scale water harvesting basins. Customize water harvesting layout for each model unit. Write covenants, conditions and restrictions to encourage water harvesting. Install separate water meters to track outdoor water use at each home (dual metering) to provide data on the benefits of water harvesting.
- Demonstrate water harvesting techniques in the common areas by placing water tanks adjacent to the community building, using the detention areas for recreation, and installing low water use landscaping (Xeriscape) that could ultimately be entirely sustained by water harvesting. If an irrigation system is used, install soil moisture sensors to prevent overwatering.
- Mulch all basins and vegetated areas in the subdivision.

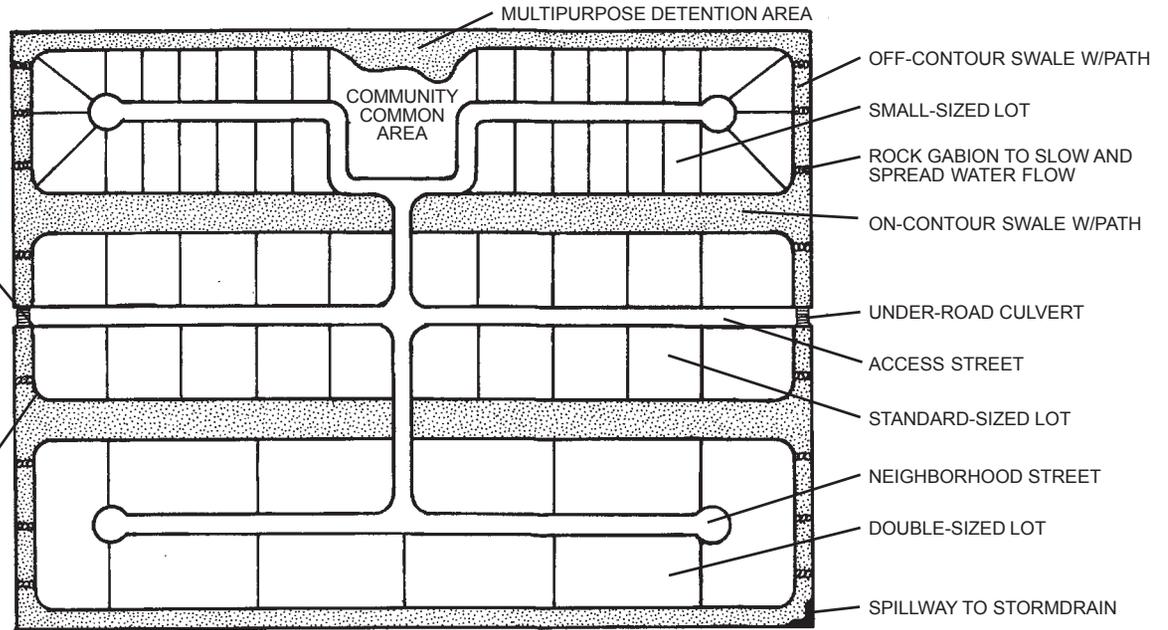
STEP 5: REVIEW AND FINALIZE THE CONCEPT DESIGN

- Have all team members review and comment on the draft concept plan.
- Prepare the final concept design. Use the final concept design as the basis for detailed site plans including lot layout, grading, drainage, building layout, architecture and landscaping plans.
- Check detailed site plans for consistency with the concept plan.

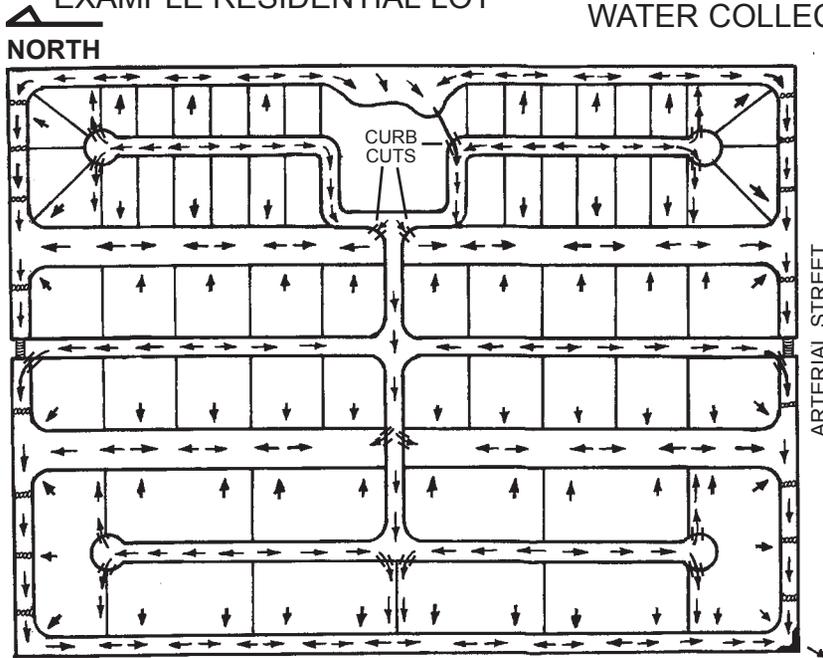
Subdivision Example



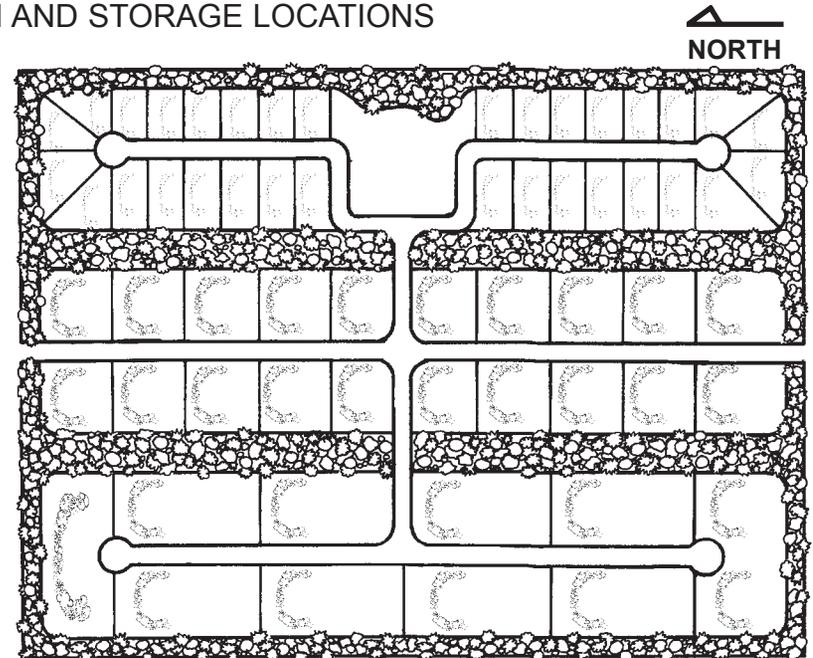
EXAMPLE RESIDENTIAL LOT



WATER COLLECTION AND STORAGE LOCATIONS



DIRECTION OF WATER FLOW



PLANTS RECEIVING HARVESTED WATER

Design Examples: Commercial Site

BACKGROUND FOR COMMERCIAL SITE EXAMPLE

A retail store that needs a large parking lot will be constructed. A small cooling tower will serve the air conditioning unit. Stormwater will be harvested throughout the site.

STEP 1: ASSEMBLE THE SITE TEAM

- Team members include the developer, civil engineer, building architect, landscape architect, and construction foreman.
- The member chosen to be the team leader should have a good working knowledge of site drainage issues.

STEP 2: MAP RESOURCE FLOWS & PHYSICAL ELEMENTS

- The contour map shows the drainage flows from east to west, with off-site flow entering the site from the east.
- Site conditions: There are no geological issues. There is existing native vegetation on the east side. There is a good view to the northeast.
- Flows and elements: A slight west-facing slope increases summer heat. There are harsh prevailing winds from the southwest. Water tends to pool at low points on the west side. There is significant traffic along the north side on an arterial street.

STEP 3: IDENTIFY POTENTIAL FOR RESOURCE USE

- Rooftop stormwater runoff will be stored to serve the cooling tower and the site irrigation system. Water harvesting systems in the landscape will store water in the soil to support vegetation and cleanse and reduce the volume of stormwater runoff, allowing a reduction in the size of required detention/retention facilities.
- Existing vegetation will be left in place, transplanted, or chipped and composted for later use onsite as mulch. New and existing vegetation will provide shade and summer cooling, aesthetics, and screening.
- The building will provide shade, a windbreak and rooftop runoff for harvesting. The longest wall of the building will face south allowing maximum winter sun to enter south-facing windows. Adequate roof overhangs will provide needed shade on the south side in summer.

