IV. Water Conservation Standards and Guidelines for Master Planned Communities, Residential Subdivisions with Five or more Units, Campuses, and Land Planning

The water conservation information and methods in this chapter apply to large multi-family and commercial developments. Corresponding zoning includes the following if they are part of a Master Planned Community, a Residential Subdivision with five or more units, a Campus or Land Plan: R-1 Single-Family Residential Zone, R-2 Apartment Zone, O-1 Office and Industrial Zone, C-N Neighborhood Commercial Zone, C-2 Community Commercial Zone, and C-LI Commercial/Light Industrial Zone, M-1 Light Industrial Zone, M-2 Heavy Manufacturing Zone, and special use permits for similar uses. The descriptions that follow mention some of the requirements for each zone. In most cases a grading & drainage plan prepared by a New Mexico licensed engineer is required. For a full listing see the Bernalillo County Zoning Code (Appendix A of the Bernalillo County Code of Ordinances).

Corresponding Zones:

R-1 Single-Family Residential Zone - Restricted to one single-family home on a lot not less than three quarters of an acre in size. Where community water and sewer services are made available, the lot size may be reduced according to development densities in the Albuquerque/Bernalillo County Comprehensive Plan.

a. Minimum lot width of 60 feet. With community water and sewer services, lot size may be decreased to 8,000 square feet if located in the Developing, Established or Central Urban Areas of the Comprehensive Plan and 14,520 feet if located in the Semi-Urban Area.

R-2 Apartment Zone - Permits, in appropriate areas served by community water and sewer services, a higher density of population than in single-family zones and still maintains a residential environment.

a. Minimum lot area and width for developments other than townhouses shall be 8,000 square feet and the minimum lot width shall be 60 feet, provided community water and sewer services are made available.
b. For townhouses, the minimum lot area shall be 4,000 square feet and the minimum width shall be 24 feet, provided community water and sewer facilities are available.
c. If community utilities are not available, then the minimum lot size shall be three quarters of an acre per dwelling unit.

O-1 Office and Industrial Zone - Provides sites suitable for office, service, and industrial uses.

a. No minimum lot area or lot width. See Appendix A,, Section 12 of the Bernalillo County Zoning Code for setback, landscape and landscape buffer requirements.

C-N Neighborhood Commercial Zone - Provides for retail businesses and services serving primarily the residents of the neighborhood.

C-1 Neighborhood Commercial Zone - Provides for office, service, institutional and limited commercial uses to satisfy the day-to-day needs of nearby residential areas.

C-2 Community Commercial Zone - Provides for appropriate community commercial uses.

a. No minimum lot area or lot width. See Appendix A, Zoning Section 15 of the Bernalillo County Code of Ordinances for setback, landscape and landscape buffer requirements.

C-LI Commercial/Light Industrial Zone - Provides for community commercial uses, light manufacturing, light fabricating, warehousing, and wholesale distribution with off-street loading and off-street parking for employees, and with ready access to arterial highways or railroads.

a. No minimum lot area or lot width. See Appendix A, Zoning Section 15.5 of the Bernalillo County Code of Ordinances for setback, landscape and landscape buffer requirements.

M-1 Light Industrial Zone - Provides for light manufacturing, light fabricating, warehousing, and wholesale distribution with off-street loading and off-street parking for employees, and with ready access to arterial highways or railroads.

a. No minimum lot area or lot width. See Appendix A, Zoning Section 16 of the Bernalillo County Code of Ordinances for setback, landscape and landscape buffer requirements.

M-2 Heavy Manufacturing Zone - Provides for industrial operations of all types except that certain potentially hazardous or nuisance-type industries as specified in Appendix A, Section 17, subsection B.2 are permitted only after public hearing and review to ensure protection of the public interest and surrounding property and persons.

a. No minimum lot area or lot width. See Appendix A, Zoning Section 17 of the Bernalillo County Code of Ordinances for setback, landscape and landscape buffer requirements.

A. Introduction and Objectives

Development and urbanization have significant impacts on water consumption, as well as on the quantity and quality of the water that replenishes Bernalillo County's groundwater and feeds into the Rio Grande and other waterways. Development reduces the amount of permeable surface that can absorb rainfall, resulting in increased runoff volumes, flow rates and durations, as well as dramatically increased amounts of pollutants washed from roads, rooftops, and other hard surfaces. These are carried downstream to receiving waterways. The resulting stormwater quality and volume adversely impacts downstream water quality and aquatic habitat and requires ever-increasing investment in expensive infrastructure to avoid flooding and erosion. The adverse effects of development on stormwater quality and runoff volumes, speeds and chemical characteristics can be mitigated through integrated water planning and management. Stormwater is a valuable resource. Approaching its management through integrated site design can enhance the functionality and beauty of a site while providing environmentally beneficial services.

Objectives

The objective of this chapter is to provide information that will assist developers in maximizing water efficiency and conservation through integrated site design that:

- Creates an efficient, functional and aesthetically pleasing site by using a holistic planning process that incorporates water conservation into the overall site development process.
- Preserves the natural drainage system to the greatest extent possible.
- Reduces or mitigates the negative impact of changes to the natural drainage system by
  - controlling runoff as close to its source as possible,
  - minimizing the amount of runoff,
  - improving the quality of runoff by reducing the total amount of suspended solids and pollutants, as well as reducing peak flow and runoff speed,
  - minimizing the amount of impervious surface in developed areas,
  - facilitating infiltration to improve shallow groundwater recharge and plant health and reduce soil salts,
  - controlling high-risk pollution sources such as industrial development areas or dumpsters by preventing toxic materials from entering the drainage system.
- Ensures that additions to the drainage system are sustainable and that the new system
  - manages the post-construction runoff to improve runoff quality and increase on-site stormwater infiltration to the maximum extent possible, and
  - is able to safely manage the runoff volumes and speeds over time without any degradation or impairment of its performance.
- Uses the most efficient and lowest impact supply source for each water need in terms of its effect on the greater environment. To that end, information on design and use of non-potable supply options is included.
- Ensures long-term performance by designing for and applying appropriate maintenance over time. To do this, drainage and infiltration systems must be designed to provide appropriate access, and processes must be developed to address all aspects of the maintenance process including ownership, inspections and frequency.

B. Planning and Community Organization

This section will address the steps required for analysis and planning to support water-resource-efficient community design. The first step in community design for water conservation is a thorough analysis of existing conditions at the site.

1. Analyze Existing Conditions

- **Surrounding Context for Development.** The first phase of developing the community organization is to understand the context of the site. The analysis should identify and evaluate the impact of surrounding land use types on the site and use this information during site layout. For example, if an adjacent parcel is exclusively residential, it may be appropriate to place the new development's residential units on land that adjoins the existing development. Similarly, a neighborhood commercial development might benefit from proximity to the existing commercial. Conversely, an adjoining industrial use may dictate placement of open space or other land uses that will buffer and screen the existing development from a new residential area.

  The context assessment should also consider existing physical improvements to adjacent areas such as buildings, parking lots, and other built features and how they relate to the site being developed. Creating linkages might be appropriate to facilitate pedestrian and vehicular traffic between the new development and the existing features and land uses. Potential synergistic relationships between new development and the adjacent features should be factored into the site development layout.

Photo 76. High Desert Community

- **External Systems and Network Connections.** Determine how the site will connect to and interface with external systems such as transportation networks and utility systems such as sewer, water supply, electrical power and gas lines. The location of existing water utilities and connection points should be identified and documented. This information should be used in conjunction with other site analysis data to strike an optimal balance between infrastructure costs, site disruption and functional layout.

- **Topography**. A detailed analysis of the site's physical characteristics and conditions provides the foundation for an integrated site design. In particular, three major factors that determine how water performs on a site must be understood to design a site that maximizes water conservation. The three factors are the quantity of runoff, the shape and steepness of the surface it runs over, and the type of surface material, such as vegetation or man-made materials. To understand these factors and their interaction, the site analysis plan should note the following characteristics.
  - **Topographic features -** Terrain and landscape elements such as slopes, depressions, swales, basins, playas and arroyos, and high points such as hilltops, ridges and mesas. The direction of water flow to and from site features should be noted to capture how they will impact the movement of water on the site. A detailed contour map of the site can be useful. Consideration of the site's location relative to the slope of nearby properties is also important to identify where water is and how quickly it may be entering.

- **Stormwater drainage patterns -** The assessment should include mapping the connection to the larger watershed within which the site resides, including floodplains, as well as the effect of adjacent sites' drainage patterns relative to the site under development. Determine the true watershed or drainage basin boundaries. The drainage basin may include areas outside of the property boundaries. The term watershed is used to describe an area within which all the stormwater drains to a common collection point; several smaller watersheds may be identified within a larger watershed as illustrated in Figure 88. Larger sites, particularly those in rural areas, are more likely to include natural topographic features such as streams and arroyos. Water does not respect property boundaries, so it is necessary to study maximum flows from upstream in the watershed as well as those from within the site. Ideally, watershed management begins at the top of the watershed, decreasing runoff volumes and thereby reducing the need for large stormwater retention or detention structures at the bottom of the watershed. Even within a single lot, approaching stormwater management beginning at the top of the on-site watershed is the most efficient way to keep stormwater on site and reduce the potential for erosion problems.

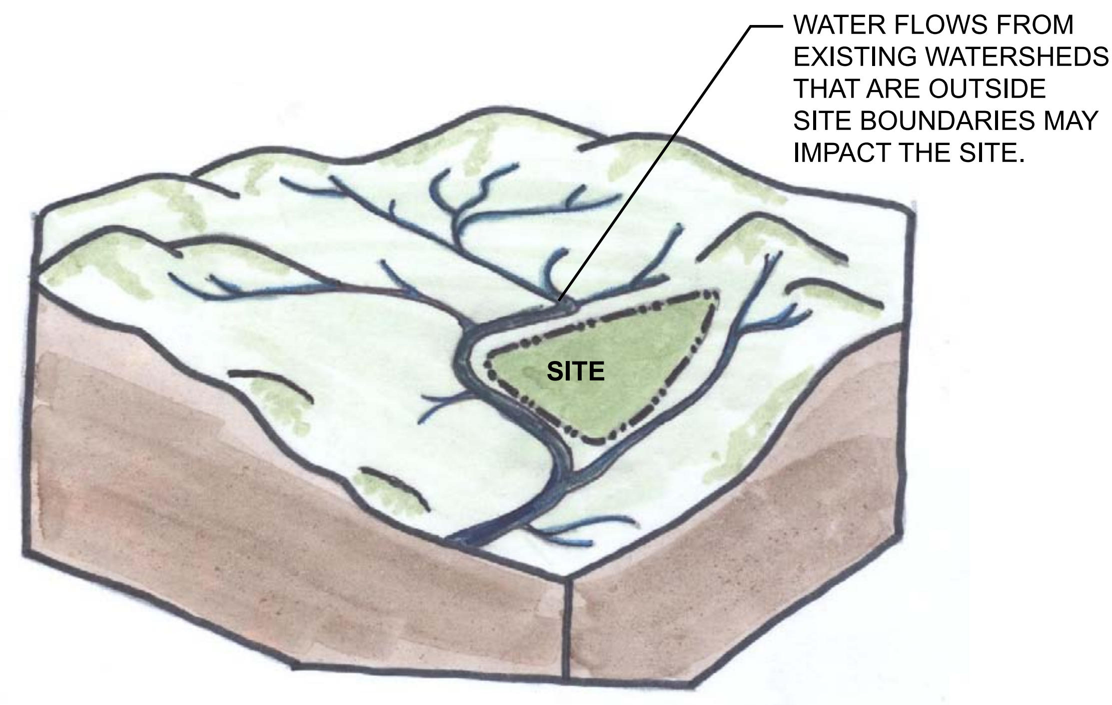

Figure 88. Watersheds

- **Erosion -** This indicates that water is moving too fast to infiltrate. Areas showing evidence of erosion need to be considered when designing the land plan in order to mitigate and avoid worsening the issue. Existing areas that would collect and convey stormwater—hard surfaces such as paving, bare earth, roof surfaces—should be noted. Runoff receiving areas, such as natural depressions, which present water-harvesting opportunities, should also be noted during site design development. For a complete list of water harvesting options see the "Water-Conserving Landscape Devices and Best Management Practices" section of this chapter.

- **Locations of existing vegetation -** Location as well as vegetation type, species, size and condition (health) should be mapped. Non-native, unhealthy, invasive or otherwise undesirable plants to be removed (e.g., Russian olive, salt cedar, Siberian elm) should also be noted. Existing vegetation influences the movement and infiltration of water on the site, as well as soil porosity and erosion prevention. The benefits of retaining existing vegetation are detailed later in this section.

  Additional factors to assess and note include:
  - Viewsheds to be preserved or screened
  - Seasonal wind patterns
  - Wildlife corridors
  - Human traffic patterns including "desire paths"
  - Historic or cultural resources such as built structures, earthworks, trails or traces of trails, hedgerows, etc.

  The information gathered and documented will inform decisions regarding the site design and layout.

2. Plan for Water Conservation

When designing for water conservation it is helpful to think of water as a system or series of linked and interdependent parts. Every part of the hydrologic cycle is interconnected with the other phases of the cycle from water vapor to precipitation, to groundwater, rivers and wetlands and back to water vapor. Water resources are also highly interactive with site features such as soils, vegetation and topography, as well as built elements such as paving and buildings. Sustainable and low impact development integrates site design and planning techniques that conserve and restore the site's natural systems and hydrologic functions through careful design of the site's functional areas and its transportation, water supply and drainage systems. The integrated techniques include:

- **Design of Community Water Supply.** Design of a community water supply provides a significant opportunity for water conservation. Use of non-potable water should be maximized for uses that do not require potable water such as landscape irrigation, toilet water and clothes washing. The range of potential supply options should be considered, including sources of non-potable harvested or reclaimed water. For example, the site can be designed to minimize or eliminate the use of potable water for irrigation by using collected rainwater, stormwater, treated wastewater or other non-potable supply to the maximum extent possible. Alternative water sources can include graywater and runoff from structures such as buildings and roadways. Graywater is wastewater produced by baths and showers, clothes washers, and sinks. Preventing contamination of potable water through cross-connection or inadvertent misuse is a key concern to address when utilizing reclaimed water. Larger systems to collect and treat graywater include satellite wastewater facilities that reuse some graywater locally and send heavier waste to treatment plant facilities. Larger scale developments may also have their own water treatment systems, producing treated water to be used on public landscapes within the development. In some instances, reclaimed water may be available from a local water utility. Other potential non-potable supply sources include cooling system condensate. Either can be harvested or conveyed onto landscape areas to provide supplemental irrigation, or collected and stored for other non-potable uses.

  Determining the amount of supply available from the various potential sources and matching that to demand is key to achieving a functional site water supply system.

- **Prevention of Water Loss and Waste.** Another major area of focus for water conservation is addressing runoff and fugitive water. Sustainable site development strives to protect or mimic the parcel's pre-development water flows through infiltration, filtering, conveyance, and collection, and by enhancing and using the site's existing topography and vegetation to increase infiltration and recharge. This reduces runoff, improves water quality, and reduces water consumption. Water features such as waterfalls or fountains, if included, should be designed for efficiency. See "Appendix G. Water Features and Amenities" in this document for more information.
- **Decentralized Solutions.** Another key sustainable design precept is using decentralized solutions that address water issues at their source, or as close to it as possible. An example would be using localized infiltration or storage techniques on each lot versus conveying all water to a single centralized storm drain system. Modern drainage systems typically collect runoff from impermeable surfaces such as streets and roofs and convey it through pipe networks to receiving waterways. This increases waterway pollution levels, temperatures, flows and infrastructure costs. It is possible to design the site to slow, capture, and treat stormwater runoff close to its source by reducing impervious surfaces, harvesting rainwater, and directing remaining stormwater runoff to soil- and vegetation-based water treatment and infiltration methods, such as vegetated bioretention facilities, constructed wetlands, green roofs, and bio-swales. For details on these and other specific water treatment measures, see the "Water-Conserving Landscape Devices and Best Management Practices" section of this chapter.
- **Identification of Site Resources.** Evaluate how harvested stormwater and other site resources could be used to improve site water efficiency, reduce water and other resource consumption and be leveraged for open space buffering and improved site aesthetics. Assess site elements for potential multi-functionality, such as using stormwater detention areas for open space or even parks and playing fields (Figure 89).

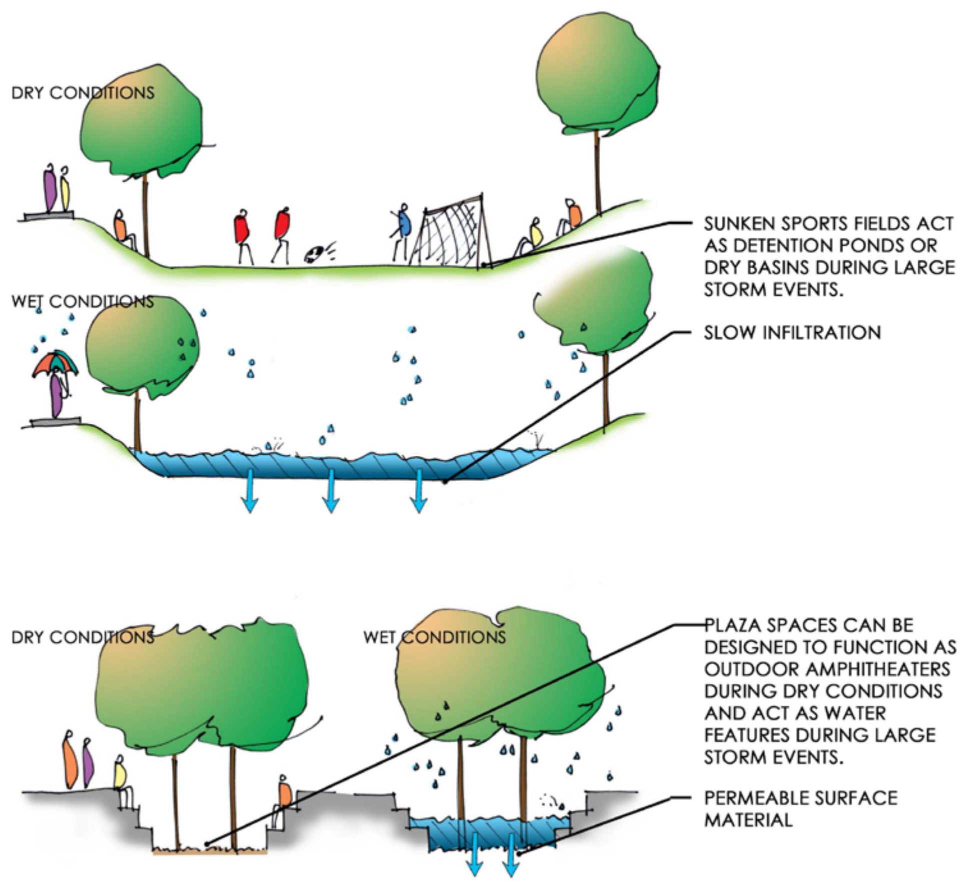

Figure 89. Multi-functional Stormwater Detention Area

- **Maximization of Permeable Surface.** Site water conservation is predicated on reducing the amount of impermeable surface to maximize opportunities for on-site infiltration and storage. This allows the site's hydrologic regime to function as closely as possible to its pre-development state. A range of strategies to maximize permeable area should be incorporated into the site design, including preservation of the site's highest-performing permeable areas and minimization of impermeable surface areas. While hardened areas are required for buildings, roofs, streets or other infrastructure elements, there are many alternatives to traditional impermeable pavings that can help to increase the amount of pervious surface. Pervious or porous paving is defined as any pavement with permeability sufficient to significantly influence hydrology, rooting habitat and other environmental effects. There are a wide range of permeable paving options to choose from, including concrete, asphalt, pavers and inorganic mulches such as crusher fines or decomposed granite. Well-constructed porous pavements have the capacity to meet or exceed a site's pre-development infiltration level. For more information see Permeable Paving in the "Water-Conserving Landscape Devices and Best Management Practices" section of this chapter.

To achieve an efficient integrated site design, a number of environmental factors that affect water conservation should considered. They include:

- **Exposure to Sun.** It is helpful to map how solar exposure of different areas of the site is impacted by existing features and topography, such as microclimate areas created by protection from or higher exposure to sunlight. The solar angle and intensity of sunlight change throughout the year, and seasonal solar changes that might influence the placement of site features to conserve water should be considered. Solar exposure also influences the rate of evaporation and watering needs of plantings. The positioning of plantings relative to buildings and other site structures can take advantage of the shade and protection, reducing irrigation needs.
- **Exposure to Wind.** Wind increases water loss through increased evaporation and evapotranspiration rates, so it is important to consider wind patterns and potential mitigation strategies when determining placement of landscape areas.
- **Soils and Geology.** Soils are a critical component in water conservation efforts as they greatly influence infiltration and runoff rates, as well as erosive potential. Soil testing can provide valuable information to guide your decision making and is critical for appropriate design of stormwater management and infiltration measures. Evaluating a soil's water-holding capacity, permeability rates, texture and composition is important in determining the types, sizes and locations of design measures to use. General soil profile information can be obtained from the Natural Resources Conservation Service; however, laboratory testing of core samples is the most accurate means of determining a site's infiltration capacities. Testing can also help to determine whether soil amendments to improve water retention are warranted. Accurate information regarding the site soils and geology is critical information best acquired through an expert such as a soil scientist, geologist or geotechnical engineer. A geotechnical assessment of the site will provide data regarding soil characteristics, compaction, bearing capacity and qualities relevant to drainage, infiltration and erosion potential. Variations in soils should be considered when determining where to place hardened and non-hardened areas. In general, Bernalillo County soils are deficient in organic matter and tend to be alkaline (moderately high pH). West Mesa Biozone soils are predominantly sandy, whereas the soils in the Rio Grande Valley biozone have high clay content. Soils in the East Mesa, Foothills, Mountain and East Mountain biozones are gravelly with some loam and silt. For additional information refer to the soil descriptions for the relevant "Bioregions" listed in Chapter I.
- **Topsoil -** Because topsoil is a valuable resource for water conservation even in desert zones, efforts should be made to preserve it. When grading a site, it is advisable to remove and stockpile the topsoil, grade only the subsoil and then reapply the topsoil to the graded area. Whenever topsoil will be disturbed or removed during construction, plan to stockpile and save it for reuse. Sites in dense urban environments may require import of topsoil for landscape areas if the site's own topsoil has been depleted or removed. (For additional information see the "Construction Phase" section below.)

- ***Structural soils -*** Structural soils are specific mixtures of stone or sand and soil designed to provide improved growing conditions for tree root systems under pavements or in highly compacted or confined situations. The soil mixtures support the pavement structure, allowing water and air to penetrate the plant root zone while protecting it from compaction. There are several types of structural soils in use today; one of the most well-known is called "CU-Soil"—a mix patented by Cornell University's Urban Horticulture Institute (UHI). Additional information on several structural soil mixtures is provided in "Appendix H. Structural Soils" of this document. Other alternatives, such as proprietary engineered cells—modular units that resemble plastic milk crates—can also be used to create tree-root-friendly zones under paved surfaces such as sidewalks, plazas or parking spaces. The systems are highly flexible, can withstand significant traffic loads, and come in an increasing variety. An advantage of engineered cells is that they provide an increased volume of uncompacted soil, allowing for increased stormwater management and room for root growth. The impact of the cells can be further increased by incorporating engineered bioretention soil mixtures that filter out the nitrogen, heavy metals, and other pollutants common in urban watersheds while providing optimal conditions for trees (Photo 77). Bioretention soil mixtures are typically 65% sand, 20% compost and 15% clay silt.

Urban Trees and Soils

Healthy urban trees provide significant stormwater management benefits and also reduce the heat island effect and pollution levels. Large trees have the greatest beneficial impact. The key constraints to urban tree growth are highly compacted, poor quality soils and small planting spaces. In streetscapes and ultra-urban sites, adequate amounts of uncompacted soil are critical to long-term tree growth and health. A general rule of thumb is to provide two cubic feet of soil volume for each square foot of mature tree canopy size. For native trees, an equivalent amount of uncompacted native soil is appropriate. For example, a 500-square-foot canopy tree should be provided with 1,000 cubic feet of good quality, uncompacted soil.

Photo 77. Engineered Cells under Parking Spaces

3. Consider Community Configurations

The site analysis is the basis for determining the optimal layout for new site components to take best advantage of water conservation. Several principles guide design for water conservation, including the design of water supply and waste and stormwater systems. Community layout is critical to achieving water conservation and should be undertaken with great care. Development should be strategically located based on existing resources and physical conditions of the site. Preservation of natural areas and minimization of land disturbance are critical components of a water-conservative community layout. Those and other key considerations for community layout are discussed below.

> ***Conservation Subdivision Design Benefits***
>
> - **Enhanced stormwater management**. Conservation Subdivision Design (CSD) protects water quality and manages water quantity by slowing and filtering stormwater runoff through wetlands, biodetention facilities, and best management practices that maximize soil water infiltration and percolation.
> - **Visual access to open space.** Views of open space and nature have been shown to be an important amenity for homebuyers shopping in new developments; CSD typically provides access to natural vistas as an added value to residents.
> - **Enhanced/protected wildlife habitat**. Sensitive site development that minimizes disturbances to streams, steep slopes and sensitive vegetation provides increased opportunities to maintain and enhance habitat.
> - **Reduced infrastructure construction costs (streets, sewers, etc.).** Smaller, sensitively placed lots require less total land coverage, reducing the lengths of utilities and streets needed to access all lots.
> - **Large-scale land reshaping and grading can usually be avoided.** Less grading means the native soil is left in place for better establishment of landscape plantings.
> - **Reduced maintenance costs.** Maintenance is a fact of life for any development, but basic CSD principles can reduce overall costs if effectively applied. Examples include less maintenance for narrower, shorter streets, fewer problems with soil erosion/sedimentation as a result of sensitive site design, and lower costs associated with use of native/adapted landscape plants that require significantly fewer inputs (labor, pesticides, etc.) than traditional plantings.
> - **Enhanced profit potential for landowner**. Many successful CSD projects have shown that net profit per lot increases when CSD principles are appropriately applied and implemented.
>
> *From University of Nebraska Water and Property Design*

- **Divide the Site into Areas to be Preserved and Those to be Developed.** Some parts of the site, such as steep slopes, wetlands or floodplains, may be inherently unbuildable and so will be preserved by default. In addition to those areas, it should be determined which existing features should be preserved. Existing features should be evaluated in terms of their impact on water use and conservation and to identify opportunities and constraints for preventing or reducing negative impacts from development.
  - ***Preserve natural drainage systems*** - This can greatly increase water efficiency within the site and can also provide a range of corollary benefits such as maintaining wildlife habitat and movement corridors. The site design should preserve the site's existing natural drainage system and tie in new sources of runoff such as roadways and buildings. It is possible to leverage the site's natural drainage system to address runoff by designing roadways to harvest stormwater and applying the collected water to common areas that connect with the existing drainage system. This can help offset the loss of water supply to vegetation within the drainageways due to development. From a water-use perspective, these areas can also lessen the need for pumps, pump stations and other water movement devices. A site design that builds upon the existing drainageways and topography can also reduce irrigation requirements by aligning irrigation zones with naturally available water in drainageways and collection points.
  - ***Preserve undisturbed areas*** **-** Native vegetated areas, arroyos, riparian or stream corridors, forests, bosques, woods or other relatively undisturbed land should be preserved.
  - ***Preserve buffer areas*** **-** Naturally vegetated areas along the edges of arroyos, perennial streams, springs, rivers, wetlands or other existing site features should be preserved.
  - ***Locate development in less sensitive areas*** **-** Avoid developing sensitive areas such as those with erodible soils, springs, wetlands, mature forest, steep slopes, critical habitat areas or areas within floodplains.
  - ***Preserve open space areas*** **-** Utilize the technique known as conservation design, clustering or open space design to preserve open space and protect water resources.
  - ***Minimize clearing and grading*** **-** Limit clearing and grading to the minimum amount required for construction and placement of roadways, driveways, and building foundations.

- **Determine Conceptual Land Use:** The next phase of design for water conservation is to lay out a conceptual, high-level plan showing placement of the various land uses, such as residential, commercial, industrial, and mixed use. The layout should take into account the previously identified areas to be preserved, the context of uses and features surrounding the site, and the site's topography, drainageways and other existing features. Work through their location relative to various existing site elements and how placement of the various land uses will change or impact water conservation.

Figure 90. Land Use Conceptual Site Plan

- ***Lot-pattern organization*** **-** This should maximize density while working with existing topographic features and drainageways. Densities should be matched to topographic conditions, placing the highest densities on the flattest land and lesser densities on sloping areas or those with other significant features such as arroyos. The building envelope approach outlines the maximum area within which any structures and water-intensive landscape should be placed. At an individual large-lot level, the envelope is configured to respond to topography, maintain natural drainage, and avoid impact on significant existing vegetation. This concept can be applied to the entire land parcel as well as to individual lots.

Figure 91. Water Conservative Lot Pattern

- ***Community common spaces and facilities -*** Consider the existing drainage system and topography in order to take advantage of water conservation provided by the site's natural high- and low-water-use zones. Open space generally works well on higher points and along drainage ways, providing habitat and connected corridors for wildlife. Higher intensity water-use areas such as parks, athletic fields, golf courses and other sports facilities, playgrounds, and commons can be sited at natural water collection points in the lower areas of the site, offsetting their irrigation needs. Placement of water tanks and reservoirs at higher points on the site will facilitate flows through the supply system. Wherever possible, the community design should create multifunctional spaces that serve as both public areas and as components of the site drainage and infiltration system.
- ***Hydrozoning -*** Higher-water-use landscapes such as recreation fields, quads and commons, and green space parks should be situated at lower elevations where they can take advantage of the inherent water-harvesting opportunities of the site's topography. Micro- and macro-scale water-harvesting strategies can be deployed to support the hierarchy of landscape types throughout the site.

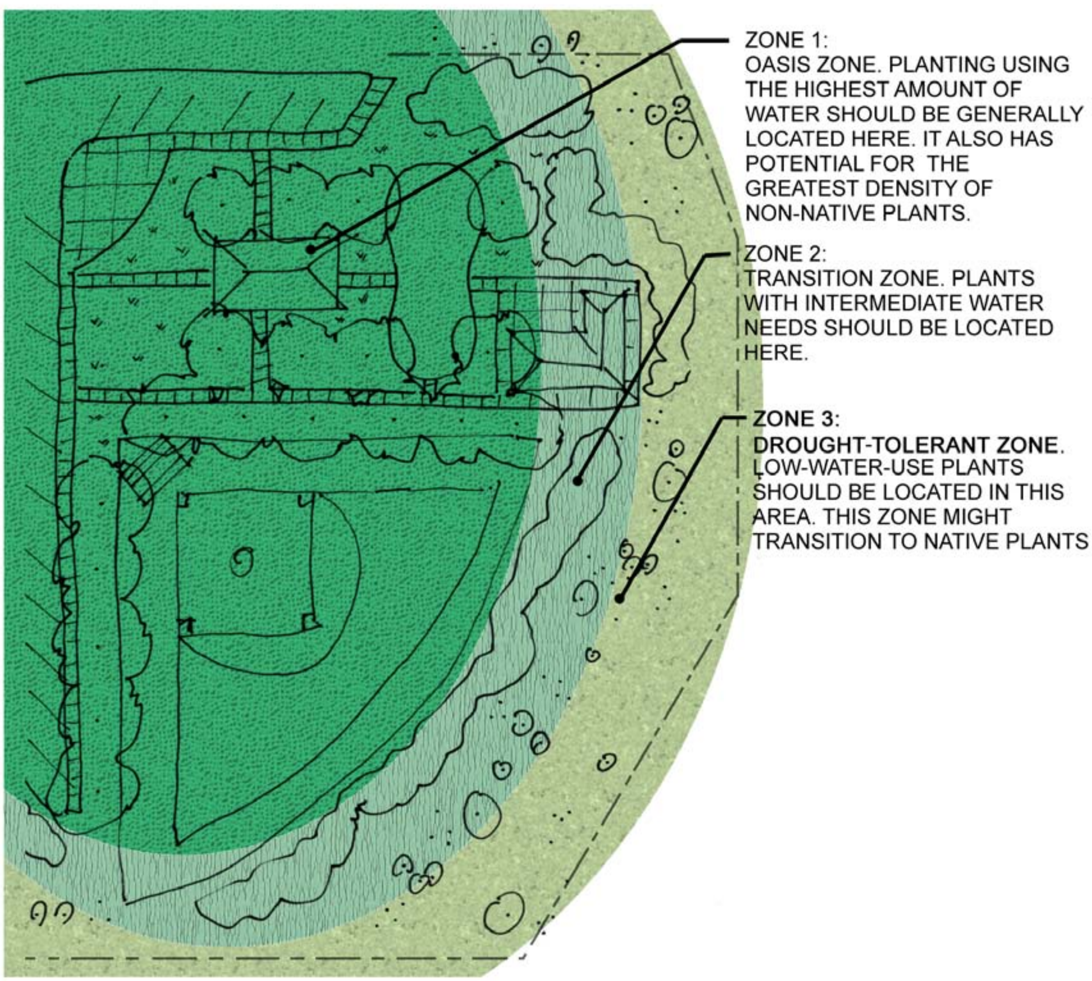

Figure 92. Hydrozoning

- ***Greenways -*** Additional opportunities for connectivity can be provided by "greenways," which leverage existing natural site features such as stream channels, arroyos, or ridges to create a non-vehicular travel network while also acting as a protective buffer for natural features. Stormwater infiltration devices such as swales and bioretention areas can be integrated into these areas to further enhance their infiltration and cleansing functions.

