City of El Paso

Engineering Department

Drainage Design Manual

May 2013

19. Green Infrastructure - OPTIONAL

19.1. Background and Purpose

Development and urbanization alter and inhibit the natural hydrologic processes of surface water infiltration, percolation to groundwater, and evapotranspiration. Prior to development, known as predevelopment conditions, up to half of the annual rainfall infiltrates into the native soils. In contrast, after development, known as post-development conditions, developed areas can generate up to four times the amount of annual runoff and one-third the infiltration rate of natural areas. This change in conditions leads to increased erosion, reduced groundwater recharge, degraded water quality, and diminished stream flow.

Traditional engineering approaches to stormwater management typically use concrete detention ponds and channels to convey runoff rapidly from developed surfaces into drainage systems, discharging large volumes of stormwater and pollutants to downstream surface waters, consume land and prevent infiltration. As a result, stormwater runoff from developed land is a significant source of many water quality, stream morphology, and ecological impairments.

Reducing the overall imperviousness and using the natural drainage features of a site are important design strategies to maintain or enhance the baseline hydrologic functions of a site after development. This can be achieved by applying sustainable stormwater management (SSWM) practices, which replicate natural hydrologic processes and reduce the disruptive effects of urban development and runoff.

SSWM has emerged as an alternative stormwater management approach that is complementary to conventional stormwater management measures. It is based on many of the natural processes found in the environment to treat stormwater runoff, balancing the need for engineered systems in urban development with natural features and treatment processes.

SSWM strategies focus on mimicking predevelopment conditions using native or improved soils, vegetation, and bioengineering applications to reduce and treat the increased flow that development creates. Unlike the conventional method of quickly discharging stormwater offsite and conveying it to a downstream watershed, SSWM treats stormwater as a resource onsite. Site assessment, site planning, and onsite stormwater management guide the initial design phases of a project to maintain a more hydrologically functional landscape even in denser urban settings.

Green Infrastructure (GI) refers to constructed features used as a strategy in SSWM. GI uses constructed, natural systems to manage stormwater in a manner that promotes capturing, cleaning and infiltrating stormwater. Unlike single-purpose gray stormwater infrastructure, which uses pipes and concrete lined channels to convey stormwater, GI uses vegetation and soil to manage rainwater where it falls. Weaving natural processes into the built environment will slow down runoff velocities, reduce erosion, increase infiltration and reduce pollutants. GI often results in wildlife habitat and generally promotes the overall health of the watershed.

This chapter is designed to inform designers, developers, policymakers, citizens, and others in the CoEP about the benefits and design criteria for the implementation of SSWM through the use of GI.

19.1.1. Philosophy and Definitions

Stormwater runoff is often viewed as a nuisance in urban developments, a waste product, something to be "gotten rid of." However, in an arid location like El Paso, it is actually a valuable resource. When managed thoughtfully, and creatively, stormwater runoff can contribute to more attractive, healthy, and sustainable neighborhoods.

The concept of GI is emerging as a highly effective and attractive approach to controlling stormwater pollution and protecting developing watersheds of urbanized communities throughout the country (Natural Resource Defense Council [NRDC], January 2009). GI integrates stormwater management controls into landscaped green spaces. In doing so, it provides many benefits. It slows and reduces runoff flows down streets, soaks rainfall into the ground to irrigate vegetation and recharge groundwater, removes pollutants from runoff, and reduces localized flooding during storm events. It also creates attractive streetscapes, restores natural habitat, buffers urban noise, filters air pollutants, and helps connect neighborhoods, schools, parks, and business districts.

The terms GI and LID are often used interchangeably to define structural and non-structural SSWM techniques. For the purposes of this guidance, the terms are analogous and the chapter will most frequently employ the term GI. The definition for GI can vary in use and meaning. GI has been used to refer to anything from trees in an urban setting to planned, engineered infrastructure in a community. For purposes of this chapter, GI refers to an adaptable term used to describe an array of materials, technologies and practices that use natural systems—or engineered systems that mimic natural processes—to enhance overall environmental quality and provide utility services.

As a general principal, GI techniques use soils and vegetation to slow, infiltrate, evapotranspirate and/or reduce stormwater runoff. The EPA defines GI similarly and recognizes GI as a means to manage stormwater runoff. Examples of GI include biofiltration basins (i.e., rain gardens), porous pavement, and median swales. These systems are planned, designed, and managed to mimic natural systems.

19.1.2. Green Infrastructure Practices Recommended for El Paso

Since the goal of GI design is sustainability and to design, in harmony, with the natural landscape and preserve and restore vital ecological services that benefit both our communities and nature, it is important to consider the ecological services provided by arroyos in the El Paso landscape. They convey stormwater runoff, recharge groundwater, support unique plant communities, and create wildlife habitat and migration corridors. All are vital functions, and worth trying to mimic in sustainable design approaches.

The design guide, *Green Infrastructure for Southwestern Neighborhoods*, noted the following about arroyos:

"As development occurs, washes have often been… relegated to backyards and blocked from view by large walls, where they are used as sites of criminal activity, used as dumping grounds, invaded with weedy/non-native plants."

By intentionally utilizing GI to create attractive, landscaped spaces in the public ROWs, CoEP has an opportunity to create added community benefits by bringing drainage features into plain site where they can be appreciated as an asset, landscaped for beauty, and not hidden and abused.

The GI concepts presented herein, can mimic some of the native landscape ecological functions on a small (neighborhood) scale and focus on biofiltration basins and park ponds because water and sediment is managed at the surface where it is visible and easy to maintain; native vegetation builds soil structure and promotes long term infiltration; they mimic natural ecological functions; and they provide supplemental benefits such as wildlife habitat, landscape aesthetics, recreation opportunities, shade, noise and air pollution reduction.

19.2. Green Infrastructure within the Public Right of Way

19.2.1. Bioretention Basins

Bioretention basins are one of the GI techniques most suitable for El Paso streets. They are small scale, distributed retention basins, planted with native vegetation. Hence, the name, "bio-retention." Conventional retention basins historically used in El Paso consist of large basins located at the downhill end of a development ("end of pipe"). They are typically eyesores, pose safety concerns, and create maintenance headaches. Conversely, bioretention basins are used to distribute stormwater controls uniformly throughout a development, control stormwater runoff near the point of generation rather than at the "end of pipe," keep individual basins small, manageable, and safe, and use stormwater to help create attractive neighborhood amenities.

Bioretention basins can take a number of shapes and forms, but they have common elements:

- Shallow basins, typically ranging from 3 to 18 inches deep;
- Inlets or some method to deliberately convey water into the basin;
- Sediment traps at inlets to catch sediment, leaf litter, or trash;
- Loose, friable soils in the basin bottom to promote infiltration; and
- Deep rooted vegetation to further promote infiltration and provide attractive landscaping.

Four bioretention basin variations are included in this section:

- Basins placed in street medians with curb cuts to accept drainage from streets;
- Basins placed along street edges with curb cuts to accept drainage from streets;
- Shallow bioretention basins located between sidewalks and street curbs, but without curb cuts so they collect runoff from sidewalks but not streets; and
- Bioretention with below-grade storage chambers to provide additional stormwater storage and infiltration space hidden beneath the basin.

19.2.2. Locating Bioretention Basins within Street Right of Ways

Bioretention basins, and other GI techniques, work best when they are located immediately adjacent to the impervious surfaces that generate the most stormwater runoff – streets, driveways, parking lots, building downspouts, and sidewalks. When used in public street ROWs, the typical goal is to distribute GI stormwater controls uniformly along every street, in medians and street edges.

Potential locations for bioretention basins along streets are shown in Figures 19-1 through 19-4. The figures show a range of options for locating bioretention basins within existing ROW widths

and expanded ROWs for residential streets, minor arterial streets, and major arterial streets. Space for bioretention basins must be created within medians and parkways. To do so, designers must consider a range of alternative and expanded ROWs to create the needed greenspace.

Figure 19-1 presents a standard 54-foot local residential ROW without GI and an alternative cross section incorporating GI and one-way streets. Figure 19-2 presents options for GI within expanded residential ROW widths. Figure 19-3 presents options for GI within major and minor arterials. Figure 19-4 presents a conceptual layout called Street Edge Alternative (SEA), incorporating one-way residential streets to create space for expanded parkways containing bioretention basins. In the SEA alternative, on-street parking is replaced with narrow temporary parking lanes for delivery vehicles plus off-street parking.

19.2.3. Distribution and Sizing of Bioretention Basins

Bioretention basins, and all GI, work best when basins are uniformly distributed along streets, and the drainage areas leading to individual basins are small, generally one-half to one acre drainages. The goal is to catch runoff close to the point of generation before runoff volumes and velocities become large.

A typical goal for sizing an individual bioretention basin is to size it to hold the runoff volume from a ½ inch to 1 inch (or greater) rainstorm from the contributing impervious drainage area. This is not an exact requirement, but if the basins are much smaller, they can become overwhelmed in larger storms.

Selecting the location, number, and size of bioretention basins must be done in conjunction with the sizing of Park Ponds (see Section 19.3) to achieve the needed retention volume for the entire development.

Estimated storage volumes for bioretention basins can be calculated from the basic geometry of each basin using the top width, bottom width, basin length, basin depth, and sideslope geometries. Basin pool depths are established by the curb cut elevation and the basin bed elevation, as shown in Figure 19-7. Storage volumes in basins can decrease significantly if the bed of the basin is not flat, as shown in Figure 19-7, and instead is located on an inclined slope. Also note that storage volumes decrease as profile slopes increase due to lengthening sideslopes. Estimated storage volumes used in example calculations presented in this chapter were based on flat slopes and should not be considered representative of project-specific conditions. Storage volumes for below-grade storage chambers/infiltration systems will be a function of the specific products used and the configuration in which they are installed. Designers must calculate retention volumes for individual basins and the total retention volume for all GI incorporated into a development based on the geometries and designs selected.

19.2.4. Bioretention Basin Design

19.2.4.1. Site Inspection and Soil Testing

The goal of bioretention is to catch stormwater runoff, filter the runoff through mulch, soil, and vegetation, and promote infiltration of water into the underlying soils. Bioretention basins are designed to infiltrate collected water within 24 hours. Thus, soil types and characteristics are important factors to basin performance and a soils investigation should be conducted to document representative conditions throughout the project area. Soil studies can be coordinated

with geotechnical investigations that may be conducted for other project needs but must collect added information to support decisions related to stormwater infiltration capacities and horticultural needs. Soils investigations should document the following in representative locations where GI will be located:

- Soil type and compaction;
- Presence of impermeable layers such as caliche or clay layers;
- Presence of topsoil and soil organic matter;
- Presence of fill or waste materials;
- Depth to bedrock and groundwater; and
- Infiltration/percolation rates.

The primary goals of the investigation are to assess the ability of the soils to support stormwater infiltration and support healthy plant growth. Inspections can be conducted via drill rig, test pits, or hand augers, as may be appropriate for the scale of the project.

Infiltration/percolation tests should be conducted at representative locations to evaluate potential stormwater infiltration rates. Such tests should be performed at a depth that will represent the bottom elevation of the future bioretention basins, typically 1 to 2 feet below ground surface.

Impermeable layers such as caliche or rock should be noted. If they are shallow, it may be possible to rip or remove them to promote deeper stormwater infiltration from bioretention basins.

Soils should be inspected for the presence of topsoil and organic matter (A Horizon Soils) that will help support healthy plant growth vs. the presence of waste, fill material, or rock that may inhibit plant growth.

Professional judgment is required in the interpretation of all soils reports and in the subsequent preparation of bioretention basin designs, as initial soil investigations will likely represent native or undisturbed conditions prior to construction. Native soils are often highly disturbed by construction activities so undisturbed conditions may not represent post-construction conditions. Topsoil is typically removed and remaining subsoil highly compacted by conventional construction methods. Both actions will impact the performance of bioretention basins to promote infiltration and support plant growth. Where native soils can be protected during construction, they should be. Where they cannot be protected, steps will need to be taken during basin construction to restore disturbed soils.

Utility conflicts can present challenges for incorporating GI. Existing or planned utility locations should be documented during the planning stage to minimize utility conflicts with bioretention basins.

Overall site slopes and geology should also be considered when locating GI features and consideration given to whether infiltrated stormwater may intercept shallow bedrock shelves or confining layers and create potential seeps in unwanted downslope locations.

19.2.4.2. Basin Locations, Shapes, Sections, and Profiles

"Off-Line" Design

In the layouts presented in this section, the bioretention basins are constructed in an "off-line" design. That means that basins are located off to the side of the stormwater flow path (the curb and gutter), water enters the basins through a curb cut, and when the basins fill up no more water will enter them until water infiltrates and the water surface drops below the elevation of the curb cut. In this configuration, water does not flow through and out of the basin, so flow velocities through the basin are limited, which helps prevent erosion and mulch wash-out.