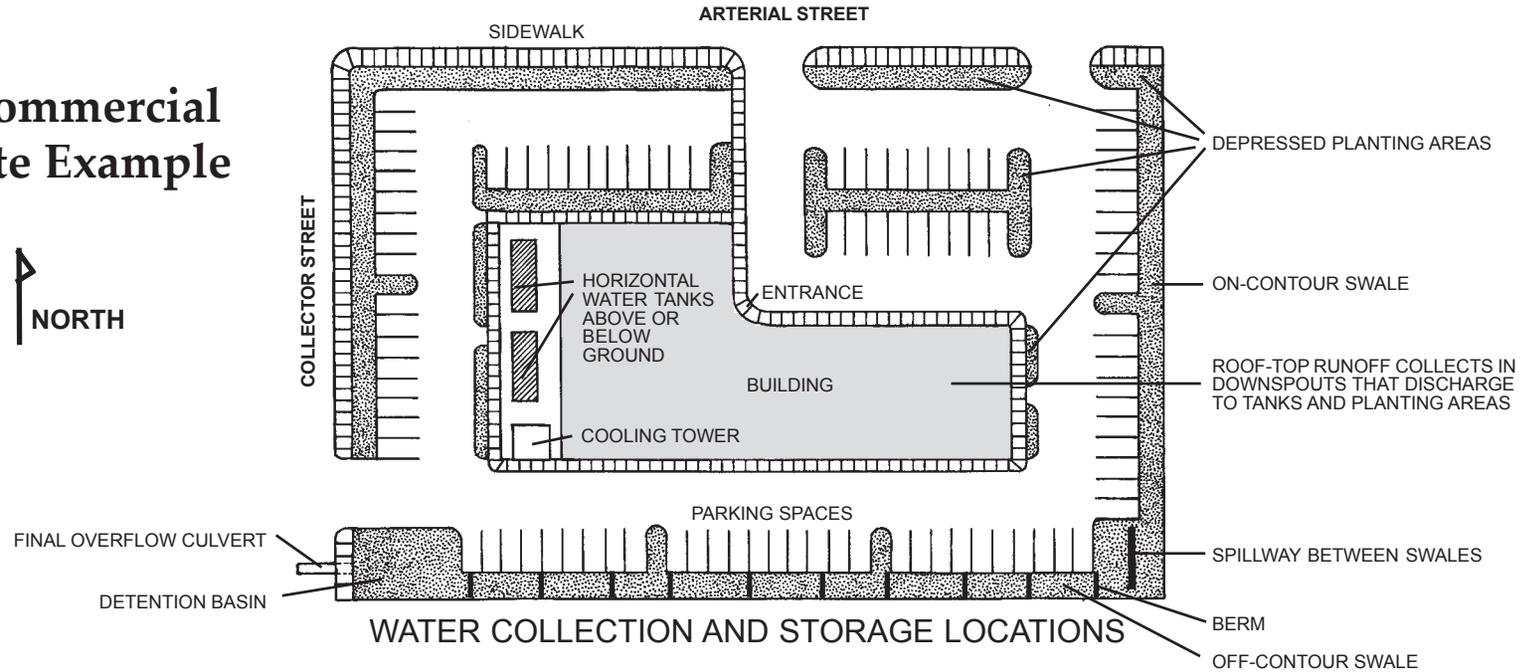
STEP 4: DEVELOP AN INTEGRATED SITE CONCEPT DESIGN

- Two water harvesting tanks will be used to capture rooftop runoff, and can be constructed above or below ground. Locate the water tanks next to the cooling tower and irrigation controls to provide rainwater to serve both. The remaining rooftop runoff and tank overflow will support vegetation located near the building including trees that help shade the water tanks and the building itself.
- Slope the parking lot to drain towards adjacent planting areas. Direct sidewalk drainage toward adjacent water harvesting features (reverse grades may require a Development Standards Modification Request [DSMR], consult a Development Services Department official).
- Existing vegetation will be retained whenever possible. The remainder of the vegetation will be transplanted or chipped and composted for use as mulch to reduce evaporation and improve soils in water harvesting areas.
- Trees and shrubs will be planted in or near the water harvesting structures to provide shade, cleanse and reduce stormwater runoff, generate mulch, reduce erosion, increase infiltration into the soil, provide visual screens, and create urban wildlife habitat. The building will be passively cooled and shaded with trees sustained by rooftop runoff. Use high profile plantings on the west side of the building to increase shade on the building in the summer. The soils report prepared for the site indicates that small, low volume depressed planting basins may be located within 10 feet of the building.
- Align the longest wall of the building to face south to utilize the warmth of the sun in winter. Overhangs on the south side reduce the sunlight entering during other times of the year. Align the narrow walls of the building to face east and west toward the rising and setting sun to reduce the amount of direct sun hitting the building in summer. The building will shade the parking lot at different times of the day, and will shield the front entrance from harsh prevailing southwest winds.

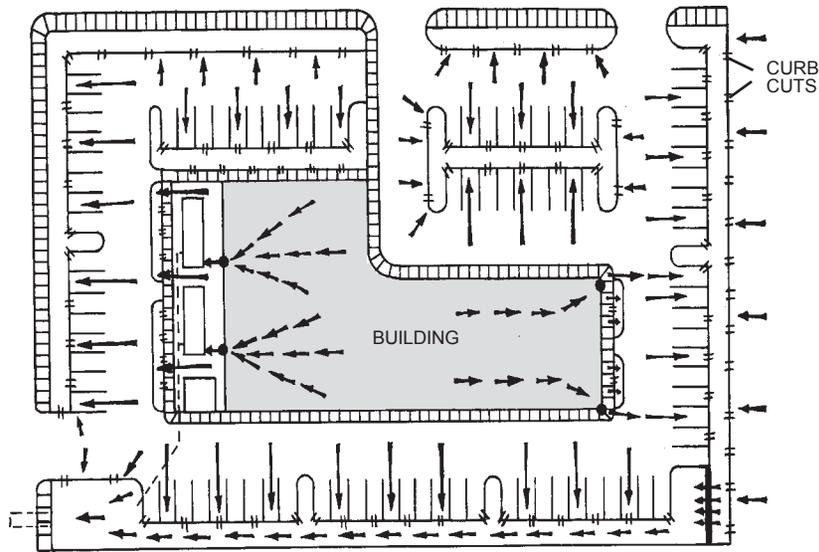
STEP 5: REVIEW AND FINALIZE THE CONCEPT DESIGN

- Have all team members review and comment on the draft plan.
- Prepare the final concept design. Use the final concept plan as the basis for detailed site plans including building layout, grading, drainage, architecture and landscaping.
- Check the detailed site plans for consistency with the concept plan.

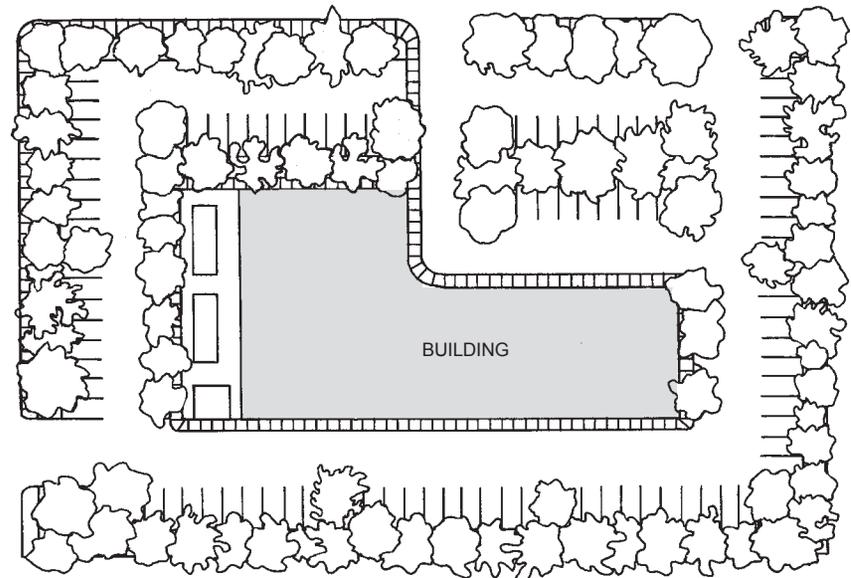
Commercial Site Example



WATER COLLECTION AND STORAGE LOCATIONS



DIRECTION OF WATER FLOW



PLANTS RECEIVING HARVESTED WATER

Design Examples: Public Building

BACKGROUND FOR PUBLIC BUILDING EXAMPLE

A public library will be built in an urban neighborhood on a nearly flat lot. The City wants the library grounds to be a water harvesting demonstration site. Neighbors have requested that an outdoor community gathering space be included in the library plan.

STEP 1: ASSEMBLE THE SITE TEAM

- Team members include the city project manager, civil engineer, building architect, construction foreman, and neighborhood representative.
- The member chosen to be the team leader should have an understanding of design for water harvesting demonstration sites and outdoor gathering spaces.

STEP 2: MAP RESOURCE FLOWS & PHYSICAL ELEMENTS

- The site contour map shows a slight slope from north to south, with no significant offsite contributions to drainage. The site will be regraded to facilitate water harvesting.
- Site conditions: The site is nearly flat and bare with type B soils.
- Flows and elements: Water flows as sheet flow from north to south. There is arterial street noise on the north side, and collector street noise on the east side. Prevailing winds are from the southwest.

STEP 3: IDENTIFY POTENTIAL FOR RESOURCE USE

- Water stored in tanks will support landscaping around the building and in the outdoor gathering space. Storing water in soils at the site will cleanse and reduce the volume of stormwater runoff and will demonstrate water harvesting techniques for the public. Water stored in the soils will support vegetation to shade the building, outdoor gathering space, paths, and cars. This vegetation will act as a visual screen and improve site appearance.
- The library building will provide shade, rooftop runoff for vegetation and will shield the outdoor gathering space from arterial street noise.
- The library grounds will serve the community by providing a gathering place and illustrating how people can incorporate water harvesting concepts into their own sites.

STEP 4: DEVELOP AN INTEGRATED SITE CONCEPT DESIGN

- Install gutters, downspouts and covered water collection tanks on the

west side of the building. As part of the water harvesting demonstration, cover the roof with a material that sheds relatively pollutant-free water, such as metal or tile. Tanks on the west side of the building will shade and cool the western wall and create a temperature-moderated microclimate. Locate the tanks near the outdoor gathering space to provide supplemental irrigation. The tanks could be custom painted with neighborhood-themed art.