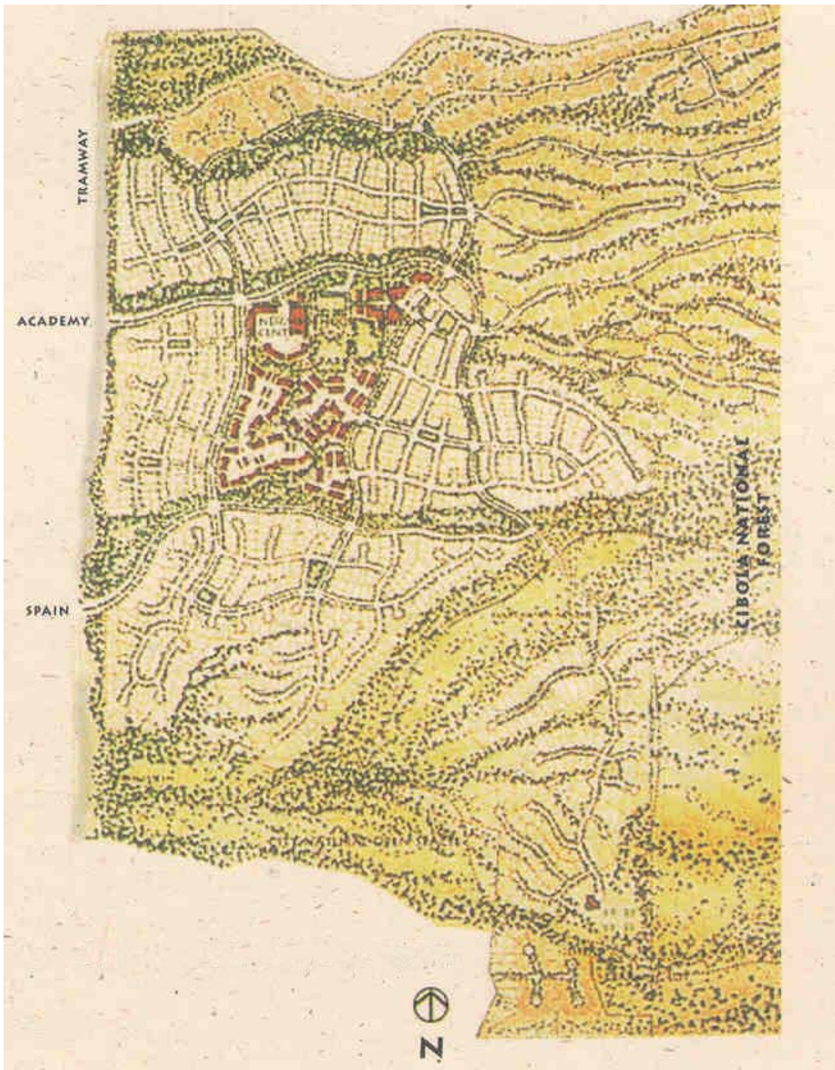

Figure 93. Water-Conserving Design Options for Large-Scale Development

- **Lay Out Road Network -** This network is the next step in the design of a community. As noted above, roadways can serve multiple purposes beyond transportation including stormwater management and harvesting. Their layout should take into consideration the existing drainage system and how to connect to it without detrimental impacts. Public streets and roads can represent up to one third of the land area in urban landscapes, representing a significant opportunity to save water. Streetscapes should be designed to function as water-harvesting systems as well as transportation networks. The roadway is an extension of the natural drainage system on a site or parcel. It is also a conveyance for water delivery. It can be helpful to think of roads and streets as water-harvesting mechanisms that feed into the site's water-harvesting and drainage systems.
  - ***Siting -*** Street network siting and layout are key considerations in designing a site that functions from both a transportation and a water conservation perspective. As noted previously, site development should strive to preserve the existing natural drainage system wherever possible, and avoid locating roads and other impervious surfaces on highly permeable soils or in low-lying areas. Designing streets to follow the site's natural contours as much as possible will reduce re-grading requirements and site disturbance while facilitating linkage of the street network to the site's natural drainage system. Aligning to the existing contours also helps to mitigate the speed and erosion potential of runoff coming from the street paving. A 2% slope will facilitate water movement without compromising pedestrian traffic. Placement of streets on or just below ridge lines will allow water to drain downhill; locating them on the least permeable soils will also improve the overall infiltrative capacity of the site. Placement of streets near arroyos and other natural drainage channels can take advantage of subsurface water migration by facilitating movement of water collected and infiltrated in landscape areas along the roads into the natural drainage system. Depending on the amount of pollutants present in the collected street runoff; additional water quality measures may be needed as well.
  - ***Street network design -*** While streets increase the amount of impervious surface, they can be valuable assets for conveying rainwater to irrigate landscaping in both medians and landscape strips along the roadway.
  - ***Street width and length -*** Designing streets to the minimum width that will support the anticipated traffic volume and required emergency vehicle access as well as any on-street parking will help reduce impermeable surface. The American Association of State Highway Transportation Officials (AASHTO) recommends a travel-way width of 18 feet for low-volume local roads with design speeds of 40 mph and fewer than 400 average daily trips. A variety of possible layouts for narrow streets can be used, including:
    - Providing a parking lane on only one side of residential streets or eliminating on-street parking entirely on short cul-de-sacs or local access roads that have low average daily volumes.
    - Determine whether one-way, single lane loop roads can be used to reduce the width of low-traffic-volume streets.
    - Restrict sidewalks to one side of the street in low-traffic areas or eliminate the sidewalk entirely (if allowable by code). The use of permeable pavings for parking lanes, sidewalks, residential driveways, emergency and service access ways offers additional opportunities to decrease permeable surface area.
    - Driveway lengths and widths should also be minimized to decrease impervious area. Additional options for driveway-area reduction include:
      - Using shared driveways to connect two or more residences.
      - Using permeable pavings (See ""Water-Conserving Landscape Devices and Best Management Practices" for a list of permeable paving options).
      - Paving only wheel track areas (double tracks) and leaving the remainder of the driveway as unpaved, permeable surface.
      - Decreasing front and sideyard building setbacks. Reducing front setbacks from 30 to 20 feet can decrease the amount of driveway and entry sidewalk paving by more than 30%.

- ***Curbless street design*** **-** Directs stormwater into adjacent landscape areas for water quality treatment and infiltration. Curb cuts provide another alternative method to move stormwater into adjoining treatment areas.
- ***Hard surfaces*** **-** Sidewalks, parking lots, streets and driveways can be designed to gather and move stormwater into the catchment and drainage systems.
- ***Multifunctional right-of-way design*** **-** Can perform multiple functions such as providing pedestrian amenities or encouraging passive recreation spaces while functioning as components of the site infiltration and drainage system. Stormwater harvesting and water quality treatment devices such as rainwater gardens, bioretention cells, vegetated swales and other options can be incorporated into streetscape design to provide functional and aesthetic benefits.
- ***Cul-de-sac design*** **-** Can significantly reduce impervious surface area in subdivisions by using the smallest practical radius. For example, reducing the radius from 40 to 30 feet decreases the amount of impermeable surface by almost 50%. Including a landscape island in the center of the cul-de-sac further decreases impervious surface and provides opportunities for stormwater collection and infiltration while creating an aesthetic amenity. The island can be curbless, have a flat apron curb (also known as an estate curb) or curb cuts to promote stormwater flows into the depressed collection basin. Placing the island to allow wider lanes at the top of the cul-de-sac bulb than on its sides allows easier turning for vehicles.
  - T-shaped or hammerhead turnarounds can reduce paved surface by more than 50% compared to a 30-foot-radius, bulb-shaped cul-de-sac design. A 20-foot by 60-foot design will accommodate most vehicles. Hammerhead designs require vehicles to make a three-point turn to exit and are most appropriate for streets with small numbers of residences, generally ten or less. Local street design code requirements should be taken into consideration when determining street layout options.
  - Looping roads provide another alternative to bulb cul-de-sacs. Depending on design, the interior of the loop can provide significant opportunity for stormwater management and public amenities.
- ***Parking lots*** **-** Reducing the overall amount of paved surface within a development supports water conservation goals by reducing impervious surface. Options for reducing total paved surface area within parking lots include:
  - Decreasing the length and width of parking stalls. Stall size reduction can also be achieved by determining the most space-efficient overall layout for the site—comparing one-way drive aisles with angled parking to two-way aisles with perpendicular stalls.
  - Using dedicated compact car and motorcycle spaces.
  - Using permeable paving for parking stalls, pedestrian walkways and lower volume and speed parking areas.
  - Sharing parking facilities. Adjacent businesses with complementary peak parking demand hours such as office buildings and restaurants or churches and businesses operating only on weekdays, can share parking facilities to reduce the total required paved surface.
  - Building parking structures that reduce the total impermeable ground area through use of vertical space. Due to cost, this option is generally feasible for high density or heavy traffic locations.
  - Designing and building parking capacity to reduce the amount of unnecessary parking spaces. Site-specific parking generation studies or analysis of parking ratio requirements can determine the maximum needed number of spaces versus designing to accommodate peak season demand. The analysis should also factor in the efforts of public transit systems on total parking needs.
  - Designing overflow parking areas with permeable paving surfaces.
  - Optimizing flows within the parking lot design to eliminate unneeded lanes and drive aisles.
  - Dispersing parking around the site versus having a single large parking area. This can reduce paved surface area and site disturbance and allow creative and attractive placement among existing site features.

Numerous stormwater treatment and storage solutions can be included in parking lot design to increase infiltration in parking islands and medians, including filter strips, bioretention areas, and vegetated swales.

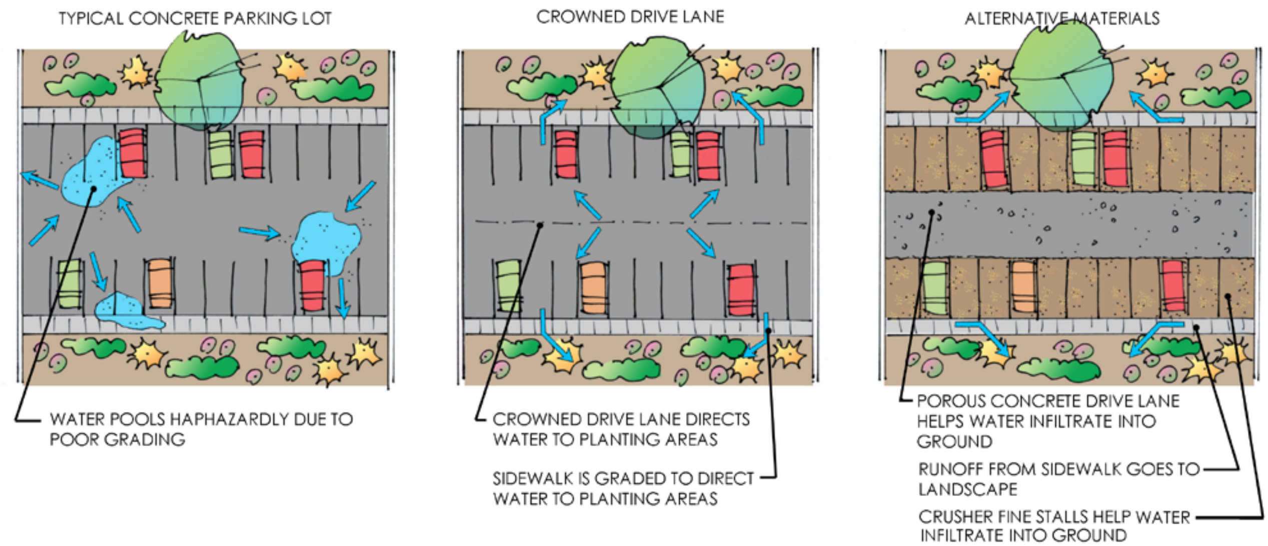

Figure 94. Alternative Parking Lot Design Options

- **Trail design -** This follows many of the same considerations as street design, in particular, placement to avoid disrupting existing site hydrology and to take advantage of lower permeability soils and elevated areas. Existing desire-path locations should be assessed for inclusion in trail networks, as should opportunities presented by edges along arroyos or buffer areas. If the trail will be paved, consider alternative paving materials such as permeable asphalt or concrete, or stabilized crushed stone.

C. Water Conservation Measures and Best Management Practices

Protect water quality and manage water quantity by slowing and filtering stormwater runoff through water harvesting devices and best management practices that maximize water infiltration and percolation.

Land Protection

Minimizing disturbance to the site during development can greatly assist in conserving water over the short and long term and should be an objective through all phases of a development project. Site design should work with existing conditions and limit alteration to the extent possible, preserving and protecting existing site resources that can help achieve a sustainable and water-efficient site. Efficient site layout, including clustering under-ground utilities and grouping them with roadways, will help to minimize disturbance. Limiting damage caused by construction processes also decreases the amount of area requiring revegetation and rehabilitation.

Surveying is one of the earliest activities associated with site development that has the potential to disturb and damage site soils and vegetation. If the survey method being used requires clear line-of-sight, care should be taken to note that vegetation and other features should be left intact and worked around if necessary. Newer survey technologies based on GPS (Global Positioning Systems) or three-dimensional laser imaging can avoid line-of-sight issues altogether.

Given that development inherently means an increase in impervious surface, offsetting that increase is essential. The specific goal should be for post-development runoff peak flows to be at or below the pre-development level. Designing for this objective by incorporating stormwater management techniques for infiltration, detention and storage can reduce or even eliminate the need for expensive traditional "pipe and pave" drainage systems.

Grading and Drainage

Traditional approaches to grading and drainage strive to collect and convey stormwater from the site as quickly and efficiently as possible. In contrast, grading and drainage for water conservation uses stormwater as a resource and strives to reduce the amount and speed of runoff while also preventing adverse impacts to downstream water quality. The core objective of grading and drainage for water conservation is to maintain or preserve the pre-development drainage patterns to the greatest extent possible by retaining existing features and utilizing natural contours and vegetation as integral parts of the site design. The grading plan should address any flows coming onto the site from adjacent properties and ensure that any flows exiting the site do not contribute to erosion or water quality issues downstream.

- ***Limit Clearing and Grading***. Clearing and grading should be limited to the minimum amount required for the development. This is key to preserving the site's natural hydrology and maximizing the amount of undisturbed natural area. Mass grading should be avoided. Grading instead should be divided into smaller areas and performed in phases. Using site foot-printing can assist in lessening disturbance by restricting clearing to the smallest area required for building footprints and construction access. Balancing cut-and-fill through careful site design will reduce the need for soil to be imported to or removed from the site. A site design approach based on conservation, clustering or open space design will also help to minimize the amount of area requiring clearing and grading.

  Limits of disturbance should be established for all development activities based on the maximum disturbance area and should take into account site conditions such as soils and slopes, as well as construction techniques and equipment.

- ***Landform Grading***. Conventional grading creates relatively flat surfaces interspersed with slopes with constant gradients, whereas natural slopes tend to comprise complex landforms that are covered with vegetation growing in accordance with the land's hydric regime. Over time, conventional straight-engineered slopes generally do not perform as well as their natural counterparts in terms of stability and erosion. Landform grading mimics natural slopes and regional landforms by incorporating various shapes such as convex and concave forms.

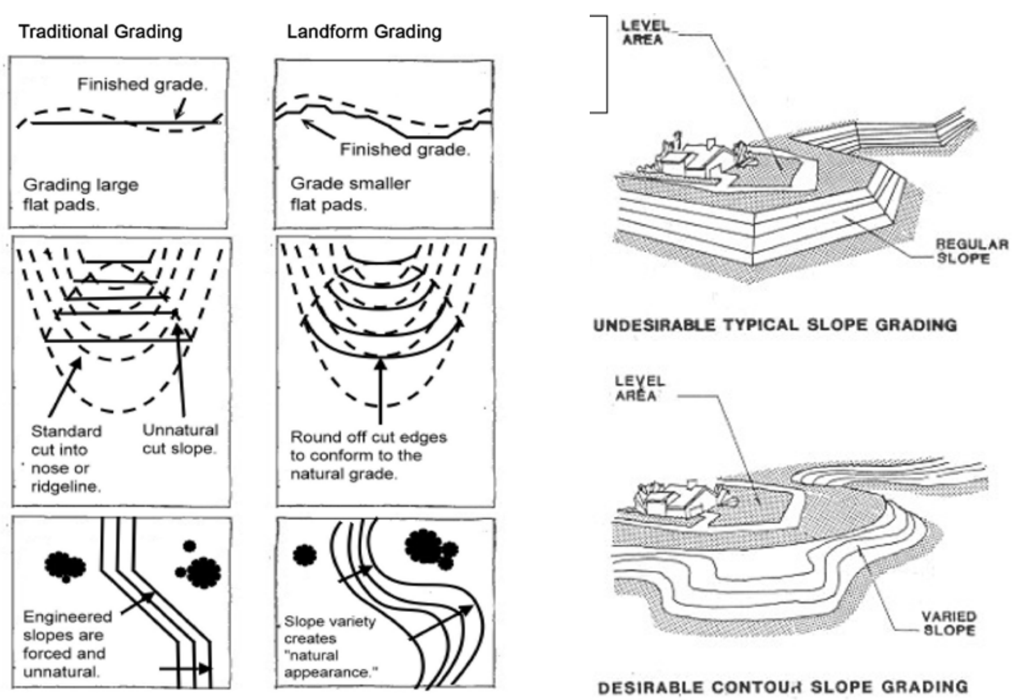

Figure 95. Landform Grading

Drainage paths in landform-graded slopes are incorporated either in contour swale and berm combinations, which create a gradual descent for water movement, or follow natural drop lines in the slope. Slowing the water movement throughout its journey is a key objective (Figure 96).

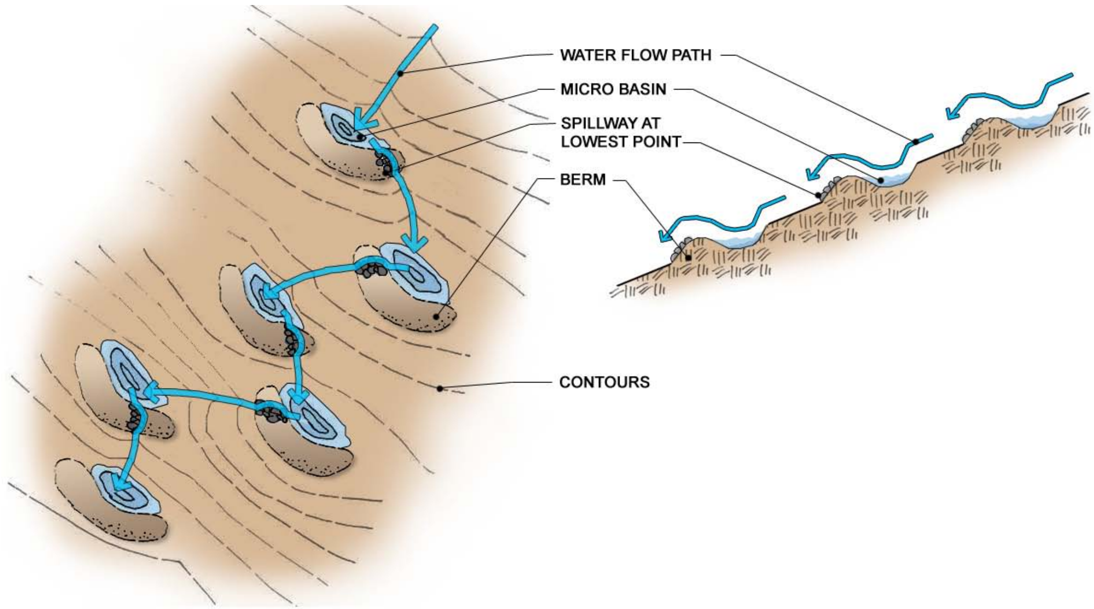

Figure 96. Contour Swale Series

Planting strategies for landform-graded areas also mimic natural vegetation patterns, grouping plants as they occur on similar slopes and landforms in nature. Landform-graded areas tend to revegetate more quickly than traditionally graded slopes, as the resulting topography closely imitates natural conditions. Research indicates that landform grading results in lower maintenance costs over time than traditionally graded slopes, while providing improved water conservation. The naturalistic look of landform grading can also make it more aesthetically pleasing and more readily accepted by the public.

- ***Compaction***. Attention should also be paid to avoiding over-compaction when grading a site. Compaction lessens the soil's ability to absorb and hold water, increasing runoff and other undesirable effects.
- ***Erosion Control***. Preventing soil loss due to erosion helps maintain healthy soil and vegetation. A thoughtful approach to grading can head off erosion issues by assessing the potential impact of grading on water movement through the site. As noted, designing the site to fit its existing drainage patterns and topography will help to minimize erosion. A general rule of thumb is to avoid creation of slopes greater than 4:1 as they tend to be highly erosive and difficult to stabilize. Revegetating newly graded steep slopes and cut banks as soon as possible is critical to minimizing erosion (see "Revegetation" section). A variety of revegetation plantings can be used, from native grasses to groundcovers and shrubs, all of which can help to stabilize and protect the exposed soils. Silt, sand or wind fences should be installed at locations where high winds could erode soils. Permanent control measures such as vegetative buffers, check dams (for swales), straw wattles and other devices should be employed where appropriate. The grading plan should include provisions for minimizing erosion on newly graded slopes by intercepting all surface runoff and conveying it to stable channels. The plans should also ensure that sediment loads are addressed.

- ***Stepped, serrated and terraced slopes***. These are alternative grading methods on long slopes to improve water conservation by slowing runoff and increasing infiltration. Soil type is important when determining which method to use, as some are less appropriate for highly sandy or loose soils and may require additional measures to avoid erosion.

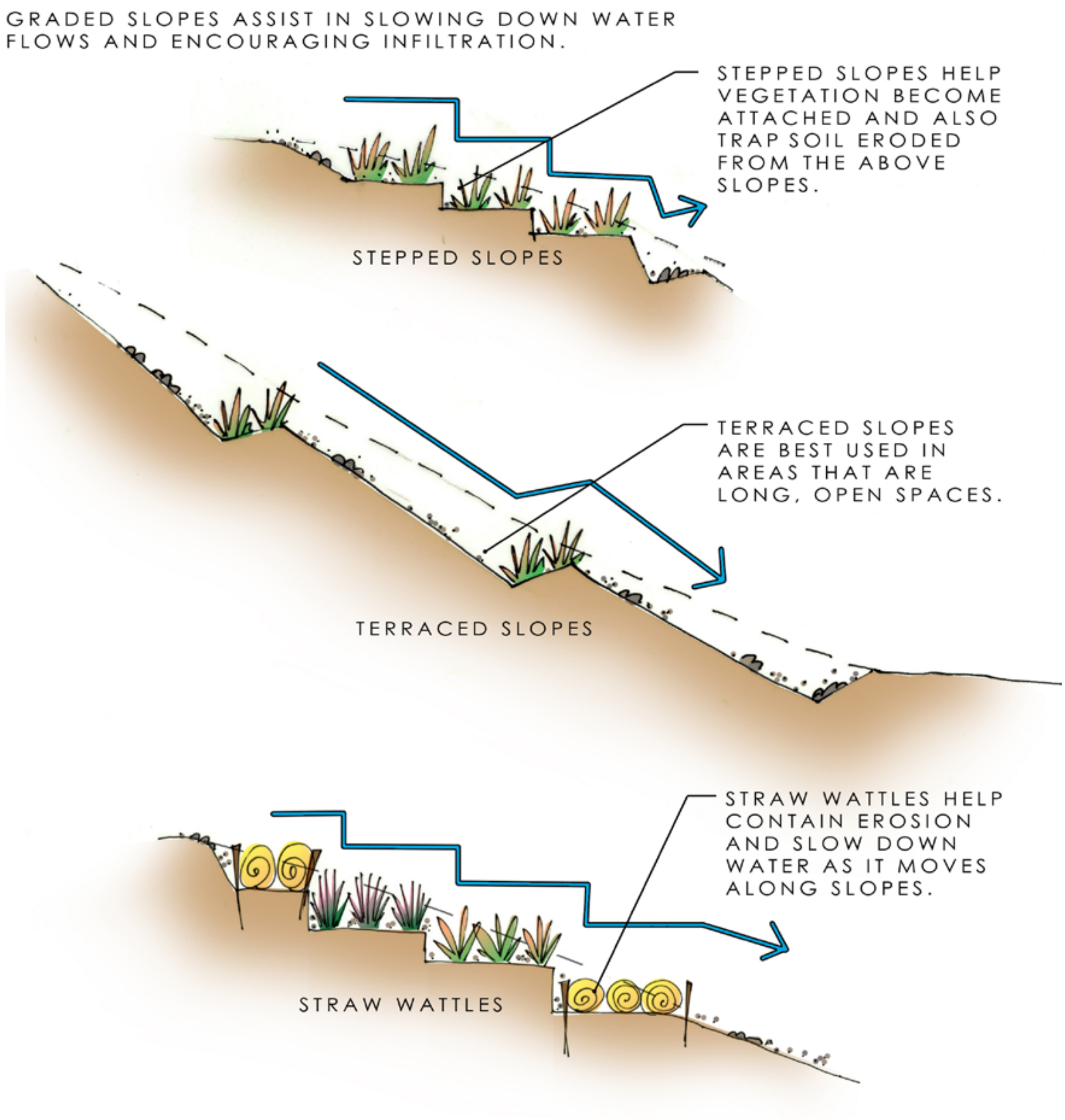

Figure 97. Slope Grading Options

- ***Slopes***. Avoid developing areas with slopes 15% or greater in order to limit erosion and excessive runoff. Areas with slopes 25% or greater should not be developed, regraded or stripped of existing vegetation. For other sloped areas, minimize the development footprint and attendant re-grading as much as possible.

  Lot benching is an effective grading approach for lots on hilly sites. The method reduces the slope and slope length of disturbed areas, decreasing the potential for erosion. Lot benching establishes drainage patterns for each individual lot as well as the entire development during rough grading so that runoff from any lot is not directed onto adjacent lots. Each lot addresses its own runoff either through on-site infiltration and storage, conveyance to a street or stormwater outlet and into the centralized drainage system, or by a combination of the two. Each lot is graded so that runoff flows towards the cut slope on the uphill side of the lot, which prevents water from spilling over a steeper slope into an adjoining lower lot.

  Design the landscape to capture and collect runoff, and grade landscapes to maximize infiltration while minimizing runoff.

  - Locate and size areas where you will hold or detain water. Undeveloped open space areas can be sited on areas of higher ground from which stormwater tends to drain. The vegetation of these predominantly natural areas tends to be more drought-tolerant and generally does not require supplemental irrigation, surviving on precipitation only. An advantage of using the higher ground areas for open space or similar non-irrigated landscapes is the elimination of the need to pump water uphill, translating to a more efficient water delivery system.
  - Try to follow the natural contours as this will help preserve major natural drainage patterns. Techniques like berms and swales can be used to enhance the natural patterns to direct water flow and prevent erosion. (See "Water-Conserving Landscape Devices and Best Management Practices").
  - Promote lot-level infiltration by directing sheet flows into infiltration areas through graded slopes and their orientation. Direct drainage flows away from buildings along gradual slopes to slow runoff and improve infiltration rates.
  - Reduce the amount of grading per lot through minimizing the building footprint. Designing buildings to leverage vertical space rather than single-story buildings can reduce the impervious footprint while maintaining the same floor-to-area ratio.
  - All individual lots should address the maximum amount of runoff generated on-site. Any runoff in excess of lot-level infiltration and storage capacity should ultimately drain into the site drainage system.

- ***Sequencing***. A construction sequence schedule should be developed in conjunction with the site development plans to coordinate the timing of installation of sediment and erosion control measures with all development activities that will result in land disturbance. Best management practices for the construction phase are outlined later in this document.

Depending on the amount of new impervious surface created when developing a site, conserving or replicating the existing natural flows of the site may not be sufficient to address the volume of stormwater as illustrated in Figure 98. Accommodations should be made for the increased volume of stormwater, preferably by retaining and infiltrating the volumes on-site, rather than by enhancing the capacity of traditional drainage facilities to eliminate the runoff from the site. Artful grading of the site can integrate attractive and functional on-site water harvesting systems that work in conjunction with buildings and other structures. The following section provides information on potential methods for increasing on-site stormwater management capacity. Also refer to Chapters II and III of this guide for more detailed information on specific water conservation strategies for these types of developments.

