For the Health of the Middle Rio Grande Valley:

A Proposal for Green Stormwater Infrastructure Practice

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May 2018

Acknowledgments

Many people generously contributed their time, expertise and support to this project.

I am grateful to my insightful and encouraging thesis committee (Kathy Kambic, Sue Frye, Judith Phillips and Alf Simon), to my patient editor Paula Panich, to the driving force of the Arid LID Coalition steering committee (Sarah Hurteau, Judith Phillips, Steve Glass, Andrew Bernard), to Bill Fleming for inspiring enthusiasm for this topic, and to all of the local experts who shared knowledge and guidance (Jim Brooks, Michael Young, Dave Gatterman, Sarah Ganley, Kali Bronson, Patrick Chavez, Kathy Verhage, Jill Cuppernell, John Mackenzie, Jennifer Dann, and Curtis Cherne).

I am grateful to Molly Blumhoefer, sustainability project manager with the Central New Mexico Community College (CNM), and to Steve Glass, environmental educator at CNM, for their generous assistance in developing the example application project.

I am grateful to the Center for Regional Studies for a graduate research fellowship, which allowed extra time and energy to be directed to this project.

I am also grateful to my partner Rachel, a steady source of thoughtful perspective and invaluable advice, and to my parents, Jim and Connie, for their enthusiastic support and home cooked meals.

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Preface

This thesis arose from love, concern, and imagination: love and concern for a certain corner of the world, and the imagined transformations that are possible with stormwater infrastructure change.

Concrete structures currently dominate the stormwater infrastructure of the Middle Rio Grande Valley (see figures 2-4). This infrastructure keeps most homes safe from floods, but could do more. If water infrastructure were instead built with soil, rocks, plants, and maybe a little bit of concrete, many possibilities would arise. In addition to flood control, benefits would include clean water flowing to the Rio Grande, a more robust tree canopy, a cooler city with vibrant habitat, and healthier, happier residents in all neighborhoods. Although often seen as strictly water infrastructure projects, the full development of green stormwater infrastructure (GSI) includes environmental justice and economic development goals.

Many technical and organizational challenges exist to changing stormwater infrastructure, but there is also a wealth of knowledge and motivation to make the change. This thesis draws on local knowledge as well as green stormwater infrastructure (GSI) and low impact development (LID) manuals from other semi-arid places in the United States. I hope that the synthesis of information generated through this research will be of use to the many people, including designers, planners, engineers, developers, policy makers, educators, and interested members of the public who also love the Middle Rio Grande Valley, who can imagine a cooler and healthier city, and who are ready to direct energy and effort to changing stormwater infrastructure.

Figure 1: Middle Rio Grande Watershed, EPA Boundary (map by author)

Grey Stormwater Infrastructure

Concrete, metal, pipes, and drains

Figure 2: Storm Drain Inlet, Albuquerque, NM (photo by author)

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Green Stormwater Infrastructure

Rocks, soil, mulch, plants, basins, swales

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Abstract

This landscape architecture research begins with an overview of the benefits and relevance of green stormwater infrastructure (GSI) and low impact development (LID) in semi-arid environments, and identifies the regulatory frameworks governing stormwater in the Middle Rio Grande Valley. Current practices as well as general and local barriers to implementation of GSI/LID are also discussed.

Research for post-construction practice draws primarily on existing GSI/LID guides from other semi-arid locations in the United States as well as local experts and documents from the Middle Rio Grande Valley. Findings are organized around foundational topics of GSI practice as well as applications of practice in the context of three common conditions: unstable slopes, parking lots, and roof runoff. Research is then applied to a specific site in Albuquerque, New Mexico.

The thesis concludes with recommendations for further research and key lessons learned.

Part One: Overview

Water management practices fall into several categories: structural and non-structural, (during) construction and post-construction. Structural practices are built, while non-structural practices involve requirements for planning, development, and behaviors (such as hazardous waste disposal or street sweeping). This thesis addresses post-construction practices that are structural and non-structural, although there is an emphasis on structural practice.

Through initial research into semi-arid GSI and stormwater regulation in the Middle Rio Grande (MRG) Valley, it became clear that although the EPA-issued watershed-based MS4 permit provides strong motivation for GSI to be included in new and redevelopment projects, a lot of information is still needed regarding guidelines and processes. It was also clear that a considerable amount of this information had already been developed, either in GSI/LID guides from similar climates in the United States, or by local experts who have spent decades committed to harvesting rainwater in the Albuquerque area. The results of this research indicated that time and effort could be saved by first consolidating and analyzing existing information. Thus, the focus of this thesis became the review, synthesis, and communication of existing information.