- Slope the parking lot and sidewalks toward adjacent planting areas. Trees will shade people and cars and buffer traffic noise. Route excess parking lot water toward the small, vegetated detention areas on the southwest and southeast corners of site. Plant trees in water harvesting structures on the southwest and west to create a windbreak, and on the east, west and north to provide shade from summer sun.
- Trees and shrubs will be planted throughout the site to provide shade, cleanse and reduce stormwater runoff, generate mulch, reduce erosion, increase infiltration into the soil, provide visual screens, and create wildlife habitat. The building will be shaded with trees sustained by rooftop runoff.
- Supply 2 to 4 years of supplemental irrigation to native and drought-tolerant plants by first using water from water tanks. Use City water only as necessary. Add a rain sensor control that shuts the irrigation system down when soil is wet from rain or previous irrigation.
- Align the shortest length walls of the library building to face east and west toward the rising and setting sun to reduce the amount of direct sun hitting the building. The longest south-facing wall will have large windows facing south so the winter sun will warm people inside. Install clerestory windows to warm the north half of the building as well. Roof overhangs allow direct sunlight to enter the building only during winter months.
- Provide a brochure and map of the water harvesting components so visitors can take a self-guided tour of the site. Place signs on the water harvesting components and associated plantings.

STEP 5: REVIEW AND FINALIZE THE CONCEPT DESIGN

- Have all team members review and comment on the draft concept plan.
- Prepare the final concept design and use it as the basis for detailed plans for building layout, grading, drainage, architecture and landscaping.
- Check the detailed site plans for consistency with the concept plan.
- Develop inspection criteria and maintenance plan for the site.

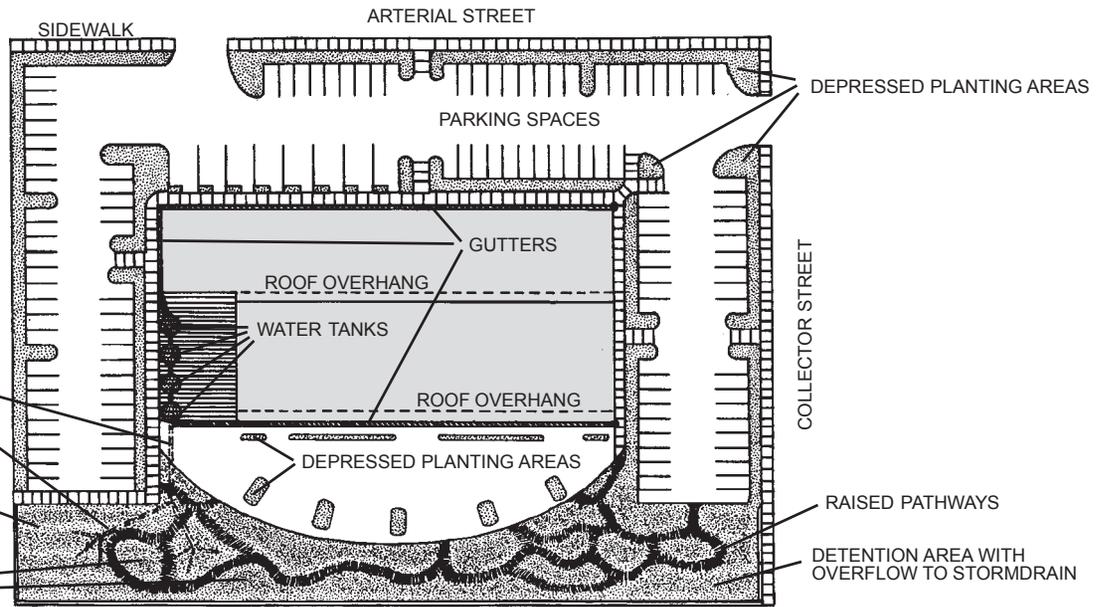
Public Building Example



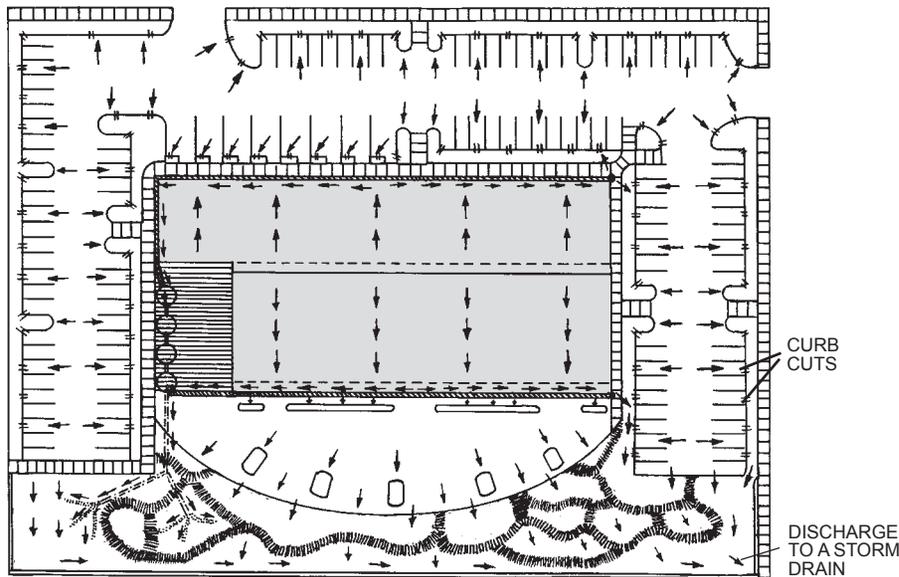
FRENCH DRAIN RECEIVING OVERFLOW FROM RAINWATER TANKS

DETENTION AREA WITH OVERFLOW TO STORMDRAIN

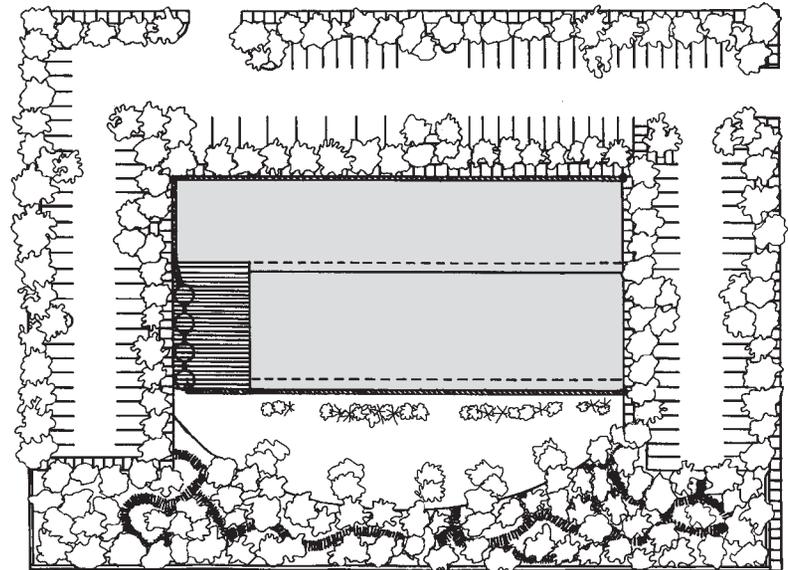
ASSORTED SWALES AND MICROBASINS IN ASSOCIATION WITH RAISED PATHS CONSTITUTING A DETENTION AREA



WATER COLLECTION AND STORAGE LOCATIONS



DIRECTION OF WATER FLOW



PLANTS RECEIVING HARVESTED WATER

Design Examples: Public Rights-of-Way

BACKGROUND FOR PUBLIC RIGHTS-OF-WAY EXAMPLE

Landscaping will be installed as part of a roadway capital improvement project, an improvement district project, or a neighborhood improvement project along the public rights-of-way. The roadways involved are an arterial with a median island, a collector street, and a local street.

STEP 1. ASSEMBLE THE SITE TEAM

- Team members include the city project manager, landscape architect, project design engineer and if possible, the construction foreman.
- The project manager should facilitate coordination between design engineering and landscape architect to maximize water harvesting on all three roadway landscaping projects.

STEP 2: MAP RESOURCE FLOWS & PHYSICAL ELEMENTS

- The contour maps indicate all three roadways are gently crowned.
- Standard street cross sections will be modified to accommodate and maximize water harvesting in associated landscaping features.

STEP 3: IDENTIFY POTENTIAL FOR RESOURCE USE

- Stormwater stored in soils adjacent to the roads will cleanse and reduce the volume of stormwater entering the roadway and stormdrains.
- Vegetation supported by runoff water will shade the roadways and sidewalks, and in the case of medians, will shield cars from the headlights of oncoming traffic. Both areas will provide green relief for both pedestrians and vehicle drivers creating a more pleasant and attractive environment.
- Drainage from the roads will initially be routed to the median and/or the shoulder. Excess drainage will be routed to stormdrains.
- Drainage intercepted within curbed areas will be collected in water harvesting areas to supplement irrigation of the landscaping and reduce or eliminate flows across the sidewalk.