Locations and Shapes

In street ROW bioretention basins can be located in medians or along street edges between curbs and sidewalks. Figure 19-5 presents an example plan view and cross sections for a basin located in a street median with curb cuts to accept runoff from the streets. Figure 19-6 presents an example plan view and cross sections for a basin located on a street edge with a curb cut to accept runoff from the street. The layouts are similar except for the inlet placements and edge dimensions.

In street medians, inlets are needed from both sides of the street. On street edges, a single inlet is needed for each basin.

On street edges, if parking is expected next to the basin, a "step out" bench should be incorporated on the street side if it is anticipated that people may step out of a car onto the edge of the basin. Similarly, it is helpful to include a buffer strip along sidewalk edges so that pedestrians do not step off the edge of the sidewalk directly onto a steep sideslope. Along street edges, it may also be helpful to include step stones across a basin if individual basins are long, there is limited room to walk around them, and it is anticipate that people may walk across the basins to/from cars.

Basin shapes can vary to suit the aesthetic design of the landscape plan.

Basin Sections and Profiles

Two approaches are typically used for basin sideslopes; see the examples in Figures 19-5 and 19-6. One approach is to maintain vertical or near vertical sidewalls using landscape rocks. This can help maximize storage volumes and create the appearance of a rocky creek bed. The second approach is to use gently sloped, vegetated soil sideslopes, at 3H:1V maximum slope if sited in the regulatory floodplain, 4H:1V if not sited in the regulatory floodplain.

Plants can be incorporated into the basin bottom, sideslopes, or elevated planting benches. See Section 19.2.8 for landscape considerations.

A conceptual basin profile is shown in Figure 19-7. Key points include the following:

- The elevation of the curb cut sets the water surface elevation in the basin. The distance between the curb cut and the bed of the basin sets the pool depth.
- On sloped streets, it is important to make sure the ground surface, curb, and sidewalk elevations on the downhill side of the basin are above the curb cut elevation so that water does not spill out of the basin over sidewalks or curbs.

- Locating the curb cut on the downhill end of the basin will result in a shallower inlet channel; locating it on the uphill end of the basin will require a longer inlet channel from the curb cut to the bottom of the basin.

19.2.4.3. Basin Depths

The depth of the basin is primarily a function of the soil infiltration rate, plus aesthetic and safety considerations. Bioretention basins should be designed so that all water infiltrates or evapotranspirates within 24 hours. This prevents the breeding of mosquitoes and allows the use of a wide range of plants.

The basin depth should first be based on the measured soil infiltration/percolation rate. For example, if an infiltration rate of 8 inches per day was calculated from the testing, the maximum pool depth should be limited to 8 inches so that all water will infiltrate in 24 hours. If a higher infiltration rate was measured in sandy soils, greater pool depths can be used.

Maximum pool depths are typically limited to about 15 inches for aesthetic and safety concerns. For larger basins located in street medians with limited access, pool depths may be increased up to 18 inches. In a small narrow basin located next to a sidewalk, the basin depth should be limited to 6 to 12 inches.

19.2.4.4. Shallow Bioretention Basins without Curb Cuts

In narrow spaces between sidewalks and curbs where it is not practical to make the basin large or deep enough to allow curb cuts and collection of water off of streets, a shallow basin can be installed without curb cuts. These basins will collect runoff from adjoining sidewalks and water will sheet flow into the garden rather than enter it through a curb cut inlet. An example cross section is shown in Figure 19-7. This configuration collects runoff from a limited drainage area but harvests stormwater to irrigate street trees or other landscaping.

Both the bed and sideslope of the basin should be mulched or covered with decorative river rock as water can cause erosion gullies on the sideslopes where it enters the garden.

19.2.4.5. Basin Construction, Erosion and Sediment Control, and Soil Bed Preparation

Streets, curbs, and sidewalks will typically be constructed prior to bioretention basins and often the area designated for the bioretention features will be disturbed and compacted during construction. To the extent possible, disturbance of bioretention basin locations should be minimized, construction equipment excluded from those areas, and debris, rubble, asphalt, or concrete washout prohibited from those locations.

Future bioretention locations can be used for temporary sediment control basins during construction as long as the locations are subsequently cleaned, soils restored, and basins properly prepared for bioretention.

It is best to construct bioretention basins, and all GI features after all adjoining and uphill properties are constructed, site soils stabilized, and erosion and sediment migration eliminated. Eroded soils from un-stabilized properties can quickly destroy a completed bioretention basin by plugging soils and smothering plants and mulch. Stringent erosion and sediment control provisions must be included in GI construction documents.

Bioretention basins should be excavated with a backhoe or excavator operating from outside the footprint of the basin. Equipment such as skid loaders or front end loaders should be prohibited in areas where basins will be constructed to avoid soil compaction. Soils in the bed of the basin must be kept loose and friable. Any compacted soils should be restored by ripping and tilling soils to a depth of 12 inches or greater, as necessary, to restore compacted soils. Soils compacted during construction of curbs, sidewalks, or inlets must be restored in the same manner. Identify all utility locations before doing so.

Most native plants adapted to the arid El Paso environment may not need a large amount of soil organic matter. However, if topsoil has been stripped from the site or soils compacted during construction it may be beneficial to till 2 to 3 inches of mature, stable, well-aged compost or similar organic matter into the soil prior to fine grading to restore organic matter and texture to the soil. Consult with a horticulturalist or landscape architect on the soil organic matter and nutrient needs for the plants selected for the basins.

19.2.5. Curb Cuts, Inlets, and Sediment Traps

Stormwater should be directed to bioretention basins in a controlled manner since flowing water will create erosion gullies on unprotected slopes, even on shallow, gentle slopes.

In shallow bioretention basins without curb cuts, water will enter basins from adjoining sidewalks by flowing down sideslopes, so all slopes should be mulched with wood or river rock.

Curb cuts and inlets are used to convey water into bioretention basins designed to collect water from streets. Inlets to basins should convey water into the basin while preventing erosion at the let-down point. Common approaches are rock chutes, concrete flumes, or stone steps, as shown in Figure 19-8. Rock chutes are easiest to install but fill up with sediment over time so require periodic removal, cleaning, and replacement for maintenance.

A sediment trap is intended to provide a location for the deposition and easy clean-out of accumulated sediment, trash, or debris preventing materials from plugging garden soils over time. It also prevents erosion and scour where water enters the basin and helps spread water across the garden bed.

19.2.6. Below Grade Storage Systems

Additional stormwater retention volume can be incorporated beneath bioretention basins through the use of below grade storage and infiltration chambers placed beneath the beds. See Figure 19-9 for conceptual plan and profile illustrations of this configuration. Numerous products are available in the marketplace for this purpose including modular block systems, perforated pipes, arch systems, and various chamber systems. Materials range from plastic to galvanized steel to concrete.

Given the range of products available, no single design detail is appropriate. The following are general considerations for this type of system. Designers should work with manufacturers to customize designs for specific project applications.

Thought must be given to how water will be directed into the below grade storage chamber. Approaches include infiltration into the chamber through permeable soils, overflow into the chamber through a drop inlet structure, or a combination of both. Approaches will depend on the type of product used. Where inlets are used, include a trash filter to prevent mulch, trash, and

large sediment from entering the chamber. The advantage of inlets is that they can rapidly convey water from sudden large storm events. The disadvantage is that they may also convey suspended sediment into the chamber, which can lead to plugging.

Cleanout risers should be installed in all below grade storage systems at ends or corners of systems to ensure all reaches of the system are accessible.

Permeable, open wall chamber systems require a filter layer to prevent soils from migrating into the chamber, while also allowing water to soak into it. Some design guides specify that such chambers be wrapped with filter fabric for this purpose. Bioretention experience in other parts of the country has found that filter fabric tends to clog with fine sediments. Due to the heavy sedimentation El Paso experiences, filter fabrics should not be used for this purpose. Other systems have been developed using graded gravel layers in lieu of fabric and can be considered.

Below grade storage systems have the potential to collect and infiltrate much larger volumes of water in the same area than can be managed in a bioretention basin alone. As a result, consideration must be given to how well and how deep the water will infiltrate based on localized soil types and geology and whether infiltration of large volumes of water in a concentrated location may cause seepage issues nearby. Soil types, confining layers that can cause the lateral migration of infiltrated water, topography, the location of structures, retaining walls, unstable soils, and locations of below grade utility lines that can potentially create water flow conduits should be considered when locating below grade storage and infiltration systems.

Landscape plans must take into account the location of the below grade storage systems. Planting zones should be created outside the footprint of the storage chamber as the chambers will inhibit deep penetration of plant roots. Deep root penetration is important for plant survival in El Paso's arid climate.

If drop inlets are used to convey water from bioretention basins into below grade storage systems, water will flow through the bioretention basin from the curb cut to the drop inlet. High flow velocities can displace wood mulch. In such situations, decorative river rock mulch may be more appropriate in the center of the basin.

19.2.7. Design Considerations for Steep Streets

Curb cuts and inlets are used to convey water into bioretention basins that collect stormwater from streets. On steep streets with longitudinal slopes greater than cross slopes, consideration must be given to directing water to curb cuts so that runoff does not bypass the inlets. It is important to assure that stormwater is readily able to enter the basins along the length of the street so that significant runoff does not accumulate at low spots, produce street ponding, or overwhelm downstream intersections and basins. As shown in Figure 19-10, options to direct stormwater to inlets on steep streets include depressed inlets with vanes, depressions (valley gutters) across the street, shallow speed bumps across the street and/or trench drains across the street.

It is important to remember that streets should be crowned to direct stormwater to the outer edges of the roadway and that curb cuts should be placed every 40 – 50 feet along the curb. As streets get progressively steeper more aggressive approaches must be used to direct stormwater into the bioretention areas. For slopes greater than 3%, speed bumps and/or trench drains are

recommended to ensure stormwater is directed to the bioretention areas and does not bypass the curb cuts/inlets.

Other design considerations for individual bioretention basins on steep streets include the following:

- It is important to make sure the ground surface, curb, and sidewalk elevations on the downhill side of the basin are above the curb cut elevation so that water does not spill out of the basin over sidewalks or curbs (See Figure 19-7).
- Locating the curb cut on the downhill end of the basin will result in a shallower inlet channel; locating it on the uphill end of the basin will result in a significantly longer inlet channel from the curb cut to the bottom of the basin since the uphill street elevation will be much higher than the downhill end.
- The basin bottom must be graded flat to maximize the basin bottom footprint and consequently the storage volume in the basin.

The distribution of bioretention basins uniformly along the length of a street upstream of intersections can significantly reduce the amount of stormwater ponding that occurs at intersections and other low lying areas. By integrating SSWM features into streetscapes, rather than conveying all runoff to the bottom of a hill, flows at important locations, such as intersections, are reduced.

19.2.8. Landscaping

19.2.8.1. Mulch

Two types of mulch are commonly used in bioretention basins, shredded wood mulch and rock mulch.

Wood mulch keeps soil cooler, retains moisture, absorbs pollutants, and degrades over time to add organic matter to soil and encourage the growth of beneficial soil microorganisms. It is also less costly than rock mulch. However, it is lightweight and can move around when water fills the basin or be washed away in locations that have high flow velocities. Coarse, shredded hardwood mulch works best where available. Small chips and nuggets float and should be avoided.

Rock mulch stays in place better than wood and can withstand higher flow velocities. It is best used for locations that need erosion protection from water flows. It can be used to create decorative creek beds. Conversely, it heats up more than wood mulch, does not retain moisture as well, does not absorb pollutants or contribute organic matter to soil, and is more costly.

Both types of mulch need periodic maintenance. Wood mulch is generally touched up on an annual basis and raked out and replaced every few years. Rock mulch can plug with sediment and must be removed, cleaned, and replaced every few years.

19.2.8.2. Plants

Vegetation provides many benefits in stormwater treatment systems. Plant roots improve soil permeability and infiltration rates as roots grow deeper each year. They add organic matter to soil increasing water and nutrient holding capacity, stabilize erodible soils, and encourage the

growth of beneficial microorganisms that help break down pollutants in stormwater. Plants also provide shade, reduce urban heat island effects, filter air pollutants, reduce noise, help restore habitat, and provide neighborhood beautification.

Native plants are recommended for use in bioretention basins because they are adapted to El Paso's soils and climate, and they provide wildlife habitat in addition to landscape beauty. Many have deep root systems that help survive drought periods without irrigation.

Even though bioretention basins are designed to collect stormwater, they are well drained planting environments that will be dry for most of the year. The water is designed to infiltrate in 24 hours and many locations will have permeable soils that will not hold water for long periods of time. Consequently, plants selected for bioretention basins should be drought tolerant species that can withstand occasional inundation when it rains, rather than wetland or water loving species.

Bioretention basins tend to have three different planting zones: the bottom of the basins, sideslopes, and top edges or planting benches. When it rains, deepest water levels will be found in the bottom of the basins, while sideslopes and edges will dry out quickly. Taller plants that can tolerate occasional inundation are planted on basin bottoms. They can include trees, shrubs, bunch grasses, and some wildflowers.