Background research also indicated the importance of involving the public in decisions about water infrastructure (Dhakal and Chevalier 2017). Another key to successful GSI implementation is inter-disciplinary communication between the fields of landscape architecture and design, engineering, planning, permaculture, arboriculture, horticulture, hydrology, soil science, education, wildlife biology, architecture, and construction. For these reasons, this thesis is written in an explanatory style while providing key pieces of technical information that will be useful to policy makers, professionals, and the public.

This research focuses on conditions or landscape types in which GSI could be broadly applied in the local context, rather than isolated Best Management Practices (BMPs). Focusing on conditions allowed for an integrated approach to water management and consideration of the site-specific factors that are critical to the successful application of GSI practice. This method provides a bridge between the decentralized, system-based thinking of GSI, and the centralized, standardized world in which GSI is applied.

The following questions arose from this framework:

- In which landscape types and conditions can green stormwater infrastructure (GSI) practices be most beneficial for the Middle Rio Grande Watershed?
- What research is available on interventions for each condition, and how can information be organized and clearly communicated?
- How will interventions be adaptable to the changing climate?

For the purposes of this project, the watershed boundary defined in the EPA watershed-based MS4 permit is used (see figures 1, 8, and 9). The watershed should not be confused with the MRG basin, which covers a much larger geographic area.

Methodology

Expert interviews were used to explore the relevance and validity of the thesis questions and formal proposal. The experts included:

- Jim Brooks and Michael Young of Adaptive Terrain Systems, a local permaculture design and construction company with 30 years of experience in New Mexico
- Patrick Chavez, stormwater quality program engineer with the Albuquerque Metro Arroyo Flood Control Authority
- Kathy Verhage, Jill Cuppernell, and John Mackenzie, Stormwater Management Section, an engineering division in the City of Albuquerque

Guiding questions for the meetings:

- Which aspects of the thesis proposal do you think would be most helpful to furthering GSI in the MRG?
- Do you have recommendations for particular landscape conditions to select?
- Do you have other advice regarding the project or research?

After meetings with the experts, three conditions for exploration were chosen: unstable slopes, parking lots, and roof downspouts. Research continued with an inventory of 12 local and regional government documents:

- *The Pima County LID and GI Manual*, a non-regulatory document for neighborhood scale development (2014)
- *The Pima County Stormwater Detention and Retention Manual*, a regulatory document for private development (2015)
- *The City of Tucson Water Harvesting Guidance Manual* (2005)
- *The Arizona Department of Transportation Post-Construction BMP Manual* (2016)
- *The City of Los Angeles Planning and Land Development Handbook for LID, Part B* (2016)
- *The County of Los Angeles LID Standards Manual*, a guide for roads and developments over 10,000 square feet (2014)
- *The County of San Diego LID Handbook* (2014)
- *The Eastern Washington LID Guidance Manual*, published by the Washington[1] Department of Ecology (2013)
- *The Ultra Urban Green Infrastructure Guidelines*, published by the City and County of Denver Public Works Department (2015)
- *The Bernalillo County Water Conservation Standards/Guidelines for Multi-Family Residential; Commercial, Office, Institutional Land Uses; & Residential Subdivisions with Less than Five Units*, produced by Sites Southwest Landscape Architecture and Planning (2011)
- *The New Mexico Department of Transportation National Pollution Discharge Elimination System Manual*, Stormwater Water Management Guidelines for Construction and Industrial Activities (2012)
- *The City of Albuquerque Development Process Manual, Chapter 22: Drainage, Flood Control, and Erosion Control* (both the current manual and proposed changes were consulted)

The inventory identified the presence and location of information on 11 topics. These topics were selected to research background information

[1] Although parts of Washington State are wet, the eastern half of the state is mostly semi-arid, with the central basin receiving around 8 inches of annual precipitation.

needed to design for all three conditions:

- Processes for site analysis and planning
- Design storm selection
- Flood risk reduction calculation
- Standard details
- Plant lists and recommendations
- Tree canopy
- Erosion Control
- Conveyance methods and design
- Bioinfiltration sizing and specifics
- Cost analysis
- Contaminant reduction

Once topics were researched, diagrams were created to condense and synthesize detailed information about each. Diagrams and written material were reviewed by the following experts to correct and validate findings:

- Judith Phillips, landscape designer and regional expert in arid adapted plants
- Jennifer Dann, urban and community forestry program manager for New Mexico State Forestry Department
- Dave Gatterman, environmental services director with the Southern Sandoval County Arroyo and Flood Control Authority (SSCAFCA)
- Sarah Ganley, engineer, Bohannan Huston, Inc
- Steve Glass, retired MS4 permit manager for Bernalillo County and member of Ciudad Soil and Water Conservation District
- Curtis Cherne, stormwater quality engineer in the City of Albuquerque Planning Department

Research findings were then applied to a test site at Central New Mexico Community College (CNM). The test site includes roof runoff from a portion of Ken Chappy Hall that flows onto an unstable slope, and a recently renovated parking lot adjacent to Ken Chappy Hall.