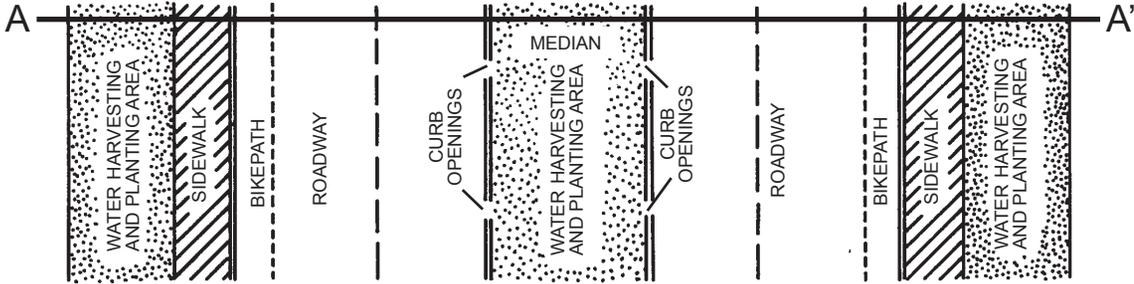
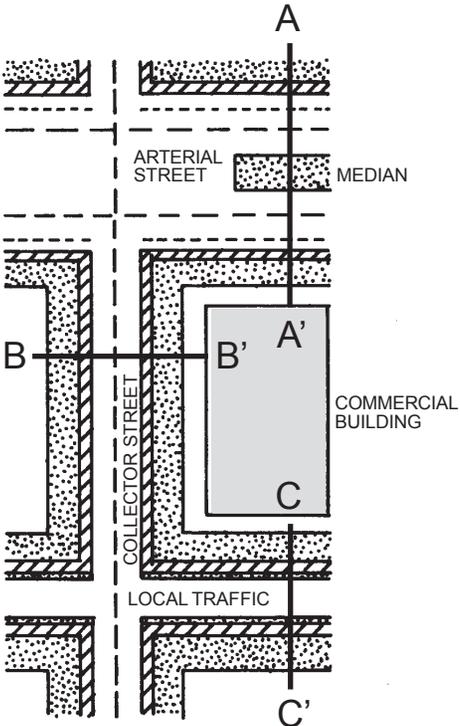
STEP 4: DEVELOP AN INTEGRATED SITE CONCEPT DESIGN

- Gently slope roads and sidewalks toward the median and/or shoulder planting areas where possible. Depress planting areas in medians and shoulders to allow stormwater to collect and infiltrate into the soil. Separate deeper water harvesting structures from sidewalks by constructing a gently sloped 2-foot wide strip of soil and vegetation between the sidewalk and water harvesting area. Shallow basins (6-inches deep or less) may be placed immediately next to sidewalks as long as no tripping hazard is created.
- Construct inlets and outlets from medians and shoulders using curb openings and scuppers. Cover inlets, outlets, and intermediate spillways with filter cloth and/or cobbles to minimize erosion.
- Choose native and drought tolerant plants that need minimal supplemental watering to become established. Irrigate the plantings periodically until the plants are fully established. Hook up the irrigation system to a rain sensor so the irrigation system shuts down when the soil has enough moisture to support the plants.
- Plant small plants at the top of the basins, plant shrubs and trees in the sides and bottoms depending on their tolerance for short-term inundation.
- Heavily mulch all planting areas. Either organic mulch, rock mulch, or decorative rock (not decomposed granite) will be used to reduce evaporation, prevent erosion and allow infiltration. Organic mulch soaks up water and builds soil. Allow plant litter to remain where it falls to replenish this mulch layer.

STEP 5: REVIEW AND FINALIZE THE CONCEPT DESIGN

- Have all team members review and comment on the draft concept plan.
- Prepare the final concept design. Use the final concept plan as the basis for detailed site plans including grading, drainage, construction, and landscaping plans.
- Check detailed plans for consistency with the final concept plan.
- Develop inspection criteria and maintenance plan for the landscaping and water harvesting areas.

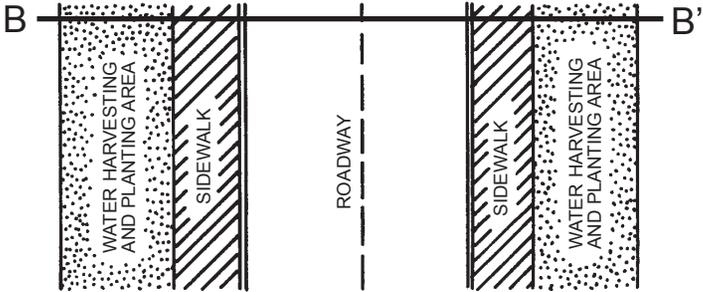
Public Rights-of-Way Example



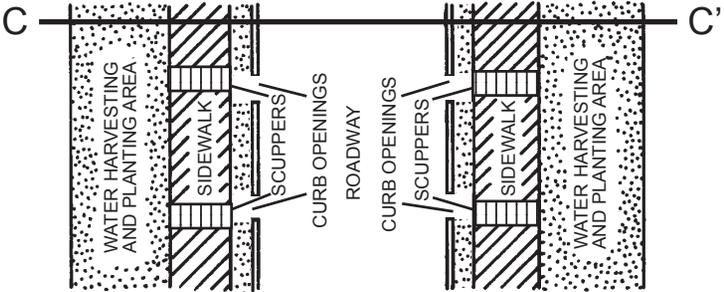
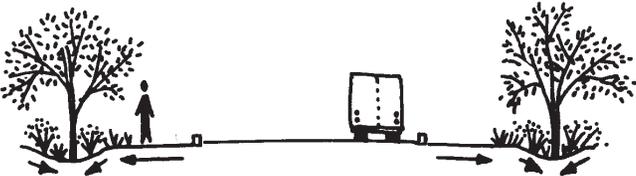
CROSS SECTION A-A'



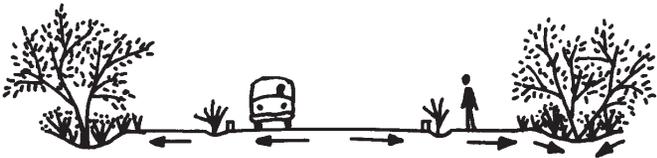
CROSS SECTION LOCATIONS



CROSS SECTION B-B'



CROSS SECTION C-C'



Appendix A. Tucson Code Requirements for Water Harvesting

The City of Tucson Code, Chapter 23, the “Land Use Code” (LUC) [Section 3.7.1.1.A](#), states that landscaping is intended to accomplish energy, water and other natural resource conservation, and, per sections 3.7.1.1.A.4 and .5, to “reduce soil erosion by slowing stormwater runoff” and “assisting in groundwater recharge.”

[LUC Section 3.7.4, Use of Water, Section 3.7.4.3.B, Storm Water Runoff](#), states “Grading, hydrology, and landscaping structural plans are to be integrated to make maximum use of site storm water runoff for supplemental onsite irrigation purposes. The landscape plan shall indicate use of all runoff, from individual catch basins around single trees to basins accepting flow from an entire vehicular use area or roof area.”

[LUC Section 3.7.4.5.B, Irrigation](#), states “Storm water and runoff harvesting to supplement drip irrigation are required elements of the irrigation system for both new plantings and preserved vegetation.”

Code Interpretation: “*Maximum use*” is interpreted to mean the maximum extent practicable. “*Maximum extent practicable*” will vary with each site. At a minimum, roof and Parking Area Access Lane stormwater shall be routed and impounded in the required landscaping areas to the extent that further stormwater harvesting would require site layout changes that would risk incompatibility with surrounding development. To achieve water harvesting to the maximum extent practicable, the developer will need to include water harvesting as an initial design criterion in an integrated design, not as a retrofit after layout is completed.

Water harvesting will aid in meeting code requirements for [Chapter 26, Floodplain and Erosion Hazard Management, Section 26-10, Detention/retention Systems](#). This code requires detention and threshold retention for developments in balanced and critical watersheds. Detention may be required for developments in non-designated watersheds depending on local hydrology. Detention requirements state that a development must match or decrease the site’s pre-development discharge rates for the 2-, 10- and 100-year flood events. Threshold retention requirements state that a development must retain onsite (no discharge) the stormwater volume difference between the pre- and post-development volumes for the 2- or 5-year flood events depending on the proposed use.

The water harvesting retention volume designed to meet the maximum use requirement for water harvesting may be credited toward threshold

retention volume requirements. Additionally, if water harvesting areas retain the entire stormwater volume for the 2-, 5-, 10- and/or 100-year flood events generated within the water harvesting areas themselves, the surface area of the water harvesting area may be deducted from the watershed area used to calculate required detention/retention quantities or volumes for those events.

Applicability: CAUTION, water harvesting on single family residential lots shall not be credited against subdivision detention/retention requirements. Section 1.4 of the Stormwater Detention/Retention Manual indicates that individual lot detention/retention to meet code requirements is not allowed. Water harvesting is a technique that validates the noncontributing area factor allowed in the flood peak estimation method detailed in Chapter 4 of the City of Tucson Standards Manual for Drainage Design and Floodplain Management. To deduct water harvesting areas and/or volumes from site detention/retention requirements, the water harvesting volumes *must* be maintained to meet code conformance. They shall not be located in areas that will be removed by future development, such as future major streets and routes rights-of-way, without provisions for volume replacement.

The City of Tucson has developed a [Stormwater Ordinance](#). Federal regulations established under the Clean Water Act require large municipalities to implement measures to reduce pollutants in stormwater to the “maximum extent practicable.” As a result, Tucson was required to obtain a Municipal Stormwater Quality permit from the Environmental Protection Agency. To effectively implement the federal permit, Tucson must implement a Stormwater Ordinance that reflects federal requirements that developments include permanent structural controls to reduce pollutants discharged from a site. Onsite retention of the Stormwater Quality Storm (SQS) rainfall depth within the required landscape water harvesting areas will qualify as an excellent tool to control stormwater quality. Currently, the SQS rainfall depth for Tucson varies with impervious cover (imp) as follows: 0.30” for <25% imp, 0.40” for >25% to 70% imp, and 0.6” for >70% imp.

Water harvesting benefits the City and its residents by reducing the volume of stormwater flowing in streets or onto adjacent properties and by helping keep potential stormwater pollutants out of our watercourses and groundwater. Water harvesting reduces the amount of potable water used for irrigation, saving development costs and reducing the demands placed on the region’s potable delivery system and declining water table.