Cacti and desert succulents such as agave and yuccas are typically planted on dry outside edges or planting benches, as can any drought tolerant grass, flower, shrub, or tree. Bunch grasses, wildflowers, and shrubs can be planted on sideslopes.

Short plants and groundcovers are typically limited to upper slopes and outside edges of gardens. In general, larger plants often tolerate deeper inundation levels than smaller plants.

Plant references for the El Paso region are listed in Section 19.2.8.

19.2.9. Related Design Guides and References

The following GI design guide for the Southwest U.S. complements this material and may be helpful to designers. It also includes color photos of example bioretention basins.

1. "Green Infrastructure for Southwestern Neighborhoods," Watershed Management Group, Tucson, Arizona, 2010, http://www.watershedmg.org/green-streets.

Native Plant References for the El Paso Region include the following:

1. El Paso Water Utilities – Public Service Board Web Site: Conservation/Desert Plant List http://www.epwu.org/conservation/plants.html

   El Paso Water Utilities
   1154 Hawkins Blvd.
   P.O. Box 511
   El Paso, TX 79961-0511
   915.594.5500

2. "Recommended Southwestern Native Plants for the El Paso/Las Cruces Area of the Chihuahuan Desert Region"

   by Wynn Anderson
   Botanical Curator, Centennial Museum, University of Texas at El Paso
   Number 8, 20 March 2006
   http://www.utep.edu/leb/pdf/recplant.pdf

3. Lady Bird Johnson Wildflower Center

   The University of Texas at Austin
   http://www.wildflower.org/

4. Recommended Species for West Texas
   http://www.wildflower.org/collections/collection.php?collection=TX_west

5. Drought Resistant Plants for Texas and Beyond
   http://www.wildflower.org/collections/collection.php?collection=centex_drought

6. Native Plant Society of New Mexico, El Paso Chapter
   http://www.npsnm.org/about/chapters/el-paso-texas/

19.2.10. Additional Green Infrastructure Approaches

In addition to biofiltration basins, a number of other GI systems can be utilized to achieve SSWM. In 2012, Crabtree and Associates developed a concept for CoEP for runoff infiltration within public ROW of new developments that led to full infiltration of on-site runoff. This concept, known as a rainwater harvesting street, was applied to the Master Plan for Northwest Hills (Crabtree, 2012). An example cross-section showing location and dimensions of subsurface drains and storage for this concept design can be seen in Figure 19-11. Design procedures for this concept for use by local developers have yet to be drafted. With this design, there is no requirement for further surface water retention for on-site generated drainage. However, systems that rely on infiltration through gravel, engineered soil, and underdrains could be prone to plugging from sediment and dust. It is recommended to limit the use of these techniques at present due to the heavy sedimentation and dust storms experienced in the El Paso area.

19.3. Park Ponds

19.3.1. Background

The CoEP development design requirements include the following:

- Retain runoff from the 24-hour, 1% annual exceedance probability (AEP), or 100-year return period storm;
- On-site retention of 100% of the runoff from the 24-hour, 100-year return period storm for properties zoned as commercial, industrial, or school/higher education; and
- Provide park facilities based upon the size of the development.

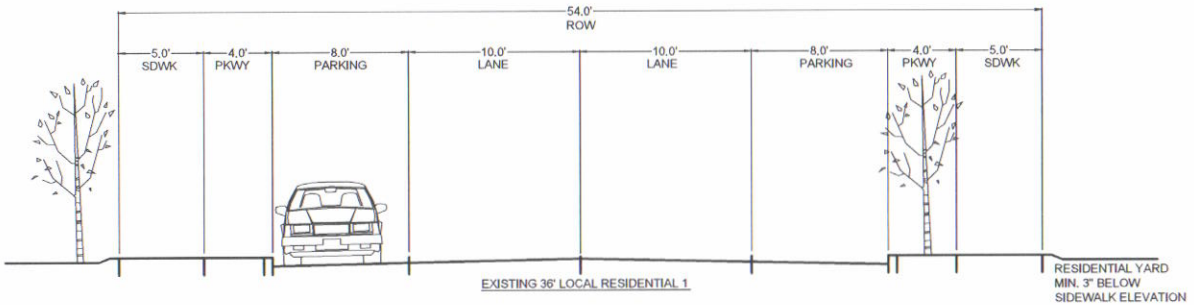
This section provides concept design guidance for retention facilities that can also be credited for meeting the park facilities requirement.

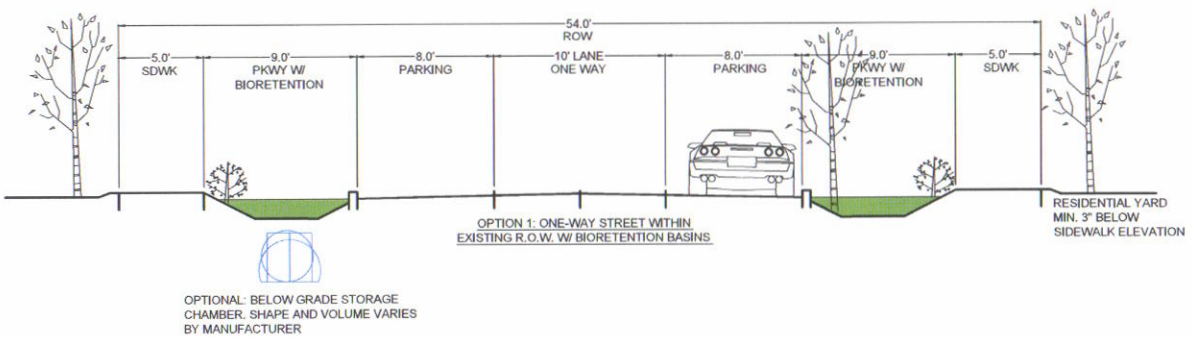
19.3.2. Concept Design Criteria

The purpose of this section is to provide design criteria guidance to encourage simultaneously addressing the separate requirements for provision of stormwater control and park facilities through design of a "park pond." The basic design criteria of a park pond are:

- Minimum of two cells ("inset pond" and "retention pond" see Figure 19-12 for flat conditions), with a total retention volume of the 100-year post-development runoff volume, considering credits for retention in GI design elements upstream and required on-site retention at properties zoned as commercial, industrial, or school/higher education;
- Maximum basin depth of four feet from ground surface or top of berm to surface of park area. This criterion facilitates public access, and simplifies maintenance;
- Maximum berm height above existing grade of three feet. Use of berms is discouraged in flat terrain. Berms on three sides of the pond will be needed in sloped terrain (see Figure 19-12, Incline). Berms on four sides will not be permitted (berms will not extend above ground surface at the extreme upstream extent), and this criterion prevents the berm from being classified as a regulatory dam.
- Maximum steepness of sideslopes for basins and berms of four horizontal to one vertical (4H:1V) for basins not sited in the regulatory floodplain, 3H:1V if sited in the regulatory floodplain. This criterion also facilitates public access, and simplifies maintenance;
- The upstream cell ("inset pond") will have a maximum depth of 1 foot. This foot of depth does not count in the maximum four feet of basin depth discussed above. This retention cell will retain approximately 10% of the design volume below the grade of the second cell. This area serves as dead storage for sediment accumulation, and to reduce the frequency of inundation of the second cell used as park space. The maximum sideslopes for the interface between the first and second cell is 1V:5H.
- Equipment access ramp per EPWU specification;
- Infiltration from the retention pond into the ground will meet the requirements of DDM Section 13.4.3.2.
- The entire surface area of the park pond facility (including berms, side slopes) can be credited against the park area requirement associated with residential development.