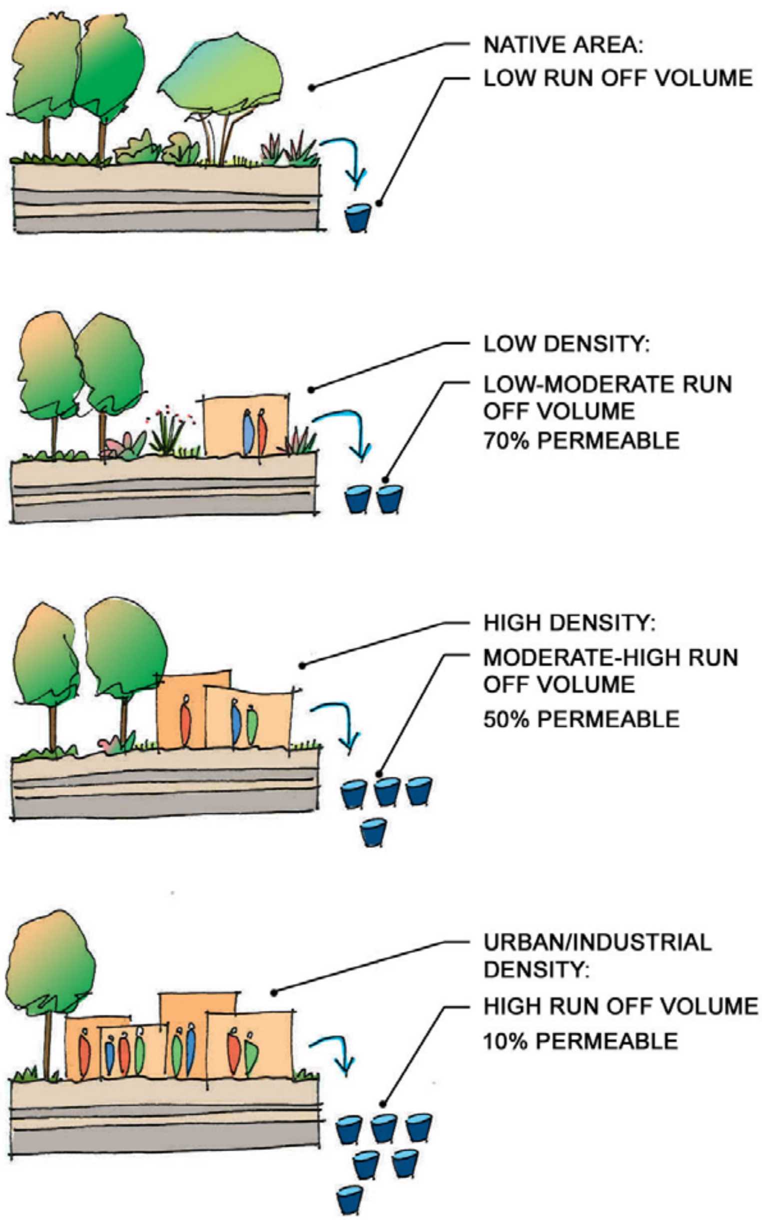

Figure 98. Runoff Volume and Development Density

D. Water-Conserving Landscape Devices and Best Management Practices

In this section, methods for conserving water in the landscape are described and illustrated. These devices and best management practices can be used to assist in meeting Bernalillo County Water Conservation Ordinance requirements and enable the developer, builder and home owner to conserve water while creating a beautiful and thriving landscape that improves the environment and enhances property value. A complete copy of the Water Conservation Ordinance (Bernalillo County Code of Ordinances, Ch. 30, Art. VII, Sec. 241-251) can be found in "Appendix A. Bernalillo County: Applicable Plans, Regulations and Ordinance".

Water Harvesting

Water harvesting generally refers to techniques used to capture and collect precipitation and stormwater runoff and direct it either into the landscape or into a storage system for future use. Using a combination of devices or techniques can maximize the amount of stormwater harvested and used. Figure 99 demonstrates several methods commonly used to direct and distribute captured stormwater on larger parcels.

Water harvesting provides multiple benefits, such as reducing the amount of irrigation required, improving water quality, and reducing erosion and the amount of site discharge into the storm sewer system. Water-harvesting devices can be used individually or in systems called "treatment trains" to collect and distribute water to the landscape efficiently. The devices can be as simple and small as rain chains and rain barrels, or as large and complex as ponds or constructed wetlands.

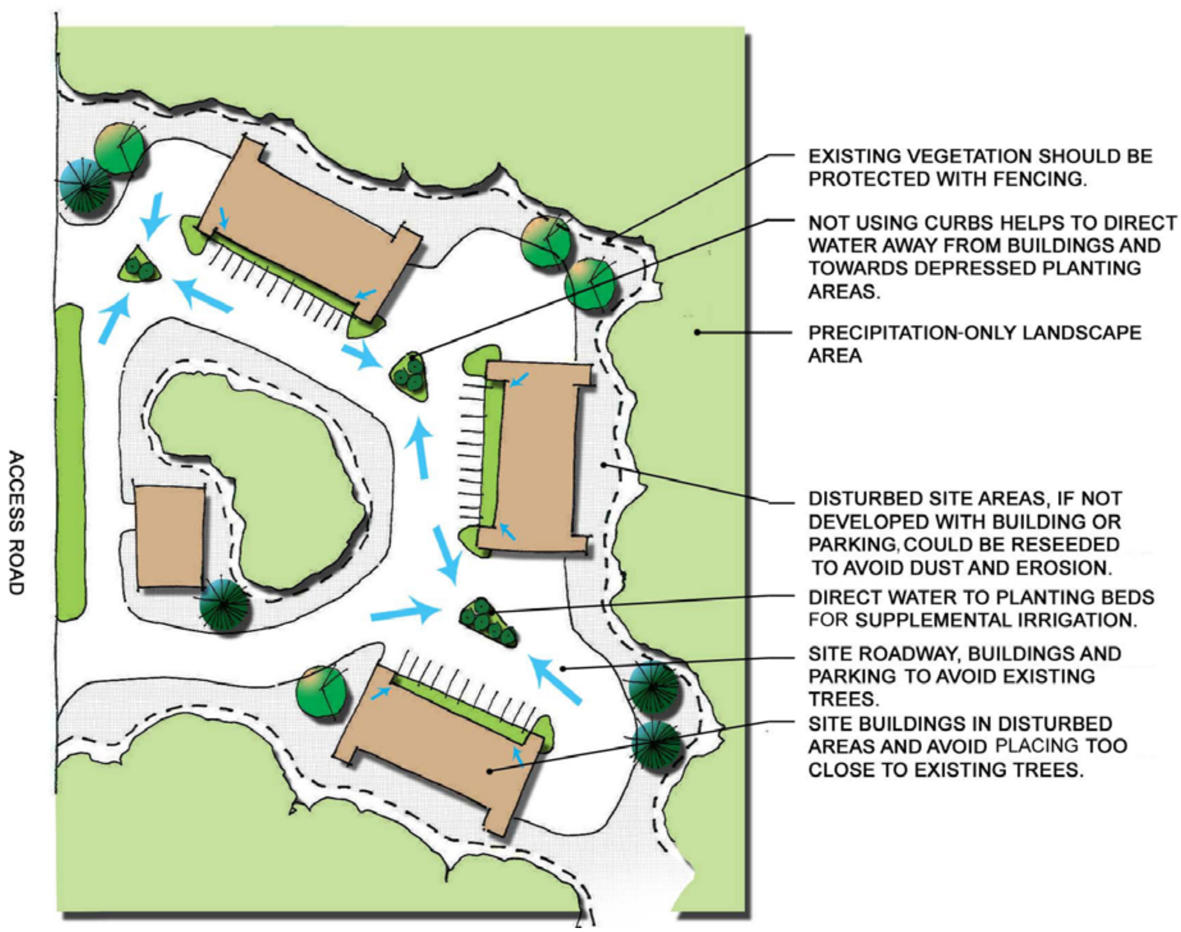

Figure 99. Water Harvesting on Large Parcel

Basic Principles for Water Harvesting

- Plan for use of harvested water to support landscape needs.
- Look for water harvesting opportunities throughout the site. Providing opportunities for stormwater to slow and infiltrate as close as possible to where it enters the site or reaches the ground will decrease the need for larger scale interventions downstream.
- Collect, slow and enable stormwater to infiltrate the ground using a variety of water-harvesting devices based on the site conditions and constraints.
- Plan for overflow from all water harvesting and storage devices used and direct the overflow into the landscape.
- Plan for water quality. Stormwater washes the surfaces it runs over, collecting and conveying pollutants and sediment that have accumulated. The potential amount and type of materials conveyed in first flush runoff should be considered when selecting and designing water-harvesting devices and systems for a site.
- Maintain water-harvesting devices and systems. Plan for and provide appropriate maintenance in order to maximize device and system performance and longevity.
- Make sure your drainage project does not negatively impact anyone else's property.

General Construction Notes
Make sure that your drainage project does not negatively impact anyone else's property. Check with utility companies about buried cables or gas lines BEFORE BEGINNING TO DIG.

Water-Conserving Landscape Device Matrix

The matrix following lists a range of potential water-harvesting techniques along with information regarding their use. More detailed information on each technique is available in the text following the matrix. To use the matrix, locate the desired primary water conservation function and then follow the rows across to see which devices perform that function. Review the ideal conditions, counter-indications and constraints regarding use and siting for each device to determine whether it is appropriate for your site conditions. If a particular technique is not appropriate for your site, review the other devices listed for the desired function to find other options to fit your needs. A summary of maintenance considerations is also provided to assist in preliminary decision making. After determining which devices are most likely to perform well for your site, review the detailed device descriptions in the section following the matrix to further assist your decision making process.

Treatment Trains

The infiltration capacity and water quality improvement impact of water conservation devices can be increased by linking treatment devices in a series or linear sequence, known as a "treatment train." In a treatment train the size of each device or measure is based on the function and stormwater output of the preceding device. By selecting a sequence of measures based on stormwater management goals and taking into consideration site conditions and constraints, a greater impact can be achieved than through the use of individual, isolated measures. The devices listed in the matrix following can be used in a variety of combinations depending on the needs of a particular site and development.

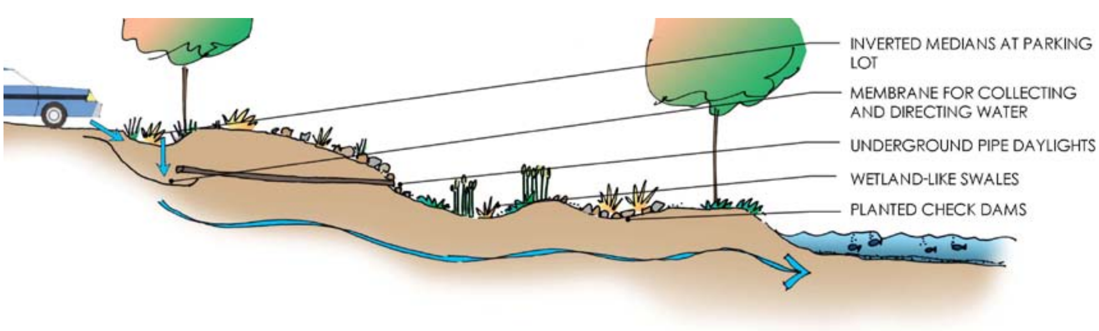

Figure 100. Contour Swale Series

Device	Primary Water Conservation Function	Additional Functions	Ideal Site Conditions	Counter indications/ Constraints	Configuration / Design Options	Maintenance Considerations / Issues	Detailed Information
Swale	Drainage water conveyance.	Infiltration/ landscape sustainability, flow reduction, flow diversion.	Slopes of 0.5% to 1.5%.	Minimum 0.5 % slope on paved surface, minimum 1.0 % slope on vegetated surface, rip-rap or vegetative armoring may be necessary for high water velocities.	On-contour swales/berms, off contour swales, armored or vegetatively reinforced. Erosion control blankets necessary on slopes of >5:1.	Visual inspection and cleaning after significant rainfall event, landscape maintenance.	page 199
Check Dam	Erosion control along drainageways/ water harvesting.	Decreases water velocity, water quality improvement/ desedimentation, infiltration for landscaping.	Drainage area <10 acres - for every one-foot drop in elevation or a minimum of 50- feet separation.	Do not place in live streams (only useful for intermittent drainageways).	Boulder/cobble weirs, wicker weirs, earthen checkdams, concrete.	Visual Inspection for damage, sediment removal, landscape maintenance; drainage should allow slow infiltration but not ponding (to avoid mosquito problems).	page 202
Gabion Structures	Erosion control. Retaining wall.	Decrease water velocity, water quality improvement, infiltration.	Hillsides and drainageways.	Landscaping needs to be carefully chosen, and proper anchorage of base should be designed by engineer to prevent failure of gabion wall.	Terraces, in drainageways.	Visual inspection and cleaning of gabion wire after significant rainfall events.	page 204
Curb Cuts (for Water Harvesting)	Parking lot and street conveyance.	Flow diversion/ water harvesting for parking and streets.	Parking lots and streets adjacent to vegetation and landscaped areas.	Should be installed per the applicable regulating agency standards and methods of construction (Bernalillo County, NMDOT, etc.).	Parking medians, streetscape rain gardens.	Because these devices are accepting drainage from streets they need visual inspection and cleaning.	page 205
Rain Chain	Water conveyance for low rooftop flows.	Aesthetics.	Rooftops with canales or gutters.	Large rooftop drainage basins may produce too much water.	Many, constricted only by style.	Sediment cleaning necessary in individual baskets.	page 206
Microbasin	Infiltration devices / water harvesting.	Water quality improvement, small infiltration basins, landscape sustainability.	Parking lots, open landscapes, gentle slopes (slopes less than 5%).	Not suitable for steep slopes, not suitable along swales or major drainageways, may need spillways.	Localized depressions, crescent depressions (for hillsides), parking islands.	Visual inspection and cleaning after significant rainfall event, landscape maintenance, drainage should allow slow infiltration but not ponding (to avoid mosquito problems).	page 207

Device	Primary Water Conservation Function	Additional Functions	Ideal Site Conditions	Counter indications/ Constraints	Configuration / Design Options	Maintenance Considerations / Issues	Detailed Information
Soil Imprinting	Slow infiltration.	Erosion control / water harvesting.	Open land unobstructed with impervious surfaces.	Steep slopes of > than 2%.	Open landscape areas, ideal for reclamation.	During establishment of seed erosion must be abated. After establishment no maintenance should be necessary.	page 209
Waffle (or Grid) Gardens and Terraces	Infiltration, reclamation.	Erosion control, flow reduction.	Steep hillsides (terraces), flat surfaces where cross migration of subsurface water needs abatement.	Extremely sandy or erosive soils.	Terraces and flat surfaces, berms surrounding may need armoring.	Rebuilding may be necessary upon large storm events.	page 209
Permeable Paving	Infiltration from parking and pedestrian areas.	Water quality improvement, groundwater recharge, pollution prevention.	Parking lots and pedestrian areas surrounded by vegetation.	Sand and silt from desert areas can clog openings in pavement.	Asphalt, concrete, or open celled pavers with underlying gravel. Permeable pavement should be sloped a minimum of 0.5% To prevent ponding. If underlying gravel is used as storage area, it must be sized per the design storm.	Periodic flushing, power blowing or vacuuming may be necessary to facilitate drainage; landscape materials should not be stored on surface.	page 213
Bioretention Cell or Basin	Water quality improvement.	Infiltration / aesthetics.	Parking lot (for runoff pollution protection).	Some plants may require irrigation.	Parking lot islands, filter strips on parking lot end points. Design so that a maximum of 6 inches of water is present at design flow to prevent inundation of vegetation.	Landscape maintenance is specialized; irrigation may be necessary; landscape may need replacement periodically to retain functionality.	page 215
Constructed Wetland	Water quality improvement.	Infiltration, water quality improvement.	Sewage treatment, landscape water quality improvement.	Maintain a minimum of 20 feet from any structure. A geotechnical report should be completed to address slope stability of pond embankments. Avoid soils with high infiltration rates (sandy soils). Water inflow should be greater than the site release rate, infiltration rate, and evapotranspiration rate.	Unlined, using soils with high water retention, lined using soils with high infiltration rates.	Routine management of vegetation (replacing dead plants and removal of plant material) and routine removal of sediment. Wetlands should be designed with vehicular access points for proper maintenance.	page 216

Device	Primary Water Conservation Function	Additional Functions	Ideal Site Conditions	Counter indications/ Constraints	Configuration / Design Options	Maintenance Considerations / Issues	Detailed Information
Retention Pond	To retain water in a pond with no outlet (storage and infiltration).	Infiltration / landscape sustainability, groundwater storage, water quality improvement.	Large open areas, sandy soils preferred. See configuration column.	Evapotranspiration calculations must be done to ensure the water in the pond will empty between significant storm events. Mass balace analysis should be done by a licensed engineer. Maintain a minimum of 20 feet from any structure. A geotechnical report should be completed to address slope stability of pond embankments.	Pond should be sized for a minimum 100-yr 24-hr storm and have at least one foot of free board at peak volume. Surface area of pond should be sized to allow for complete evaporation of water volume between significant storm events. Pond should be designed with an overflow structure to prevent failure of embankments during extreme storm events.	Visual inspection and cleaning of pond bottom and outfall structure after significant rainfall events.	page 219
French Drain	Below grade infiltration, flood protection.	Temporary shallow groundwater storage, conveyance, infiltration/landscape sustainability, pollution prevention.	Rooftops with canales, land slopes of 0.5% To 1.5%.	Non-porous / clayey soils (poor drainage), below grade use only, steep slopes. Size according to target flow/velocity (should not drop below 2 ft/s, not greater than 7 ft/s).	Perforated pipe, w/wo gravel bed and filter fabric surrounding, gravel bed with filter fabric (gravel grain size distribution should be such that geomenbrane & perforated pipe do not clog).	Due to below grade installation difficult to clean; if installed with landscape adjacent difficult to replace / clean.	page 219
Wicking Systems	Below grade infiltration/ passive irrigation for individual plants.	Minimal drainage protection.	Landscape plantings with minimal irrigation, on-contour swales.	Non-porous/clayey soils (poor drainage).	Must be located near root system of plant.	Due to below grade installation difficult to clean; if installed with landscape adjacent, difficult to replace/clean.	page 223
Mulches (gravel, wood, other)	Reduce evaporation in landscape areas.	Aesthetics.	Landscape areas.	When place adjacent to hard surfaces depth of mulch must be considered.	Matches landscaping.	Most mulches must be periodically replaced; blowing sand and dirt can inundate mulches.	page 224
Green Roof	Reducing roof drainage and demand for ground ponding.	Reducing energy needs of building, reducing heat island effect, landscape amenity.	New roofing on buildings.	Should not be installed on old roofs as a rehabilitation project. Planting mix may not be appropriate for some plants.	Rooftops without cisterns.	Landscape maintenance is specialized, irrigation may be necessary, landscape may need replacement periodically to retain functionality.	page 226

Device	Primary Water Conservation Function	Additional Functions	Ideal Site Conditions	Counter indications/ Constraints	Configuration / Design Options	Maintenance Considerations / Issues	Detailed Information
Rain Barrel	Minor water storage.	Water quality improvement, landscape irrigation.	Rooftops with canales or gutters.	Minimal water storage possible.	Single barrels, multiple barrels installed in series.	Sediment collection or filtering may be necessary; overflow devices necessary.	page 237
Cisterns	Water storage.	Water quality improvement, landscape irrigation.	Availability of non-porous surfaces (i.e, Roofs and parking lots).	Cannot collect water from turf grass or graveled surfaces (porous surfaces).	Above and below ground.	Sediment collection or filtering may be necessary; overflow devices necessary.	page 237

Conveyance Devices

These methods are designed to collect, slow, and deliver captured storm runoff to the desired location. They also allow some water to infiltrate into soils as it passes along the conveyance channel.

Swales

Function: A swale is a depressed open channel designed to capture sheet flow runoff and convey it slowly in broad, shallow flow to where it can be stored or used for landscaping. Swales are designed to slow and spread the water to allow pollutants to settle and filter out as the water infiltrates the ground. Swales can be lined with hard materials like rip-rap or cobble, or planted with a range of plant materials to enhance their function. Swales can be built to depths of between one and three feet and with widths of from one to four feet or more, with a roughly equally dimensioned berm on the downslope side. This can be constructed with soil excavated from the swale. Swales can be designed as single channels or connected in a series to increase their water distribution and infiltration capacities. The addition of check dams for swales on sloping sites can further enhance their infiltration capacity. Swales slow stormwater while diminishing its volume, simultaneously improving water quality through vegetative and soil filtration.

There are two basic types of swales, **on-contour** swales and **off-contour** swales. Detailed descriptions and applications for each type are listed below.

- ***On-Contour Swale*** **-** On-contour swales are constructed parallel to the site elevation contours as depicted in Figure 101.

  Siting: On-contour swales are suited to small and large drainage areas with gentle to steep slopes, such as open spaces, parks and landscaped areas. Swales should be constructed at least 10 feet away and downslope from building foundations. They are not appropriate for use in drainage channels, on fill areas or on sites with extremely sandy soils that may erode even at low-water-flow velocities.

  Construction: Swales should be sized to convey both smaller flows at speeds that facilitate stormwater cleaning and infiltration functions as well as peak flows without damage to the berms and spillways. Swales should be as long as possible to increase the time water is held, maximizing water quality improvement and infiltration. Water travelling in the swale should move at speeds less than or equal to 1.5 feet per second for the water quality design storm level, and less than 5 feet per second (or the erosive velocity of the channel) for the peak flow design storm level. The swale's water storage volume should be based on the amount of runoff coming from watershed above the swale and the slope at the swale location (see "Appendix B. Pre- and Post-Development Calculation Worksheets").

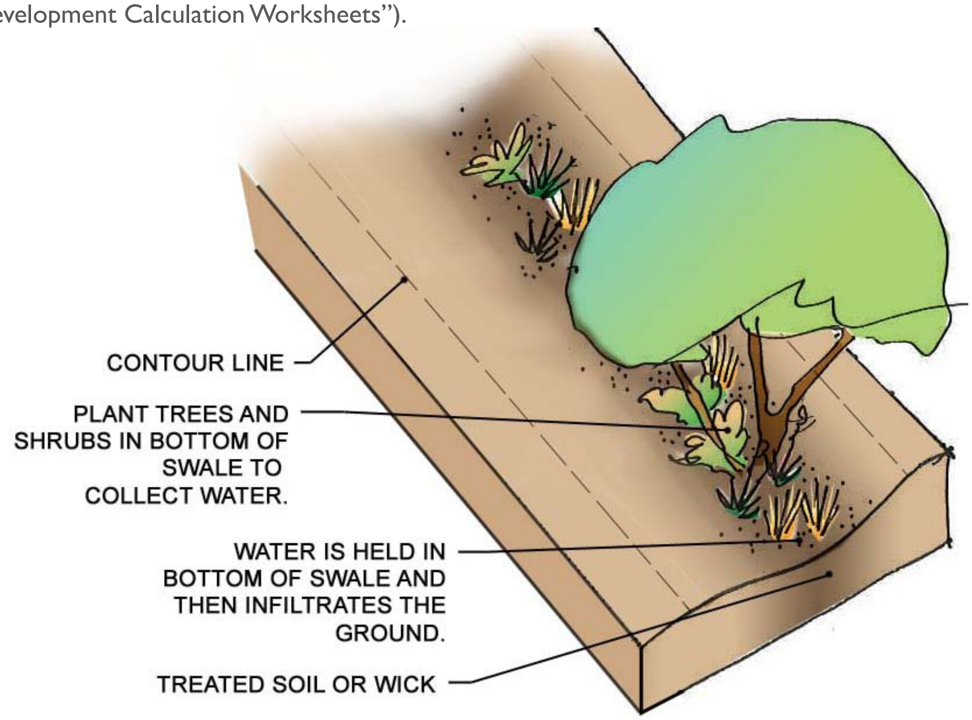

Figure 101. On-Contour Swale

- To construct a swale, dig a curvilinear depression parallel to the selected line of elevation (contour), placing the excavated dirt on the downhill side of the swale to create a berm. The top of the berm should be roughly level, except for spillway areas, which should be the lowest point in the berm and armored with cobblestone or other hard material. The bottom of the swale can be uneven as long as it is lower than the spillway,and should be mulched and vegetated. Swales should be a minimum of 6 inches deeper than the maximum design-flow depth to prevent overflow onto adjacent areas if runoff exceeds the design size or the swale is obstructed. The swale bottom should be less than 8 feet wide to avoid erosion issues such as rilling and gullying, and should be at least 2 feet wide if the swale will be mowed.
- Smooth the swale and berm, and only compact the berm soil to maintain permeability of the swale bottom. Reinforce the berm with rip-rap or vegetation as needed, depending upon water velocity and soil types. Native vegetation that is tolerant of both drought and periodic inundation is an appropriate choice for planting in and near swales. Plants requiring more moisture should be planted on the swale sides and bottom where the soil moisture level is higher. The plants' root systems will help to stabilize the structure. Plants with an upright form will help to help slow stormwater in the swale. Plants should be placed so they do not block flows at spillway locations, and should have root structures that will enable them to withstand swale water flows. Wicks can be used to further augment the water-retaining capacity of the swales to provide for plant water needs (see additional information in the "Wicking Systems" section).
- Swales should have an internal longitudinal slope of 2% in order to convey stormwater at rates that facilitate infiltration and avoid standing water, which can create mosquito problems. Installing check dams can help to slow the movement of water within the swale to prevent erosion and to mitigate slopes in excess of 2% and up to 6% (see additional information in the "Check Dams" section).

Alternate Configurations:

- It is generally preferable to construct multiple swales at several points in the watershed versus a single large swale. On-contour swales can be built in linked series with spillways that allow overflow from one swale to flow into swales at lower elevation levels (see Figure 102). Spillways should be positioned so that the water is forced to move along the swale for as long as possible before flowing to subsequent swales. The top of the berm should be level except for spillway areas. The spillway should be lined with stone or other non-erosive materials. A rock apron or splash pad should be installed on the downstream side to absorb the erosive impact of water exiting the spillway.

Maintenance: Maintenance tasks include checking for signs of overflow following heavy rain events, and periodically removing sediment. Sediment can be removed with shovels or machinery. Reseeding or replanting may be necessary after sediment is removed.

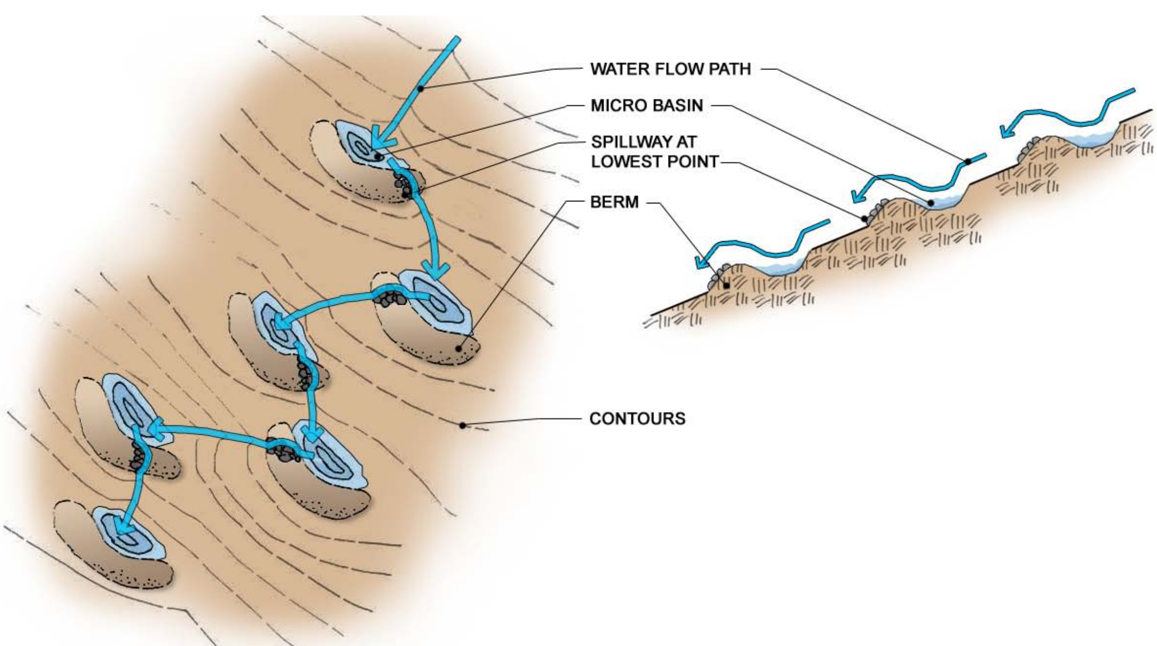

Figure 102. Linked Contour Swales

- ***Off-Contour Swale*** - Off-contour swales are constructed so that the swale and berm are at an angle to the contour line.

  Siting: Off-contour swales and berms are appropriate for moderate-sized drainage areas with gentle slopes, large landscaped areas and open spaces. Setting the swales at a slight angle to the contour elevation allows stormwater to move downhill slowly in a controlled manner to maximize infiltration and eventually discharge at the desired location as illustrated in Figure 103. Swales should be constructed at least 10 feet away and downslope from building foundations, and are not appropriate for use in drainage channels, on fill area or on sites with extremely sandy soils that may erode even at low water flow velocities.

  Construction: Determine the storage volume needed for the water-harvesting swale (see "Water Harvesting Calculations" in Appendix B) based upon the watershed area above the swale, the slope at the swale location and the runoff from impervious surfaces on the site. Construct a curved swale so that it is at a slight angle to the contour, with one end a little higher and the other a little lower as it follows the curve of the land. Deposit the excavated dirt on the downhill side to create a berm. Series of swales can also be constructed using a spillway to connect and allow overflow from the swale placed at higher elevations to spill into the swale at the next lower elevation. Spillways should be placed so that the water is forced to move along the contour for some distance before flowing to subsequent and downhill swales.
  - Smooth the swale and the berm, compacting only the soil of the berm. The top of the berm should be level except for spillway areas.
  - Reinforce the berm with materials as necessary (depends upon soils and velocity) using rockwork such as rip-rap. Vegetation can also be used to reinforce berms but may require the use of other reinforcement strategies as interim measures until the vegetation is established.
  - Native, drought-tolerant plants with massive and fibrous root systems are appropriate choice for planting in and near swales as they will hold the soil, reducing sediment problems. Root systems help to stabilize the structure but should be placed so they do not block spillways flows. Plants requiring more moisture should be planted in the swale on the sides and bottom where the soil moisture level is likely to be higher. Trees and large shrubs can be planted in the swale, on the berm and immediately downstream as the roots can seek moist soils.

  Maintenance: Maintenance tasks include checking for signs of overflow following heavy rain and periodically removing sediment and debris. Sediment can be removed with shovels or machinery. Reseeding may be necessary after sediment removal.

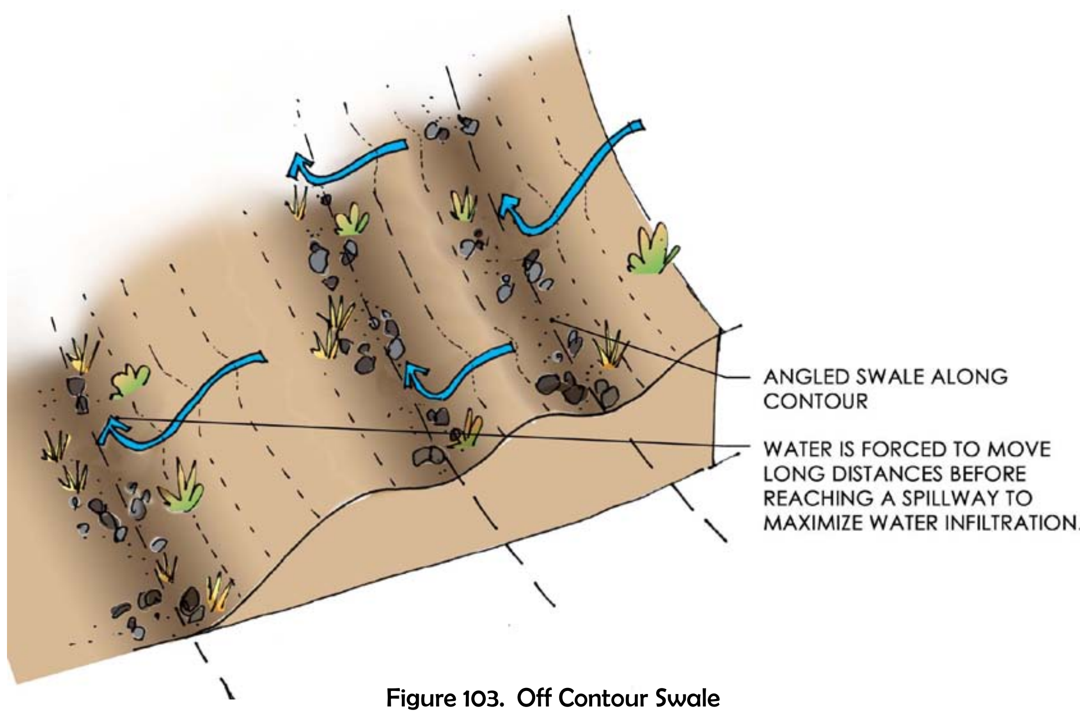

Figure 103. Off Contour Swale

Check Dams

Function: Check dams are small barriers or weirs that decrease the velocity of concentrated stormwater flows and create small ponded areas. They help to prevent channel erosion and allow suspended sediment to settle out. An added benefit is that they create excellent areas for landscaping, as the harvested water can be well-utilized. By slowing the water, the dams also promote water infiltration within the channel. Check dams also aerate runoff as it flows over the dam crest (Figure 104).