Appendix B. Engineering Considerations for Water Harvesting

GENERAL CONSIDERATIONS

- Capturing water in small increments beginning at the top of the site watershed will reduce the volume concentrating at the bottom.
- Existing topography will influence storage locations, site layout, water harvesting design and layout, and types of water harvesting features.
- Design water harvesting systems to add value to the project.
- Capture as much runoff as possible without depriving adjacent or downstream vegetation of water, and without violating downstream water rights (see note 5, page 17). If all runoff cannot be permanently captured, then slow the flow of the remaining volume to increase percolation (remember to “maximize use” per the Land Use Code).
- Design for inevitable overflow from large rainfall events with erosion controls and overflow conveyance to useful and safe discharge locations.
- Design water harvesting areas to avoid ponding or soil saturation within 10 feet of building foundations (2000 IBC section 1803.3).
- For simple systems, the technique on page 30 may be used to determine how much of the water harvesting area may be considered off line and deducted from retention/detention requirements calculations (See Appendix A for applicability).
- Multiple small harvesting techniques distributed throughout a site will harvest and utilize water more effectively than a few large techniques.

ABOVE-GROUND LANDSCAPE STORAGE

- Landscaping basins should be configured with generally flat uncompacted bottoms to maximize the water storage volume.
- Use erosion-protected spillways between basins.
- A 10-foot wide, 6-inch deep water harvesting basin (level pool) with 3:1 side slopes provides 4.25 cubic feet of storage per linear foot. Deeper harvesting basins will provide more storage volume per linear foot.
- The 10-foot wide, 6-inch deep water harvesting basin described above will contain the 100-year rainfall event volume that lands within the basin. The area of landscaping basins configured to contain the 100-year rainfall is considered to be noncontributing to site runoff and may be subtracted from site area for drainage facility design (See Appendix A for applicability). At the same time, the landscaping storage volume may be used to offset threshold retention volume requirements, provided enough site drainage is routed to the landscaping storage areas to meet stormwater volume requirements for the rainfall event.
- Construct and manage above-ground storage basins to infiltrate storm-

water completely within 12 hours to avoid mosquito problems (Appendix E).

- Above-ground storage may occur in small basins or linear features.
- Take into account the displacement volume of riprap and mulches when calculating water storage capacity in depressions.

BELOW-GROUND LANDSCAPE STORAGE

- Water can be quickly infiltrated and stored under land surfaces using French drains (rock-filled trenches), which are effective in providing storage on flat to moderate slopes. Be sure water harvesting efforts do not destabilize slopes. Consult a soils engineer when designing water harvesting structures for any slopes that are not completely stable.
- Over-excavation of basins and backfilling with 3/4-inch screened gravel or rock provides additional storage volume of approximately one-third of the gravel-filled volume.
- Perforated underground pipes can provide additional storage volume.

ABOVE- AND BELOW-GROUND TANK STORAGE

- Storage of rooftop runoff water in tanks reduces the volume of runoff draining to stormwater detention/retention basins.
- Design tanks and piping so stored water will not be accessible to mosquitoes (Appendix E), insects, sunlight, or animals.
- Above-ground tanks maintain head pressure to allow some gravity flow. Below-ground tanks take less space but usually require pumps.
- For all tanks, install a tank overflow and route it to a logical location in the landscape where it will be put to beneficial use. The overflow capacity must be equal to or greater than the inflow capacity.
- Plumb the site irrigation system to accept both potable water and tank water, supply hose bib piping for the tank.
- Screen inflow from roof to tank to keep debris out. Screen tank outflow before it enters the irrigation system to prevent clogging.
- Evaluate the potential to use tank water in site cooling towers or for wash water uses; design location and piping accordingly.
- Select roofing surface based on planned uses of tank water (metal or tile roofing provide high quality runoff water).
- Carefully plan roof slopes to direct water to specific downspouts based on tank capacity.
- Consider installing a bypass to allow direct drainage of rooftop runoff when tanks are full. Route bypass water to a beneficial use area.

Appendix C. Water Harvesting Calculations

RUNOFF VOLUME FOR SMALL WATERSHEDS

The following technique works best for watershed areas of 2 acres or less that are not extremely flat. Using this technique for a larger watershed area will result in over estimation of both volume and discharge. Chapter 4 of the Standards Manual for Drainage Design and Floodplain Management is recommended for watersheds larger than 2 acres.

1. Determine the area of the watershed.
2. Determine the hydrologic soil type for the watershed (see page 29).
3. Determine the percent impervious cover (rooftops, pavement, sidewalk, driveways, etc.).
4. Determine which storm event (2-, 5-, 100-year) is to be used.
5. Use the chart at right and equation below as follows:
 - a. Locate the percent impervious cover on the x-axis (bottom of the chart).
 - b. Project vertically to intersect the line for the soil type and storm event of interest (n^{th} -year is the event; B, C, and D are hydrologic soil types).
 - c. Project horizontally to the y-axis (left side of the chart) to determine the runoff coefficient Cw_n for the watershed (read to the 1/100th unit).
 - d. Substitute the value for Cw_n into the equation below.

Runoff Volume (V) = $Cw_n * A * X$, where

Cw_n = runoff coefficient for the n^{th} storm event (2-, 5-, 100-year)

A = watershed area in ft^2 , $X = P_n$ in feet (see page 29)

$X = 0.25$ ft for the 100-year event

$X = 0.158$ ft for the 10-year event

$X = 0.125$ ft for the 5-year event

$X = 0.092$ ft for the 2-year event

Example:

Watershed = 20,000 ft^2 , hydrologic soil type = B, impervious cover = 40%

$Cw_{100} = 0.74$, $V = 0.74 * 20,000 * 0.25 = 3,700\text{ft}^3$

$Cw_5 = 0.51$, $V = 0.51 * 20,000 * 0.125 = 1,275\text{ft}^3$

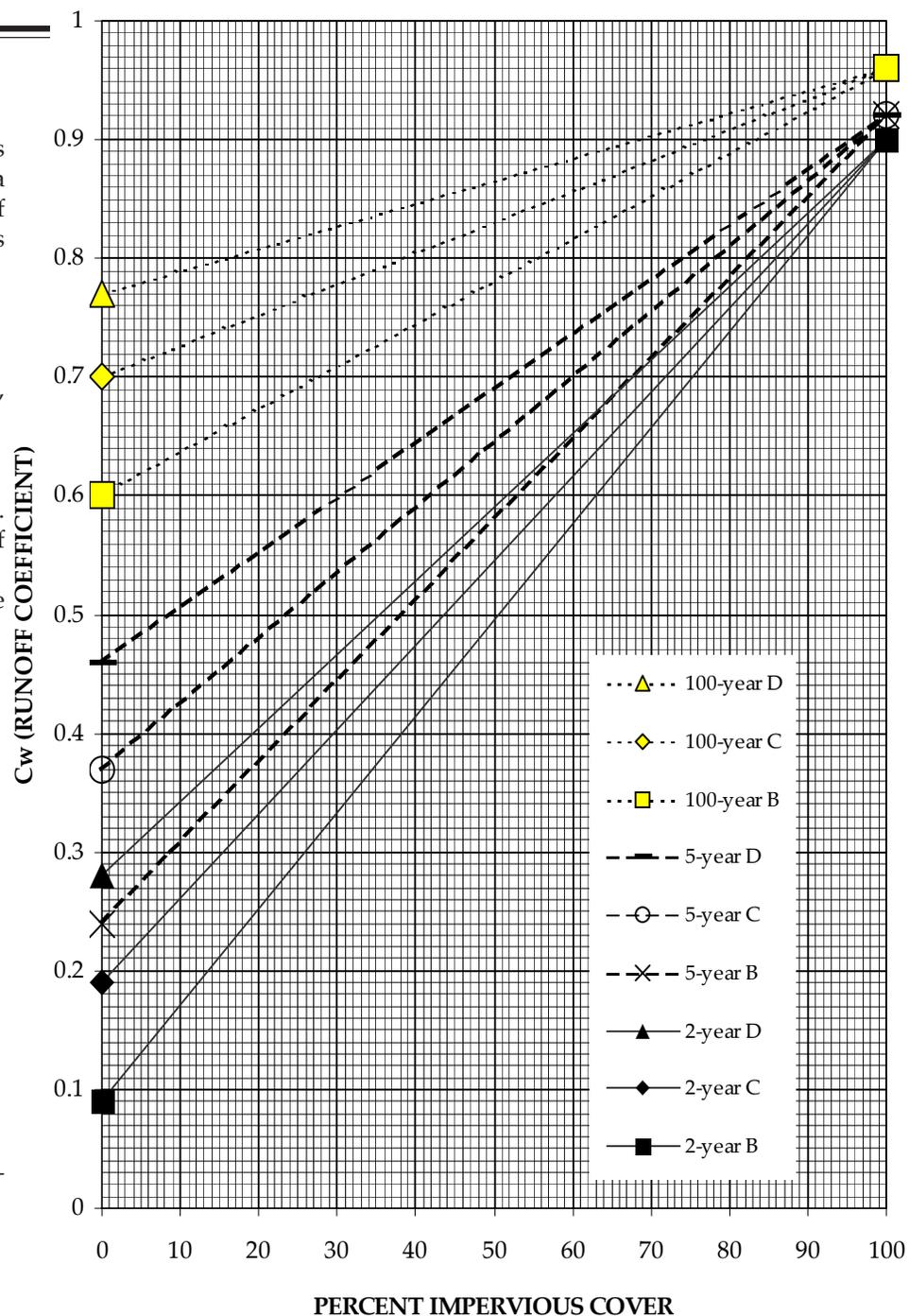
$Cw_2 = 0.41$, $V = 0.41 * 20,000 * 0.092 = 754.4\text{ft}^3$

To convert ft^3 to gallons, multiply ft^3 by 7.48 gallons/ ft^3 .