FIGURES

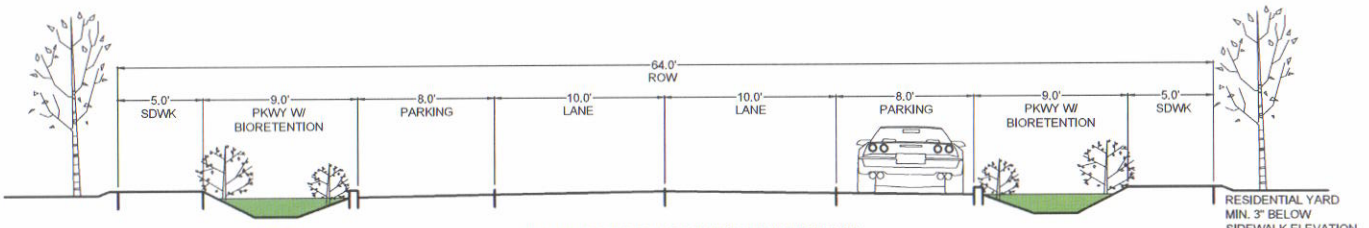




STORAGE OPTIONS WITHIN
EXISTING RIGHT-OF-WAY
LOCAL RESIDENTIAL STREETS

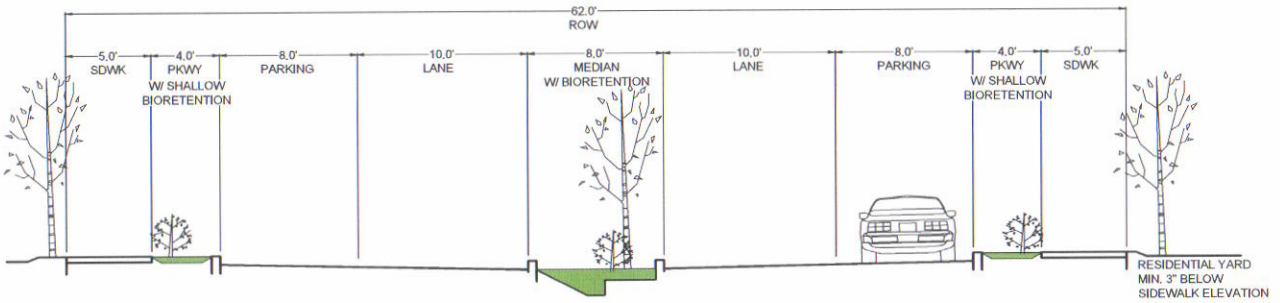
CITY OF EL PASO
DRAINAGE DESIGN MANUAL

MAY 2013	FIGURE 19-1

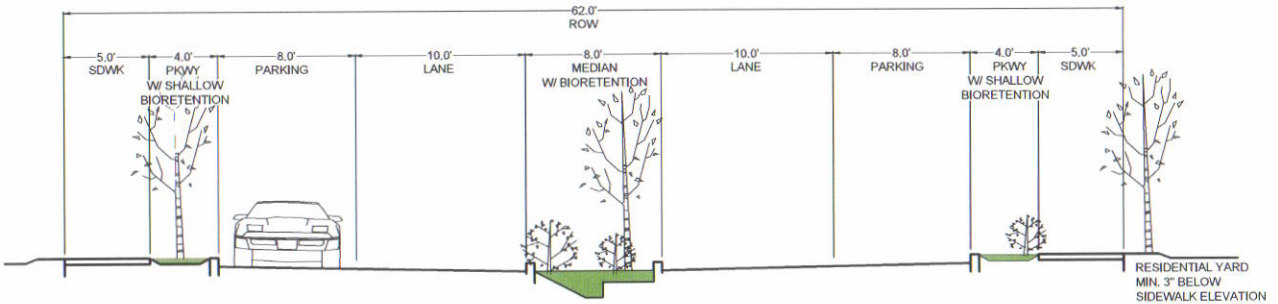


OPTION 2: EXPANDED 64' R.O.W. W/ BIORETENTION BASIN PLUS SUBSURFACE STORAGE

OPTIONAL: BELOW GRADE STORAGE CHAMBER. SHAPE AND VOLUME VARIES BY MANUFACTURER



OPTION 3: EXPANDED 62' R.O.W. W/ BIORETENTION BASIN



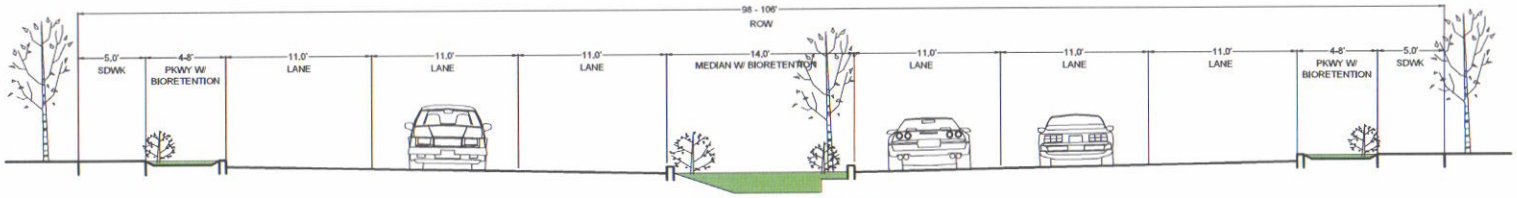
BELOW GRADE STORAGE CHAMBER. SHAPE AND VOLUME VARIES BY MANUFACTURER

OPTION 4: EXPANDED 62' R.O.W. W/ BIORETENTION BASINS, PLUS SUBSURFACE STORAGE

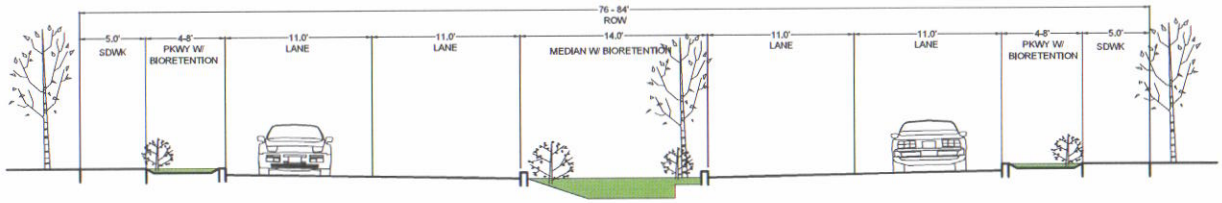
STORAGE OPTIONS WITHIN EXPANDED RIGHT-OF-WAY LOCAL RESIDENTIAL STREETS

CITY OF EL PASO
DRAINAGE DESIGN MANUAL

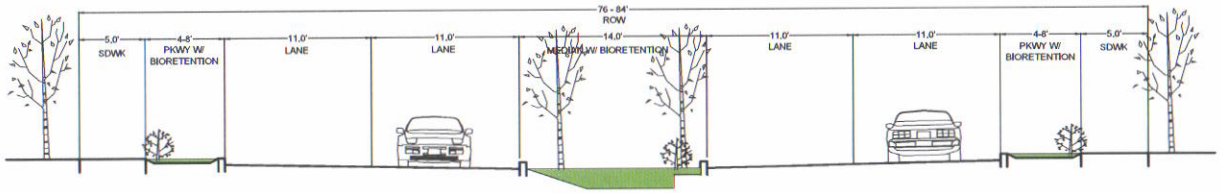
MAY 2013	FIGURE 19-2



OPTION 5: MAJOR ARTERIAL W/ BIORETENTION BASINS



OPTION 6: MINOR ARTERIAL W/ BIORETENSION BASINS



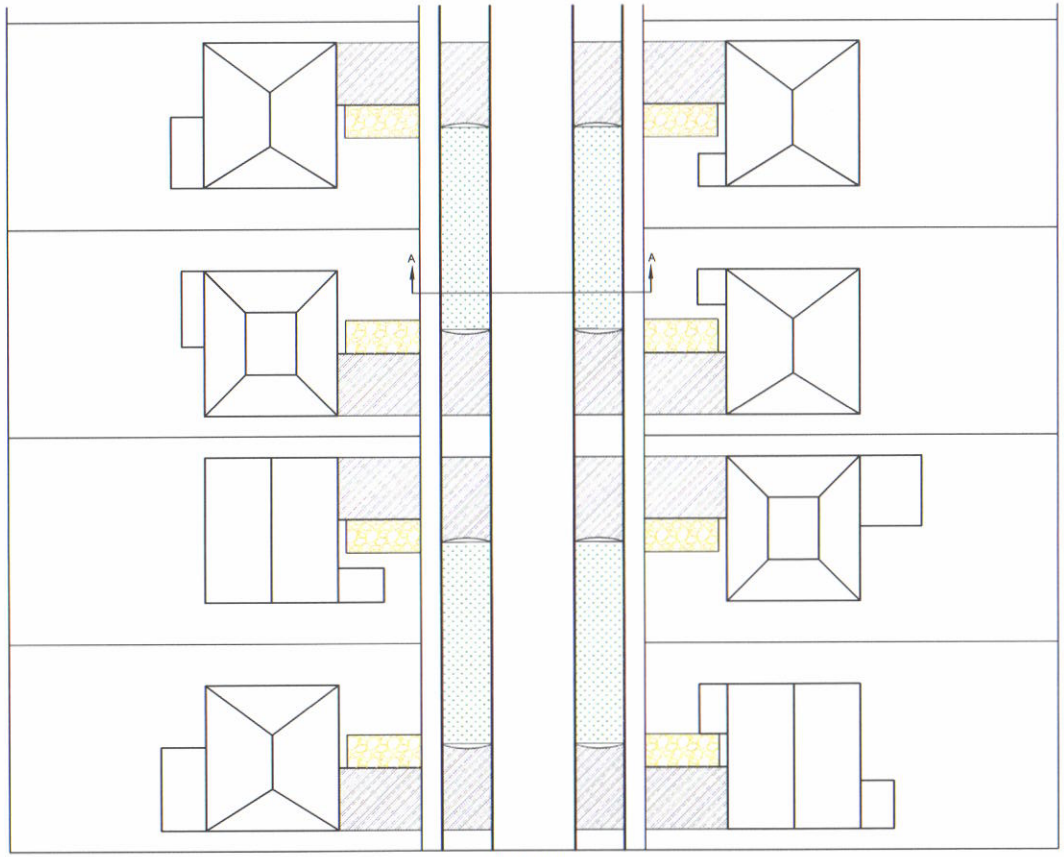
BELOW GRADE STORAGE CHAMBER, SHAPE AND VOLUME VARIES BY MANUFACTURER

OPTION 7: MINOR ARTERIAL W/ BIORETENTION BASINS PLUS SUBSURFACE STORAGE

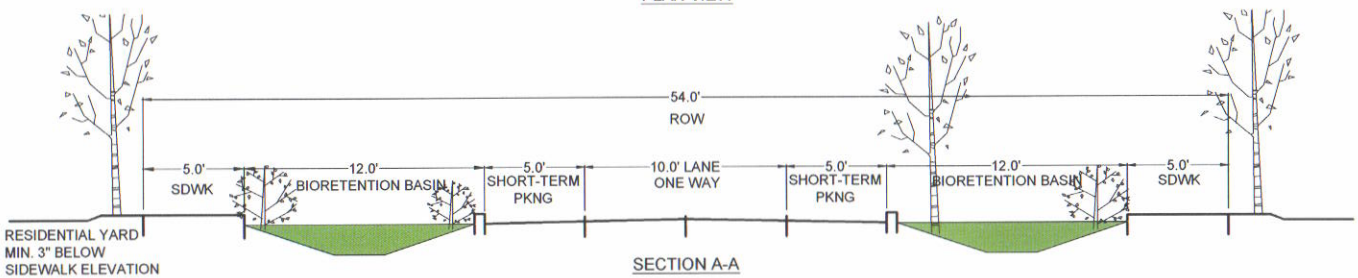
STORAGE OPTIONS WITHIN RIGHT-OF-WAY OF MAJOR AND MINOR ARTERIAL STREETS

CITY OF EL PASO
DRAINAGE DESIGN MANUAL

MAY 2013	FIGURE 19-3



PLAN VIEW



SECTION A-A

LEGEND

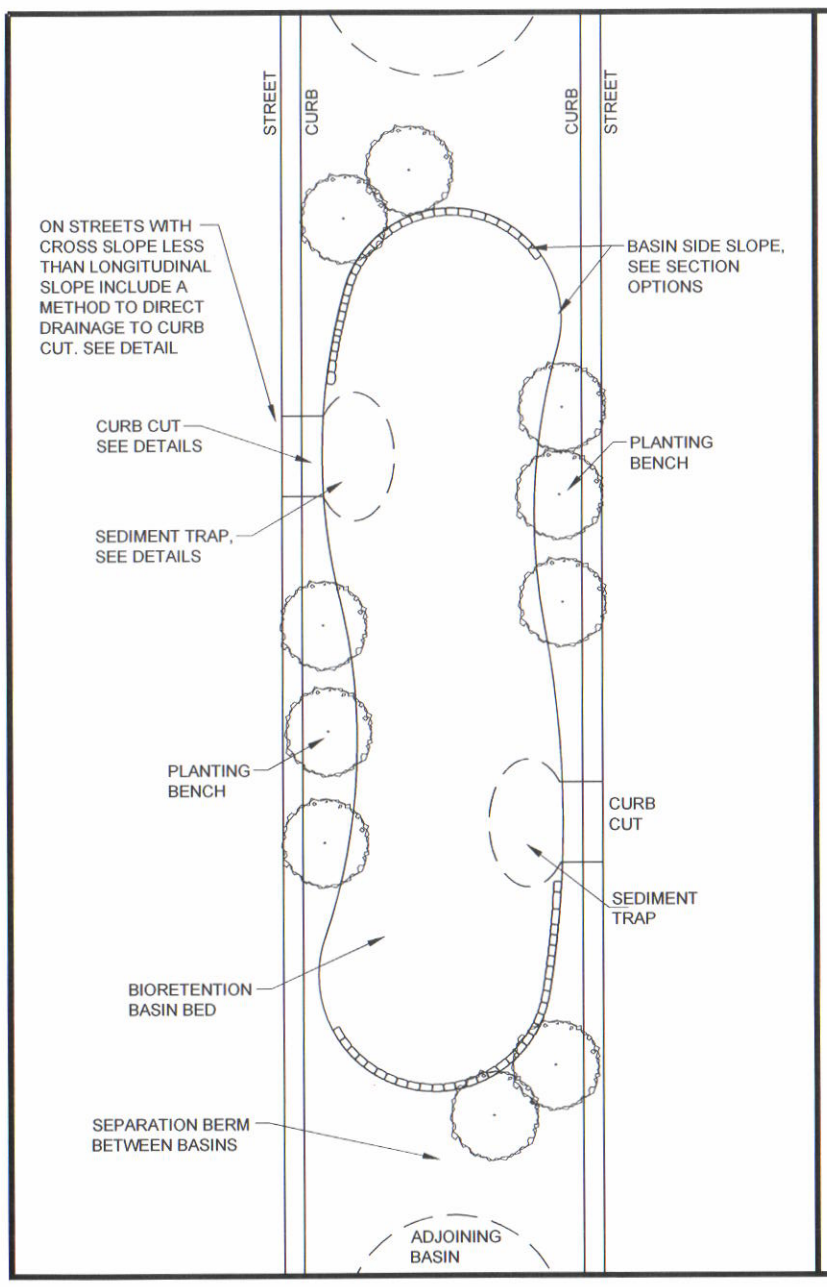
- BIORETENTION BASIN
- OFF-STREET PARKING SPACE, GRAVEL OR PERMEABLE
- DRIVEWAY

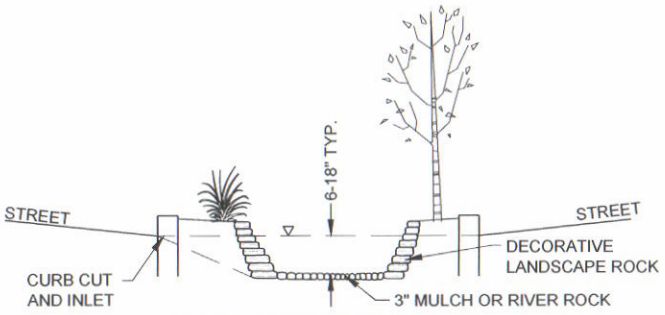
NOTE:
HOUSE/DRIVEWAY LAYOUT PATTERN DESIGNED TO MAXIMIZE AVAILABLE CONNECTED GREENSPACE FOR GREEN INFRASTRUCTURE FEATURES.