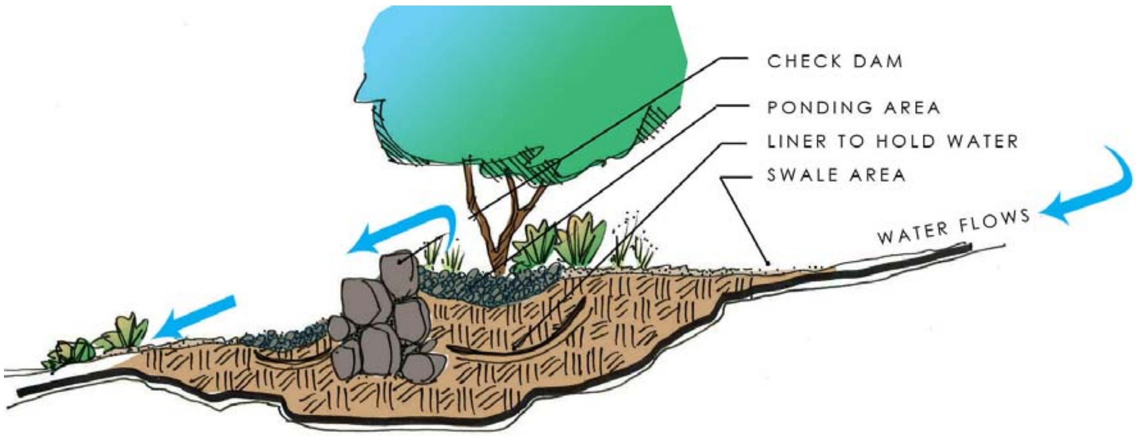

Figure 104. Check Dam

Siting: Check dams can be constructed across swales, small channels or drainage ditches. They are particularly useful for steeply-sloped swales and channels where vegetation has difficulty holding the channel banks. The total drainage area should not exceed 10 acres. Consultation with a professional engineer is advised. Check dams should not be constructed in live streams as they will disrupt movement of fish and other aquatic fauna (Figure 105).

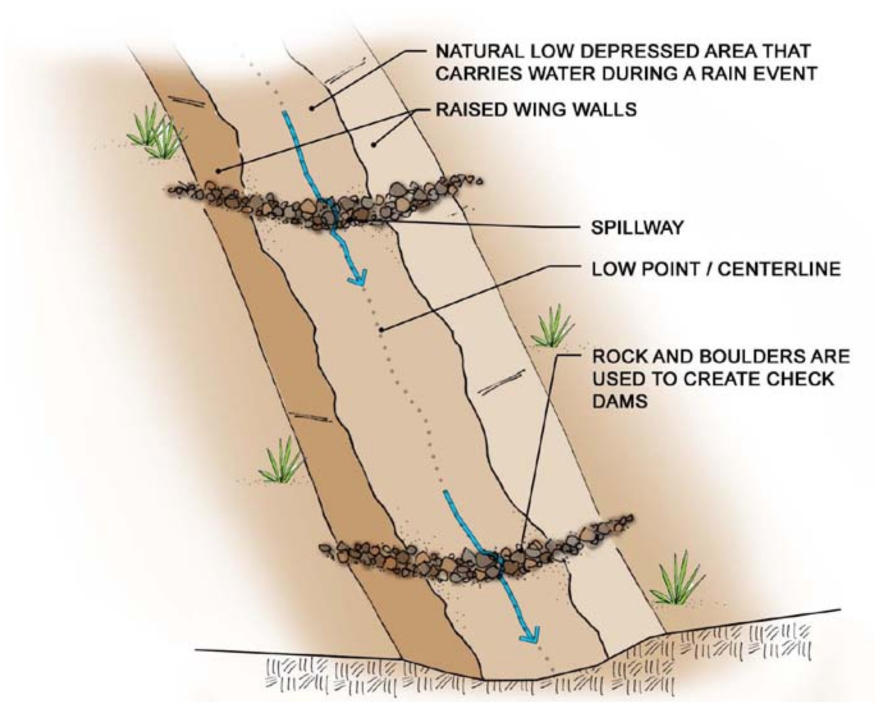

Figure 105. Check Dam Series

Construction: Check dams can be constructed from a variety of materials including logs, lumber, gravel bags, brick, concrete blocks, cast-in-place concrete, fiber rolls, boulders, cobblestone or rip-rap, all constructed in conjunction with earthen dams. The materials should be non-toxic and durable. Check dams can also be made from rock-filled gabion baskets (see "Gabion Structures" later in this chapter).

Check dams should span the swale or channel completely to avoid erosion at dam edges. The materials used should be anchored or heavy enough to resist the pressure of heavy flows. In general cobble or rocks should be a minimum of 8 inches to 12 inches in size. Rock or stone can be encased in geotextile to prevent shifting during high flows. The geotextile can also be extended up and downstream of the dam to help prevent erosion on the front and rear aprons of the dam.

Logs should be 4 inches to 6 inches in diameter and embedded at least 18 inches into the soil or secured to vertical support logs that have been buried to that depth.

The center of the dam should be lower than the sloped ends of the check dam edges to ensure that water flows over, rather than around, the dam.

It is possible to use erosion control blankets, which are biodegradable open-weave blankets, in conjunction with check dams to facilitate vegetation growth on channel slopes and bottoms.

Check dams should be installed at heights and distances apart to allow small pools to form in the widened channel behind them, taking into account the length of time standing water will remain if the channel does not run between storm events. Standing water provides mosquito habitat and can kill vegetation in the channel if it remains for an extended period. In general check dams should be a minimum of 12 inches thick, as wide as the swale, and a minimum of 3 inches to 6 inches high. Check dams should be placed at every one foot drop in elevation or a minimum of 50 feet apart. For channels with steep slopes running their length, check dams should be spaced so the crest of each dam is at least as high as the toe of the next dam upstream, creating continuous ponding along the length of the channel and preventing erosive flows (see Figure 106).

Maintenance: Look for evidence of scouring, channel erosion or damage on the dam front, rear apron, or at the outer ends of the dam and repair or adjust the dam layout accordingly. Periodic excavation of built-up sediment behind the dams may be required when sediment depth reaches half the dam height. If dam materials have been removed or misplaced by high flows, replace them and consider whether the dam design should be augmented to address similar volumes and velocities in future.

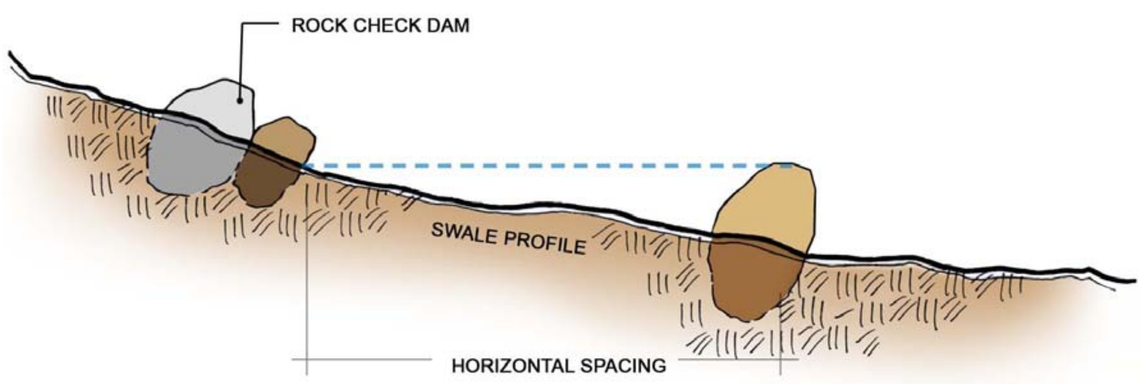

Figure 106. Check Dam Spacing

Gabion Structures

Photo 78. Gabion

Function: Gabions are semi-permeable structures that can be used to construct check dams to slow flows within water channels, or for retaining walls or channel revetment to stabilize highly erosive or steep slopes along channels. The resulting decreased water velocity helps to prevent erosion, allows sediment to settle out and facilitates water penetration into the channel and adjacent soils.

Siting: It is advisable to consult a qualified professional regarding appropriate siting and design. Gabion structures incorrectly constructed or placed can create or aggravate erosion problems and pose safety risks. Gabion walls are sometimes placed at or around curves to prevent erosion during large storm events. Erosion problems at the base and edges of the gabion wall can be lessened by providing a rip-rap apron. In smaller water channels that drain areas less than four acres, several smaller gabions constructed at frequent intervals are more effective than a single gabion greater than 3 feet in height. Channel banks at gabion locations should be firm or rocky and not sandy.

Construction: Gabions are large, multi-chambered, welded wire or wire mesh cages or baskets filled with 4-inch to 8-inch stones or other similar material that is appropriately sized to stay within the baskets. The cages are then wired together to construct flexible and permeable larger blocks which are then set in courses to build various structures. Gabion construction is simple and does not require skilled labor. Pre-fabricated gabion baskets can be purchased, or they can be custom-built. The baskets can be lined with geotextile to prevent buildup of sediment within the void spaces between fill stones; however, soil deposition and subsequent plant establishment can be desirable as it further stabilizes and naturalizes the structure. If the structure is being used as a check dam, it is important to include a downstream rock apron with a length double-to-triple the height of the gabion as shown in Figure 107. The depth of the structure should be double the diameter of the rock used in the rock apron. A minimum depth of 1 to 2 feet or a depth equal to twice the diameter of rock, whichever is greater, should be used. The apron should also span the entire width of the gabion. The apron should be encased in wire mesh and tied to the gabion in several places to prevent shifting.

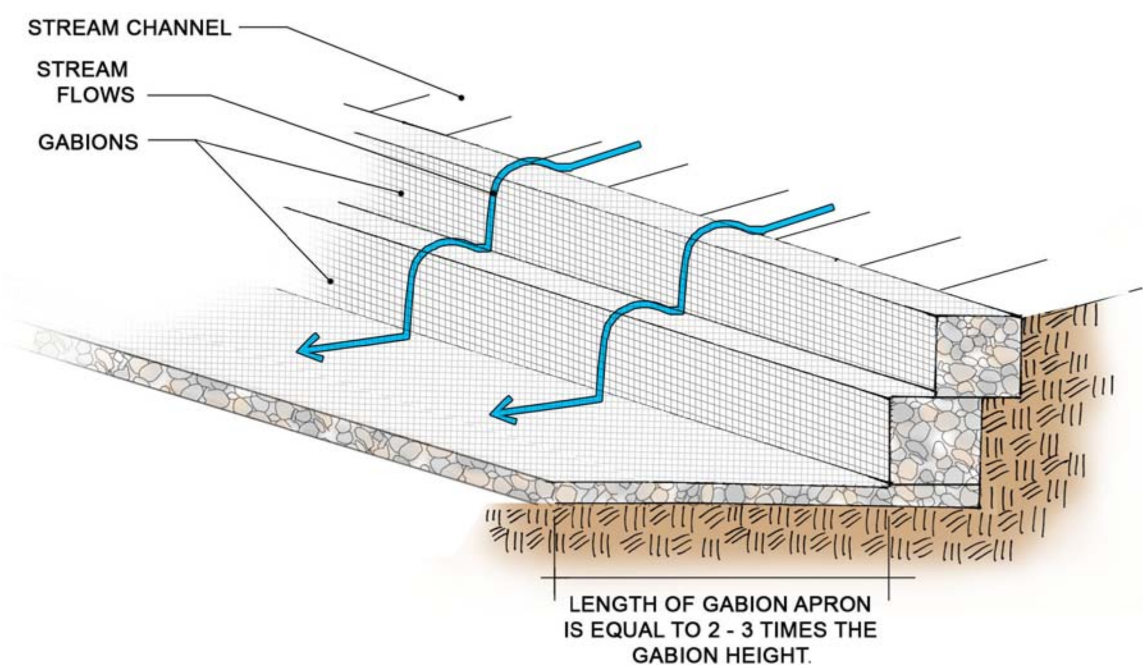

Figure 107. Gabion Structure

The wire mesh baskets are galvanized and can also be coated with PVC to prevent corrosion of the metal. Site conditions that could contribute to excessive corrosion, such as poor water quality and acidic soils, should be considered when determining whether coating is needed.

It is important that foundation surfaces are smooth and reasonably level and that the gabions are securely tied into them as well as into abutting surfaces. The baskets can be filled mechanically or manually.

Gabions should be placed perpendicular to the channel so that the water flows straight into the gabion rather than at an angle. Gabions can be placed at angle or parallel to the flow path to prevent erosion or slope stabilization problems at the banks of the channel. The gabion should be sunk 12 inches to 18 inches into the channel bottom and banks to hold it in position. The top of the gabion structure should be lower in the middle than at its edges at the channel banks to ensure that water flows in the center of the channel. It is advisable to consult a qualified professional regarding appropriate siting and design for gabion structures.

Maintenance: Properly constructed gabions are very robust structures as their permeable structure allows them to dissipate the energy embodied in stormwater flows. The porosity is useful in retaining wall applications as the voids allow evaporation and drainage to remove excess moisture from the backfill. When correctly built and sited they require very little maintenance. Periodic inspection is advisable to confirm baskets are intact and to look for evidence of undercutting or excessive erosion at transition areas. If such evidence is found, adjust the gabion or apron dimensions to correct the problem.

Curb Cuts

Function: Divert stormwater from paved surface and direct it into landscape areas or conveyance devices.

Siting: Can be used to divert stormwater into parking lot islands or other adjacent landscape areas and to direct water into medians or landscape areas along roadway edges.

Construction: There are several types of curb cuts, such as simple openings in a standard concrete curb (Photo 79), or one with additional features designed to facilitate, slow and direct flows (Photo 80). In some cases it is also possible to eliminate curbs by sinking parking island areas and installing car stops with perforations (Photo 81). In all instances, inflow areas should be protected from erosion by installing boulders, rip-rap, cobble, landscape fabric or similar materials.

Maintenance: Monitor openings to remove trash and debris. After storm events check for evidence of erosion and, if present, add materials to prevent further degradation.

Photo 79. Curb Cut

Photo 80. Modified Curb Cut

Photo 81. Curbless Option

Roof Drainage

Roofs are designed to shed rain in order to protect buildings from damage. In conventional designs, the water that falls on roofs is conveyed away from building foundations, then flows to the storm drain. Roof drainage can be captured and used on site through a variety of water-harvesting systems. The first components in such a system are the gutters and downspouts that collect and move the water down to the next component. As a general guideline, gutters should be at least 5 inches wide and should be composed of galvanized steel, aluminum or other non-corroding material. The front of gutters should be 1/2-inch lower than the back. Gutters should slope along their length at rates of 1/16-inch per foot for sectional gutters and 1/16 inch per 10 feet for seamless gutters. Consulting a company that specializes in gutter design and installation is advisable to ensure gutters are appropriate for the roof type, potential snow load and other factors.

Photo 82. Rain Chain with Rain Barrel

Downspouts should be spaced 20 feet to 50 feet apart and should be provided at a rate of one square inch of downspout area for every 100 square feet of roof area. Downspouts should direct water into the landscape or water storage devices such as rainbarrels or cisterns.

Rain chains or open canales can be used in place of downspouts to direct water to storage devices (Photo 82), or to conveyance devices such as gutter extenders or swales that divert it to landscaped areas. The various devices can be used alone or in combination; for example, rain chains and rain barrels could be used for individual units of an office complex or small apartment units. Large structures with vast areas of impermeable surfaces will require more complex site drainage systems with greater storage and infiltration capacity.

Photo 83. Roof Drainage using Canale Beams

Photo 84. Interior Crickets for Canale

Infiltration Devices

The water-harvesting methods described below are all types and scales of basins designed to collect, slow, and allow storm runoff to infiltrate into soils on the site. Water catchments and infiltration devices should be located at least ten feet away from building foundations and can be integrated into the landscape design.

Microbasins

Function: Collect and retain stormwater in localized basins.

Siting and Water Volume: Microbasins can be used to collect runoff from smaller areas with gentle slopes or from relatively flat land with low volumes of stormwater runoff. They can be built in a variety of sizes to support the differing water needs of single or multiple plants. In parking lots, planter areas can be designed to harvest runoff that comes through curb cuts (Photo 85). Microbasins are not appropriate for use in locations with heavy stormwater flow such as arroyos or washes. The scale of the basin must be based on site-specific conditions and potential stormwater flows. A series of basins with spillways connecting them can be constructed to address areas with more concentrated runoff; however, this approach requires consulting an engineer. Microbasins should be designed and constructed to capture and infiltrate stormwater quickly enough to avoid mosquito problems. Bernalillo County Ordinance, Chapter 38. Article III. Division 3 Design Standards requires that retention ponds drain in 24 hours or less, with some exceptions.

Photo 85. Parking Island Microbasin

Construction: Microbasins can be constructed in a variety sizes and configurations, individually or in a series. Type and configuration options include:

- ***Localized Depression*** **-** This is the simplest form of microbasin, comprising a depression without berms (Figure 108). A variation of this type of basin would be depressing the interior of a parking island within a curb. Water collection potential could be further augmented by curb cuts.

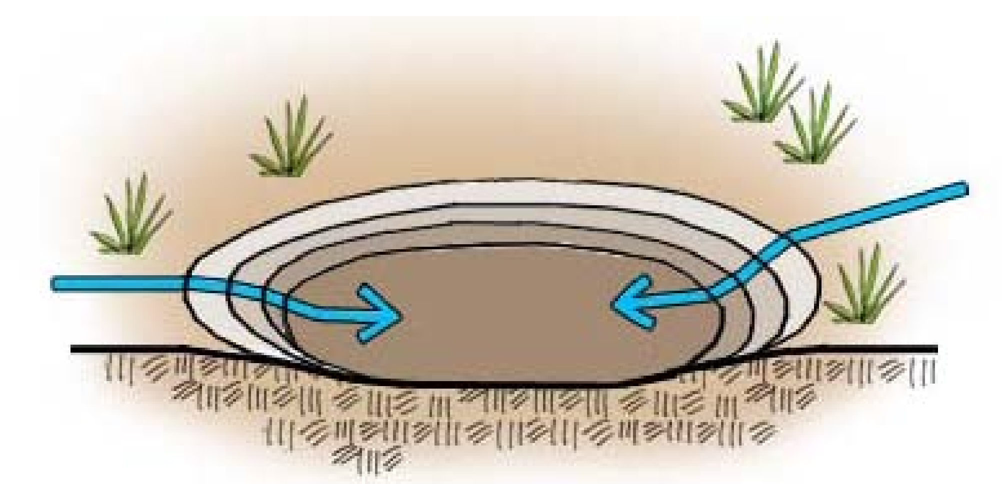

Figure 108. Localized Depression

- ***Eyebrow* - ** Dig out a depression (basin) and deposit the excavated dirt downhill and on the sides of the basin to create a thick, gently sloped berm in the shape of a crescent pointing away from the water entry point as shown in Figure 109. A spillway to direct overflow can be created with an armored depression at the desired point along the berm. Compact the berm to help prevent it from eroding. The berm can also be armored with rip-rap or cobble or planted to further prevent erosion. Planting selections should consider conditions in the basins, such as the potential for temporary flooding in the bottom. The bottom of the basin can be flat or concave to concentrate water at the desired location or to provide more even infiltration across an area. Flatten the bottom of the basin without compacting. Microbasins should also be mulched and planted to facilitate rapid water infiltration.

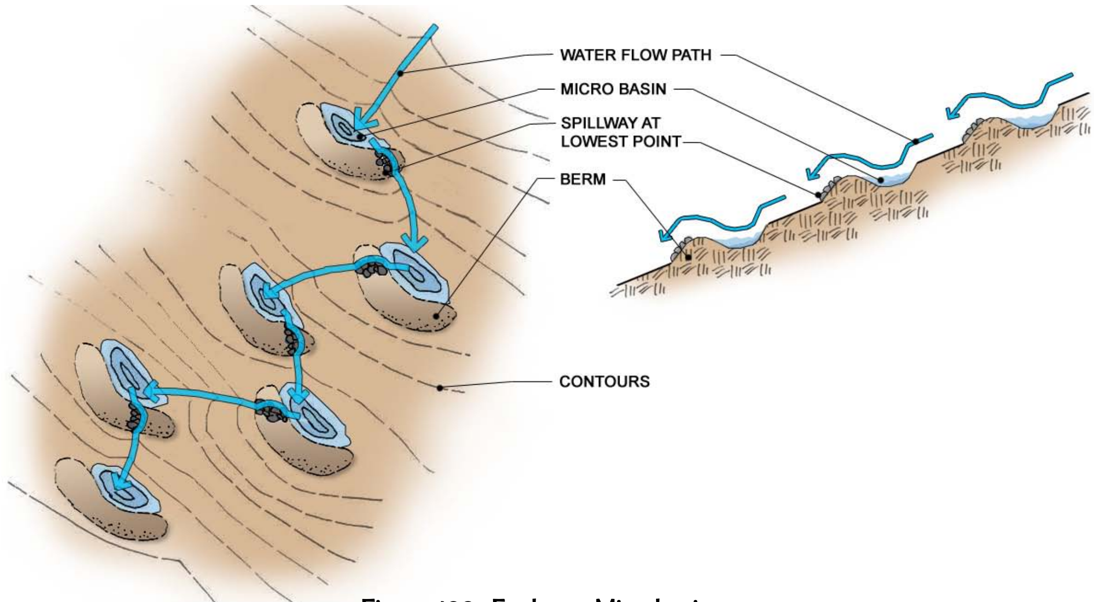

Figure 109. Eyebrow Microbasins

- ***Series* -** Microbasins can be constructed in a series to address moderate flows. Placing them in an offset path relative to each other lengthens the flow path and affords additional opportunity for infiltration. Spillways should be constructed as noted previously to direct overflow from one basin to the next.

- ***On-contour Series* -** Microbasins can be constructed in series along one or both sides of a ridge or elevated area to capture and infiltrate runoff. The basins should be placed to follow the contour line around the ridge, with their upslope ends at the same elevation. The same principle can be applied to collect runoff from elevated surfaces such as sidewalks (Figure 110).

Maintenance: Monitoring is critical. Microbasins should be checked following large rain events for evidence of overflow, which can indicate the need for adding or adjusting a spillway. If the basin is appropriately sized, sited, and constructed, overflow should rarely occur, with the exception of series basins that are designed to overflow into one another.

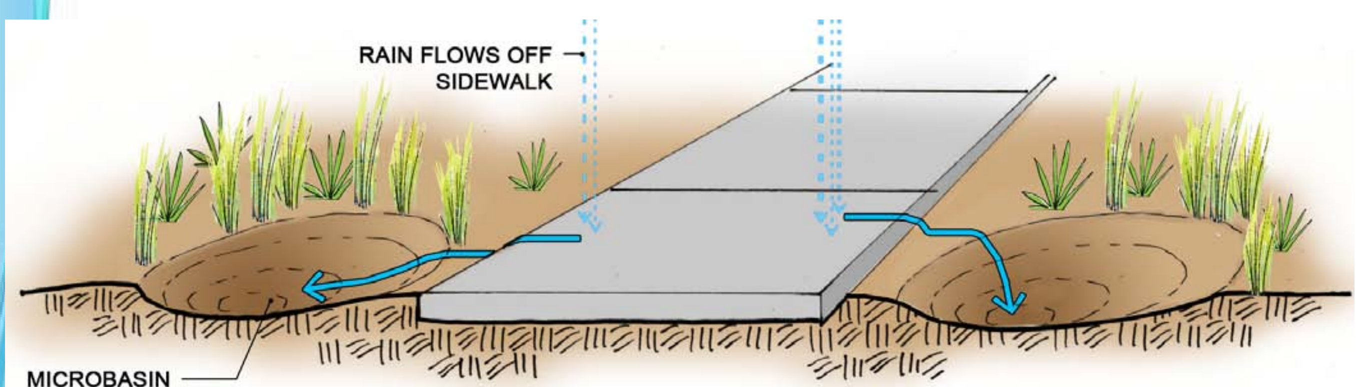

Figure 110. Microbasins along Sidewalk

Soil Imprinting

Photo 86. Soil Imprinting

Function: Imprinting roughens the land surface to increase its water-holding capacity, which facilitates increased infiltration of precipitation. The imprints funnel water into depressions. Water, seed, plant litter and topsoil mix together at the bottom where they help to germinate seeds and establish seedlings. Seedlings in the imprints are protected from drying winds and sunlight, providing increased germination and survival rates.

Siting: Imprinting is appropriate for reseeding areas that have compacted or degraded soils. It can be used on flat or sloping areas.

Construction: Imprints are formed by running a roller with angular steel teeth over the target soil surface. The steel teeth form troughs or indentations by compressing and shearing the soil, as well as crests or ridges that are lifted between the troughs. A well-designed imprinter produces these two interacting features with minimal soil disturbance or compaction.

Maintenance: Depending on the site conditions, imprinting and seeding may need to be repeated over a period of several years to achieve the required revegetation density.

Waffle (or Grid) Gardens

Function: Creates a series of square or rectangular depressions laid out in a grid (similar to a waffle) which collect and infiltrate water to support plant material requirements.

Siting: Waffle gardens can be used on flat or sloping terrain so long as the waffle basin bottoms are relatively level. This distributes water evenly and prevents it from accumulating in one area of the waffle or eroding the waffle wall.

Construction: Create small depressions either by excavation or by building up small berm walls between waffle basins. To work well, the waffle depressions should extend at least partially below grade to abate subsurface migration of water. Once they are planted, mulch the basins to increase moisture retention.

Maintenance: Re-excavate waffle basins as needed to ensure sufficient depth for water collection. If basin bottoms become compacted, amend soil or aerate to increase permeability.

Permeable Paving

Function: Porous, pervious or permeable pavings allow stormwater and air to filter through them and infiltrate the soil below, reducing stormwater runoff. Some pollutants are also removed. Permeable pavings can be used alone or in conjunction with sub-surface storage or water treatment devices such as vault reservoirs. Permeable pavings come in a variety of materials and can be used for a range of applications including parking lots, sidewalks, driveways, plazas and courtyards, tennis and basketball courts, bicycle trails, fire lanes and low-traffic roadways. The use of pervious paving can save money by reducing stormwater impact fees and the amount of land dedicated to stormwater retention or detention areas. Paved surfaces play a major role in transporting stormwater runoff and contaminants to receiving waters. Permeable paving can be used to infiltrate stormwater and reduce the amount of runoff leaving the site, helping to improve runoff quality and decrease downstream flooding. Using permeable paving materials reduces the effective imperviousness of the site while maximizing land use. Permeable paving also has the potential to reduce or eliminate the requirement for conventional stormwater retention/detention systems and sewer pipes.

There are several types of commonly available permeable pavings:

- ***Permeable concrete and asphalt*** are similar to standard concrete and asphalt, but are open-graded, meaning the aggregate is of a consistent size with no fines, or small particle, content. A special binder is frequently included in the material mixture as well. The open-graded aggregate creates void spaces throughout the paving material which allow water and air to pass through it and into the ground below. Methods for installing permeable pavements differ from the standard, impervious types. Most permeable paving systems have an aggregate base to provide structural support, act as a base reservoir to provide runoff storage, remove pollutants through filtering and adsorption. Well-constructed porous pavements have the capacity to meet or exceed a site's pre-development infiltration level.

  When properly installed, **permeable concrete** contains 15 to 30 percent void space throughout its entire volume which allows water to drain through to the soil below (Photo 87). The void spaces increase in size from top to bottom of the concrete's cross section, reducing the chance of clogging. Potential flow rates through pervious concrete range from 140 inches per hour to more than 1,000 inches per hour. An additional benefit of pervious concrete is its performance during precipitation and freezing events. The moisture does not remain on the surface but instead moves down into the voids and base course reservoir, providing a safer driving surface. As an example, a 1-inch by 1-inch by 6-inch deep column of permeable concrete can store 1.5 inches of stormwater. The voids also harbor beneficial bacteria, which help to break down pollutants such as hydrocarbons. The cement-based concrete does not leach harmful chemicals, though it can slightly impact the pH of soil it contacts. Pervious concrete can also reduce the heat island effect as it can be as much as 12 degrees cooler than conventional pavement. Porous concrete can be constructed to a range of load-bearing strengths but when used for roads is generally restricted to lower and lighter traffic loads.

Photo 87. Permeable Concrete

  Porous asphalt surfaces are used on highways and other roads to improve driving safety by removing water from the surface. It can also be used for jogging paths, bike trails and similar applications. Porous asphalt does present some potential issues that should be taken into account, however. Asphalt is oil-based and can leach toxins, which can be carried into the receiving soils along with infiltrating stormwater. Healthy soils can remediate some of these toxins, but care should be taken to ensure adequate remediation capacity exists to prevent problems. Another consideration is the potential for "drain-down" that can occur when porous asphalt is exposed to higher temperatures such as during New Mexico summers. Drain-down happens when the asphalt binder migrates downward through the asphalt's void spaces due to heat and gravity. As the softened binder flows downward, it carries particulate matter such as sand and dust from the surface until it encounters a cooler area. The binder then fills the void spaces at that level and hardens. Over time drain-down can greatly reduce or eliminate the asphalt's permeability. At the time of this writing, the only solution is to replace the asphalt.

- ***Open-jointed pavers*** can be made of concrete or stone and are laid with open, permeable spaces between the pavers. The built-in drainage spaces can be filled with rounded gravel or a well-draining soil mix and planted with grass or groundcover. These pavers are not as structurally stable as interlocking pavers and so are appropriate for slower speed and lower weight traffic-related applications (Photo 88).

Photo 88. Open-jointed Pavers

- ***Interlocking concrete or brick pavers*** are precast with spacers that automatically provide a consistent drainage space around each paver. The drainage spaces can be filled with gravel or a well-draining soil mix and planted with grass or groundcover to allow stormwater to filter through to the underlying soils. Interlocking pavers are very durable, require minimal maintenance and have heavy weight-bearing capability. Interlocking pavers may in some cases be placed over a stone reservoir base to increase water detention and infiltration capacity. An additional advantage of pavers is their ability to be reused.

Photo 89. Interlocking Pavers

- **Grass paving grids** (also called reinforced turf) are composed of a flexible grid of plastic rings placed over a base course that is usually a blend of gravel, sand and topsoil when topped with turf. The ring grid is filled with topsoil and planted with grass or a groundcover. Grass paving grids are appropriate for low-speed, low-traffic-frequency areas such as overflow parking, residential driveways and fire and maintenance access lanes.

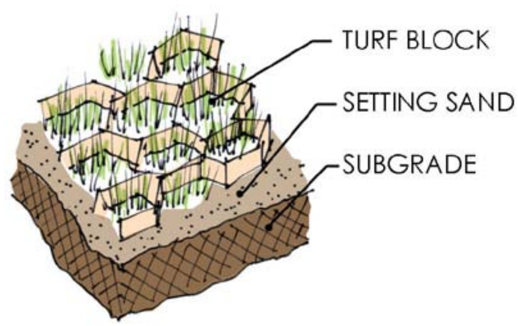

Figure 111. Grass Paving Grid

- **Gravel pavers** are based on the same flexible plastic ring grid as grass pavers but are placed over a geotextile and filled with gravel, which provides increased load-bearing capacity compared with grass pavers. Potential uses for gravel pavers include any low-speed, high-frequency traffic areas such as parking lots and vehicle storage yards, service yards or outdoor bulk storage areas. The ring grid structure of grass and gravel paver systems, along with the base course layer, distributes loads and help to prevent soil compaction and erosion. These paving solutions also help to reduce heat island impacts. In addition, the ring grid system is frequently manufactured from post-consumer recycled plastic.