Calculate the 100-year storm discharge flow rate for overflow erosion protection and conveyance design with the following equation:

$Q_{100} = Cw_{100} * A(\text{ft}^2) * 0.00022(\text{ft}/\text{sec}) = 0.74 * 20,000 * 0.00022 = 3.26\text{cfs}$

RUNOFF COEFFICIENT CALCULATOR



Appendix C. Water Harvesting Calculations (continued)

VARIABLES USED IN THIS APPENDIX

A = watershed area in square feet
 Cw_n = runoff coefficient for the n^{th} year event
 i_n = n^{th} event rainfall intensity for a watershed, reported in inches per hour
 P_n = rainfall depth (in) for the n^{th} year event
 Q_n = n^{th} year peak discharge rate in cfs
V = runoff volume in cubic feet
 $X_n = P_n$ (rainfall depth) value in feet

n^{th} year event	P_n	X_n
2-yr storm	1.1 inches	0.092 ft
5-yr storm	1.5 inches	0.125 ft
10-yr storm	1.9 inches	0.158 ft
100-yr storm	3 inches	0.25 ft

UNITS USED IN THIS APPENDIX

cfs = cubic feet per second
ft = feet
ft² = square feet
ft³ = cubic feet
gal = gallons
hr = hour
in = inches
sec = seconds

FURTHER REFERENCES

City of Tucson Standards Manual for Drainage Design and Floodplain Management, 1989. Chapter 4, revised 1998.

Stormwater Detention/Retention Manual for the Pima County Department of Transportation and Flood Control District and the City of Tucson, 1987.

Soil Survey of Pima County, Arizona, Eastern Part. Natural Resource Conservation Service report 669, interim publication - 1999.

RUNOFF VOLUME AND FLOW RATE EQUATIONS

The runoff volume equation $V = Cw_n * A * X_n$ is a simplification of equation 3.1, of the Stormwater Detention/Retention Manual: Runoff Volume $V = Cw_n * P_n * A / 12$. The equation simplification converts the rainfall depth, P_n , from inches to feet by dividing by 12 in/ft ($X_n = P_n / 12$) yielding the value of X in ft. This allows the use of watershed area, A , in ft² yielding a runoff volume in ft³.

The 100-year flow rate equation, $Q_{100} = Cw_{100} * A * 0.00022$ is a simplification of the rational equation $Q_n = Cw_n * i_n * A$ (in acres). The 100-year rainfall intensity (i_{100}) is 9.6in/hr for **small** (<2 acres) watersheds with times of concentration of 5 minutes. The value 0.00022 (ft/sec) is a units conversion for i_{100} derived from [(9.6in/hr)/12in/ft]/3,600 sec/hr allowing the use of area (A) in ft².

A five minute time of concentration is assumed for both equations. Using these equations for larger watershed areas or very flat watersheds could overestimate the storm event volumes and discharge rates. This technique is based on the flood peak estimation method in Chapter 4 of the City of Tucson Manual for Drainage Design and Floodplain Management.

HYDROLOGIC SOIL TYPES - SOIL MAPS

The Natural Resource Conservation Service (NRCS), previously known as the Soil Conservation Service, has prepared soils maps for Eastern Pima County. Electronic (Arc-Info) copies of the mapping can be downloaded from the NRCS at <http://soildatamart.nrcs.usda.gov/Survey.aspx?County=AZ019>. Paper copies can be purchased from Tucson Blueprint. Soils maps for reference use are available at the City/County Public Works Building on 201 N. Stone Avenue at the City of Tucson Engineering/Floodplain counter on the 3rd floor, and at the Engineering counter of the Development Services Center on the 1st floor. Each location has personnel who can provide assistance in determining the appropriate hydrologic soil type (B, C, D or mixed) for site modeling. The same information is available on the internet at <http://dot.ci.tucson.az.us/mapcenter/>. Just click on the Hydrologic Data and Wash Info selection, zoom into the area of interest, and turn on the Soil Type layer shown under Research Info on the selection menu on the left side of the screen. The MapGuide plug-in (freeware) needs to be installed before layers on this site can be viewed.

MIXED HYDROLOGIC SOIL TYPES

Most smaller sites will have only one hydrologic soil type. If mixed hydrologic soil types are present, simply use a weighted average of the runoff coefficients (Cw_n) reflecting the percentages of the soil types and the percentage of impervious cover:

Example calculation: 30% B soils, 70% D soils; 40% impervious cover, 100-year event.

B soils, $Cw_{100} = 0.74$, determined by using the runoff coefficient calculator on the opposite page
D soils, $Cw_{100} = 0.85$, determined by using the runoff coefficient calculator on the opposite page
The site 100-year Cw for the mixed soils is calculated as follows:

$$Cw_{100} = (0.3 * 0.74) + (0.7 * 0.85) = 0.225 + 0.595 = 0.82$$

Appendix C. Water Harvesting Calculations (continued)

DETENTION/RETENTION IMPACTS

Assume the commercial site shown on page 21 measures 200 ft by 400 ft, or 80,000 ft² (1.84 acres), lies within a balanced watershed, and fronts on both an arterial (a major transportation route) and a collector street (a street that funnels traffic into an arterial street). The site was originally undisturbed desert with dispersed flow over hydrologic type B soils. The site will be developed as a commercial use with 90% impervious cover. Standard hydrologic treatment (Chapter 4 of the City of Tucson Standards Manual for Drainage Design and Floodplain Management, 1989, revised 1998) would result in the following:

Original site:	1.84 acres (80,000ft ²)	Q ₁₀₀	= 10.5cfs
	B type soils	Q ₁₀	= 3.9cfs
	0% impervious cover	Q ₅	= 2.4cfs
		Q ₂	= 1.0cfs
Developed site:	1.84 acres (80,000ft ²)	Q ₁₀₀	= 16.3cfs
	B type soils	Q ₁₀	= 8.1cfs
	90% impervious cover	Q ₅	= 5.7cfs
		Q ₂	= 3.6cfs

Since the site will be a commercial use over 1 acre in size and in a balanced basin, both detention (temporarily hold stormwater onsite to match the pre-developed 2-, 10-, and 100-year event discharge rates) and 5-year threshold retention (permanently hold the difference between the pre- and post-development stormwater volume for the 2- or 5-year event) are required.

The 100-year estimated detention volume per equation 3.4 of the Stormwater Detention/Retention Manual is 6,528ft³. The required 5-year threshold retention volume per equation 3.3 of the Stormwater Detention/Retention Manual is 6,181ft³.

To harvest stormwater in the required 10ft landscaping borders along the arterial and collector streets, use stormwater harvesting basins 6 inches deep or more with 3:1 side slopes. Six-inch deep basins designed as level pools, will provide 4.25ft³ per linear foot of water harvesting basin volume, resulting in the following retention volumes:

Arterial Street; 400ft of frontage less two 24-foot driveways (25ft wide with curb) and one 4ft wide sidewalk:
 $400\text{ft} - 54\text{ft} = 346\text{ft} * 4.25\text{ft}^3/\text{ft} = 1,470\text{ft}^3$

Collector Street; 200ft of frontage less 10ft (arterial landscape border), one 24ft driveway (25ft wide with curb), one 4ft wide sidewalk,
 $200\text{ft} - 39\text{ft} = 161\text{ft} * 4.25\text{ft}^3/\text{ft} = 684\text{ft}^3$

Arterial Street + Collector Street: $1,470\text{ft}^3 + 684\text{ft}^3 = 2,154\text{ft}^3$

The resultant 2,154ft³ of retention volume equals 34.9% of the required retention volume for the site.

The level pool configured water harvesting areas no longer contribute runoff to the site (see Appendix A). Therefore, the area of the water harvesting basins may be deducted from the site area to recalculate detention and retention volume requirements.

$(346\text{ft} * 10\text{ft}) + (161\text{ft} * 10\text{ft}) = 5,070\text{ft}^2$
 $80,000\text{ft}^2 - 5,070\text{ft}^2 = 74,930\text{ft}^2$ or 1.72 acres.

The resultant 100-year detention volume estimate is reduced to 6,102ft³ and the required 5-year threshold retention volume is reduced to 5,778ft³.

The retention volume provided in the water harvesting areas may be deducted from the new 5-year threshold retention required volume, reducing the required 5-year threshold retention volume to 3,624ft³. *This is a 41.4% reduction in required retention volume from the conventional calculation method simply as a result of maximizing stormwater harvesting within the Land Use Code-required 10 ft landscaping border.* More water harvesting area is available. However, there must be enough site area draining to the water harvesting area to provide the 5-year storm volume to the water harvesting area (easily back-calculated by solving for area). Less frequent, larger rainfall events will overflow the water harvesting areas and flow should be directed to the detention basin and/or to a logical discharge location. The estimated detention basin volume requirement has been reduced by 6.5%.

Results

By configuring the required landscape borders to maximize water harvesting in 6-inch deep retention basins with little or no impact to site layout, the required retention volume is reduced by 41.4% and the estimated detention volume is reduced by 6.5%. Larger reductions can be achieved if water harvesting is incorporated into the remaining available landscape areas, by using deeper basin, and/or by the use of alternative materials such as porous pavement, French drains, and/or cisterns. Further reduction can also result by performing an engineering route analysis of the stormwater through the system.

Appendix C. Water Harvesting Calculations (continued)

FURTHER CONSIDERATIONS

With additional water harvesting/retention in interior landscaping areas, between parking areas, and with the use of water tanks to further supplement landscaping irrigation or a cooling system, the detention and retention volume requirements in the previous example can be reduced further. Sites with less impervious cover or other soil types can realize even larger reductions of required stormwater storage volumes. Site elevation change and length of street frontage will affect the percentage of benefit for each site.

EXAMPLE 1

On page 28, runoff volume was calculated for a 20,000ft² watershed area for the commercial site (pages 20-21). Assume that the 20,000ft² watershed area represents the northern quarter of the 80,000ft² commercial site on page 30, and that the 20,000ft² drains to the landscape border water harvesting area along the arterial street. The runoff volume calculation shown on page 28 indicated the areas would generate approximately 754.4ft³ in the 2-year event, 1,275ft³ in the 5-year event, and 3,700ft³ in the 100-year event. The area would also generate a 100-year flow rate of 3.26cfs.