STREET EDGE ALTERNATIVE WITHIN EXISTING RIGHT-OF-WAY

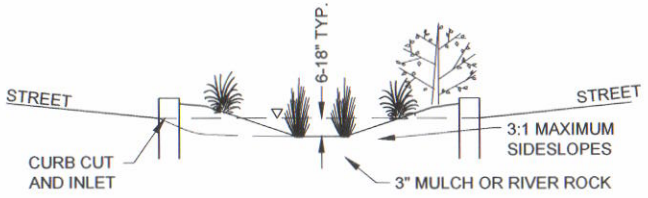
CITY OF EL PASO
DRAINAGE DESIGN MANUAL

MAY 2013	FIGURE 19-4





BASIN WITH ROCK EDGES

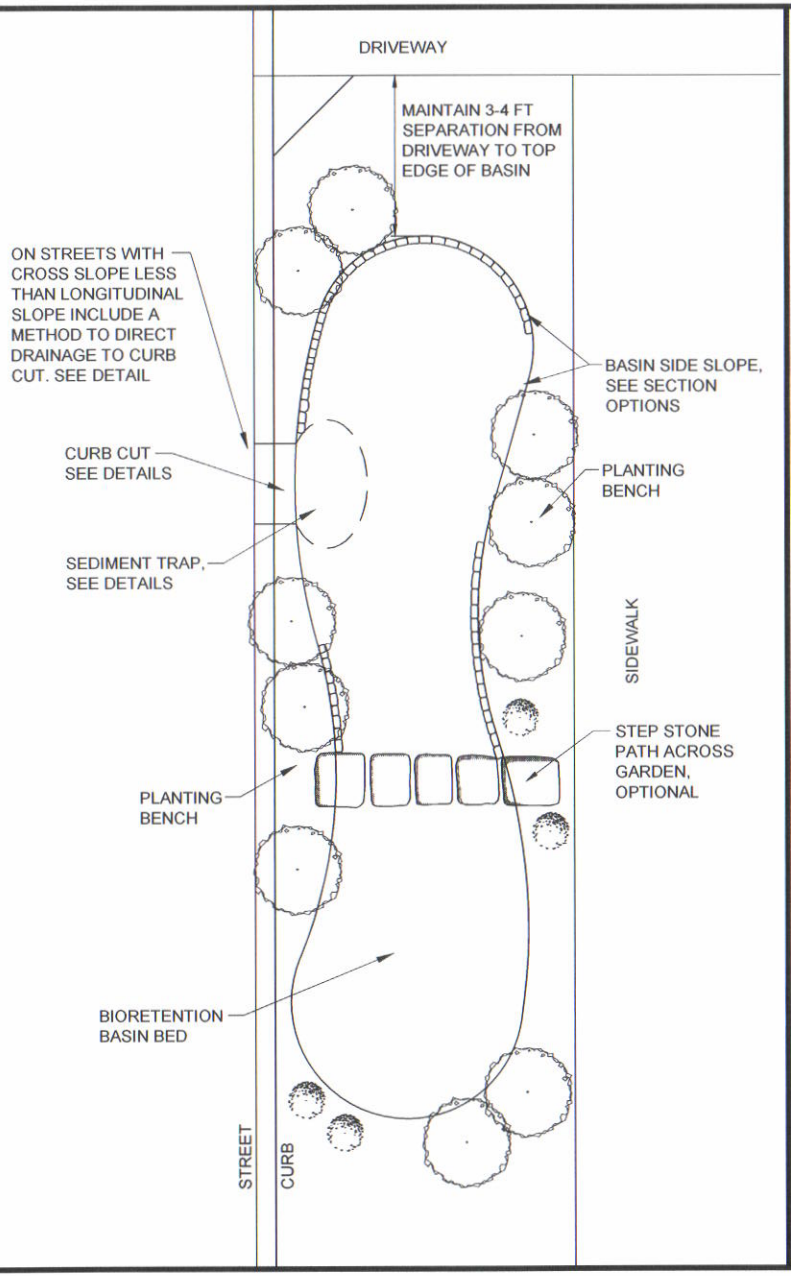


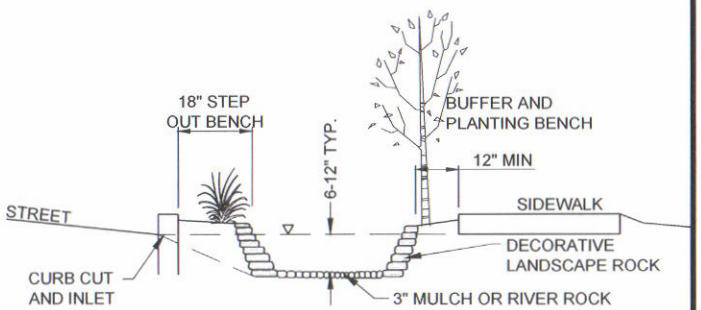
BASIN WITH VEGETATED SIDESLOPES

BIORETENTION BASIN
IN STREET MEDIAN
WITH CURB CUTS

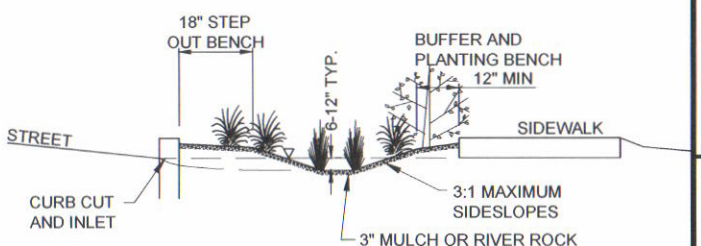
CITY OF EL PASO
DRAINAGE DESIGN MANUAL

MAY 2013	FIGURE 19-5





BASIN WITH ROCK EDGES

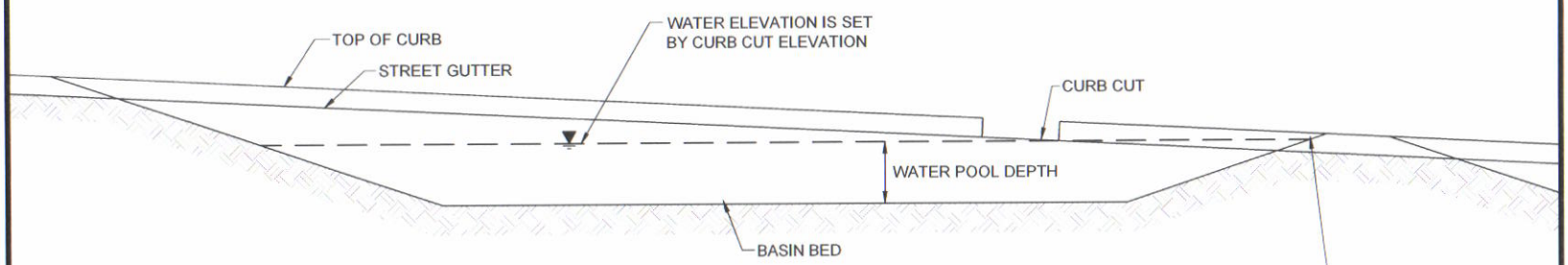


BASIN WITH VEGETATED SIDESLOPES

BIORETENTION BASIN
STREET EDGE WITH CURB CUT

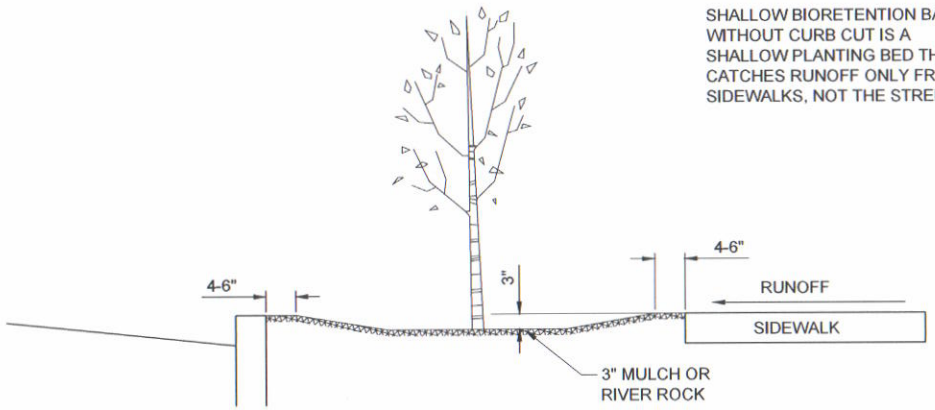
CITY OF EL PASO
DRAINAGE DESIGN MANUAL

MAY 2013	FIGURE 19-6



NOTES:
ADJACENT SIDEWALK ELEVATION SHOULD BE HIGHER THAN WATER SURFACE ELEVATION ALONG THE ENTIRE LENGTH OF THE GARDEN.

SET CURB CUT ELEVATION 2" MIN. BELOW LOWEST DOWNHILL CURB AND BERM ELEVATION TO AVOID WATER OVERTOPPING GARDEN, CURB, OR SIDEWALK.

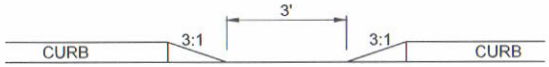


SHALLOW BIORETENTION BASIN WITHOUT CURB CUT IS A SHALLOW PLANTING BED THAT CATCHES RUNOFF ONLY FROM SIDEWALKS, NOT THE STREET.

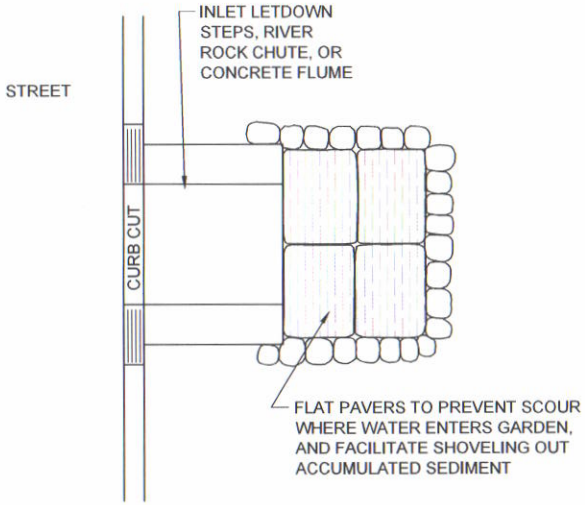
BIORETENTION BASIN PROFILE ON SLOPED STREETS AND SHALLOW BIORETENTION BASIN SECTION WITHOUT CURB CUT