- **Crusher fines** are a mixture of aggregate and small stone particles, typically 3/8-inch or less, and are available in a range of colors. Fines with no binder added are appropriate for low-use walkways or trails. With the addition of binding agents such as polymers, resins or plant-based binders such as psyllium, **stabilized fines** can be used for higher-use walkways and trails, as well as areas such as outdoor break rooms or recreation areas. An advantage of fines is ease of maintenance; they require only raking and compaction and periodic replacement of displaced or degraded material. Fines also contain no oils or toxins that could leach out, and depending on color, can have a lower heat reflectivity level than other regular concrete or asphalt. Fines provide a more cushioned surface for running and mountain biking than concrete or asphalt and are less expensive than those materials.

- **Single-sized aggregate** such as loose gravel or stone-chips without any binder, is a highly permeable and relatively inexpensive paving option appropriate for low-speed, low-traffic settings such as car-parks and driveways.

Siting: Generally, permeable pavings should be placed at least 3 feet to 4 feet above the level of the seasonal high-water table to avoid water pooling within the paving or base course material and potentially causing damage. Permeable pavings also generally require either well-draining subsoil (sandy soil or sub-grade treatment) to provide sufficient temporary storage space to allow water to infiltrate the receiving soil. The infiltration capacity of the underlying native soil is a critical design consideration for determining the necessary base course depth for stormwater storage and for determining whether an under-drain system will be required. The paving design should infiltrate the design storm runoff into the underlying soil within 24 to 48 hours. If the subsoil is composed predominantly of clay, silt or other expansive soils, care should be taken to ensure the paving design will drain and infiltrate water effectively within the required time frame. If the underlying soil type does not allow for complete infiltration within that time frame, modifications such as an overflow drainage pipe, increased subbase storage capacity, or water draining to alternative temporary storage and infiltration devices may be required. Fines and aggregate pavings should be applied on slopes greater than 6% to avoid loss due to surface runoff erosion. When placing fines on expansive or hydric soils such as clay, use of filter fabric is advisable to avoid saturation and surface-cracking. Permeable concrete, asphalt and some pavers are laid over a rock base course that has large void, or pore, spaces. The base course supports the pavement and acts as a reservoir, holding stormwater until it can infiltrate the native soil below, or in systems with under-drains, by slowly release to the storm drain system. Highly permeable soils, such as sandy soils, have the greatest load-bearing capacities. The lower capacities of other soil types can be offset by the design of the base course underlying the permeable pavement. Care should be taken to avoid placing permeable pavings in locations where they will be subjected to large amounts of sediment being deposited by wind or water onto the paving surface. This can clog the pore spaces and inhibit drainage and infiltration over time. Such issues can be mitigated through use of other water quality devices such as filter strips, which help to reduce the amount of sediment in stormwater flowing onto the paving. Always follow manufacturers' recommendations for siting and installing manufactured paving materials.

Construction: The general construction steps for permeable pavings are listed below. Detailed design and construction specifications are commonly available for manufactured pavers and paving systems.

Permeable pavings are composed of the surface material, either permeable paving or pavers, laid over a storage layer, which is usually a coarse stone aggregate topped by a layer of smaller aggregate. This acts as a choker course, separating the surface material from the storage layer. The aggregate layer may be wrapped in non-woven geotextile. The geotextile keeps soil from clogging the storage layer.

The depth of the rock or gravel subbase should be based on the weights, frequency and speeds of the traffic it will carry, the infiltrative speed and capacity of the underlying native soils, and the amount of stormwater to be handled. An under-drain system can also be used to connect to the storm drain system to address runoff in excess of the soil infiltration and storage reservoir capacities.

Additional factors for consideration include winter conditions, such as numerous freeze-thaw cycles that may dictate increased base thickness to protect the permeable paving from heave damage.
The basic steps of the construction process are excavation, subbase installation, and finally overlay of the selected permeable paving. If a turf or gravel paving system is being used, the voids in the paver grid are filled with the relevant material (topsoil and turf, loamy sand, pea gravel, larger-sized washed gravel, etc.) depending on the system's purpose and use. Permeable pavers are placed on a layer of sand that is spread over permeable geotextile fabric laid on top of the base course. The pavers are then leveled with a vibrating plate compactor, and the joints filled with sand or the appropriate permeable fill material. Whereas most paver systems can be used immediately after installation, permeable concrete or asphalt should be allowed to cure according to the installer recommendation (usually a few days). Grass-pave systems require sufficient time for the plant material to establish before receiving significant traffic.

Crusher Fines pavings should be compacted in moist (not wet) fines in 3-inch to 4-inch lifts with a vibrating plate. It is possible to add a subbase of 3/4-inch rock wrapped in filter fabric (like a burrito) in areas with drainage issues. Use of a geo-web product in addition to commercially available binders will further stabilize the fines. The surface of the pathway or trail should be sloped or crowned 3% to 5% to ensure positive drainage.

Maintenance:

- **Grass and gravel pavers.** Minimal maintenance is required to ensure good infiltration. Keep the paver surface clear of organic materials (leaves, grass clippings, etc.). Periodic vacuuming or low-pressure washing should be used to clear out voids. The required frequency should be based on site conditions. Gravel fill may also need to be added after cleaning gravel pavers. Grass pavers require watering and mowing like any turf system. If the paver area will be subject to snow removal, care should be taken to lift the plow blade to clear the grass or gravel surface. Avoid using sand, salt, ash or other chemical de-icers as they may clog the paving pore spaces.

- **Permeable concrete and asphalt.** The surface should be kept clear of sediment, dirt, sand and organic debris to avoid clogging the pore spaces. With New Mexico's high winds and sandy soils, also include a minimum cleaning frequency. The maintenance considerations for permeable pavers are similar to other permeable pavements but care must be taken when vacuuming the space between pavers so that small drainage aggregate is not removed,;this can cause clogging problems downstream. Periodic vacuuming is recommended to clear out voids and extend the functional life of the paving, with the frequency based on site conditions. During winter avoid using sand, salt, ash or other chemical de-icers as they may clog the paving pore spaces.

- **Crusher fines.** Surface repairs should be done as-needed based on compaction and wear, generally every couple of years. Edges of paths or trails may also require weed removal, and hardeners should be reapplied to **stabilized fines** on an as-needed basis.

- **Single-sized aggregate.** Simply requires replenishment as needed.

Water Quality Improvement Devices

Bioretention Cell or Basin

Function: Bioretention basins are shallow landscaped depressions or basins used to slow and treat on-site stormwater runoff. Stormwater is directed into the basin and filtered through the basin soil and plants. The cleaned water then infiltrates underlying native soils or can also be used with conveyance or storage devices as part of a stormwater treatment and infiltration system. In addition to stormwater control and filtering functions, bioretention cells can help to address on-site erosion issues and provide habitat for birds and insects.

Siting: Bioretention basins are appropriate for residential, commercial and industrial sites. Potential locations include median strips, plazas and parking lots as well as other areas on the site. The drainage area feeding the basin should not exceed two acres in size and should not contain significant sediment. If surrounding areas will contribute significant amounts of sediment, the basin should be designed with water quality improvement devices such as vegetated swales or filter strips for pretreatment to reduce sediment loads to acceptable levels. The pretreatment devices should be selected based on site conditions and constraints. Areas feeding the basin should have a minimum slope of 0.5% for paved areas, and 1% for vegetated areas in order to maintain positive flow into the basin.

Construction: Bioretention basins typically include several key components: the contributing drainage area; any pretreatment devices; the ponding zone; a layer of mulch, vegetation, engineered basin soils; a storage layer and an underdrain system to address excess runoff that cannot be infiltrated as quickly as needed. The ponding zone should be 12 inches or less in depth with side slopes of 2:1 or less, and should drain within 24 to 48 hours. If the infiltration rate of the underlying native soils is less than 3.6 inches per hour, a 3-inch layer of sand mixed to a depth of 2 to 4 inches with the native soil, topped by a storage layer of uniformly-sized, washed gravel or stone should be added to facilitate infiltration. For locations with extremely dense, low permeability soils such as caliche, greater measures may be necessary. The depth of the storage layer should be based on needed storage capacity to address runoff and should not exceed 48 inches. An under-drain pipe with a 6-inch minimum diameter should be installed at the top of the storage layer and should include a clean-out for maintenance. The under-drain should be wrapped in a filter sock to prevent clogging and should discharge into a stable infiltration outlet such as a swale, or into the storm sewer system. Compacting basin soils during construction should be avoided in order to achieve maximum infiltration rates. The engineered basin soil mixture can be structural soil or a mixture of sand, compost and topsoil. This should be premixed and placed in 12-inch-deep lifts. A layer of permeable geotextile or a 2- to 4-inch layer of pea gravel should be placed below the engineered soil mixture to prevent them from permeating and clogging the storage layer. Plants should be selected for their ability to deal with basin drought and flood conditions. The mulch should be permeable but large enough to avoid excessive floating,and should be installed in a 2- to 3-inch layer after planting is completed.

Maintenance: Bioretention basins should be regularly inspected to insure infiltration is occurring at the desired rate and that water is not ponding in the basin longer than 48 hours. Any eroded areas should be repaired following storm events, and the drain structure should be checked for clogging. Debris and accumulated sediment should be removed annually and plant material replaced if needed. The mulch layer should also be replenished annually.

Tree box filters are a variation of bioretention cells placed in sub-grade containers containing trees. They are used in urban streetscapes and parking lots to capture and treat runoff by removing pollutants as the runoff filters through the box soil media. The runoff also provides irrigation to the tree or other plant material in the box filter system. The basic components of a box filter system are a container filled with a highly permeable bioretention soil mixture over a layer of gravel or crushed stone with an under-drain system that discharges either into surrounding soil or the storm system. Stormwater runoff drains directly from impervious surfaces through a filter media. Because of their relatively small individual capacity, use of multiple box filters in a stormwater drainage area would be needed to significantly reduce peak flow rates. Tree box filters provide a space-efficient stormwater management solution with high pollutant removal rates while providing a beneficial environment for street trees.

Proprietary tree box filter systems are also available for purchase and can offer cost-effective and high-performing runoff reduction and water quality improvement capability.

Filter or Buffer Strip

Function: Filter strips are used to slow runoff, allowing pollutants and sediment coming from large or significantly polluted impervious surface areas to filter out before the runoff reaches other water-harvesting and treatment measures or receiving areas. Filter strips also help to prevent sheet and rill erosion. Rill erosion results from overland flow that is focused by the soil surface roughness and creates narrow, shallow incisions into the soil. They are best suited to provide water quality improvement and infiltration of runoff from roadways and parking lots generated by lower intensity rain events. Most higher velocity runoff from intense rain events is generally only conveyed by the filter strip, so they are often used in conjunction with other water-harvesting devices. There are a variety of filter strip types including sand, gravel, turf or grass, and vegetated filter strips. In the arid Southwest, sand or gravel filter strips are generally more viable than vegetated strips. Filter strips located adjacent to bodies of water are called buffers. In general, filter strips have a uniform mild slope stretching downward from the surface contributing the runoff.

- **Sand or gravel filters -** To achieve maximum reduction of peak flow and stormwater runoff, it is important to locate filters in soils that accommodate infiltration and to minimize ponding depth. Careful site analysis is required to design an effective, integrated network of these systems throughout a landscape.

  Design depends largely on the drainage area's characteristics. Underground sand filters are suited to urban areas with limited open space and a high percentage of impervious surface. Above-ground systems are suited to large drainage areas with adequate open space, such as highway interchanges, that have soils suitable for infiltration. Diatomaceous earth can also be used for filter strips. As with any infiltration/filtration system, when sand, gravel or diatomaceous earth filters are used in pollution hotspots or in poorly draining soils, they should be lined and outfitted with sub-drains that discharge to the surface.

Siting: Generally filter strips are most effective on slopes greater than 1% and less than 5%. They should be at least 2 to 4 feet above the groundwater level to avoid permanently wet conditions that can breed mosquitoes and other disease vectors. Typical filter strip configurations are long and narrow, with a minimum flow path length of 15 feet to provide adequate area for water infiltration. The width of the strip should be equal to that of the contributing surface. Filter strips should not be used as paths or roadways. Additional considerations include use of de-icers or sand on the runoff-contributing surface. The former can impact the health of grass or vegetated filter strips, whereas large amounts of sand can diminish the useful life of the filter strip, requiring increased maintenance.

Construction: The filter strip should be uniformly graded with a slope between 1% and 5%, with the toe and top of slope as flat as possible to ensure even sheet flow and avoid ponding and erosion issues. If flows from the contributing area above the strip are concentrated, a level spreader may be needed to ensure even sheet flow, which is critical for correct filter strip performance. A range of level spreaders can be used, including concrete curbing or a 1-foot by 2-foot-deep gravel-filled trench can be constructed to deliver even sheet flow to the filter trench area.

For vegetated filter strips, either grasses or a range of native xeric, low-growing plants are appropriate. If vegetation will be started from seed, erosion control measures should be used to protect seed and seedlings until they are sufficiently established to withstand erosive flows moving across the filter strip area. Supplemental irrigation may be required during the establishment period of vegetated strips. Adding a low permeable berm at the downstream end of the strip can reduce the required strip width by lengthening the time runoff is in contact with the strip. The berm should be one foot or less in height and made of permeable material such as a mixture of gravel and sand. Generally filter strips are designed to address flows from smaller, higher frequency storm events, usually one- to two-year storms. If flows from larger storm events have the potential to damage the strip, include a bypass mechanism to move those flows into other stormwater devices.

Maintenance: Check for and repair any eroded areas, such as channels formed by concentrated flows, to facilitate even flow over the filter strip area. If large amounts of sediment have unevenly accumulated, they should be removed to avoid disrupting sheet flow over the strip. Periodic re-grading and refurbishment of the upslope filter strip edge may be needed, depending on sediment deposition rates. Weed, remove invasive species, mow and trim appropriate for vegetation health. Reseeding or replanting may be needed for grass or turf filter strips if concentrated flows have eroded vegetation away. Use of erosion control blankets for repair areas can aid re-establishment. Turf strips should be mowed regularly to maintain a 3- to 4-inch grass height. Mowing should be done when the soil is dry to avoid compaction and tracking damage which can disrupt even sheet flow and filter strip function. If vegetation is sparse or grass has not established appropriately, consider replacement with alternate species. If the filter strip design includes a gravel trench level spreader, periodic removal of sediment will be needed.

Constructed Wetlands

Function: A constructed shallow, vegetated basin or series of linked basins that are permanently or seasonally flooded, constructed wetlands are extremely effective for water quality improvement. They remove pollutants and also perform varying degrees of infiltration functions depending on underlying soil types.

Siting: Constructed wetlands are generally more appropriate for larger sites. They require a relatively large amount of space as well as sufficient base flow to maintain the water level for wetland vegetation health and appropriate pollutant removal – a key consideration in the arid Southwest. Safety is a critical concern when siting and designing wetlands, and public access should be addressed with care. Constructed wetlands are especially useful for mitigating high nutrient loads in runoff from areas such as golf courses. Constructed wetlands are not appropriate for areas with steep or unstable slopes, and untreated runoff should never be directed into existing natural wetlands. Depending on the depth, volume, and discharge amounts of the ponding areas, approval from the New Mexico Environment Department may be required.

Construction: Given the complexity of constructed wetland design, utilizing the services of a professional for siting, design and construction of constructed is highly advisable to ensure appropriate water quality function and to avoid potential nuisance and disease vector issues. A few construction considerations include the potential use of an impermeable liner to maintain adequate ponding levels in areas with high porosity soils and ensuring that pipes and outlet structures are appropriately designed and constructed to prevent structural failure from water erosion of the berm or dam fill.

Storage Systems

Detention Pond

Function: Detention ponds are reservoirs designed to reduce peak flow associated with large storm events by temporarily detaining a set amount of stormwater runoff while it infiltrates or is slowly discharged to another location. The ponds improve runoff water quality by removing sediment particles and the pollutants that cling to them by allowing them to settle out in still water. During storm events, runoff enters the pond's upstream inlet, and the heavier sediment-laden stormwater displaces cleaner, lighter water held in the pond by moving it up and out through the discharge outlet. The recently added stormwater then remains in the pond, allowing the sediment and pollutant load to settle out. Detention ponds can also help to prevent channel erosion. Recent studies indicate that designs that provide detention for a period of 12 to 24 hours and are based on smaller design storms, such as a one-year storm, are more effective for this particular purpose.

Detention ponds can take the form of dry or wet ponds or constructed wetlands. Detention ponds allow sediment particles and pollutants to settle out of detained stormwater. Dry detention ponds do not have a permanent pool and are often designed with small pools at the inlet and outlet of the pond. Detention ponds can be used to provide flood control capacity by including additional detention storage beyond the extended detention level.

Dry detention ponds can serve multiple purposes in addition to their stormwater management functions, such as being used as plazas, sports areas and park-like spaces during the dry season. They can also be designed with multiple levels to keep low-frequency storm events segregated to allow use of the majority of the pond area. In other situations they can be small oases of lush plants that can take advantage of the additional water (see Figure 112).

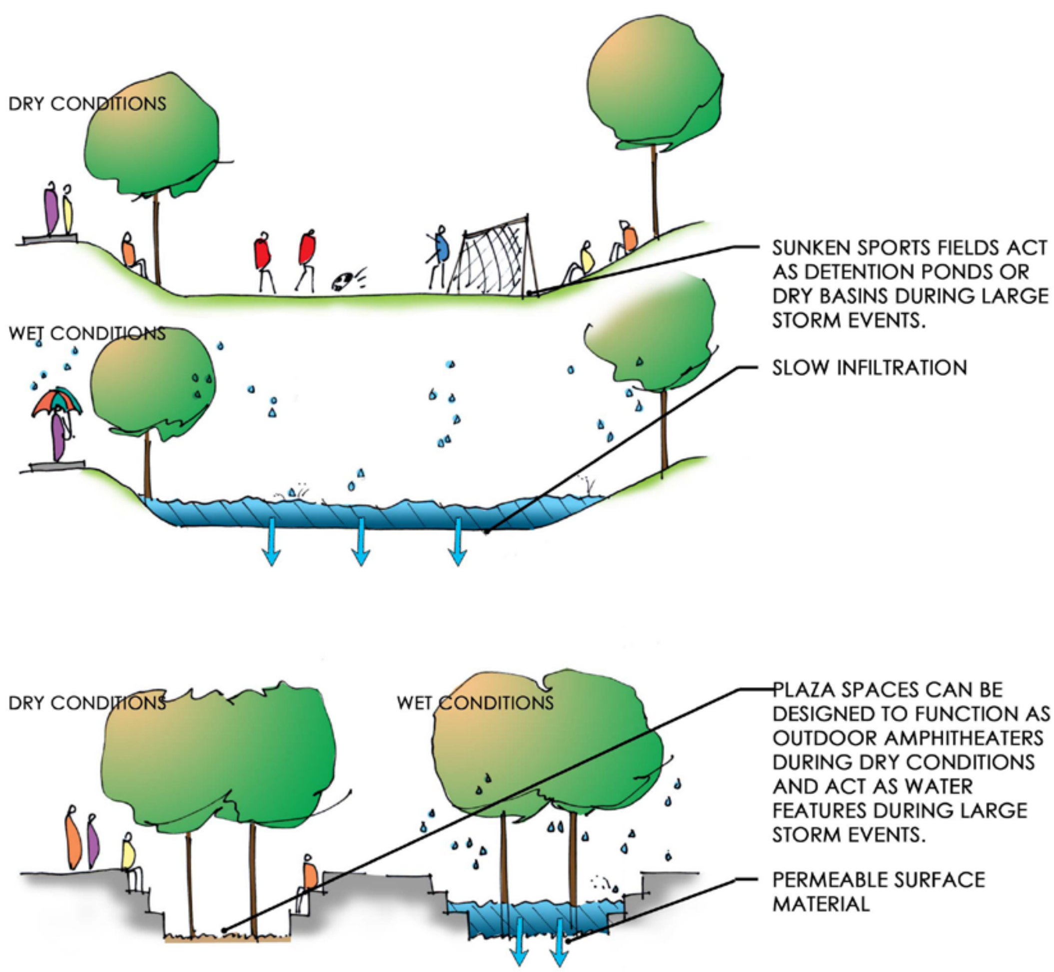

Figure 112. Multipurpose Detention Pond Areas

Detention ponds can be designed to address multiple stormwater control and quality objectives, as shown in Figure 113. Detention pond outlets can be any type of conveyance device that allows water to flow out at a controlled rate. Multiple outlets can be used to address different flows from various design-storm levels.

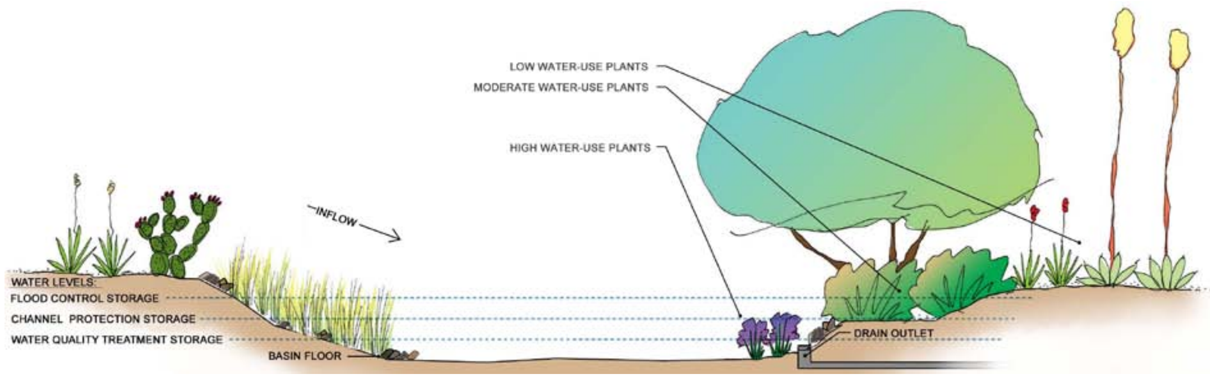

Figure 113. Detention Pond Storage Levels

Siting: Dry, extended detention ponds can be constructed on sites with stable slopes up to 15% as long as the basin bottom is relatively level. Pond drainage can be problematic in low-relief terrain areas, however. A minimum drainage area of ten acres is generally advisable for dry extended detention ponds due to pond construction costs and the potential for outlet orifice clogging. It is important to ensure that the elevation drop from the pond inlet to the pond outlet is sufficient to enable water to flow through the system. The slope of the area upon which the pond will be built should be relatively flat, as side slopes of the pond should not exceed 3:1. A minimum separation of three feet between the water table and pond bottom is recommended.

Detention ponds can be used on any soil type, with minor design adjustments needed for quick-draining soils. Dry, extended detention ponds should be a sufficient vertical distance above the groundwater table to avoid permanent wetness in the pond bottoms which can lead to mosquito issues. If the pond will receive highly contaminated runoff from point-pollution sources, increased separation distance from groundwater will be required.

If the pond will be located on rapidly draining soils such as sand, an impermeable liner may be needed to prevent possible sinkholes or groundwater contamination.

Construction: It is advisable to consult a qualified professional when designing and constructing detention or retention pond facilities in order to ensure a safe, appropriately functioning pond that meets the requirements of applicable engineering standards. Detention and retention ponds used to control stormwater runoff are required to be certified by a New Mexico licensed engineer. Pond size is driven by the desired outflow water quality level and rate based on a chosen design-storm level. The design capacity of stormwater ponds is frequently based on 200-year, 100-year, 5- to 10-year or 1- to 2-year storms. In addition to the design-storm level, determination of the water storage volume needed for a detention/retention pond is based upon the area of the contributing watershed, amount of impermeable surface within that area, soil type, and vegetative cover (see "Appendix B. Pre- and Post-Development Calculation Worksheets"). The required pond size can be reduced by maximizing the number of on-site infiltration areas. In general the pond's length should be greater than its width. This prolongs total detention time by maximizing the flow path, increasing filtration and infiltration. Remember, detention and retention ponds used to control stormwater runoff are required to be certified by a New Mexico licensed engineer.

A range of features can be included in the detention pond design, but basic pond design should include runoff pretreatment, treatment,and conveyance, as well as maintenance reduction and vegetation features. Pretreatment removes larger sediment particles in a small pool called a sediment forebay before the water moves into the treatment area or main body of the pond. In the arid Southwest, a dry sediment chamber may be used in place of a wet forebay. Plants used in detention areas should be selected based on their ability to tolerate drought and flood conditions that will prevail in the ponding area. Pond design can also address periodic high runoff volumes created by snowmelt. Vegetation for ponds handling snowmelt runoff from roads may need to be salt-tolerant. Combination retention-detention ponds have outlets that are installed at a higher elevation than the bottom of the pond so that some stormwater can be retained and the remainder can be directed to landscaping or stormwater facilities. Conveyance features to move water into and out of the pond should be designed to prevent erosion from occurring along them.

In order to maximize land use, extended dry detention ponds can be designed to serve multiple functions, such as providing a recreation or playing field area during dry periods.

Wet detention ponds generally have a primary function of improving stormwater runoff quality because they can significantly reduce pollution. Wet ponds must be properly designed and maintained to achieve their stormwater quality functions and can take from three to six years to reach the ecological balance necessary to do so. During that initial establishment period, issues such as excessive algal growth and nuisance odors may be experienced. The design of wet ponds requires a few additional considerations to ensure appropriate function.

The pond length should be three to five times its width and simply shaped to promote adequate water circulation. The permanent ponding depth should be a minimum of three feet—ideally six feet—to decrease light penetration and prevent sediment scouring. The sides of the pond should be designed with slopes that help to promote safety, minimize mosquito habitat and prevent excessive rooted aquatic plant growth, such as those noted in Figure 114. An underwater planted shelf around the pond perimeter can help to improve pollutant removal and prevent physical access to the deeper pond areas.

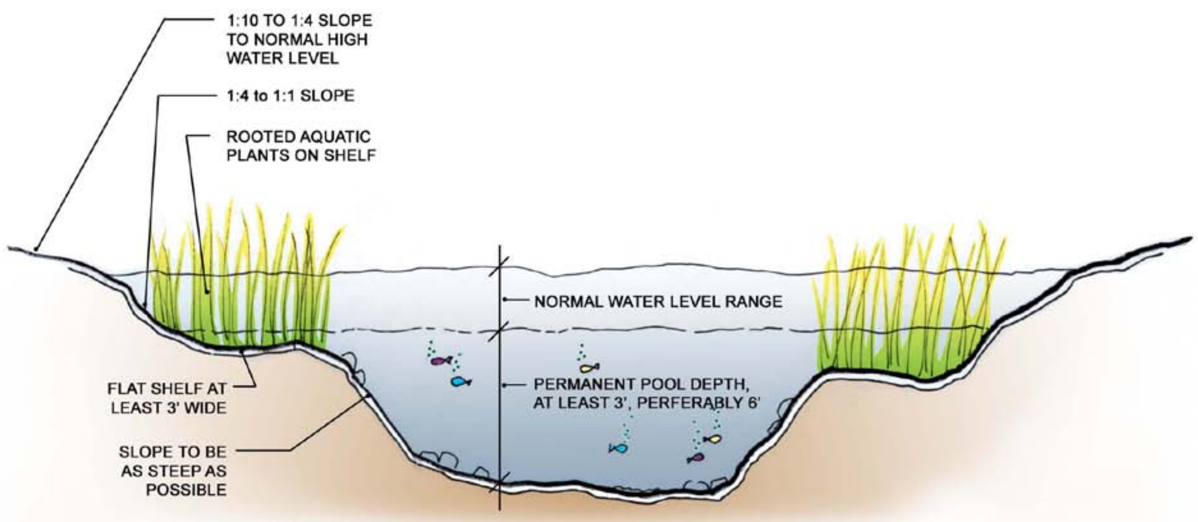

Figure 114. Wet Detention Pond

Pond inlets and outlets should be spaced well apart to avoid malfunction and designed to prevent erosion due to scouring. Outlet design should maximize sediment retention during periods of low pond depth through low outflow volume. Inlets and outlets should be designed to prevent safety issues, and an appropriately-sized emergency spillway should be included. The emergency spillway allows extreme-storm-event flows that exceed the pond design capacity to safely exit the pond without causing structural damage.

If the water sources flowing into the pond are contaminated or highly polluted, inclusion of preliminary water treatment devices may be needed to avoid exceeding the pond's pollutant-bearing capacity. A drain to facilitate pond maintenance and access routes for maintenance equipment should also be included.

Maintenance: Periodic inspection—at least twice annually—is advisable. Inspection should include checking for signs of bank or bottom erosion and damage to embankments, verification that inlets and outlets are functioning and free of debris, and monitoring of sediment build-up in the pond and forebay area. If runoff feeding into the pond is high in sediment, the latter two inspections may need to be performed more frequently. Sediment should be removed when total pond volume has been reduced by one quarter. Accumulated debris or litter should be removed, dead vegetation replaced, and any erosion or undercutting damage repaired. Wet detention ponds require periodic dredging to remove contaminated sediment. Dredging frequency can be reduced through pond design that includes excess or sacrificial volume.

Retention Pond

Function: Retention ponds are designed to hold stormwater and allow it to infiltrate; therefore, do not incorporate outlets. These ponds can be used in conjunction with a variety of water-harvesting techniques such as swales and other conveyance devices, or can receive stormwater directly as it is diverted from a paved surface. The design considerations listed above for wet and dry detention ponds are applicable to retention ponds, with the exception of outlets; however, the design should account for emergency overflows.

Siting: Retention ponds can be constructed on sites with slopes up to 15% as long as the basin bottom is relatively level. The slope of the area upon which the pond will be built should be relatively flat, as side slopes of the pond should not exceed 3:1. A minimum separation of three feet between the water table and pond bottom is recommended unless the pond is designed as a wet pond.

Construction: Key objectives of retention pond design include safety (due to the potential hazard represented by standing water) disease vector prevention (such as mosquitoes), and appropriate and excess capacity management. Generally pond depth should not exceed eight feet. It is advisable to consult a qualified professional when designing and constructing detention or retention ponds in order to ensure a safe, appropriately functioning pond.

Maintenance: Periodic inspection, at least twice annually, is advisable. Inspection should include checking for signs of bank or bottom erosion and monitoring of sediment, build-up in the pond and forebay area (if applicable). If runoff feeding into the pond is high in sediment, the latter two inspections may need to be performed more frequently. Sediment should be removed when total pond volume has been reduced by one quarter. Accumulated debris or litter should also be removed, dead vegetation replaced and erosion or other damage repaired. Verification that mosquitoes and other disease vectors are not present should also be performed, and any issues addressed.

In-ground Temporary Storage and Infiltration Systems

These comprise a variety of methods devised to temporarily hold stormwater in the ground and allow it to infiltrate. They usually employ minimal technology and can be easily installed by a landscape contractor or homeowner.

French Drains

Function: French drains are rock-filled trenches designed to facilitate infiltration of stormwater. The concept is to allow the water to infiltrate surrounding soils through the trench sides, ends and bottom. French drains can be constructed independently, as shown in Figure 115, or as part of a more complex water-harvesting network.