The water harvesting area along the arterial street has 1,470ft³ of retention/storage volume so the 2-year and 5-year events are entirely contained in the water harvesting area. The 100-year event will overflow the water harvesting area and must be accommodated in the site design. Erosion protection and conveyance for the full 100-year flow rate is required and may be as simple as 4-inch diameter riprap over filter fabric on spillways between water harvesting areas, with final discharge to a detention basin. The entire 100-year storm event volume of 3,700 ft³ could be contained along the arterial landscape border in level pool water harvesting basins only 1.6 feet deep with 3:1 side slopes (3,875 ft³), as long as the stormwater percolates into the soils in 12 hours or less. French drains can provide additional storage volume.

EXAMPLE 2

Again, using the commercial site on pages 20-21, the site developer/owner decides to incorporate water tanks to store stormwater for both landscaping irrigation and supplemental, low-salt content water for evaporative cooler use. The roof watershed area totals 11,350ft² with half of the roof draining to one tank and half to another tank. The total stormwater volume from the roof will vary with rainfall depth. A rare 100-year storm event yields a 3in rainfall depth, and the average annual total rainfall depth for Tucson is 11in. The following results may be considered for sizing the water tanks.

Volume can be calculated using the equation $\text{Volume} = Cw_n * A * X$. Use rooftop runoff coefficients (Cw_n) for 100% impervious cover for respective event/rainfall depths. For the 11in total annual rainfall depth, a Cw of 0.88 is reasonable since the 11in total rainfall depth is a summation of many smaller rainfall depths. X is the rainfall depth in feet.

The 2-year, 1.1in rainfall depth yields = $0.90 * 11,350 * 0.092 = 939\text{ft}^3$ or 7,029 gal or 0.62 gal/ft²
The 5-year, 1.5in rainfall depth yields = $0.92 * 11,350 * 0.125 = 1,305\text{ft}^3$ or 9,763 gal or 0.86 gal/ft²
The 100-year, 3in rainfall depth yields = $0.96 * 11,350 * 0.25 = 2,724\text{ft}^3$ or 20,376 gal or 1.8 gal/ft²
The 11in average total annual rain depth = $0.88 * 11,350 * 0.92 = 9,188\text{ft}^3$ or 68,733 gal/year, or 6 gal/ft²

Now all that remains to be decided is how big to make the water tanks and how to direct the overflow so it can be used by the vegetation. (See information on water tanks on pages 14 and 27 and in references in Appendix G). Tanks could conceivably be filled and emptied twice during each rainy season (monsoon season and winter rainy season). If a facility installed sufficient tank capacity to store 25% of annual rooftop runoff, this would theoretically allow the facility to pass up to 100% of annual available rooftop runoff through the tank system. For any given facility, the determination of how much tank capacity to install should be based on the volume of rooftop runoff available, the position of existing gutters and downspouts and the costs to add new ones, availability of space for above- or below-ground tanks, costs of tanks and associated pipes and pump, and the potential uses of the stored water. If the tanks have the capacity to contain all the runoff for the 2, 5, 10, and/or 100-year events (whichever is applicable based on tank capacity) the roof area may be deductible from the site area for detention/retention calculations. Consult with a City Development Services Department official to determine applicability.

Appendix D. Xeriscape Landscaping for Water Harvesting

PLANTING LOCATIONS

- Always strive to achieve multiple functions in the placement of plants such as providing shade, habitat, passive cooling, screening, etc.
- Trees placed on the west, north and east side of buildings reduce heat load in the summer and benefit from water provided from rooftop runoff. Use deciduous trees or low shrubs on the south side to allow sunlight to enter the building in the winter.
- In Tucson hot prevailing winds are typically from the west and southwest. Plant trees on the west and southwest sides of buildings and outdoor spaces to provide a shield from drying winds.
- Tree-shaded parking areas greatly improve customer and employee comfort by creating pleasant microclimates.
- Trees and understory plants act as visual barriers to surrounding sites, and in some cases may, with approval of a Development Services Official, be able to replace the need for a wall to screen the view.
- Combine landscape buffers with detention/retention basins to achieve multiple benefits from one feature.
- When placing plants in the landscape, consider the volume and frequency of stormwater they will receive from water harvesting structures, the plant's tolerance for sun and cold, whether the plant has thorns (needs to be pruned along pathways), what the plant's maintenance needs are, and other site-specific considerations.
- Trees should be 15 to 20 feet from buildings to allow full development.
- Integrate the irrigation system into the water harvesting structure until plants are well established. After establishment, native and drought-tolerant plants typically do not need supplemental irrigation except during extended dry periods.

MULCHING

- Heavily mulch all planting areas to reduce evaporation and maintain soil moisture. Avoid mulching against shrub and tree trunks.
- Organic mulch (composted bark, wood chips, leaves, twigs, straw, grass clippings, etc.) improves soil. Periodically renew mulch if plants do not generate enough mulch from normal leaf drop (self mulching). Organic mulch tends to float; design basin depth accordingly.
- Inorganic mulches such as cobbles, gravel, decorative rock (not decomposed granite) help stabilize berms and spillways, reduce erosion over broad areas, and are very effective at reducing evaporation.
- Mulching in water harvesting areas helps increase the speed at which standing water is absorbed or infiltrated.

PLANT SELECTION

- Use native and drought-tolerant plants (Xeriscape techniques), that adjust well to seasonal rainfall patterns, and look good during the dry season with minimal supplemental irrigation. Native and drought-tolerant plant lists have been compiled by the Arizona Department of Water Resources (520-770-3800), Trees for Tucson (520-791-3109), and the University of Arizona Cooperative Extension/Low 4 Landscape Water Conservation Program (520-622-7701), and in the City of Tucson Land Use Code, Native Plant Preservation section (Chapter 23. Section 3.8), City of Tucson Development Standard 2-06.5, Xeriscape Landscaping.
- Use plants tolerant of occasional inundation in areas where ponding will occur.
- Combine understory, midstory and overstory plants to encourage beneficial relationships and self-mulching, and to minimize maintenance.
- Choose planting themes including pollinator-attracting gardens, native edible plants, fragrance gardens, bird/butterfly gardens, plants used by early inhabitants, or other themes. These plantings in association with water harvesting structures improve aesthetics and provide educational opportunities.

WATER HARVESTING STRUCTURES

- Include landscape planning in the integrated design process to coordinate with site drainage, road layout, building locations, etc.
- Fine-tune the designs of water harvesting features to make their configuration suitable for selected plants.
- Fine-tune the designs of erosion control features and spillways to make them functional and aesthetically pleasing.
- Plants can be placed in the upper edges of water harvesting areas to avoid prolonged inundation and encourage deeper root growth.

IRRIGATION

- Establish plants in water harvesting basins using several years of supplemental watering, then gradually wean plants off extra watering.
- Hook water tanks (filtration may be needed) into irrigation systems to use stormwater in place of potable water when tank water supply is sufficient.
- Install soil moisture and rainfall-detecting devices in association with irrigation systems to prevent unneeded use of both potable and harvested water for irrigation.

Appendix D. Xeriscape Landscaping for Water Harvesting

MAINTENANCE

- Maintenance of water harvesting systems is essential for effective operation. Planning for on-going maintenance will ensure a successful project.
- Inspect water harvesting structures after major rains and on a periodic basis to monitor infiltration capacity, remove trash and other obstructions, maintain berms, treat erosion problems, and adjust the systems as necessary.
- Allow plant litter to accumulate. Chip and reuse plant clippings onsite.
- As climate allows, reduce and try to eliminate supplemental irrigation to native and drought tolerant plants once they are well established.

Appendix E. Mosquito Considerations for Water Harvesting

Mosquitoes are an increasing problem in Tucson due to lush, heavily watered landscapes and many small shallow pockets of standing water (plant trays, bird baths, old tires, etc.). This is a concern because some mosquitoes harbor disease-causing organisms that can be passed to people through mosquito bites. By carefully planning, sizing, and maintaining water harvesting systems, the inadvertent creation of mosquito habitat can and should be avoided.

To control mosquitoes in water harvesting systems, avoid conditions that allow the mosquito to complete the cycle from egg to larvae to adult. It is important that water harvesting structures be designed and built to rapidly infiltrate water below the land surface, and that water does not pool at land surface for more than 12 hours. While mosquitoes are found all over Tucson during the monsoon season, you can avoid contributing to the situation by taking the following precautions in water harvesting systems:

- Do not compact the bottom of water harvesting structures such as swales, microbasins and French drains; loose soil will facilitate infiltration.
- Mulch the bottoms of basins and swales with 3 to 4 inches of mulch.
- Establish plants in water harvesting structures. Roots break up the sub-surface and improve infiltration.
- Size structures appropriately for the amount of runoff received; construct overflow spillways to release excess water and prevent erosion.
- If soil is clay rich (hydrologic type D soils, etc.), mix sand, gypsum and gravel into the first 2 feet under basins to increase pore space and infiltration capacity, and/or use French drains to convey water underground quickly.
- If using inorganic mulch, make sure rock has been screened to remove fine-grained material that can clog soil pores. Do not use decomposed granite unless the fines have been removed.
- Observe your system after initial and heavy rainfalls. If water stands for more than 12 hours in a structure, it might be necessary to loosen the bottom of the basin, add more mulch, lower the spillway, and/or construct smaller, more frequent structures upslope (check applicability in Appendix A).
- Securely cover all tanks, and put fine-mesh screens on all inlet and outlet pipes to keep mosquitoes from entering tanks. Tank overflow water can be routed through a French drain to keep it underground.
- Microbasins positioned along the flow path of a large detention feature should be appropriately sized, planted, and mulched to allow rapid infiltration. Maximize infiltration upslope of the final detention area.
- Do not plant high water use landscape plants that must be watered frequently. Use drought tolerant plants.
- Keep all bowl-shaped structures (plant trays, wheel barrows, tires, etc.) emptied of any standing water. Avoid standing water features such as fountains and birdbaths. If these features are desirable, use *Bacillus thuringiensis israelensis* (BTI), a larvae-killing bacteria that inhibits completion of the mosquito life cycle but will not harm the environment of bird baths and fish ponds. It is sold under the name "Mosquito Dunk."
- Periodically inspect your system to see if mosquitoes are breeding. If so, adjust the water harvesting areas accordingly and/or put BTI in the basins.