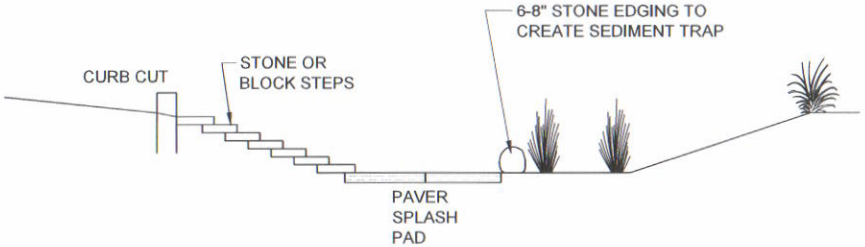
CITY OF EL PASO
DRAINAGE DESIGN MANUAL

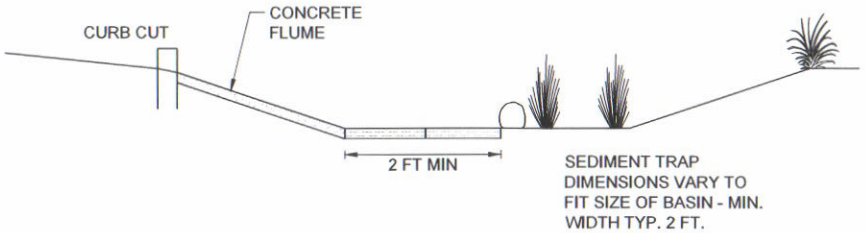
MAY 2013	FIGURE 19-7



CURB CUT DETAIL



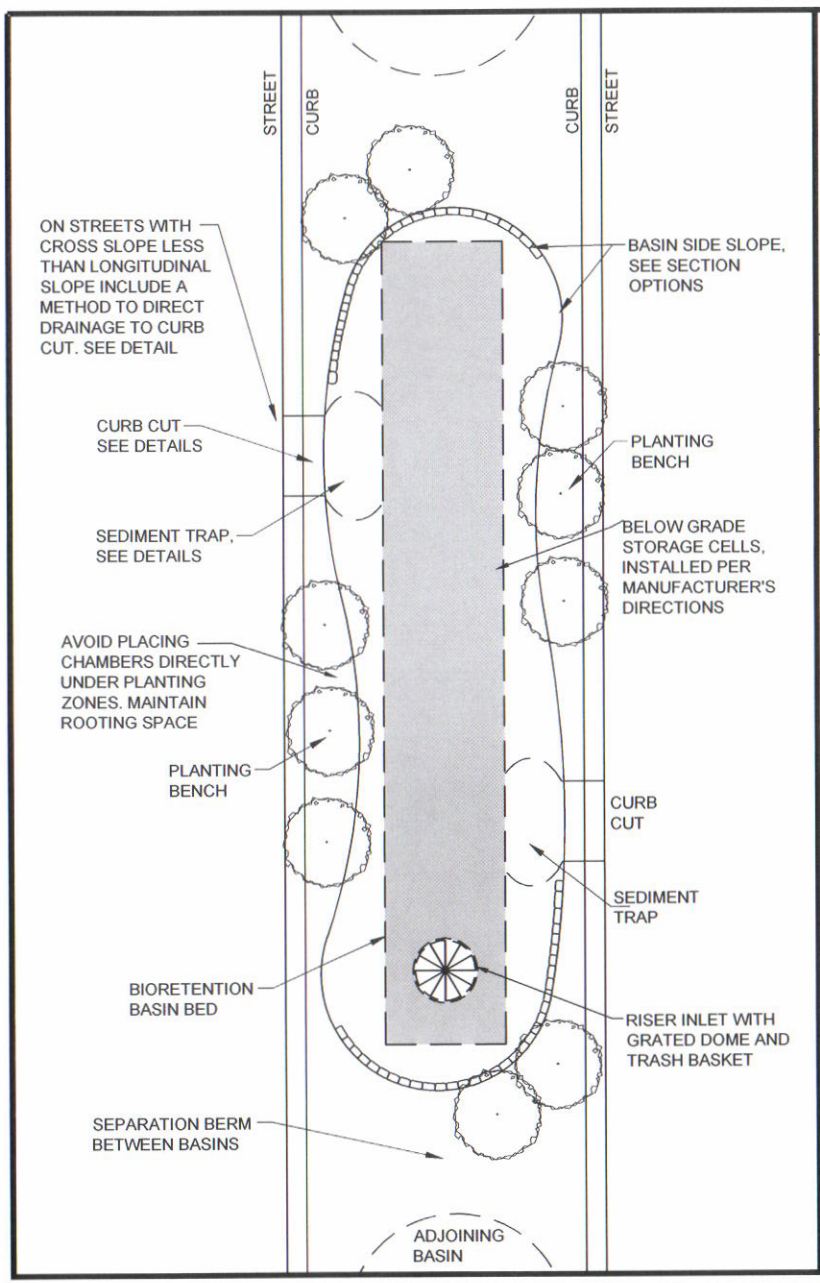


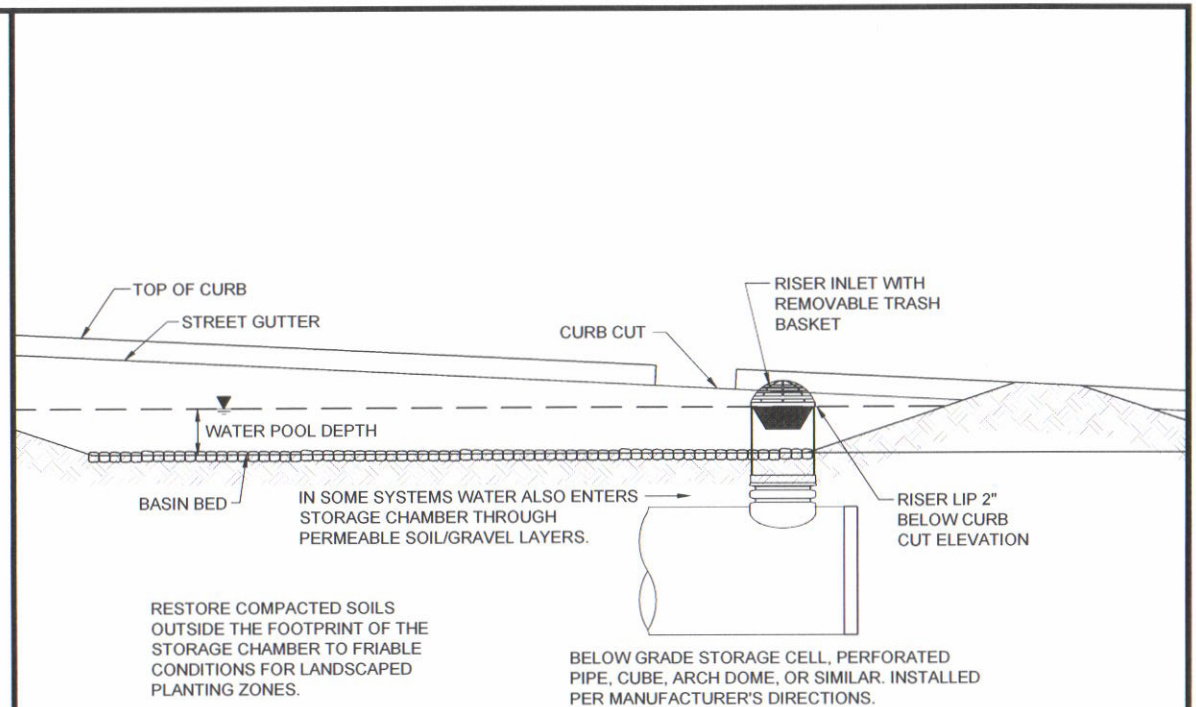


CURB CUT AND SEDIMENT TRAP OPTIONS

CITY OF EL PASO
DRAINAGE DESIGN MANUAL

MAY 2013	FIGURE 19-8

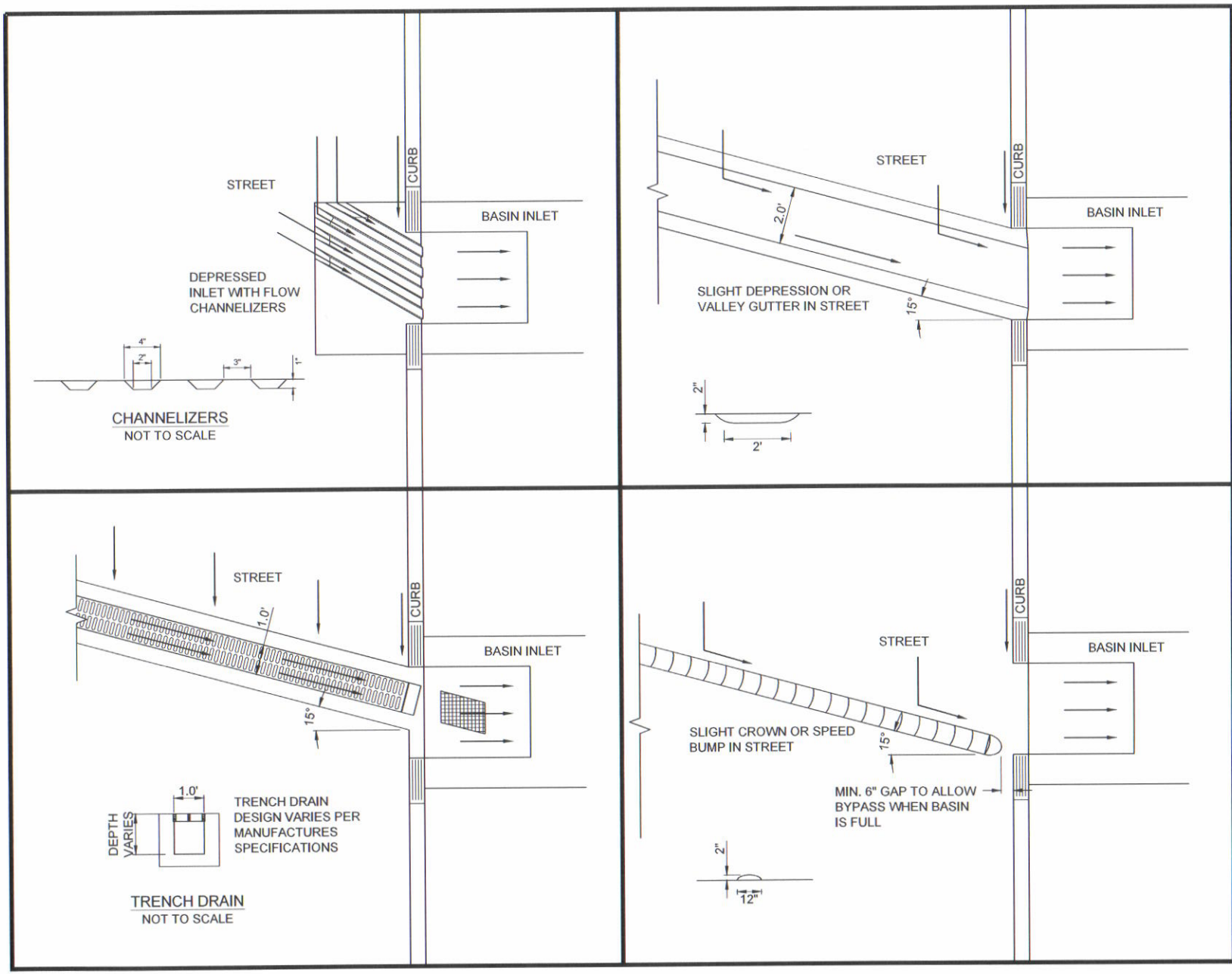




BIORETENTION BASIN
WITH BELOW GRADE STORAGE

CITY OF EL PASO
DRAINAGE DESIGN MANUAL

MAY 2013	FIGURE 19-9



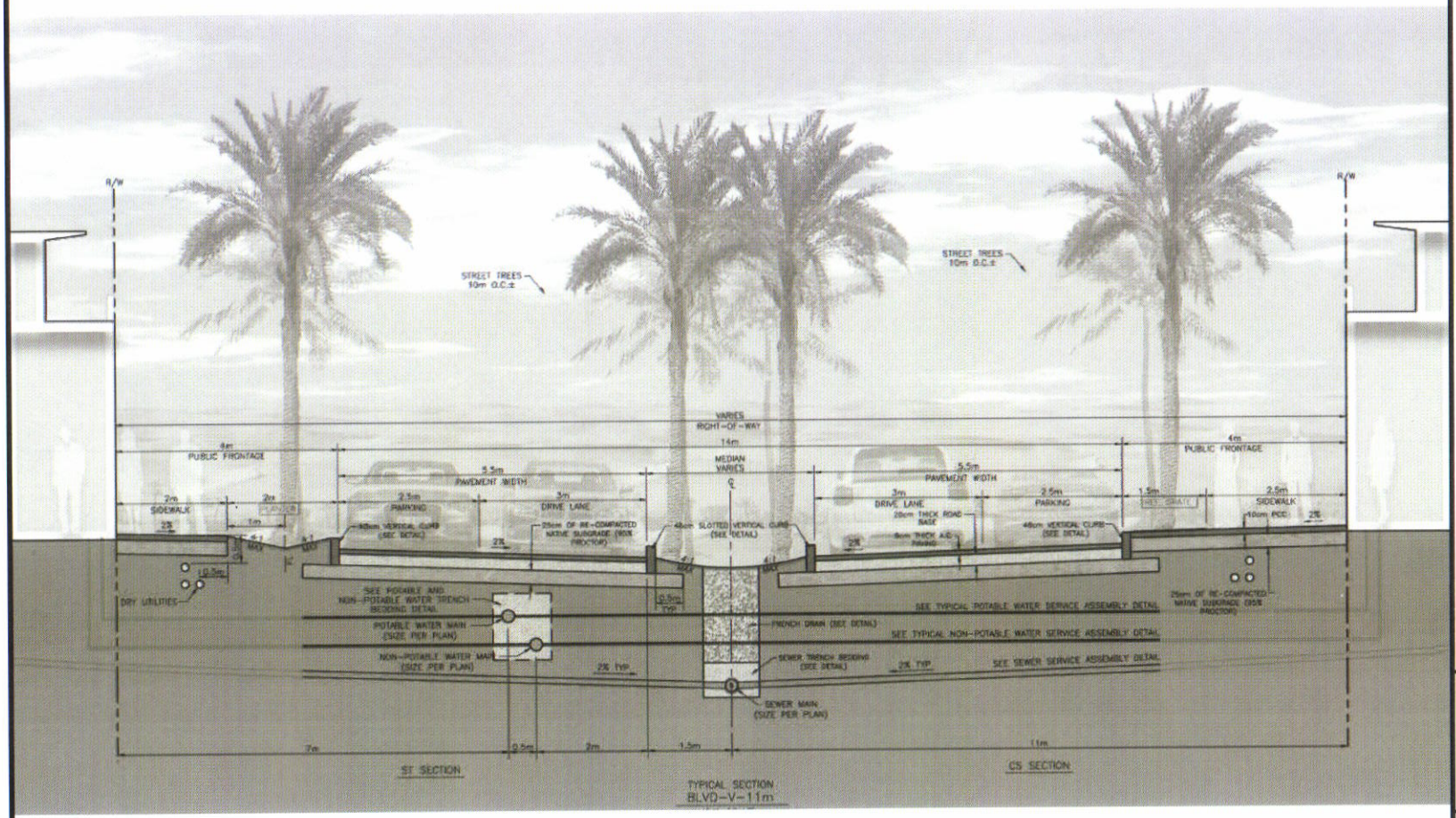
ON STREETS WITH CROSS SLOPE LESS THAN LONGITUDINAL SLOPE INCLUDE A METHOD TO DIRECT DRAINAGE TO CURB CUT.