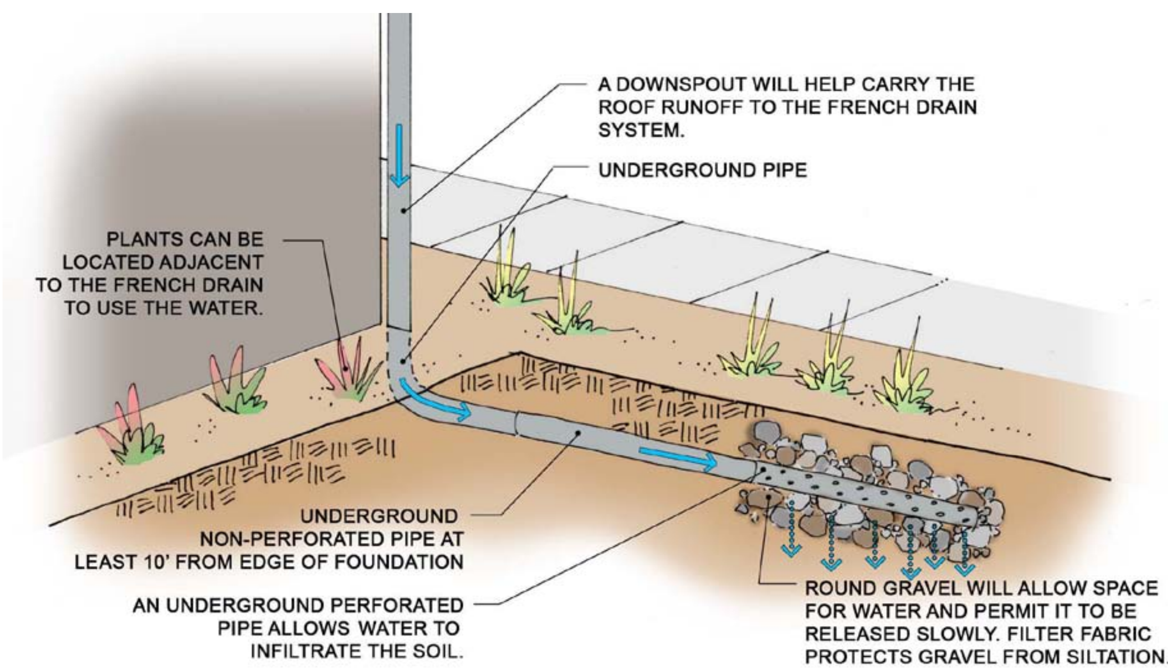

Figure 115. French Drain

Figure 116 illustrates the incorporation of French drains, swales, and microbasins in a residential landscape. When these techniques are used in conjunction with devices such as rainchains and rain barrels, they can provide 30% to 80% of the water needs for the landscape.

Siting: French drains are appropriate for low to moderate flows on flat to moderately sloped areas and can be used in steeply sloped areas to provide greater storage volume than would be possible with surface basins.

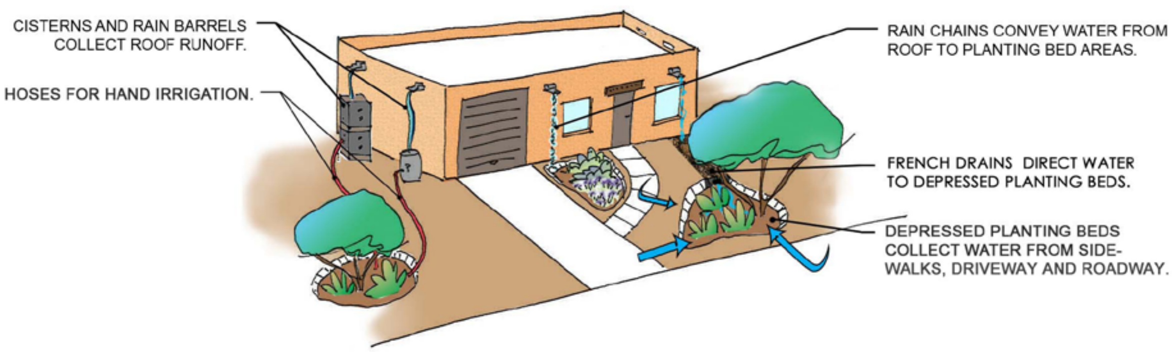

Figure 116. Water Harvesting Using French Drain, Swales and Microbasins

The soil surrounding the drain determines how quickly water will be able to infiltrate. Sandy or gravelly soils drain fastest, whereas heavier, clay soils drain more slowly. Thus the soil type should be taken into account when determining the size of and location for the drain. French drains have about one-third the water-holding capacity of an open trench due to the space consumed by their rock fill.

French drains can be placed either on or across contours; either configuration can help to prevent erosion by capturing and slowing water, allowing it to infiltrate.

To avoid diminished infiltration over time, the runoff feeding into French drains should be low in sediment. If some sediment will be present, wrapping the rock fill in filter fabric or placing the drain in conjunction with filtering devices such as filter strips or microbasins can help to prevent clogging. French drains should not be placed in watercourses due to the high sediment potential.

Try to avoid placing French drains within the root zones of existing trees as the excavation will destroy roots and could compromise the tree's health. If placing the drain within an existing tree root zone is the only or best option, orienting the drain to run radially towards the tree trunk will minimize root destruction (see Figure 117).

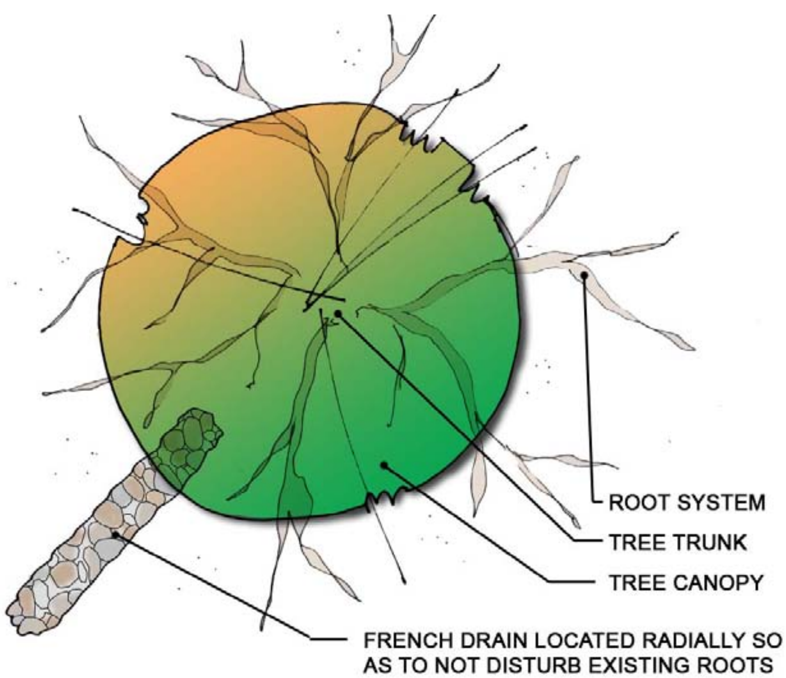

Figure 117. Placement of French Drain within Tree Root Zone

French drains should not be placed underneath driveways or other drivable surfaces as they are not structurally appropriate for heavy load-bearing, however; they can be used to move water under sidewalks or pathways.

French drains should not be located within 10 feet of building foundations. In order to harvest roof drainage from building downspouts and maintain the minimum 10-foot distance, it is possible to use non-perforated pipe to link the downspout to the French drain. Install the non-perforated pipe run from the downspout to the edge of the French drain, where it will connect to a perforated pipe that runs the length of the drain basin. The perforated pipe should be placed so that the basin rock or cobble fill does not crush it. Be sure to install a screen at the top of the downspout to prevent debris from entering and clogging the pipes or French drain.

If there is potential for the drain to contribute to slope destabilization, it is advisable to engage a qualified professional to assist with design and placement.

Construction: As with all drainage projects, check with utility companies to verify locations of buried cables or gas lines BEFORE BEGINNING TO DIG, and make sure that the drain will not negatively impact adjacent properties.

French drains should have a minimum 1% grade (a drop in elevation of one foot per every 100 feet of length) to ensure water movement through the structure. Grading should be plotted out before you begin digging. Trench size depends on how much water needs to be managed. For French drains that are not completely buried, dig the trench and fill with washed small-diameter rock, cobble or gravel until the surface is even with the adjacent ground level. Rounded rock, while not as stable as interlocking angular rock, is preferable as it provides greater void space. Depending on the surrounding soil type, it may be advisable to line the trench with filter fabric prior to filling it with rock to prevent soil from gradually filling the void spaces within the French drain. If the length of the French drain exceeds 20 feet, include a perforated pipe to facilitate even flow and release of the harvested water within the drain area. The trench should be a minimum of 5 or 6 inches wide and three to four times as deep as the pipe diameter. For drains containing perforated pipe, lay a 2-inch layer of coarse, washed gravel in the bottom of the trench. Then place landscape fabric on the gravel, ensuring there is enough fabric to wrap up and around the pipe and additional fill gravel, creating a fabric tube. Lay the pipe in the trench on the gravel layer with the drainage holes facing down, if they are only on one side of the pipe. Shovel more washed gravel over and around the pipe to the required depth. Wrap the ends of the landscape fabric over the top of the gravel layer. Place a layer of coarse sand and topsoil over the top of the drain and then either an additional layer of filter fabric and mulch, plants or sod according to the location within your overall landscape. Plantings can be located at the end or along the sides of French drains to take advantage of the captured water.

Maintenance:
Preventing silt or sediment from entering or building up in the French drain is important to ensure good continued infiltration function over time. If the top surface of the drain is not completely buried, keep it free from debris and ensure it is draining within 24 hours to prevent mosquito issues.

Alternate French Drain Configurations:
French drains can be constructed in a branching pattern with a large one branching into smaller side French drains to make better use of a large amount of runoff (see Figure 118). The bottom of the entire system must be sloped away from the building to direct the water toward particular locations such as planting areas.

French drains can also be installed vertically to create infiltration columns as illustrated in Figure 119. These can be particularly effective for improving water and oxygen availability around the perimeter of trees. Depending on the surrounding soil type, the columns may fill with silt over time but will still provide more infiltration and aeration to tree roots than the unaltered native soil. Pre-fabricated versions of tree-root watering systems, both stand-alone and linked to irrigation, are available from some manufacturers.

Dry wells are another alternate configuration, consisting of pits filled with gravel or aggregate used to address runoff from smaller impermeable areas.

Siting: Not appropriate for areas with high sediment loads that would clog the well. An advantage of dry wells is their potential use on steep slopes that preclude other infiltration devices.

Construction: Dry well size should be based on the desired capacity and runoff amount from the contributing area.

Maintenance: Keep surface free of debris and check for sediment buildup, which should be removed if well function is significantly diminished.

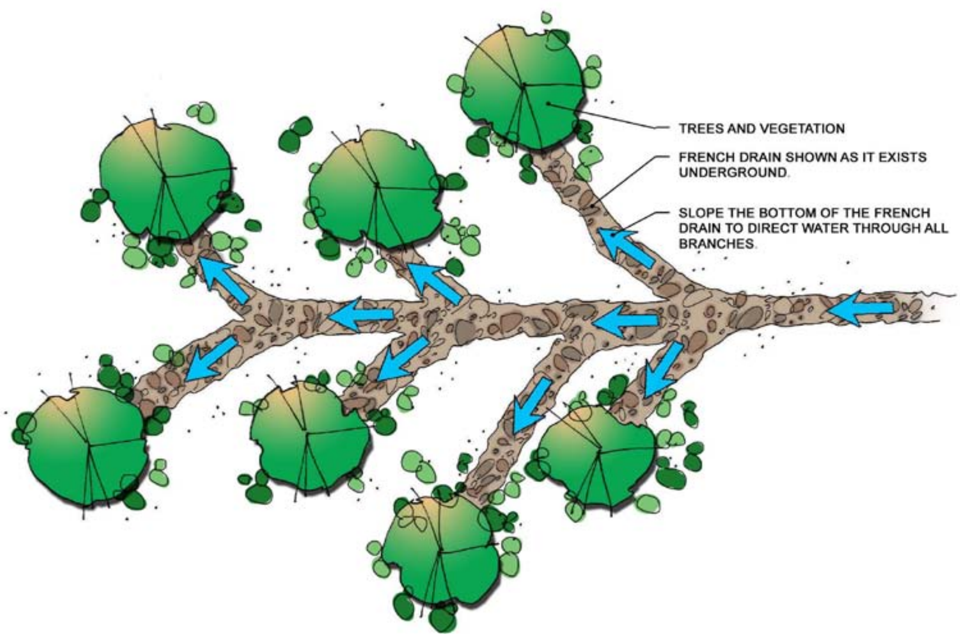

Figure 118. French Drain in Branching Series

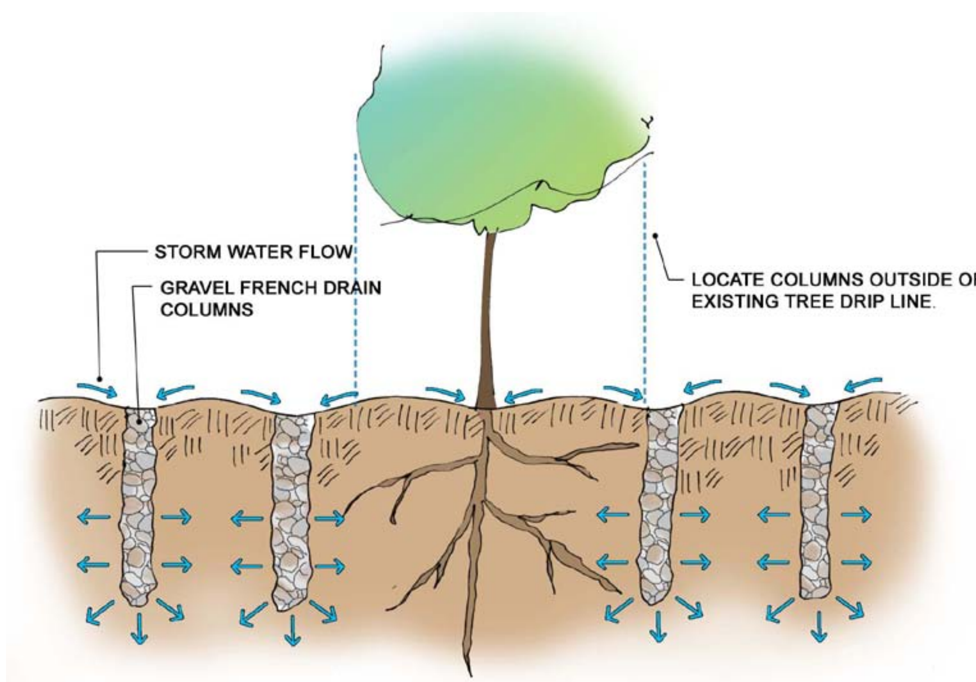

Figure 119. Vertical French Drains

Wicking Systems

Function: Wicks act like sponges, collecting stormwater runoff via a swale or other landform, storing the water and making it available to the root systems of plants over time. Depending upon the amount of water, the soil type and plant water needs, wicks can provide water for an extended period of time and act like a shallow aquifer (see Figure 120 and Figure 121). Wicks have a secondary function of erosion control as they help to reduce the amount and velocity of runoff. This secondary function can be useful when mitigating eroding slopes. Wicks can be constructed from gravel, pumice stones, straw bales or other organic material, and installed like a column or "curtain" in depressions between large plants such as shrubs or trees. When plants are placed on either side of the wick, they are given a supply of moisture at their root zones for weeks or even months after rain events. The basic idea behind wicks is to harvest runoff from the surface and direct it to a wick. The wick slowly releases the water into the soil where it can be absorbed by plant roots. Wicks can also be used in conjunction with regular and perforated piping to collect and move water from downspouts or canales away from building foundations and out into the landscape.

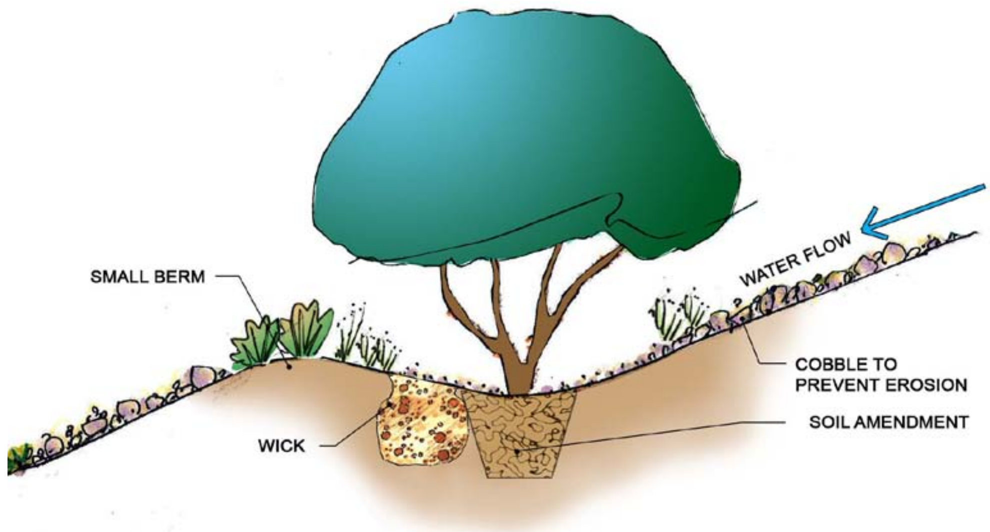

Figure 120. Wick System

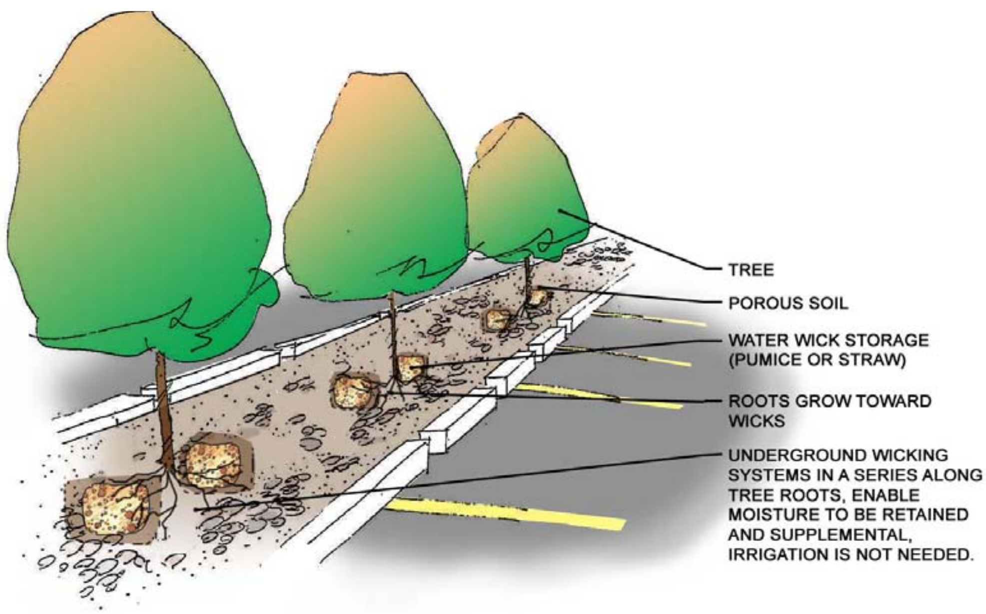

Figure 121. Wicks in Parking Island

Siting: Wicks can be positioned in a variety of locations in the landscape, preferably a minimum of 10 feet from building foundations. One option is to locate the low points near where you will be planting and simply excavate them to accommodate the wick. Another alternative is to grade the site so there is a low point, or simply dig a trench to the appropriate depth where the wick is needed. Plants can be placed along either or both sides of a wick. Locations that are cut off from adjacent stormwater flows, such as parking lot islands, are ideal locations for wicks. Wicks can also be useful for providing a supplemental water source to trees or plantings in precipitation-only landscapes, or for plantings that would benefit from an additional water source. In placing wicks near existing vegetation, care should be taken to avoid damaging the plants' root zones.

Construction: Dig a hole large enough to contain a straw bale or a large amount (8 to 9 cubic feet) of water-absorbing material such as pumice. Pea gravel or similarly sized pumice stone particles work very well. Cover the wick with a layer of filter fabric, or several (20 to 25) layers of newspaper, which will help to prevent dirt from clogging it, and then with a 3-inch to 4-inch layer of cobble or other mulch.

To connect roof downspouts to wicks located at least 10 feet away from the building foundation, excavate a 3-foot diameter hole at the bottom of the downspout and then dig a trench sufficiently wide to accommodate a 4-inch pipe from the hole to the wick location. The trench should slope between 0.5 to 1% to facilitate drainage to the wick. Fill the 3-foot hole with pea gravel to a depth of 1 foot and then place a 12-inch box drain on top of the gravel. Connect the 4-inch pipe from the drain box outflow opening to the wick area. If the length of the wick itself exceeds 20 feet, include a perforated pipe to facilitate even flow and release of the harvested water within the wick. Fill the remainder of space around the drain box with gravel, and then fill and cover the wick as noted above. In case the wick becomes completely saturated, the design should also accommodate excess water by allowing any overflow to feed an adjacent water-harvesting device such as a French drain or bioretention area.

Maintenance: When properly constructed wicks require little to no maintenance. If runoff coming into the wick is high in sediment, however, the wick can become clogged over time, requiring sediment removal or replacement of the wick material. Preventative maintenance includes checking and clearing downspout debris screens which keep material from entering and potentially blocking the pipe.

Evaporation-Loss-Reduction Devices

Mulches

Function: Some parts of Bernalillo County receive only about eight inches of precipitation per year, while potential evaporation may exceed 100 inches annually. By covering and cooling the soil, mulches can significantly reduce surface evaporation water loss, as well as weed growth and erosion. Mulches improve water and air penetration and protect shallow-rooted plants from soil temperature fluctuations and freeze damage. Over time, as they decompose, mulches also improve soil structure and nutrient availability. Mulches also provide an aesthetic benefit. There are two basic categories of mulches: inorganic, such as gravel, cobble, decomposed granite/crusher fines or other stone material, and organic, such as pecan shells, shredded bark, pine needles, straw, leaves, grass clippings, oyster shells and the like. Inorganic mulches can also be used to help prevent erosion from slopes and berms.

Siting: Mulches can be applied over bare soils, either alone or over landscape fabric. Mulching planted areas provides the benefits noted above, and mulching water-harvesting basins, depressions and swales improves their performance. Mulch particles should be appropriately sized to address potential loss due to wind or water flow erosion. Organic mulches tend to be lighter and are best in low-flow areas, while inorganic mulches such as cobble are more appropriate for areas that will experience higher velocity flows.

Construction: Inorganic mulches should be applied 2 to 3 inches deep and can be applied over filter fabric. Extremely fine-grained mulch can inhibit infiltration and clog soil pore spaces. When using decomposed granite crusher fines as a mulch it is important to wash off fine sediments first.

Organic mulches should be applied 3 to 4 inches deep directly on the soil surface. Leave several inches of space between the tree trunks or the base of plants and the mulch edge. This helps to avoid rot or mold issues.

Maintenance: Both organic and inorganic mulches deplete over time. They should be periodically replenished to maintain optimal depths for soil cooling and evaporation loss reduction. If any areas show evidence of erosion, determine and address the root cause of the issue.

Some of the soil nitrogen in contact with mulch is consumed as organic mulches decompose. This can potentially result in nitrogen deficiency, which is indicated by yellowing, primarily of lower leaves. This can be rectified by nitrogen fertilizers, applied at a rate of 2 pounds of a complete fertilizer, preferably organic, or 1/4 pound of ammonium sulfate for every 100 square feet of mulched area. Do not use "weed-and-feed" fertilizers in mulched areas.

Area and Coverage Depth of One Cubic Yard of Mulch	
Area (sq. ft.)	Depth of mulch (inches)
80	4
100	3
160	2
325	1

Advantages and Disadvantages of Mulch Types			
Mulch type	**Advantages**	**Disadvantages**	**General Comments**
Inorganic, inert mulches			
Filter fabric	Initially reduces weeds. Allows air and water penetration. Long-lasting if covered with mulch. Relatively easy to apply.	Can be costly. Degrades if exposed to sunlight or direct wear.	Preferable and better performing than black plastic. Allows water and air to infiltrate.
Decomposed granite/ crusher fines, gravel, stone, pea gravel, pebbles	Available in colors to match or complement the architecture. Relatively inexpensive.	Will not prevent growth of some weedy grasses.	Extremely fine-grained mulch can inhibit infiltration and clog soil pore spaces. Inorganic mulches can add heat load to areas lacking overstory of vegetation.
Cobble, rip-rap	Available in colors to match or complement the architecture.	Will not prevent weed growth. More labor intensive to install.	Supplementing with smaller diameter gravel or fines to fill in crevices can help prevent erosion between cobbles.
Organic Mulches			
Cocoa-bean hulls	Long-lasting, dark brown color.	Poisonous to many animals including dogs and cats. Compact; forms a crusty surface. Expensive.	Molds may form on surface; harmless if stirred to break crust.
Crushed corncobs	Uniform in color.	May retain too much moisture at surface or compact if kept wet.	Availability limited in some areas.
Grass clippings	Readily available. Nutrient recycling.	Must be applied loosely, in thin layers to reduce matting. Herbicide residues may harm plants. Some potential to be nitrogen-robbing.	To prevent matting, allow to dry prior to application.
Leaves (composted)	Readily available. Nutrient recycling.	Not very attractive. May become matted.	
Leaves (fresh dried)	Readily available. Nutrient recycling.	Not very attractive. May blow away. Can be a fire hazard. Wet leaves compact into slimy mats.	Most appropriate in naturalized gardens or shrub masses.
Newspaper	Readily available. Good for preventing soil splashing (disease) on lower leaves or vegetables.	Don't use color inserts or red ink. Not very attractive unless covered.	Use 3 to 6 sheets thick and cover with organic mulches.
Pine needles	Do not compact.	Difficult to obtain in quantity. Can be a fire hazard.	Best for winter protection of fall-transplanted material.
Shredded bark, bark chips, chunk bark	Long-lasting, attractive. Somewhat resistant to wind erosion.	Cost relatively high. Shredded bark may compact. Large bark chunks may impede spreading perennials.	
Straw	Readily available. Inexpensive.	Blows easily. Highly flammable. Weed seeds often present.	Best used as a temporary mulch around plants needing protection in winter. Anchor with wire mesh.
Wood chips, shavings, recycled shingles	Long lasting. Readily available. Does not blow away.	Texture and color not uniform. Can cause nitrogen deficiencies in plants if incorporated into the soil.	Rustic but usually attractive. Will not compact readily.
Pecan shells	Attractive red-brown color, which weathers to a silvery grey.	Can blow away, can be scattered somewhat after installation by birds picking out remaining nut meat.	Will not compact readily.

Source: Derived from J.E. Klett, Colorado State University Extension landscape horticulturist, and professor, department of horticulture and landscape architecture. Revised from original fact sheet authored by J.R. Feucht, retired. 11/97. Revised 1/07.

Impervious-Surface-Reduction Devices

Living or Green Roofs

Photo 90. New Mexico Court of Appeals Green Roof

Function: Living or green roofs are living systems contained on top of built structures. The two major categories of living roofs are a) extensive, which tend to be shallow-depth systems with a narrow range of plant species, and b) intensive, which have a deeper substrate layer and a wider variety of plants.

Green roofs can absorb up to 75% of the precipitation they receive, greatly reducing runoff rates and volumes. They also provide additional benefits such as improved insulation for the building beneath, reduction of the heat island effect and rooftop heat load and additional wildlife habitat and open space in urban areas. They can also be quite beautiful. Green roofs are relatively rare in the desert southwest and must be adapted to the arid climate and other conditions particular to the region. Depending on the plant materials used, supplemental irrigation may be required, and maintenance requirements during plant establishment may be significant.

Siting: Green roofs can be constructed on residential, commercial, public and industrial buildings, and on structures such as parking garages. They are applicable to both above- and below-grade structures and are particularly useful in highly developed areas where green space is at a premium.

Construction: Design of a green roof involves a number of considerations and is best managed with professional assistance. It is advisable to involve a multi-disciplinary team in the design and installation of a green roof. Ideally the team should include representatives with expertise in structural and stormwater engineering, architecture, landscape architecture and horticulture. The building must have sufficient load-bearing capacity, and the roof design must be able to withstand water flows associated with the green roof. The basic components of a green roof are: 1) the underlying roof structure that supports the green roof materials, 2) a waterproof membrane, 3) a root barrier layer to prevent roots from reaching and penetrating the waterproof membrane, 4) a drainage layer of aggregate or similar material, 5) a filter membrane to prevent fine soil from washing down into the drainage layer, 6) a growing medium such as a soil matrix, 7) vegetation – usually smaller, more shallow-rooting plants although trees have been used on some green roofs, and 8) an irrigation system.

Maintenance: Green roofs should be designed for maintenance access. In particular, under-drain systems should be readily accessible to facilitate cleanout. Other system components requiring regular preventative and corrective maintenance are the irrigation system, plant materials and the growth media or soil matrix.

Landscaping

A range of vegetation strategies can be used to increase site water conservation.

- ***Choose appropriate plants*** - Take cues from the surrounding environment and choose plants that are appropriate to the site biozone conditions and climate. There is a tremendous range of native and appropriate non-native vegetation adapted to local site conditions, climate, and any design. The ABCWUA plant list is an excellent resource and includes detailed environmental and water requirements for a large range of plants appropriate for use in Bernalillo County.
- ***Group plantings according to their water needs*** - As noted elsewhere in this document, a highly effective strategy is to match water-use zones to the physical layout of the site, placing high-water-use plantings along drainageways and in low-lying areas where water flows and collects, and lower-water-use plantings in higher areas which tend to shed water and are generally drier. High-water-use plant groupings should be limited to highly visible and highly used public and private areas. Moderate-water-use zones are designed with plantings that require less frequent watering and are appropriate to less utilized areas such as streetscapes, commercial areas and bleed thru portions of residential landscapes. Low-water-use areas are planted predominantly with drought-tolerant and native species which require little care. These plants generally need irrigation only during establishment and subsequently become precipitation-only landscape areas. The transition between the various water use zones must be thoughtfully designed to avoid over- or under-watering of plantings.

- ***Preserve and enhance native vegetation*** **-** Use revegetation and reclamation seeding and plantings to rehabilitate disturbed areas. Restoring and maintaining vegetation helps to ensure that water can percolate into the soil and helps to prevent erosion.
- ***Limit disturbance of native vegetation*** **-** This is particularly important on slopes and at the site periphery to reduce the need for revegetation and irrigation in those areas.
- ***Do not fertilize unless it is recommended based on soils testing*** **-** Even then use only organic or slow-release fertilizers to promote plant health and increase drought tolerance. As a general rule, avoid the use of pesticides and fertilizers to lessen pollutant loads in runoff and groundwater.
- ***Use additives to help conserve water*** **-** Zeolites, diatomaceous earth, and hydrophilic polymers (hydrogels) can help conserve water by increasing the soil's capacity to hold water and retain nutrients.
- ***Use plants that can survive without supplemental water (irrigation) once established***.
- ***Limit the amount of turf areas*** **-** Turf areas generally consume alot of water and should be limited to those areas where turf is truly necessary or beneficial. When determining the location of turf areas, consider the site conditions. Avoid putting turf in areas that will be difficult to irrigate efficiently, such as steep slopes, or in narrow strips or small areas. There are a number of low-water-use grasses available (Blue grama, buffalo grass, fescue) that are better adapted to the central New Mexico climate than traditional turf grasses, so substitution of drought-tolerant turf grasses should be explored.
- ***Install Plants for water conservation*** **-** Install the plants themselves with water conservation in mind. Generally speaking plants, whether trees, shrubs, or ground covers should be installed at an elevation lower than the ambient land around them or with basins. This is done to ensure that irrigation that is applied to the plant will remain where it is needed at the plants roots. As the plant grows the basin will need to be graded to maintain its water holding capacity and potentially widened to accommodate the plants growing root system. In "Appendix K. Plant and Turf Grass Installation Details" we have included a range of diagrams showing how plants should be installed in Bernalillo County and the desert southwest for a reference.
- ***Install Turf grass for water conservation*** **-** Turfgrasses too should be planned for water conservation. They should be installed a low points on the site if possible to capture water from landscapes and drainage at higher elevations. Turfgrass areas should not be bermed for water conservation. Also, planting grasses on slopes should be avoided. When installing turfgrasses the finished grade should always about 1" lower than adjacent surfaces such as sidewalks, drivepads, mulches and other surfaces to allow for drainage. See "Appendix K. Plant and Turf Grass Installation Details" for details on installation.