Appendix F. Water Harvesting Sites in and around Tucson, Arizona

DOWNTOWN

Dunbar/Spring Organic Community Garden and Mini-Nature Park

NW corner of 11th Ave. and University Blvd.

- Signs provide information, see bulletin board located in the garden.
- Raised pathways shed runoff to sunken garden beds.
- Water harvesting basins and microbasins are constructed and mulched, arid-region plants are cultivated.
- Rain sensor shuts down solar powered irrigation system when soil is moist.
- Perennial vegetation was chosen for multiple uses (edible, medicinal, wildlife attracting, nitrogen-fixing, shelter, dye products, beauty).

CENTRAL

Nature Conservancy

1510 E. Ft. Lowell, (520) 622-3861

- 30,000 square foot parking lot has an innovative porous surface consisting of a subsurface grid made of 98% post-consumer content plastic, and covered with 3/8 inch gravel.
- The parking lot is designed to infiltrate all the rainfall in a 100-year rainfall event, so no detention basin was required at the site.
- Rooftop water goes to landscaping before discharging to the parking lot infiltration surface.

Sonoran Cohousing Community

531 E. Roger Rd., just east of First Avenue

- Roof runoff is initially directed into meandering shallow drainage paths planted with vegetation and mulched.
- Heavy flows reach a series of larger drainage basins that are planted with a mix of native and low to moderate water use trees and shrubs including fruit trees.

Tucson Botanical Garden

2150 N. Alvernon Way, southeast of Grant & Alvernon
(520) 326-9255. (Membership or small fee charged for entrance).

- Rooftop runoff from two buildings captured in two 5,500-gallon tanks.
- Approximately 14,000 gallons per year of harvested stormwater is available for irrigation.
- Sunken basin gardening techniques are used in native gardens.

FAR EAST

Civano

Houghton Rd. and Seventh Generation Way

- Depressed central street medians collect street runoff water to provide water to median plantings.
- Individual homes have microbasins and swales.
- Large gabions are used to control erosion and promote infiltration in drainage features.

NORTHWEST

Tohono Chul Park

7366 N. Paseo del Norte (take Ina west of Oracle, turn north on Paseo del Norte), (520) 742-6455, <http://www.tohonochulpark.org/>

Grounds open to public with a suggested donation.

- Rooftop water is harvested into a 500-gallon below-ground fiberglass water tank in the Ethnobotanical Garden; this water is used to supplement irrigation in food garden.
- Water bars (berms) cross trails to direct runoff water to adjacent plants.
- Tree wells are lowered to collect runoff water, with overflow conveyed to other trees.

WEST

Milagro Cohousing

3057 N. Gaia Place, call (520) 743-2097 for tours, <http://milagrocohousing.org>

- Minimal disturbance subdivision with numerous water harvesting features (over 50 microbasins), graywater use, gabions, 13 cisterns, permeable surface paving and more!

ADDITIONAL LOCATIONS WITH WATER HARVESTING

- CENTRAL: Office building, southwest corner of Swan and Pima Road. Water harvesting off parking lot; manicured detention area.
- CENTRAL: Pima Federal Credit Union building, Stone Ave. north of Prince Rd. Gravel mulch around plantings, use of rooftop runoff water for plantings, vegetated retention basin.
- SOUTH: ASARCO Mineral Discovery Center, Pima Mine Road and Interstate 10, 20 minutes south of downtown Tucson. Multiple water harvesting basins with rock mulch. (520) 798-7798
- EAST: Pantano Road, Golf Links to Escalante, numerous small harvesting basins in the right-of-way behind the sidewalk.

Appendix G. Water Harvesting-Related Resources and Contacts

PUBLICATIONS ADDRESSING WATER HARVESTING

HARVESTING RAINWATER FOR LANDSCAPE USE, Arizona Department of Water Resources, Dec. 1999. To obtain a copy write to Arizona Dept. of Water Resources, Tucson Active Management Area, Water Conservation Specialist, 400 W. Congress, Suite 518, Tucson, AZ 85701, or call (520) 770-3800 <http://ag.arizona.edu/pubs/water/az1052/>

RAINWATER HARVESTING FOR DRYLANDS, "A how-to book about welcoming rainwater into your life, landscape, and soil." by Brad Lancaster. Available summer 2003. www.harvestingrainwater.com

SECOND NATURE. Adapting LA's Landscape For Sustainable Living edited by Patrick Condon and Stacy Moriarty. Metropolitan Water District of Southern California, 1999. Concepts such as passive rainwater harvesting and multi-use landscaping for sustainability are presented. TREEPEOPLE, 12601 Mulholland Drive, Beverly Hills, CA 90210, <http://www.treepeople.org/trees>

TEXAS GUIDE TO RAINWATER HARVESTING, 2nd Ed., by Wendy Price Todd and Gail Vittori. Texas Water Development Board in cooperation with the Center for Maximum Potential Building Systems, 1997. Obtain a copy by writing to Conservation, Texas Water Development Board, PO Box 13231, Austin, TX 78711-3231. Easy to read, primer on water quality, descriptive and detailed manual on how to build water harvesting systems; includes glossary and reference section. Also available digitally at http://www.twdb.state.tx.us/assistance/conservation/Alternative_Technologies/Rainwater_Harvesting/Rain.asp

THE SUSTAINABLE BUILDING SOURCE BOOK, City of Austin Environmental & Conservation Services Dept., Austin, TX, 1995. Comprehensive guidebook of materials and methods of building, including information on water harvesting; lists professional assistance, materials and systems, and general information. Order from: Austin Energy, 721 Barton Springs Rd., Austin, TX 78704, Tel: (512) 494-9400 Also available digitally at: <http://www.greenbuilder.com/sourcebook/Rainwater.html>

WATER HARVESTING CLASSES

Dawn Southwest, <http://www.greenbuilder.com/dawn> (520) 624-1673.

Pima County Cooperative Extension classes - For more information, call (520) 626-5161.

Sonoran Permaculture Guild, Water Harvesting Teachers and Consultants, <http://www.sonoranpermaculture.org>

WEB SITES

A LANDSCAPER'S GUIDE TO MULCH by the Alameda County Waste Management Authority and the Alameda County Source Reduction and Recycling Board. 777 Davis Street, Suite 100, San Leandro, CA 94577. Email: acwma@stopwaste.org. Web: <http://www.stopwaste.org/docs/mulchguide2.pdf>. Very good mulch site. Look around the site for other good information.

American Rainwater Catchment Systems Association, Good links and publications, especially the Forgotten Rain link. <http://www.arcsa-usa.org>

DESERT WATERS - From Ancient Aquifers to Modern Demands by Nancy R. Laney. Arizona-Sonora Desert Museum, 1998. A good short and concise publication on our water situation in the southwest with tips on how to reduce our water use. <http://www.desertmuseum.org/books/catalogue.html>

RAINWATER COLLECTION FOR THE MECHANICALLY CHALLENGED: http://www.rainwatercollection.com/rainwater_collection_how.html

STORMWATER AS A RESOURCE "HOW TO HARVEST AND PROTECT A DRYLAND TREASURE" by David Morgan and Sandy Trevathan. A brief, clear, and concise guide for harvesting rain and snow on your property. On-line copy at http://www.nmenv.state.nm.us/swqb/Storm_Water_as_a_Resource.pdf

Sustainability of semi-Arid Hydrology and Riparian Habitat, Check out the residential water conservation page. <http://www.sahra.arizona.edu/>

GRAYWATER

CREATE AN OASIS WITH GREYWATER, Your Complete Guide to Choosing, Building and Using Greywater Systems 4th Ed. Art Ludwig, published by Oasis Design, 2000. <http://www.oasisdesign.net/index.htm>

HOME USE OF GRAYWATER, RAINWATER CONSERVES WATER AND MAY SAVE MONEY, by Joe Gelt University of Arizona. <http://ag.arizona.edu/AZWATER/arroyo/071rain.html>

Rainwater Collection and Gray Water as Alternative Water Supply Sources. Many good links. http://www.geckodance.com/Family_Focus/Rainwater_Collection.html

RELATED RESOURCES

Arizona Native Plant Society, Box 41206, Sun Station, Tucson, AZ 85717 Web: <http://aznps.org>

Bowers, Janice Emily. SHRUBS AND TREES OF THE SOUTHWEST DESERTS. Tucson: Southwest Parks and Monuments Association, 1993.

Mielke, Judy. NATIVE PLANTS FOR SOUTHWESTERN LANDSCAPES, Austin: University of Texas Press, 1993

Nabhan, Gary Paul. GATHERING THE DESERT, Tucson: University of Arizona Press, 1985

Native Seeds/SEARCH, 526 N. 4th Ave., Tucson, AZ 85705, tel: (520) 622-5561: open-pollinated, native edibles, both domesticated and wild. Free seed available for Native Americans

Tucson Audubon Society, 300 E. University Blvd., Ste 120, Tucson AZ 85705. Information on avian and riparian habitat restoration using water harvesting. (520) 206-9900

Wildlands Restoration, 2944 N. Castro, Tucson, AZ 85705, tel: (520) 882-0969: Drought tolerant native seed source. Habitat restoration mixes, native grass mixes, wildflowers, butterfly mix and others.