STORMWATER FLOW

FLOW DIVERSION OPTIONS FOR STEEP STREETS

CITY OF EL PASO
DRAINAGE DESIGN MANUAL

MAY 2013	FIGURE 19-10

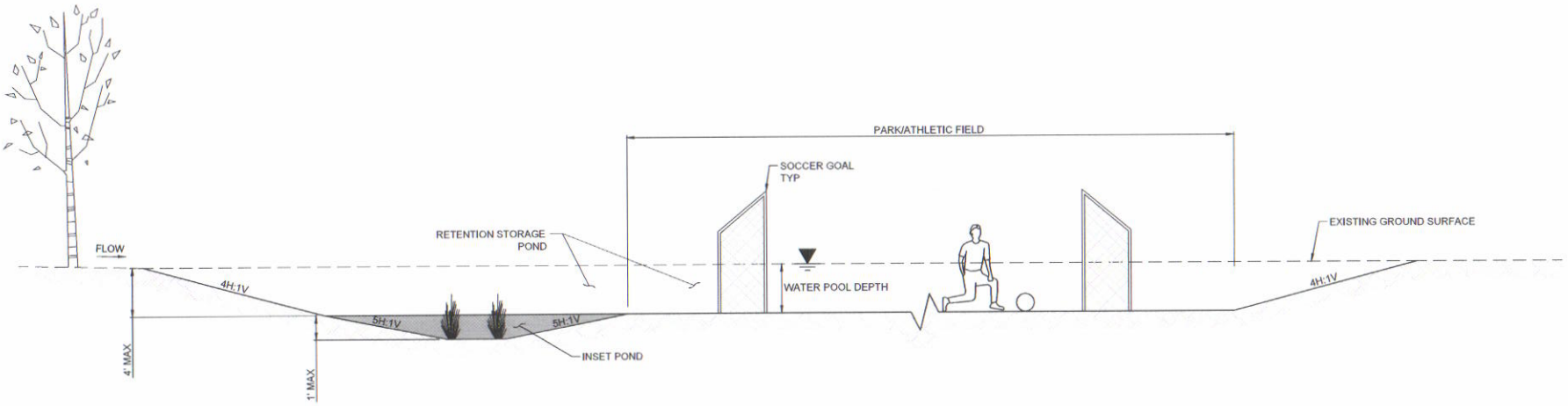


Reference: Crabtree Group, Inc. 2012

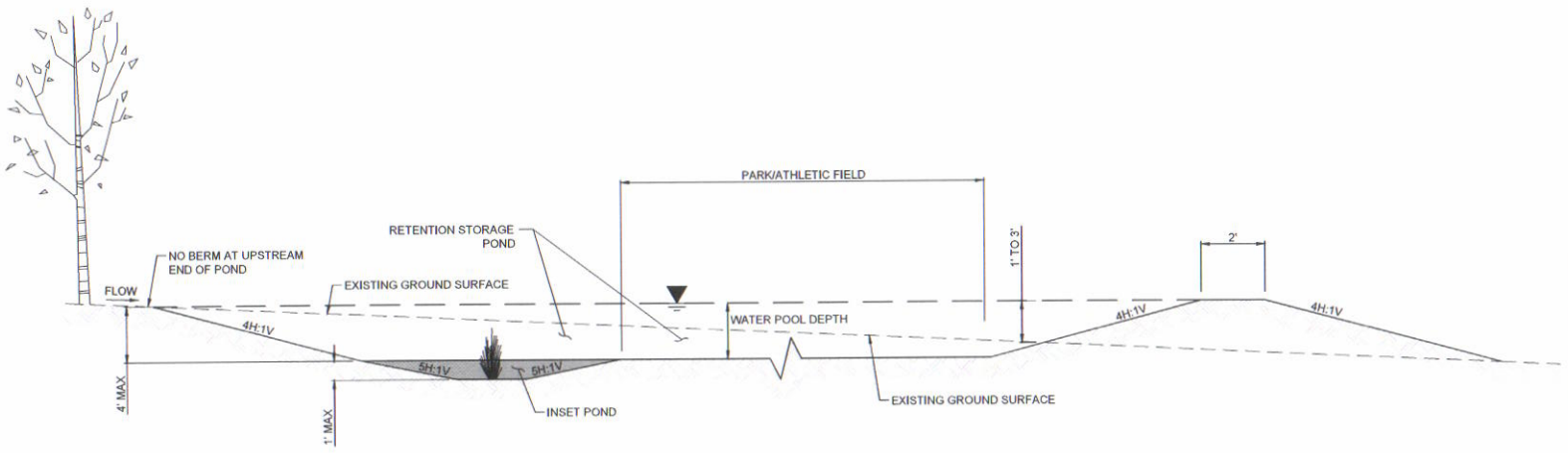
RAINWATER HARVESTING AVENUE WITH BIOSWALES AND FRENCH DRAINS

CITY OF EL PASO
DRAINAGE DESIGN MANUAL

MAY 2013	FIGURE 19-11



PARK POND ON FLAT EXISTING GROUND SURFACE
N.T.S.



PARK POND ON INCLINED EXISTING GROUND SURFACE
N.T.S.

CONCEPTUAL PARK POND
CROSS-SECTION

CITY OF EL PASO
DRAINAGE DESIGN MANUAL

MAY 2013	FIGURE 19-12

16. Sediment Transport

16.1. Purpose and Need

16.1.1. Sediment and Debris Mechanisms

16.1.1.1. Routine Sediment Deposition

Routine sediment deposition is a common problem in the El Paso area due to the high intensity precipitation that the area receives, the numerous topographic transitions from steep to flat slopes, and the sandy soils that are present. The precipitation and the resulting runoff dislodge particles from the sandy soils and transport them to downstream arroyos. The arroyos transport the sediment to downstream portions of the watershed, while contributing additional sediment eroded from arroyo bed and banks. The combined sediment load is ultimately deposited at locations of decreased velocity (i.e., stormwater infrastructure locations, breaks in slope, etc.).

16.1.1.2. Debris Flow Events

Although not as common as routine sedimentation, debris flow events are a problem in the El Paso Area, as demonstrated in the August 2006 floods. Debris flow events generally result from prolonged intense precipitation and initiate on the steep slopes in the upper portion of the watershed. Prolonged rainfall results in saturation of sediment and debris historically accumulated within arroyo beds. Saturation can ultimately lead to liquefaction of these sediment/debris, with sudden release of the full sediment/debris load downstream. As the sediment/debris flow moves down through the watershed additional sediment and debris is incorporated in the load. The combined sediment load is ultimately deposited at locations of decreased velocity (i.e., stormwater infrastructure locations, breaks in slope, etc.). This rare event results in much larger volumes of transported sediment/debris than routine erosion-based sediment deposition.

16.1.2. Sediment and Debris Hazards

There are a number of hazards associated with routine sediment deposition and debris flow events. The results of these hazards can generally be classified as indirect damage or direct damage.

16.1.2.1. Indirect Damage Resulting from Sediment and Debris Hazards

Indirect damage to property occurs when sediment or debris causes downstream infrastructure to function improperly and causes flooding that impacts property. Indirect damage generally occurs at areas of reduced velocity where deposition occurs. The deposited sediment reduces the capacity of the drainage structure, resulting in flooding of adjacent and downstream structures.

16.1.2.2. Direct Damage Resulting from Sediment and Debris Hazards

Direct damage to property occurs when sediment or debris comes into direct contact with property. Direct damage generally affects drainage structures located in channels or arroyos, structures located at or near the mouth of an arroyo or the outfall of a channel, or structures located adjacent to arroyos or channels.

16.1.3. Purpose

The purpose of this section of the DDM is to:

- Identify design criteria to reduce negative impacts from sediment deposition and debris flows; and
- Develop and specify design criteria to control routine sedimentation and debris flows.

16.2. Design Criteria Sources and Types

A number of sources were consulted as background for this section. These sources consisted primarily of design manuals for arid counties with soil types and topography similar to El Paso. The most useful sources are listed below:

- Clark County Regional Flood Control District (CCRFCD) Hydrologic Criteria and DDM (CCRFCD, 1999);
- Maricopa County Hydraulics DDM (Maricopa County, 2010);
- Mohave County DDM (Mohave County, 2009);
- Pinal County DDM (Pinal County, 2004);
- Pima County Department of Transportation & Flood District (PCDOT & Flood Control District [FCD]), Stormwater Detention and Retention Manual (PCDOT & FCD, 1987);
- Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA) Sediment and Erosion Design Guide (Mussetter Engineering Inc. [MEI], 2008);
- Sparks Arroyo Flood Control Project Draft Sediment Appendix (USACE, 2004-2007);
- International Boundary and Water Commission (IBWC) Rio Grande Canalization Improvement Project, Sedimentation Analysis from the Rio Grande Tributary Basins (USACE and Resource Technology Inc. [RTI], 1996); and

From the sources listed above the following types of sediment design criteria were identified:

- Sediment basin design criteria;
- Channel design criteria;
- Culvert design criteria; and
- Storm drain system design criteria.

16.3. Sediment Basin Design Criteria

All sediment basins shall be designed to contain a minimum of ten years of average annual sediment yield volume from the contributing watershed and with a layout similar to Figure 16-1. There are three different levels of analysis that can be utilized to estimate the average annual sediment yield. Each level of analysis provides the user of the manual an approved method for estimating the sediment yield, with a varying degree of required effort and site-specific

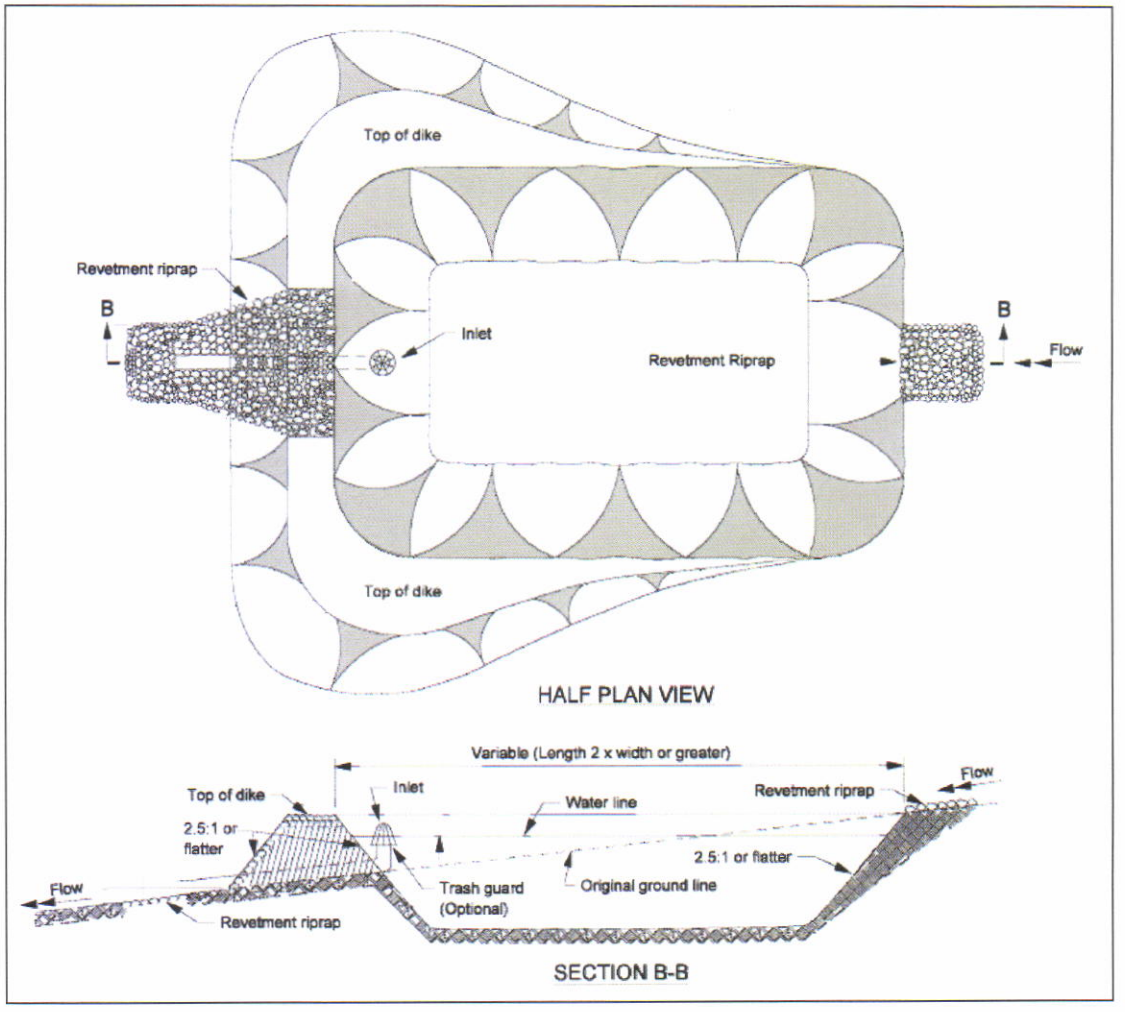
consideration associated with each level. General descriptions of each of the three levels of analysis are provided below.

- Level I: Default method incorporating minimal site specific considerations.
- Level II: More detailed method incorporating site specific considerations, but requiring more detailed analysis.
- Level III: Mechanism to allow other methods, approved by the CoEP, to be utilized.

Sediment basin locations at risk from debris/sediment flows require additional design consideration. All sediment basin locations within proximal or medial alluvial fan zones (see Figure 16-16) and immediately downstream of areas identified as known or potential debris/sediment flow sources (see Figures 16-2 to 16-9) must be designed to accommodate the additional volume associated with the potential debris/sediment flow. There are two different levels of analysis that can be utilized to estimate the debris/sediment flow volume required.

Sediment basins constructed along arroyos in El Paso may require additional environmental considerations. Section 18 provides information on permitting for this topic.

Figure 16-1: Example Sediment Basin Layout



Source: Adapted from Sedimentation and Erosion Control Guidelines (INDOT, 2010)

16.3.1. Average Annual Sediment Yield Volume Estimate

16.3.1.1. Level I Average Annual Sediment Yield Volume Estimate

The average annual sediment yield volume for a given watershed shall be estimated as the greater of 20% of the 10-year, 24-hour flow volume at the proposed basin location or ten times the average annual sediment yield from the watershed calculated using the equation shown below:

$$y = -0.0121 * x + 1.25 \qquad 16\text{-}1$$

Where:

y = average annual sediment yield in acre-feet per square mile (sq mi) per year (yr); and

x = the percentage of urban area in the watershed (entered as %, e.g. for 30%, x = 30)

As noted above, the minimum storage requirement is ten times the average annual sediment yield or ten times "y" in the above equation.