Irrigation

Landscape irrigation accounts for a significant portion of water consumption, representing a major opportunity for reduction and conservation. One study notes that US demand for water has risen 209% since 1950[1] and that up to 60% of municipal water consumption is attributable to landscape irrigation. As much as 50% of irrigation water can be lost due to evaporation processes, wind and over-watering, so efficient irrigation system design and operation is critical to water conservation. Another key to water conservation is good irrigation system design. An efficient system saves water while supporting healthy plant growth and development. Key steps in irrigation design are:

- ***Divide the landscape into water use zones*** **-** Efficient distribution of water is based on a zoning system, generally known as hydrozones. This process creates irrigation zones based on plant types and their differing water needs. As a general practice, trees and shrubs should be irrigated with non-spray irrigation systems.
- ***Take advantage of the site's layout and terrain*** **-** Placement of higher-water-use zones on the lower areas within the site facilitates efficient irrigation system design and can help avoid having to pump irrigation water uphill.
- ***Use non-potable water for irrigation*** **-** Wherever possible, utilizing reclaimed or harvested water for landscape irrigation is more energy- and resource-efficient. Guidelines for wastewater reuse are available from the New Mexico Environment Department.
- ***Use the optimum available irrigation technology*** **-** Irrigation technology is developing at a rapid pace, and so researching current best-in-class irrigation components and systems is essential. Among the technologies and irrigation system elements to consider are:
    - Centrally controlled systems. A central control system links and manages other devices such as controllers and rain or soil moisture sensors to regulate irrigation cycles and durations. Some estimates note that weather station-based irrigation systems can reduce irrigation water use by 20 percent.[1] Climate-based controllers for irrigation systems can also be used to lower water consumption.

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1. U.S. Environmental Protection Agency. 2007. Outdoor water use in the United States. (EPA Pub 832-F-06-005) Department of the Interior, Editor

- Devices that track evapotranspiration (ET), soil moisture, and weather can be located on site and tied into the irrigation control system. The data from these devices are incorporated into calculations of irrigation needs, and the system adjusts water output accordingly. When properly installed and maintained these systems can provide highly efficient and effective irrigation, promoting both water conservation and healthy vegetation. Many water-conservation features are currently available in automatic irrigation controllers, including multiple start times, flexible programming, rain and soil moisture sensors, flow disruption monitors and ET programming.
- Design the system by hydrozones, aligning irrigation zones to the range of plant water needs in the landscape. Set up irrigation zones and schedules for plants based on the water needs of your plant groupings. This will require more zones and may cost more initially but will save water and result in healthier vegetation in the long run. Having separate zones allows you to tailor the irrigation schedule to the needs of each plant group, avoiding over- or under-watering.
- Using pressure-regulating devices when the system is at high pressure can save water. Industry estimates note potential water usage reductions between 6% and 8% for every 5 psi reduction in water pressure. Examples of pressure-regulating devices are pressure-reducing valves and pressure-regulating spray heads.
- In situations where the system pressure is low, a high-efficiency pump can help avoid water waste due to uneven coverage.
- Water will flow to the lowest point in an irrigation system and can drain out of irrigation heads in that area, wasting water and causing issues such as erosion. Check valves trap water in the lateral lines and keep it from draining out.
- Consider non-spray, low-volume irrigation techniques such as drip and subsurface irrigation. Drip irrigation allows water to be applied directly where it is needed at a rate that allows the water to be completely used without runoff or waste. It is a highly efficient irrigation solution for non-turf applications. Correctly installed drip irrigation delivers close to 95% of the water directly where it is needed and is from 30% to 65% more efficient than spray irrigation.

For more information and specifics on irrigation system design, see the "Water-Conserving Irrigation" section below.

E. Water-Conserving Irrigation

Introduction

Well-designed and maintained irrigation systems are essential to achieving a beautiful, healthy and water-conservative site and landscape. This section of the guidelines provides basic descriptions of the different types of irrigation systems, issues to consider when determining how to irrigate, and recommended best practices for designing and maintaining an irrigation system. Additional information is available through the resources listed at the end of this section.

Nationwide it has been estimated that between 40% and 60% of municipal water consumption is used for landscape irrigation, and that more than 1.5 billion gallons of water are lost daily due to irrigation system inefficiencies. By some estimates more than 50% of the water used for landscape irrigation is lost due to evaporation or runoff caused by overwatering. A water-conserving irrigation system applies water by the most efficient method possible and only when and where it is needed. A good rule of thumb is to water deeply but less frequently in order to encourage deeper root growth. This enables plants to draw moisture from a larger area of soil, increasing their ability to tolerate drought. It is important to account for the soil type of the site when planning irrigation watering durations and frequencies. As an example, water travels more quickly through sandy soils, so more frequent watering may be needed than for a site with higher clay content soils, which drain more slowly, dependent on landscape type.

As noted in the section, "Recommended Steps for Water-Conserving Landscape Design," an irrigation system based on hydrozones is fundamental to reducing landscape water use. A hydrozone-based landscape design groups together plants with similar water requirements. The irrigation system can then be designed to align the most appropriate and efficient type of irrigation to each hydrozone, allowing each zone to be watered separately. For example, lower-water-use plant groups may be drip-irrigated, whereas higher-water-use turf areas may use sprinklers.

There are basically two major approaches to irrigation, passive and active. Passive irrigation systems are "low technology" solutions that use gravity to deliver water to targeted areas in the landscape via channels, hoses or other conveyance devices. Active irrigation systems are mechanized and move water under pressure through the delivery network of pipes or hoses and out to the targeted landscape areas. Additional information on passive irrigation and water harvesting devices is available in the "Water-Conserving Landscape Devices and Best Management Practices" section of this document.

Irrigation System Components

The basic components of most irrigation systems are:

Controller – The clock or brain of the irrigation system, determining when and for how long each irrigation zone (with an automatic valve) will be watered. Photo 91 shows a typical controller. Care should be taken in programming basic controllers to ensure watering schedules are based on the irrigation needs of each hydrozone, as well as on soil and slope conditions.

Photo 91. Irrigation Controller

Smart controllers enable irrigation to occur when it is actually needed rather than on a preset schedule. They utilize data from sensors and weather stations to determine when and how much irrigation is needed, offering the greatest potential for water-efficient irrigation. A range of sensor and weather station data types can be included such as rain, wind, evapotranspiration, flow and soil moisture. Researching current product offerings is essential as irrigation technology is constantly evolving, providing an ever-increasing range of cost-effective options for improving the irrigation system water efficiency.

There are many additional controller features that can help promote water-conserving irrigation including:

- Cycle-and-soak or interval programming options, which help reduce runoff by accommodating site conditions such as hard, compacted or clay soils or slopes that require watering in increments to allow the soil adequate time for absorption, enabling deeper penetration of subsequent irrigation.
- Percentage increase/decrease or water budgeting features, which allow quick uniform adjustment of watering periods for all zones on a system. These are useful when adjusting irrigation schedules up or down to accommodate seasonal or monthly changes in plant water needs.
- Rain-delay features, which adjust irrigation schedules to avoid watering during or immediately after rain.
- Soil moisture sensors measure the amount of water in the soil and let the controller know when it is dry enough and the plants need water.
- Weather-based controls (Smart Controllers) rely on data gathered from nearby weather stations. This information is relayed to the controller via a pager signal and automatically adjusts the programmed watering schedule.
- Multiple programming allows the flexibility to water plants of varying microclimates or water needs.
- Non-volatile memory retains the programs in the controller's memory in the event of a power outage.

Backflow preventer – Required by ordinance to keep irrigation water from being siphoned back into the potable water supply and potentially contaminating it. There are several types of backflow preventers: reduced pressure, pressure vacuum breaker, anti-siphon valve and double check type. Be sure to verify local requirements when selecting a backflow prevention device.

Pressure regulator – Used to reduce system water pressure. They are often needed to deliver the lower pressure required for optimal operation of a drip system.

Automatic control valves – Activated by a signal from the controller to control the flow of water into the designated irrigation zone. The concept of hydrozoning is the foundation of a water-efficient irrigation system. An irrigation system based on hydrozones can significantly reduce landscape water use by providing separate valves for irrigation zones that match the water requirements of the various plant groups, allowing them to be watered separately. Also, lower-water-use plant groups may be drip irrigated, whereas higher-water-use turf areas may use sprinklers. It is necessary to select the proper type of irrigation for each hydrozone.

Irrigation System Types

An irrigation system is composed of a set of components that generally includes a water source (meter or well), a water distribution network and water delivery devices. Irrigation systems can typically be classified into five types: Drip and low flow, bubbler, sprinkler, flood and hand-watering. Flood irrigation will not be discussed in detail as it is subject to regulations by irrigation organizations such as the Middle Rio Grande Conservancy District and Acequia Associations; however, it should be noted that this irrigation method loses significant amounts of water to evaporation.

Drip and Low-Flow Systems

Drip irrigation systems are highly efficient for providing water to plants in the landscape and are ideal for xeric landscapes. A properly designed system using low-flow drip irrigation can achieve efficiency levels of more than 90% and virtually eliminate water waste. Drip systems provide a slow, steady amount of water directly to the root zone of the plant, minimizing loss due to evaporation and application in areas that are not planted. They also reduce loss due to runoff and overspray.

Drip irrigation systems are typically operated at a lower water pressure than sprinklers, and pressure regulation is needed to maintain this lower pressure. The water pressure needed for drip systems is typically in the range of 10-20 psi. A wide variety of products are available for drip irrigating, including individual emitters, multi-outlet emitter devices, dripline and microsprays. The components of drip systems are described below (see also Figure 122).

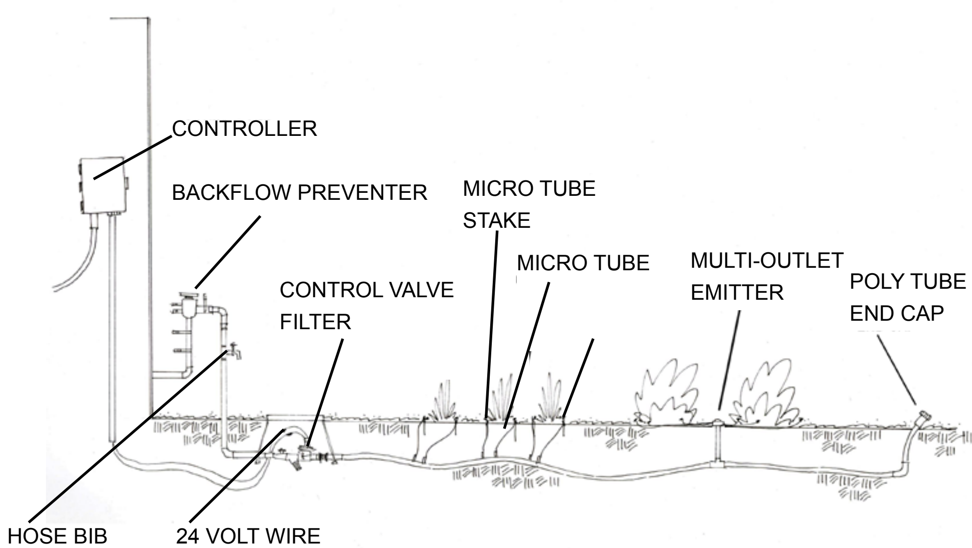

Figure 122. Drip Irrigation System Components

- **Filter** – A filter is often included in drip systems upstream from all control valves to prevent particulate matter in the water such as sand or silt from building up and clogging any part of the system. Some filters can be removed and washed while others are self-cleaning.

- **Micro-tubing** – Is flexible polyethylene distribution tubing that connects to individual drip emitters. It is generally available in 1/4-inch or 1/2-inch diameter sizes, is relatively inexpensive, easy to install and repair, and is resistant to UV damage.

- **Drip emitters** – Are small watering devices that deliver water at very low pressure and rates that are measured in gallons per hour (gph). They are available in a variety of types and forms, including self-cleaning, pressure-compensating, and micro-spray emitters. Output from "non-compensating" emitters increases or decreases as tube line pressure increases or decreases whereas emitters categorized as "pressure-compensating" are designed to deliver the same amount of water over a fairly wide range of tubing line pressures. Depending on the design of the drip irrigation system this can be an important consideration.

Photo 92. Drip Emitter

The number of emitters should be based on the plant type and size, the soil type, and be sufficient to deliver the maximum daily water requirement for the mature plant size. Emitter flow rates should be proportional to the plant type and size.

Higher-water-use plants may need more emitters than native or drought-tolerant plants of the same size.

Suggested Drip Emitter Quantities			
Plant Type	**Mature Canopy Size in Feet**	**Number of Emitters**	**Emitter Flow Rate (gallons per hour)**
Groundcover/Small Shrub/Ornamental Grass	1-3	1	0.5 - 1
Large Shrubs	4-6	2	2
Small Trees	7-10	3	2
Trees	11-14 15-20 21+	4-6 6-12 12+	2-4 2-4 4

Emitters should be placed uphill from the plant. For plants located on steep slopes, create mini-basins or a depression around the base of the plant to receive water from the emitters while preventing erosion and runoff.

For new plantings, install emitters halfway between the base of the plant and the outer edge of the rootball. This is termed the dripline. As plants grow and mature, emitters should be moved to water the root zone (the soil area that surrounds the plant's roots) (see Figure 123).

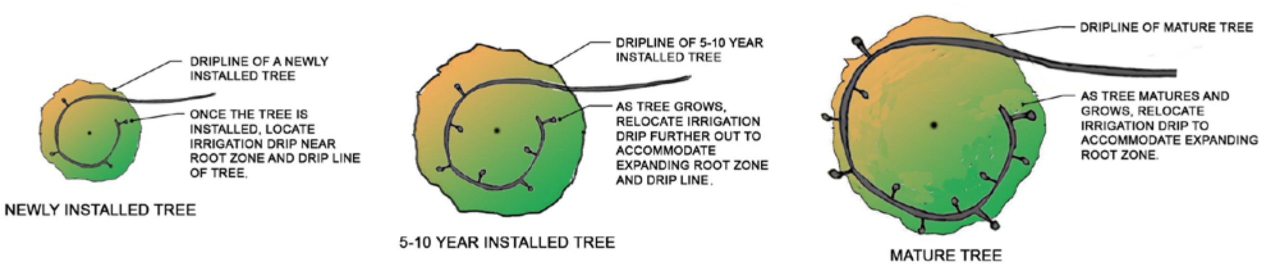

Figure 123. Adjusted Emitter Placement Over Time

Most roots spread 1.5 to 4 times the plant's canopy and penetrate 2 to 3 feet deep. For existing or mature plants, place emitters to deliver water at the edge of the mature root zone, (see Figure 124).

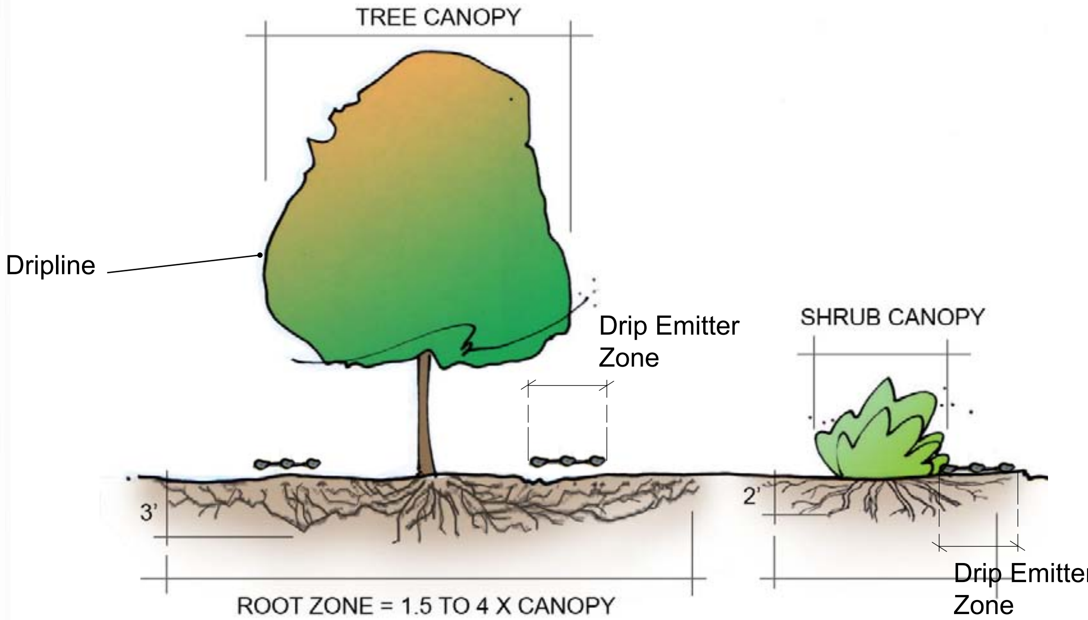

Figure 124. Approximate Sizes of Mature Root Zones

- **Dripline** – Is plastic tubing that has been pre-drilled with regularly spaced holes or in-line emitters that deliver water at a consistent rate and can be used for watering containers or narrow planting areas. Another type of dripline is made of porous tubing similar to soaker hose that allows water to seep through the entire tube wall.

Photo 93. In-line emitter

Photo 94. Soaker Hose

- **Multi-outlet emitters** (also known as multi-emitter hydrants) – Deliver water from one central riser pipe to multiple independent outlets. Each outlet's flow rate can be connected to micro-tubing with drip emitters to deliver different amounts of water to the landscape. Multi-outlet emitters with pressure-reducing components can be used to replace existing sprinkler heads when converting turf areas to xeriscape.

Photo 95. Multi-outlet Emitter

Bubblers

Photo 96. Bubbler

Bubblers are most effective when deep watering is desired, such as for trees or shrubs. They are simple to install and provide water in an "umbrella" pattern over a small area, usually at higher gallon-per-hour rates than drip emitters. They can be installed on pop-up heads or fixed risers. Pop-up heads are an additional expense; however, they are preferable when the bubblers will be located in areas subject to foot traffic, as they can prevent damage to the bubblers.

Bubblers are also available as part of pre-fabricated Root Watering Systems that apply irrigation water to trees or shrubs directly in the root zone. These systems also increase oxygen supply to the root zone and can be especially beneficial in situations involving compacted soils. An illustration of this system is shown in Figure 125.

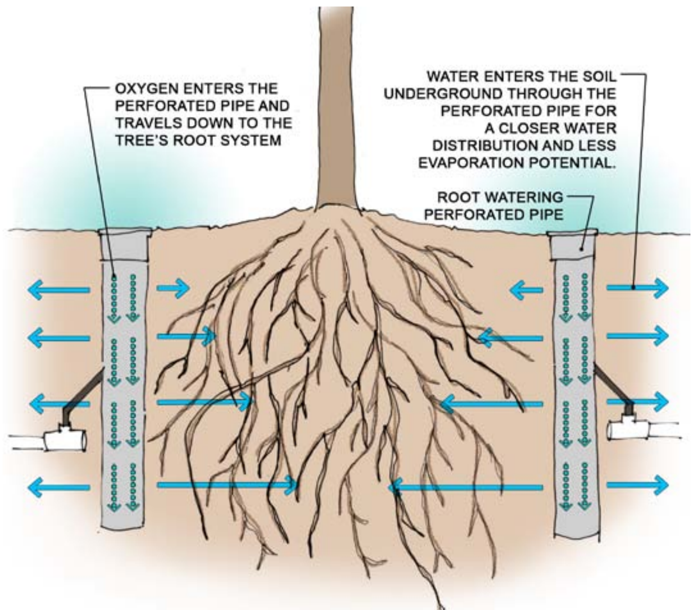

Figure 125. Root-Watering System

Photo 97. Stream Bubbler

Stream bubblers can be used when irrigating densely planted shrub or ground cover areas. They provide a consistent stream of water with a variety of choices for the radius of throw (Photo 97).

Spray Systems

Spray systems are most commonly used for turf grass or large areas of other groundcovers and are generally viewed as the most efficient irrigation method for lawns. Spray systems apply water in gallons per minute and lose significant amounts of water due to evaporation. They must be carefully designed, installed and maintained to avoid additional loss due to overspray issues (application of water to adjacent areas that do not require irrigation such as sidewalks, walls or driveways). Pressure regulation is particularly important to avoid producing overspray or mists that waste water. Another key design and maintenance objective for water-efficient spray irrigation is uniform application of water. Poor uniformity of irrigation application can result in some areas being drier than others. Often the irrigation being supplied by the entire system is increased in an effort to address the dry areas, which results in some areas being over-watered and water being wasted. Verifying and adjusting heads to ensure that they are positioned and operating correctly is an important maintenance task. The efficiency of older systems can be improved by replacing old sprinkler heads with newer, more efficient models.

There are several types of sprinklers available:

- **Pop-up sprinklers** – Are activated by water pressure when the control valve is opened and retract when the valve is shut off. This is useful in situations where the sprinklers may be walked on, or where there is potential for vandalism. They are available in a variety of pop-up heights, heads and nozzle-types that allow the irrigation system to be tailored to the site. Sprinklers emit a fixed spray in a 5- to 15-foot radius and so are generally appropriate for smaller areas.

- **Fixed-spray heads** – Deliver a fan of small water droplets and are appropriate for watering smaller areas.

Photo 98. Pop Up Sprinklers

- **Nozzles** – Are an interchangeable part of a sprinkler head and create the spray pattern such as full- half- or quarter-circle. They determine the radius of throw and the rate of water application for the head.

Photo 99. Full Radius

Photo 100. Half Radius

Photo 101. Quarter Radius

- **Matched precipitation rate sprinklers** – Also called rotary nozzles, these provide more uniform coverage by allowing a variety of spray arcs and radii to be used on the same irrigation zone while still achieving consistent spray distance and application rates. They can be installed onto pop-up spray heads and are more water-efficient than conventional spray heads as they apply water at lower speeds and lower precipitation rates, allowing the soil to absorb more of the water received.

- **Rotors** – Can be gear-driven or impact types. Rotors are appropriate for larger watering areas such as playing fields or parks, with coverage ranging up to a 45-foot radius. Rotors rotate slowly as they distribute single or multiple streams of water. Rotors are less likely to cause runoff, as they apply water at a slower rate than spray heads. Like spray heads, rotors are available on fixed or pop-up risers.

  - **Impact rotors** project a single rotating stream of water in a circular or part-circular pattern.

  - **Stream rotors** have multiple rotating streams of water and are appropriate for medium-sized watering areas.

  - **Micro-rotors** and **low-pressure rotary heads** are now available and provide a more efficient alternative to the spray head for smaller areas.

Photo 102. Impact Rotor

- **Rain shutoff devices or rain sensors** – Prevent the irrigation system from running if it has rained recently. These relatively inexpensive devices generally allow the user to specify the amount of precipitation that will trigger the shutoff. Irrigation resumes when the sensor has dried out and returned to the baseline condition.

Photo 103. Rain Sensor

- **Soil moisture sensors** – Measure the level of moisture in the soil and trigger the irrigation system to run when the conditions are sufficiently dry, preventing it from operating when the soil is saturated. Many soil sensors allow the user to program the moisture level that triggers the system.

Photo 104. Soil Moisture Sensor

- **Hand watering** – The efficiency is highly dependent on the person doing the watering and can easily result in over- or under-watering. When hand watering, care should be taken to apply water deeply but less frequently to encourage deeper root growth and create a healthy root zone. The depth to which water is penetrating can be verified by pushing a 1/4-inch or 3/8-inch diameter metal rod into the ground after watering. The rod will stop when it hits dry soil, indicating the water penetration depth. Ideally the water should percolate down only to the bottom or slightly below the bottom of the plant root zone, as water beyond this level is not usable by the plant. Attaching a sprayhead or nozzle with a shut off valve at the dispensing end can increase the efficiency of hand watering by allowing the user to cut off water quickly whenever necessary. Installing a faucet timer that automatically shuts off the water, or using a timer as a reminder can help to avoid over-watering.

WATER-CONSERVING STRATEGIES FOR SPRINKLERS

- Sprinklers are designed to irrigate with "head to head" coverage. Improperly spaced sprinklers will have poor uniformity in their coverage, leading to over- or under-watering.
- Use sprinkler heads with built-in pressure regulators that allow the system to operate at lower pressures, saving water that can be lost due to misting. For every 5 psi that the system pressure is lowered, water use is lowered from six to eight percent.
- Nozzles control the amount of water flowing from a sprinkler and the distance the water will travel. High-efficiency nozzles save water by creating larger water droplets that produce a more uniform spray pattern.

Irrigation Water Supply Options

The supply options listed below should be considered, as they can reduce or eliminate reliance on municipal, county or other potable water sources. The use of natural precipitation should be also maximized through thoughtful site design for water harvesting to supplement artificial irrigation systems and lessen demand on other water supply sources.

Recycled and Reclaimed Water

- ***Graywater*** - Non-potable water is an excellent alternative irrigation supply and offers the opportunity to reduce use of potable water.

  The New Mexico Environment Department (NMED) defines graywater as "untreated household wastewater that has not come in contact with toilet waste and includes wastewater from bathtubs, showers, washbasins, clothes washing machines and laundry tubs, but does not include wastewater from kitchen sinks or dishwashers or laundry water from the washing of material soiled with human excreta, such as diapers." NMED notes that, "Graywater is distinguished from 'black water,' which is wastewater from toilets, kitchen sinks and dishwashers."

  A permit is not required to use graywater for **residential** irrigation if the daily amount of graywater discharged does not exceed 250 gallons. Other uses may require permits and be subject to particular requirements. For detailed information on current graywater use requirements and restrictions see the New Mexico Environment Department website at http://www.nmenv.state.nm.us and search on the term "graywater."

In a typical graywater system, water that would normally be discharged for sewage treatment is collected, treated to remove suspended solids and contaminants and then reused. At a minimum, graywater systems normally include the following components:

- storage tank(s)
- filter(s)
- pump
- valves
- purple PVC piping (purple designates the water being piped as non-potable)
- irrigation heads with protected openings or purple non-potable marker)

It is important to use valves and filters designed for gray or reclaimed water as they are designed to address potential issues such as clogging and wear caused by impurities in non-potable water.

Graywater systems must be installed in accordance with local plumbing codes. Appropriate design, installation and maintenance of a graywater system are critical to ensuring a safe and reliable supply of graywater.

Graywater Use

- Graywater should not be used for irrigation if there is not more than five vertical feet between your landscape and the water table below.
- Graywater should never be discharged into a lake, stream or arroyo.
- Graywater must be discharged using a hose, drip system or bubblers and should never be sprayed.
- Any piping used for discharge of graywater should be marked as non-potable.
- Be sure that the water used cannot run off your site.
- Take measures to reduce contact with humans or pets.
- Graywater should not be permitted to pond.
- Overflow from the graywater distribution system should be directed into the sanitary sewer.

The amount of graywater available for irrigation is a function of the amount of wastewater produced by the users of the site's facilities. Water-conserving fixtures and appliances will impact the amount of wastewater produced. When designing graywater irrigation systems it is important to calculate the amount of wastewater available and to match that to the landscape irrigation needs. If graywater supply is not sufficient to meet total demand, supplemental water sources may be needed. It may be necessary to divert some or all graywater to the sewer or septic system if year-round demand does not match supply. Outdoor irrigation needs are largely seasonal, but including evergreen plant materials can help boost non-growing season demand.

> Graywater contributes nutrients that are beneficial to plant and soil health. Gray or reclaimed water can also be more conducive to plant health than treated potable water that contains chlorine and other chemicals which can adversely impact plant health. Graywater is generally alkaline and typically contains more salts than potable water. Native plants adapted to local conditions are less likely to be impacted by the additional alkalinity and salts, but plants that are not alkaline and salt-tolerant may be impacted. Combining reclaimed water with potable water, or rotating irrigation with fresh water can help to address this issue, and are recommended if irrigation system monitoring shows evidence of salt build-up.

- ***Other recycled and reclaimed water sources*** **-** Condensate from central air systems is another potential source of supplemental irrigation water supply. Condensate is essentially equivalent to distilled water as it is mineral-free and has a total dissolved solids (TDS) level near zero. It should be noted that the lack of minerals in the water makes it corrosive to metals such as steel and iron and can also inhibit plants' nutrient uptake ability. The latter issue can be addressed by including a fertilizer injection system to add nutrients to the condensate before applying it to the planting areas. Because it might contain heavy metals from contact with cooling coils and other HVAC equipment, condensate should not be used for human consumption. Condensate can be used for landscape irrigation and since condensate is simply water collected from HVAC coils it is also usable for fruits and vegetables. However, be careful to watch for potential for contamination from the HVAC unit. Depending on the amount of condensate available, combining rainwater harvesting and recovered condensate for irrigation can deliver a more consistent amount of harvested water. Mixing supply in this manner can also help to dilute heavy metal content.

Another potential source of reclaimed water is the Albuquerque Bernalillo County Water Utility Authority. For more information contact the ABCWUA http://www.abcwua.org.

Storage Systems

Storing harvested rainwater under or above ground is a viable option for many sites. Most ground-storage methods are simple enough to be installed by a landscape contractor, although the calculations for sizing them may require professional services. Regulations for ground-storage systems exist for particular areas within each of the biozones identified in this document due to flood plain designation, as in the Rio Grande Valley, or other factors. Contact Bernalillo County Public Works for applicable requirements for your site.

- ***Rain barrels*** **-** Rain barrels are tanks that hold roof runoff until it can be used either for hand watering or by an irrigation system. It is important to consider the capacity of the tank versus the potential volumes of water coming off the roof. Rain barrels typically range in size from 20 to 150 gallons and can be purchased in a variety of materials such as heavy plastic or wood (Photo 105). They can also be linked together to increase capacity. The barrel should also have an overflow mechanism to handle excess water. Most rain barrels include a spigot or hose attachment near the bottom so the collected water can be drained for use. Both the overflow mechanism and hose attachment should be oriented to drain excess water away from the building, avoiding potential foundation damage. A screen cover is required to keep out debris and prevent mosquito breeding. The barrel cover should also be designed to prevent animals or children from climbing into the barrel. Rain barrels should be placed on a secure, level base as they can weigh over 500 pounds when full. Elevating the bottom of the barrel one foot above grade can make it easier to maintain and fill water buckets.

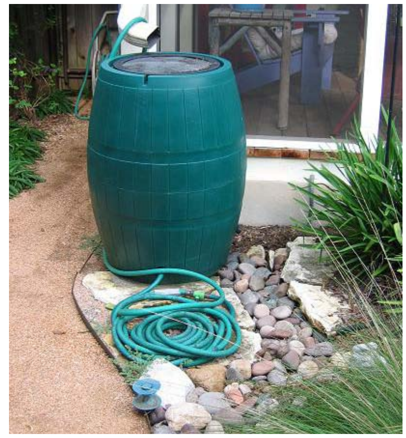

Photo 105. Rain Barrel

  Maintenance: Check that lids and hoses are attached and properly placed, that the spigot or other hardware is functioning properly, and that water is being dispersed in expected locations. Check and clear screens and downspouts feeding barrels.

- ***Cisterns*** **-** Cisterns are water storage tanks that can be used to store harvested stormwater above or below ground, as shown in Photo 106 and Photo 107. Relatively common in some parts of the US in the first half of the 20th century, the popularity of cisterns is increasing once again as water conservation is being encouraged. Present-day cisterns are predominantly used for irrigation due to concerns over water quality; however, modern cisterns can be outfitted with filters or other water purification methods when the water is meant for human or animal consumption.

Photo 106. Above-ground Cistern

Photo 107. Below-ground Cistern

Cisterns come in a wide range of sizes, materials and shapes, and can be constructed individually or in a connected series where the overflow from one cistern flows into the next. A number of manufacturers offer modular cistern systems which provide highly flexible configuration and capacity options. Some manufacturers also offer turn-key cistern design and installation services.

The appropriate tank volume is based on average rainfall amounts and the total square footage of area that will collect stormwater. Groups of residential units, such as apartments and commercial and office buildings, offer significant opportunities for collecting rainwater using cisterns. Cost and space required for the tank are additional considerations.

A cistern should be placed on a level surface or pad. Potential damage to adjacent features should be taken into account when determining where to locate the tank. Cisterns should be located for ease of maintenance or replacement. The locations of downspouts feeding into the cistern are also a factor. If the water stored in the tank will be accessed via a gravity-feed system, the height of the tank location relative to the landscape areas that will use the stored water is also a consideration. Water from the cistern can also be discharged using a pump connected to an irrigation system, hose, perforated pipe or surface channel that conveys water to the landscape (see Figure 126).

Roof Water Harvesting Capacity

Roof Area (sqft)	Total Water Harvested (cuft)	(gal)
1000	633	4737
2000	1267	9475
3000	1900	14212
4000	2533	18949
5000	3167	23687
6000	3800	28424
7000	4433	33161
8000	5067	37899
9000	5700	42636
10000	6333	47373
11000	6967	52111
12000	7600	56848
13000	8233	61585
14000	8867	66323
15000	9500	71060
16000	10133	75797
17000	10767	80535
18000	11400	85272
19000	12033	90009
20000	12667	94747
25000	15833	118433
30000	19000	142120
35000	22167	165807
40000	25333	189493
45000	28500	213180
50000	31667	236867

Note: Harvesting calculations based upon a 9.5 in/yr annual rainfall and an 80% collection efficiency

Cisterns have a removable lid or entry port for maintenance access. Cisterns can be left open to catch rain or connected to more elaborate systems that collect water from several locations and direct it into the cistern. Open systems should be designed to minimize water loss due to evaporation and to prevent algae growth. Outlet pipes should be positioned a few inches above the bottom of the tank to avoid sucking out sediment settled on the tank bottom. The tank should have an overflow pipe that does not require a pump to function with a capacity equal or greater than the inlet pipe. All inlets and outlets should be screened to keep mosquitoes, animals and debris out of the tank. In addition cistern water should be filtered prior to entering the irrigation system to avoid potential clogging issues.

Maintenance: The tank, screens on inlet and outlet pipes, and any gutters feeding into the cistern should be cleaned periodically to remove accumulated debris. The interior of the tank should also be checked periodically and maintained in accordance with manufacturer's requirements or according to best practices for the tank material. Performance of the overflow pipe should also be verified following significant storm events.

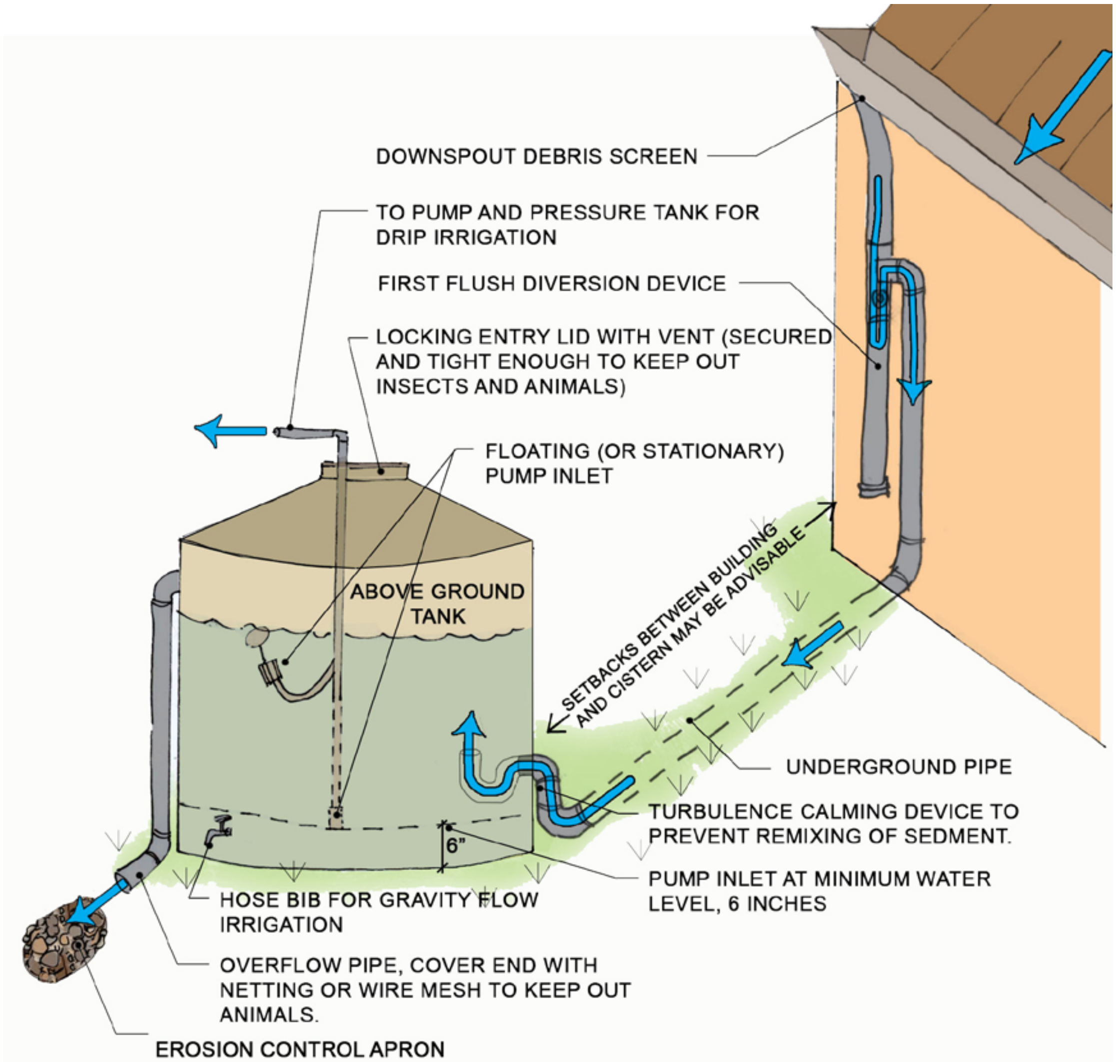

Figure 126.Cistern System

Irrigation System Design, Installation and Management

Designing an irrigation system requires an understanding of how the many aspects of the landscape work together. These aspects include site grading, microclimates, soil types and infiltration rates, and the water requirements of different plants. It also involves a basic understanding of hydraulics in order to calculate pipe sizes and system pressure losses. In order to develop an effective watering schedule, a basic working knowledge of plant types and evapotranspiration rates is needed. In addition, local plumbing codes and ordinances must be followed. Licensed irrigation designers and contractors and some irrigation supply companies offer irrigation system design and installation services. For information regarding considerations when selecting a professional see the "Hiring a Professional" section in this chapter.

Hiring a Professional

Certified irrigation designers are trained to evaluate specific site conditions and develop irrigation plans tailored to irrigate the site for optimum water efficiency and plant health. They are able to provide installation oversight to ensure the project is built according to their specifications. They should also be well-versed in the latest irrigation technology available. As-built or record drawings should be provided to document any variations in the installation of the system design, and the end user should be provided with all product warranties and operating instructions.

If your site will have a landscape maintenance manager, you may wish to consider hiring a Landscape Irrigation Auditor certified by the Irrigation Association. Certified Landscape Irrigation Auditors are trained in exterior water management and can help to ensure that water efficiency is maximized in your landscape.

- **Water Management -** Ensure your contractor will design your system with water efficiency in mind and use appropriate irrigation methods, such as drip irrigation, to achieve that efficiency.

Reducing Water Use

When initially installed, most plant materials will require more frequent deep watering in order to establish a healthy root zone. Once established, plants should be irrigated on an evapotranspiration (ET) watering schedule as recommended by Irrigation Association guidelines. When adjustments in the watering schedule are needed, these should be done monthly based on historical ET rates.

Some native and very-low-water-use plants may be weaned off irrigation over time, especially if they have been planted in water-harvesting swales or water catchments. This process should be carried out very slowly. Careful monitoring is necessary to delay irrigation until the maximum allowable depletion of soil moisture has occurred. This will vary based on soil type and the depth of the root system. Plants with shallow root zones will likely wilt more rapidly than those with deeper root zones.

It also may be possible to reduce irrigation to higher-water-use plants by watering less frequently but longer to encourage deeper root growth. It is important, however, to consider the soil type: faster-draining, sandy soils will require more frequent watering than those with higher clay content. Extra care should be taken when reducing or eliminating irrigation to trees. Even native, drought-tolerant trees will require some supplemental irrigation in times of drought. Trees may take several years to die, and regular observation to monitor for change is the best method for determining when a plant is experiencing stress.

Large shrubs and trees require that the irrigation zone be expanded as the roots and canopy reach farther and farther out from the original placement of the water source, as illustrated in the diagrams below. As this occurs, additional bubblers or drip emitters should be moved or added at the dripline of the tree (the area directly located under the outer circumference of the tree branches or canopy. Figure 127 demonstrates the evolution of a bubbler system to accommodate increasing plant size. Figure 128 shows modification of drip emitters over time to account for plant growth.

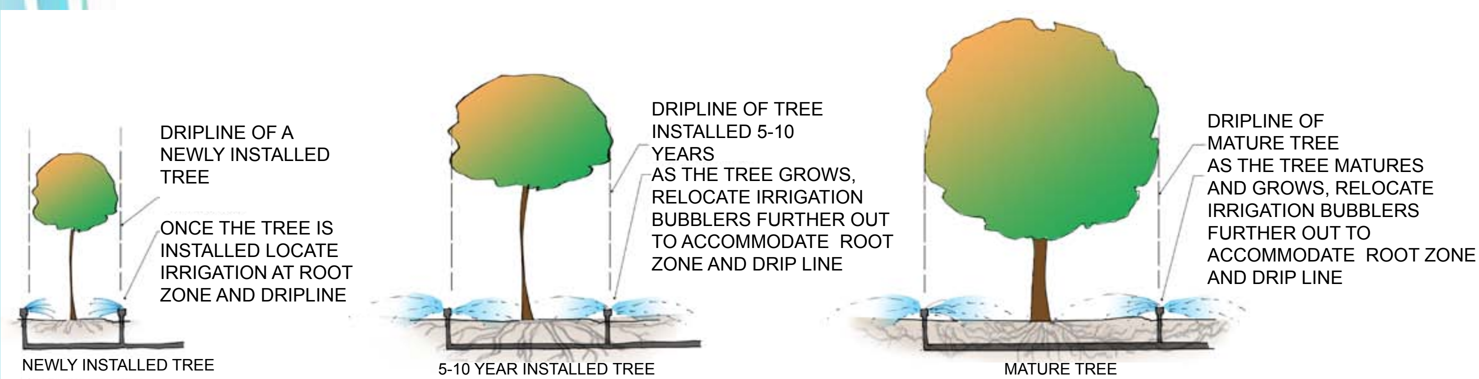

Figure 127. Bubbler Placement Modification Over Time

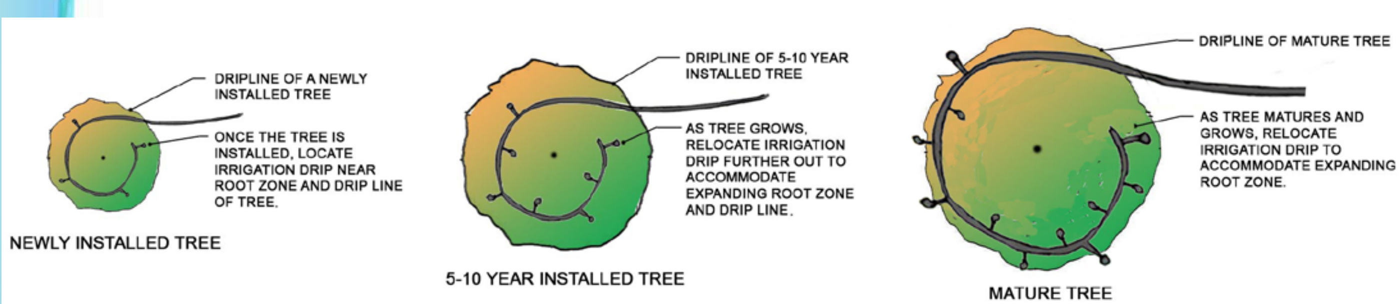

Figure 128. Drip Emitter Placement Modification Over Time

An efficient landscape irrigation system should have a watering schedule that delivers the proper amount of water for the root depth of the plants. Over-watering wastes water by allowing it to infiltrate to below or beyond the root zone, where the plant cannot access the water. Under-watering causes plants to develop shallow, more fragile root systems that inhibit robust growth and long-term plant health. Use a soil probe to check irrigation penetration depth. Push the probe into the ground as far as it will go easily and mark the surface grade level on the probe. Pull it out and measure to determine how deeply water has penetrated the soil.

Moisture Probe Depth Chart				
Plant Type	**Root Zone Depth (in inches)**	**Depth of Probe**		
		Water	**Wait to Water**	**Overwatered**
Groundcover / turf	6-12"	0-4"	4-12"	>12"
Shrub	12-24"	0-4"	4-18"	>24"
Tree	18-36"	0-4"	4-36"	>36"

For all plantings, water slowly, deeply and less often. Drip irrigation can achieve this automatically by applying water slowly and directly to the soil. Establishing an evapotranspiration (ET) watering schedule based on Irrigation Association guidelines will help to ensure that irrigation is applied at appropriate levels.

Irrigation frequency and duration should take into account both the needs of the plant species in the landscape as well as the soil type. Sandy soils drain rapidly, whereas clay soils hold moisture for longer periods. Soils around newly constructed buildings are often compacted, which inhibits moisture penetration. Make sure that water is penetrating to the appropriate root zone depth for each plant type and do not water again until it is needed.

Watch for signs of over- or under-watering and adjust the irrigation schedule accordingly. Over-watering can cause root rot, which can be indicated by dried green leaves on the plant. Soil that is consistently damp or has mushrooms or other fungus growth can also indicate excessive irrigation. The appearance of tree roots running on top of or near the soil surface can indicate watering that is too shallow.

- ***Turf Grass Irrigation***

  Wherever possible, it is best to choose low-water-use plants or turf grass. Turfgrasses typically employed for lawns and landscaping in Bernalillo County are either cool season or warm season grasses. Cool season grasses include Bluegrasses (Poa species) and its cultivars, and many varieties of Tall-Type Fescue (festuca species). These grasses generally grow in the cooler months of the year typically in March/April and September/October; they are dormant in the winter and in the summer. However irrigation of these grasses should continue in the summer months as they are not drought tolerant grasses. Warm season turfgrasses include Bermuda (cynodon species), buffalograss (Bouteloua syn. Buchloe dactyloides), and sometimes Grama Grass (Bouteloua gracilis) or others. These grasses generally grow from April/May through August/September. During the summer months it is important that they be irrigated; however they are generally more able to withstand the heat with less water than cool season grasses and can therefore be categorized as drought tolerant grasses. Grama grass for instance should need very little irrigation once established in all of Bernalillo County; buffalograss on the other hand will require some irrigation in the West Mesa, Rio Grande Valley and East Mesa bioregions. When turf grass is used be sure to:

  - Let the grass grow taller (to 3 inches) to promote water retention in the soil. The longer grass blades make the grass more water-efficient by shading the root zone and promoting deeper root growth.
  - Follow the Bernalillo County Water Conservation Ordinance regarding turf areas sizes and do not plant turf grass areas that are less than 10 feet wide in any dimension, as they are extremely difficult to water efficiently.
  - Water turf grass areas in the evening or early morning to avoid evaporation losses.
  - Do not operate sprinklers when it is windy or raining.
  - Install and maintain sprinkler head heights per the manufacturer's recommendation to avoid water waste from spray being blocked by plants.
  - Aerate turf grass areas and de-thatch to allow for proper infiltration of irrigation water. Thatch is the fibrous area between the soil and the grass shown in Photo 108.

Photo 108. Turf grass thatch

  - Water only when necessary, generally every three or four days. Watering less frequently promotes deeper root growth which increases the lawn's water efficiency. It takes 660 gallons of water to supply 1,000 square feet of lawn with one inch of water.
    - A good way to check whether turf needs watering is to step on the grass. If it springs back up when you move, it doesn't need water. If it remains flat, watering is appropriate.

- ***Irrigating Trees***
  - Provide gaps in the watering schedule to allow soils to dry. This permits needed aeration for tree roots.
  - Proper irrigation will promote tree health and make trees less prone to insect damage and disease. The depth of soil infiltration after watering should be checked to verify that trees are not being under- or over-watered. Deeper irrigation encourages deeper root growth, and deeper roots are less apt to be stressed by higher soil temperatures closer to the surface.

- ***Irrigating on Slopes***

  In Bernalillo County (and the arid southwest in general) it is important to minimize the use of irrigation on slopes as much as possible because irrigation of sloped landscapes can cause soil erosion and water waste. However, for very specific cases, irrigation may be necessary and should follow the general guidelines below. It should also be noted that spray irrigation should be avoided on slopes greater than 1:5 (1 foot of vertical rise to 5 feet of horizontal distance).
  - Place bubblers on the uphill side of plants. See Figure 129 for an example of this type of installation.
  - Construct a watering well around the base of the plant or plant group to hold and allow irrigation water to infiltrate the plant root zone.
  - Program your controller to irrigate slopes over several cycles, allowing water to infiltrate while preventing excess runoff.

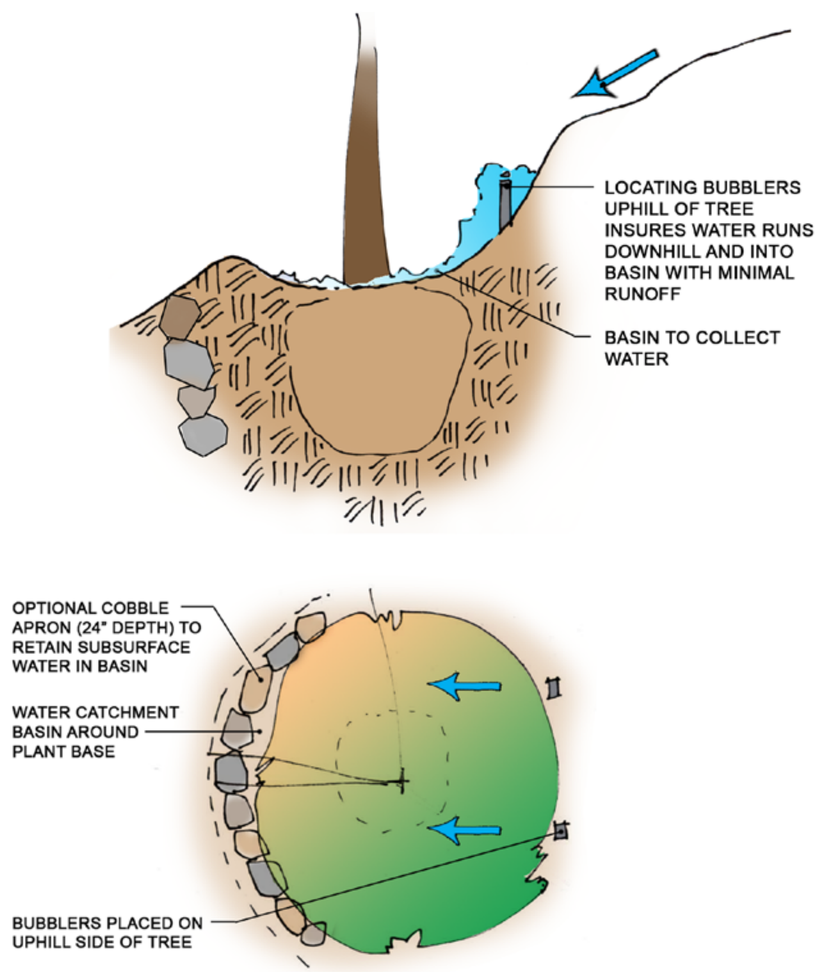

Figure 129. Bubbler Placement on Slopes

Best Management Practices for Irrigation System Maintenance

Irrigation systems should be inspected, adjusted and repaired on a monthly basis. Inspection should include adjusting valves, heads, checking nozzles and verifying the operation of sensors. Drip irrigation filters and emitters should also be checked monthly and cleaned or replaced as needed. Turn on the irrigation system and visually make sure that all emitters are operating properly.

An annual water audit should be performed to check the system's efficiency and determine if modification to the irrigation water schedule is needed. The following issues are typically checked during an irrigation system audit and provide a good initial starting point for improving water efficiency:

- Improper operating pressure – Operating at the wrong pressure causes inefficient system operation, wasting water and potentially damaging equipment.
- Tilted sprinkler heads (should be straightened).
- Broken heads or pipes.
- Obstructed spray patterns.
- Low head drainage – Loss of the water that remains in the pipe after the system turns off. Gravity will cause the water to flow through the pipe to the lowest point, where it leaks in to the landscape. By using sprinklers with built-in check valves, this water will be retained within the pipe and not lost as excess water in the landscape.
- Clogged nozzles or emitters.
- Improperly mixed equipment – Never mix different types, brands or models of sprinklers or different nozzles' on the same irrigation zone as this will contribute to water loss due to inefficiencies.
- Sprinklers not installed at the proper height – Sunken sprinklers will often not pop up high enough to spray over the height of the grass, disrupting the proper spray pattern of the water.
- Improper arc adjustment of sprinkler head.
- Rotary heads that no longer rotate.
- Use of non-pressure-compensating emitters.
- Leaking pipes and equipment.
- Compaction and excessive turf thatch.
- Backflow prevention devices – Inspect periodically, at a minimum as determined by local ordinance.
- Hidden leaks – Use your water meter to check for hidden leaks. Read the meter at the beginning and end of a two-hour period when no water is being used in the house or landscape. If the meter reading isn't exactly the same, there is a leak somewhere in the system.
    - Check for leaks in hose bibs as they can lose more than 73 gallons per day depending on the size of the leak.
- Freeze damage – winterize systems in areas where freeze damage is a real threat. In warmer areas, the system should be maintained and operated to compensate for typical winter drought times.

Additional information on designing and installing irrigation systems, designers, and irrigation technologies is available through the websites listed below.

EPA
http://www.epa.gov/watersense/docs/home_draft_spec508.pdf
Information and resources for commercial and institutional water users

Bureau of Reclamation- Smart technology
http://www.usbr.gov/waterconservation/docs/SmartController.pdf

Irrigation Association Turf and Landscape Irrigation Best Management Practices
http://www.irrigation.org/Resources/Turf___Landscape_BMPs.aspx

Hiring a Professional
http://www.irrigation.org/hirecertified/
http://findalandscapepro.pbwiki.com/How+to+Hire+a+Pro

Construction Phase

The EPA notes that sediment runoff rates from construction sites can be much greater than those from developed and undeveloped sites. It can cause both physical and biological harm to receiving waters by contributing large quantities of sediment in a short period. A range of Best Management Practices for the construction phase of site development are available to help prevent or reduce adverse impacts from construction activities. The focus of this section is proper selection, design, construction and maintenance of these practices.

Compacted Soils and Construction Activities

Compacted soils occur when the weight of heavy machinery, vehicles, built structures or persistent foot traffic compress soil, reducing soil structure and pore space to create a hard, solid mass. The amount and impact of compression varies depending on the soil type. Soils high in clay content, such as those in the Rio Grande Valley, compact very easily. Water infiltration into densely packed soils slows and diminishes, and much of the water flows in a sheet across them. The result is increased volume and frequency of runoff carrying higher amounts of sediment and pollutants such as pesticides, fertilizers and oils. The sediment and pollutants are ultimately deposited in receiving waterways such as the Rio Grande.

Topsoil is a valuable water conservation resource and efforts should be made to preserve it during construction. When topsoil will be disturbed or removed during construction, plan to stockpile and save it for reuse. After construction, a thin layer of the stockpiled topsoil can be spread over the subsoil, which has been highly compacted by construction activities. Then the area is landscaped. Because the subsoil is compacted, water does not easily infiltrate, commonly resulting in erosion and poor plant growth. Preventing soils from becoming compacted helps to conserve water and saves money by protecting the investment in landscape plantings. It also minimizes the need for dust control during construction and for post-construction reclamation efforts.

To prevent unnecessary soil compaction and destruction of existing vegetation construction activities, vehicles, equipment and materials should be kept within a prescribed area. During the demolition and construction periods, existing trees and other vegetation to be retained should be surrounded with protective fencing out to the canopy dripline, at a minimum, to prevent compaction of soils within the root zone as shown in Figure 130.

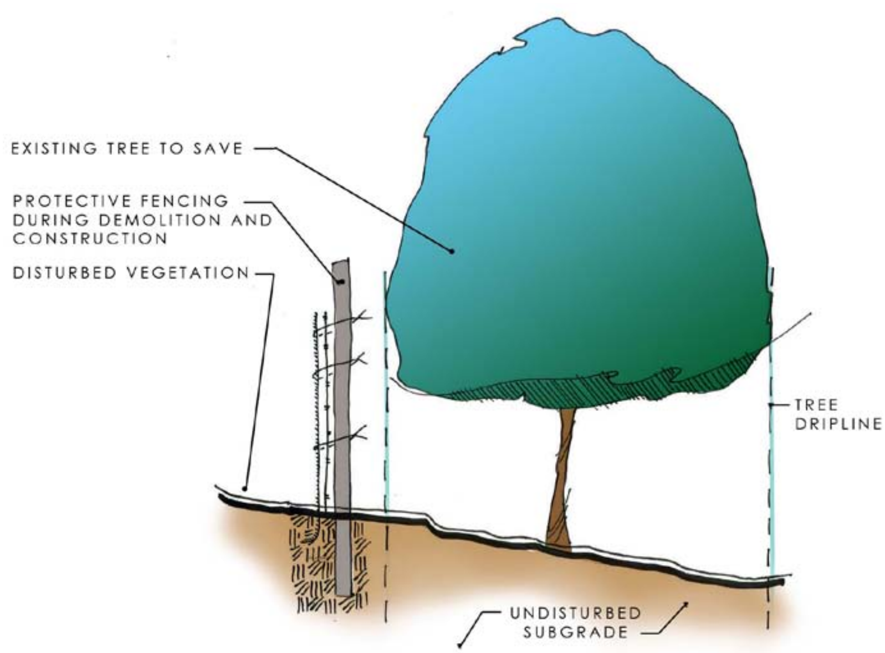

Figure 130. Tree Protection During Construction

Compacted soils can also occur on sites after construction due to high volumes of foot traffic. Thoughtful design and planning for pedestrian circulation keeps people on walkways and avoids soil compaction.

Pre-existing compacted areas can be mitigated through selective tilling or deep plowing to break up the compacted soil and enable the movement of water and air through it. Deep plowing should be performed prior to the application of salvaged topsoil. The addition of soil amendments can also help to restore soil infiltration capacity and fertility.

Best Management Practices for Construction Site Runoff Control and Water Conservation

A comprehensive approach to addressing and minimizing construction site runoff should include the following areas (adapted from Brown and Caraco, 1997):

1. Minimize Clearing and Grading

Limit clearing and grading to the minimum area required for the build-out. Take all possible measures to avoid clearing or grading highly erodible soils, steep slopes, stream buffers, wetlands, springs or stormwater infiltration areas. The site limits of disturbance should be mapped and clearly delineated with flags, fencing, or other means. Construction personnel should be made aware of expectations regarding the limits of disturbance.

2. Protect Waterways

Clearing and grading activities near waterways should be kept to a minimum. Silt fencing and earthen dikes should be installed to prevent deposition of sediment from the construction area into the waterway.

3. Limit Soil Exposure through Phased Construction

Divide construction into phases and limit grading activities to the phase currently under construction in order to decrease the time that soil is exposed. This helps to decrease the potential for erosion. Subsequent construction phases should begin only when the last phase is near completion and exposed soil has been stabilized. Construction scheduling should include the installation of erosion and sediment control measures prior to beginning construction and should set time limits for soil stabilization after each phase of grading.

4. Immediately Stabilize Exposed Soils

Soils exposed during construction should be stabilized as quickly as possible and within no more than two weeks of being exposed. If permanent stabilization measures cannot be put in place within the two-week window, temporary erosion control measures should be used on exposed areas to protect the soil. Potential temporary control measures are listed below.

- Seeding is appropriate for areas where vegetative cover is the most effective and practical soil stabilization technique. It can also be used on rough-graded areas that will not be regraded for at least one year or growing season. Seeding plans should include a detailed seed list, as well as seeding application requirements such as timing, mulching, and irrigation to facilitate good germination rates and successful vegetation establishment.

- Soil roughening is a temporary stabilization technique that involves tilling, tracking or scarifying. It can be used to address areas of disturbance when revegetation efforts are limited due to seasonal planting requirements. Roughening can be done either after final grading or for temporary stabilization of areas that will be inactive for a short time during the construction period. The depressions created by roughening should be between 2 inches and 6 inches deep and spaced approximately 6 inches apart. Roughening is appropriate for all slopes but should follow the contours of the sloping areas. The technique can be used to stabilize piles of excavated soils. If construction equipment is used to perform the tracking, care must be taken to avoid over-compaction of disturbed soils. Roughening is not effective for sandy or extremely rocky soil types.

- Geotextiles or pervious filter fabrics can be used for matting to stabilize flow channels or swales and to protect seedlings on slopes until established. They are also useful for temporary protection of exposed soils, for example, temporary soil piles left overnight during construction. They can also be used to separate and enhance the effectiveness of erosion control measures such as rip-rap by preventing soils from eroding underneath. For all applications, the geotextile must be properly anchored to achieve continuous contact with the soil surface, avoiding potential erosion underneath it.

- Gradient terraces or stepped slopes prevent or reduce erosion damage by collecting, slowing and redistributing runoff flows while increasing the amount of overland flow. They are suitable for use on slopes lacking existing vegetation, but they require stable runoff outlets that direct exiting runoff to appropriate receiving areas. They are not suitable for slopes composed of sandy or rocky soils, or those with shallow soils.

5. Protect Steep Slopes and Cuts

Avoid cutting and grading steep slopes (slopes in excess of 15%). For sites with steep slopes, diversions or a temporary slope drain should redirect all water flowing onto the slope. Silt fencing should be installed at the top and toe of the slopes during the construction period and left in place until revegetation efforts have succeeded. To facilitate revegetation on steep slopes, techniques such as straw or compost wattles or geotextile erosion-control blankets should be used in conjunction with seeding or mulching.

6. Install Perimeter Controls to Filter Sediments

The entire perimeter of the construction site should have properly installed silt fencing. The addition of a fiber roll or wattle applied on the site-facing or internal side of the silt fence will provide additional sediment filtration capacity. For areas that experience heavy runoff flows, a properly-sized earthen dike with a stabilized outlet should be created. Adequately-sized inlet controls should be included at catch basin inlets that receive stormwater flows from the construction site.

7. Use Sediment Settling Controls

Temporary sediment basins should be created where space is available to detain runoff and allow sediment to settle out. It is important to ensure that discharge from basins is non-turbid. Using multi-cell basin design and skimmers will increase sediment drop-out rates.

8. Train Contractors on Stormwater Site Plan Implementation

Contractors and construction staff should be trained to install and use required erosion and sediment control measures and processes.

9. Control Waste at the Construction Site

Plan for, document and educate construction personnel about site construction waste disposal (including discarded building materials, concrete truck washout, chemicals, litter, and sanitary waste) and how waste materials will be dealt with to minimize adverse water quality impacts. Plans should designate waste material storage areas and ensure that they are located away from catch basin inlets and waterways.

10. Inspect and Maintain Best Management Practices (BMP)

The site stormwater plan should address site construction runoff and erosion control BMP inspection procedures and frequencies. Inspections should occur at regular intervals as well as immediately before and after precipitation events. The plan should also describe how BMPs will be maintained.