This equation was developed by the USACE for a watershed in eastern El Paso as part of the Sparks Arroyo Flood Control Project Draft Sediment Appendix (USACE, 2004-2007). The equation is based on data from a number of sediment studies for El Paso.

The results of this level of analysis have been validated for reasonableness through use of available sedimentation maintenance records for CoEP Stormwater Detention Structures (URS, January 2011).

16.3.1.2. Level II Average Annual Sediment Yield Volume Estimate

The average annual sediment yield volume can be estimated using analytical equations for the wash load sediment yield and bed load sediment yield for a given watershed. The average annual sediment yield volume is equal to the sum of the wash load and the bed load.

Wash Load Sediment Yield

The wash load sediment yield shall be calculated using the Modified Universal Soil Loss Equation (MUSLE) for the 100-, 50-, 25-, 10-, 5-, and 2-year return interval storms using the equation shown below:

$$Ys = R_W * K * LS * C * P \qquad 16\text{-}2$$

Where:

Y_S = sediment yield (wash load) for a storm event of particular return interval, in tons;

R_W = storm runoff energy factor for a storm event of particular return interval;

K = soil erodibility factor;

LS = slope length and steepness factor;

C = vegetative cover and management factor; and

P = erosion control practice factor.

Storm Runoff Energy Factor

The storm runoff energy factor is calculated as follows:

$$R_W = a * (V * q_p)^b \qquad 16\text{-}3$$

Where:

a = coefficient; estimated to be 285. This coefficient was originally estimated to be 95 from experimental watersheds but was increased by a factor of three to reflect conditions in New Mexico (MEI, 2008);

V = runoff volume for a storm event of particular return interval, in acre-feet;

q_p = peak discharge for a storm event of particular return interval, in ft^3/sec; and

b = coefficient; estimated to be 0.56 from experimental watersheds.

Soil Erodibility Factor

K factors for each soil series are tabulated in USDA NRCS soil surveys found online at: http://soildatamart.nrcs.usda.gov/.

Slope Length and Steepness Factor

The slope length and steepness factor is calculated as follows:

$$LS = (L/72.6)^m * (0.065 + 0.0454 * S + 0.0065 * S^2) \qquad 16\text{-}4$$

Where:

L = slope length from the top of the basin to the point where the flow becomes concentrated into a gully, arroyo, or watercourse, in feet;

S = slope, measured as an average overland slope within the basin, in % (e.g. for 1%, S = 1); and

m = exponent dependent upon slope steepness (0.3 for slopes 1 to 3%, 0.4 for slopes 3.5 to 4.5%, and 0.5 for slopes >5%).

Vegetative Cover and Management Factor

The vegetative cover factor represents the effectiveness of the land surface to prevent detachment and transport of soil particles. It is calculated as the ratio of soil loss from land under specified crop or mulch conditions to the corresponding loss from tilled, bare soil. Users shall refer to USDA Agricultural Handbook No. 537 (USDA, 1978) for selection of a site-specific vegetative cover factor. A conservative value of 1 may be used in the MUSLE in lieu of a site-specific factor.

Erosion Control Practice Factor

The erosion control practice factor is the ratio of soil loss with a given surface condition to soil loss with up-and-down-hill plowing. Users shall refer to USDA Agricultural Handbook No. 537 (USDA, 1978) for selection of a site-specific erosion control practice factor. A conservative value of 1 may be used in the MUSLE in lieu of a site-specific factor.

Wash Load Volume Estimation

The wash load volume shall be estimated for the 100-, 50-, 25-, 10-, 5-, and 2-year return interval storms using the results from the MUSLE and the following equation (Maricopa County, 2010) for a Level II analysis:

$$y = 51 * (P + 2)^{0.13} \qquad 16\text{-}5$$

Where:

γ = specific weight of each soil type, pound (lb)/ft^3; and

P = the percentage (entered as %, e.g. for 30%, P = 30) of material larger than 0.05 mm (can be estimated from NRCS Soil Survey).

and

$$W_s = Y_S * 2000) / y \qquad 16\text{-}6$$

Where:

W_S = sediment yield (wash load) for a storm event of particular return interval, in ft^3; and

Y_S = sediment yield (wash load) for a storm event of particular return interval, in tons

γ = specific weight of each soil type, lb/ft^3.

Geographic Information System Applications for Wash Load Sediment Yield Calculations

Slope Length and Steepness Factor

The length-slope factor can be calculated utilizing ArcGIS and the following process:

- Download a USGS Digital Elevation Model (DEM) for the study area;
- Calculate the slope in each cell of the raster using the ArcGIS Spatial Analyst Slope function and reclassify into bands of % slope;
- Convert the reclassified raster to polygons, reflecting each slope band classified in the previous step;
- Create a flowline that is representative of the typical slope variation;
- Intersect the flowline with the slope band polygon shapefile;
- Break the flowline into segments at slope band break points, and assign each segment of each line a length and slope;
- Calculate the LS factor for each line segment using the equation below:

$$LS = (l / 72.6)^m * (0.065 + 0.0454 * S + 0.0065 * S^2) \qquad 16\text{-}7$$

Where:

L = slope length from the top of the basin to the point where the flow becomes concentrated into a gully, arroyo, or watercourse, in feet;

S = slope, measured as an average overland slope within the basin, in % (e.g. for 1%, S = 1); and

m = exponent dependent upon slope steepness (0.3 for slopes 1 to 3%, 0.4 for slopes 3.5 to 4.5%, and 0.5 for slopes > 5%).

Soil Erodibility Factor

The soil erodibility factor can be calculated utilizing ArcGIS and the following process:

- Download a NRCS soil survey shapefile and tabular data for the study area; and
- Assign a K value to each soil type in the shapefile utilizing the tabular data.

*LS * K Factor*

After LS is assigned to each segment of the flowline in each subbasin, intersect each segmented flowline shapefile with the NRCS soil file (including the K factor). Calculate a single LS * K value for each flowline by taking the length-weighted average of all segment LS * K values in each flowline.

Bed Load Sediment Yield

The bed load sediment yield shall be calculated using the Zeller and Fullerton bed material load transport capacity equation for the 100-, 50-, 25-, 10-, 5-, and 2-year return interval storms. The equation is shown below:

$$q_S = 0.0064 * n^{1.77} * V^{4.32} * G^{0.45} / (Y^{0.3} * D_{50}^{\ 0.61}) \qquad 16\text{-}8$$

Where:

q_S = unit width bed material transport capacity for a storm event of particular return interval, in $ft^3/sec/ft$;

n = Manning's Roughness Coefficient;

V = peak velocity for a storm event of particular return interval, in ft/sec;

G = gradation coefficient;

Y = hydraulic depth for a representative channel cross section for a storm event of particular return interval, in feet; and

D_{50} = 50% finer sediment, in millimeters.

Gradation Coefficient

The gradation coefficient is calculated as follows:

$$G = 0.5 * ((D_{84.1} / D_{50}) + (D_{50} / D_{15.9})) \qquad 16\text{-}9$$

Where:

$D_{84.1}$ = diameter where 84.1% is finer by weight, in millimeters;

D_{50} = diameter where 50% is finer by weight, in millimeters; and

$D_{15.9}$ = diameter where 15.9% is finer by weight, in millimeters.

Bed Load Volume Estimation

The volume of bed material shall be estimated using the results from the Zeller and Fullerton Equation for the 100-, 50-, 25-, 10-, 5-, and 2-year return interval storms, the water flow discharge hydrograph, and the equations below:

$$Q_s = q_s * W \qquad 16\text{-}10$$

Where:

Q_S = bed material transport capacity for a storm event of particular return interval, in ft^3/sec;

q_S = unit width bed material transport capacity for a storm event of particular return interval, in $ft^3/sec/ft$; and

W = width of representative cross section, in feet.

and

$$B_s = V_W * (Q_s / Q) \qquad 16\text{-}11$$

Where:

B_S = total volume of sediment for a storm event of particular return interval, in ft^3;

V_w = total volume of water for a storm event of particular return interval, in ft^3;

Q_s = bed material transport capacity for a storm event of particular return interval, in ft^3/sec; and

Q = peak flow rate for a storm event of particular return interval, in ft^3/sec.

Average Annual Wash Load and Bed Load Sediment Yield

The average annual wash load sediment yield and the average annual bed load sediment yield shall be estimated for a Level II analysis using the following equations (Maricopa County, 2010):

$$W = 0.015 * W_{100} + 0.015 * W_{50} + 0.04 * W_{25} + 0.08 * W_{10} + 0.2 * W_5 + 0.4 * W^2 \qquad 16\text{-}12$$

and

$$B = 0.015 * B_{100} + 0.015 * B_{50} + 0.04 * B_{25} + 0.08 * B_{10} + 0.2 * B_5 + 0.4 * B_2 \qquad 16\text{-}13$$

Where:

W = average annual wash load, in ft^3;

W_{100}, W_{50}, W_{25}, W_{10}, W_5, and W_2 = wash load volumes for the 100-, 50-, 25-, 10-, 5-, and 2-year return interval storms, respectively, in ft^3;

B = average annual bed load, in ft^3;and

B_{100}, B_{50}, B_{25}, B_{10}, B_5, and B_2 = bed load volumes for the 100-, 50-, 25-, 10-, 5-, and 2-year return interval storms, respectively, in ft^3.

Total Average Annual Volume of Sediment Loading

The total annual average annual sediment yield shall be estimated by adding the average annual wash load volume and the average annual bed load yield volume.

16.3.1.3. Level III Average Annual Sediment Yield Volume Estimate

The average annual sediment yield from a watershed shall be estimated using other methods approved by the CoEP for a Level III analysis.

16.3.2. Debris/Sediment Flow Volume Estimate

16.3.2.1. Level I Debris/Sediment Flow Volume Estimate

The additional volume required for sediment basins located within or upstream of proximal or medial alluvial fan zones (see Figure 16-16) and immediately downstream of areas identified as known or potential debris/sediment flow sources (see Figures 16-2 to 16-9) shall be estimated as the top 2 feet of the contributing known or potential debris/sediment flow source. The following method shall be used to estimate this additional volume:

1. Determine the upstream area of the known or potential debris and/or sediment source impacting the sediment basin (The ArcView shapefile shown in Figures 16-2 to 16-9 may be obtained from EPWU upon request); and
2. Multiply this area by 2 feet to represent the top 2 feet of debris/sediment flow depth from the source.

The potential debris/sediment areas shown on Figures 16-2 to 16-9 were identified and delineated by a professional geologist based on field observations and aerial imagery.

16.3.2.2. Level II Debris/Sediment Flow Volume Estimate

The additional volume required for sediment basins located within proximal or medial fan zones (see Figure 16-16) and immediately downstream of areas identified as known or potential debris/sediment flow sources (see Figures 16-2 to 16-9) may be estimated by a professional geologist using methods approved by the CoEP. If a Level II analysis is desired, it is recommended that the professional geologist follow the procedure shown on Figure 4 in *Guidelines for The Geologic Evaluation of Debris-Flow Hazards on Alluvial Fans in Utah* (Giraud, 2005) in estimating potential debris/sediment flow volume.

16.4. Channel Design Criteria

16.4.1. Minimum Velocity Requirement

All constructed channels shall be designed to facilitate a minimum velocity of 2 ft/sec at design flow to minimize sedimentation and vegetative growth in the channel. Maximum permissible velocities for channel lining must be considered when adhering to this requirement (See Section 10.2.4).

16.5. Culvert Design Criteria

16.5.1. Minimum Velocity Requirement

All culverts shall be designed to facilitate a minimum velocity of 2.5 ft/sec for partial flow depths. This velocity is specified to minimize sedimentation in the culvert. Maximum permissible outlet velocities and maximum permissible velocities for channel lining must be considered when adhering to this requirement.

The CoEP may require the clogging factors shown in Table 16-1 to be applied to the design cross section area of culvert openings in high debris/sediment areas where there are no or undersized (per these guidelines) upstream sediment controls. The locations of these areas may be identified from Figures 16-2 to 16-16.

Table 16-1. Clogging Factors

Culvert Area (ft^2)	Clogging Factor (%)
$0 < x \leq 4$	50
$4 < x \leq 9$	40
$9 < x \leq 16$	30
$16 > x$	20

ft^2 = Square feet.

16.6. Storm Drain System Design Criteria

16.6.1. Minimum Velocity Requirement

All storm drain systems shall be designed to facilitate a minimum velocity of 3 ft/sec for the 10-year storm flow. This velocity is specified to minimize sedimentation in the storm drain system. Maximum permissible outlet velocities for channel lining must be considered when adhering to this requirement.