Molly Blumhoefer, sustainability project coordinator with the physical plant department of CNM, suggested the site and provided documents needed for the example design. Steve Glass, environmental science instructor at CNM, participated in site selection and contributed ideas on possible monitoring of the site by CNM classes. The example design was presented to the CNM Physical Plant Department for feedback and revision before inclusion in the thesis.

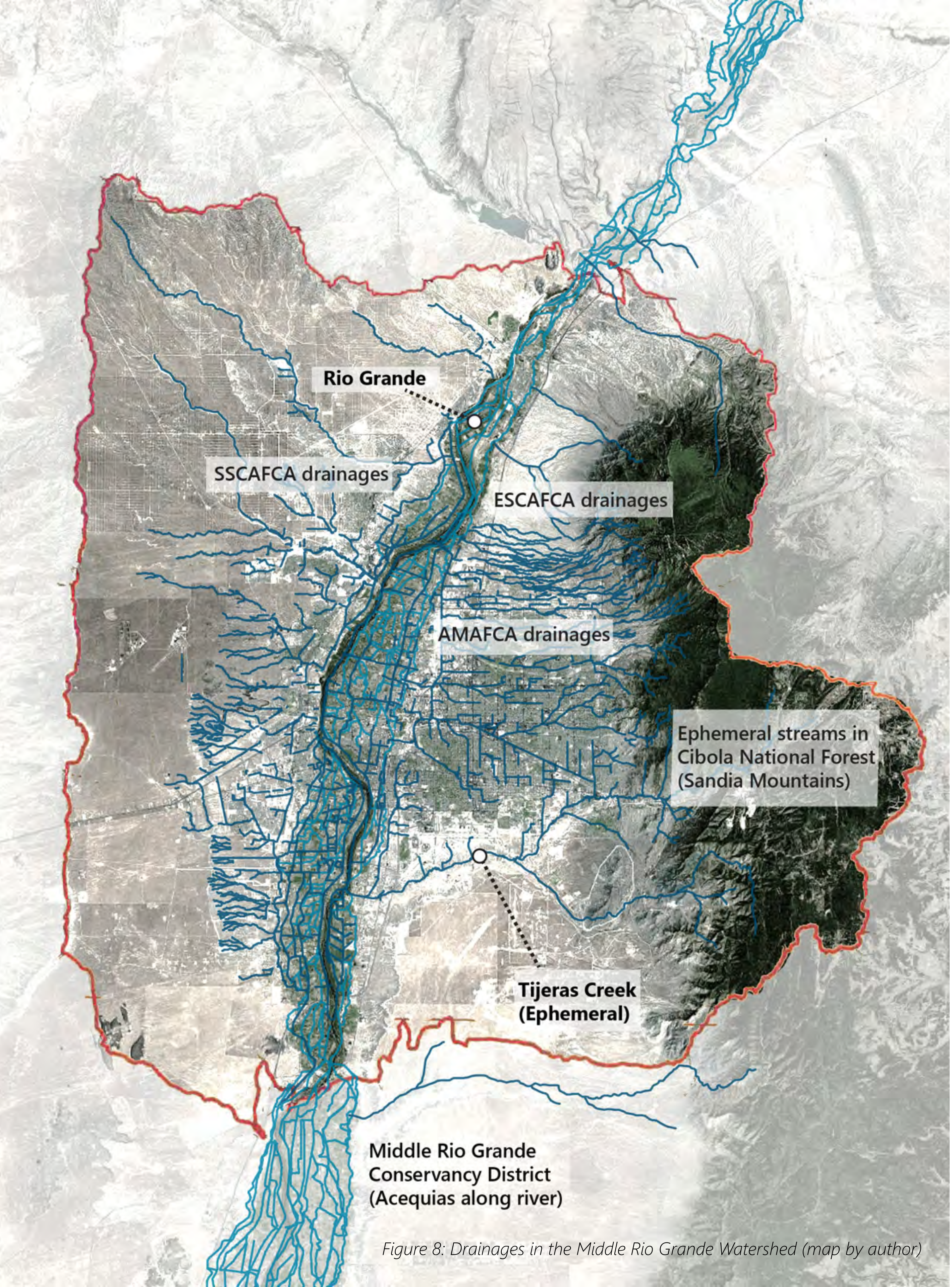


Figure 8: Drainages in the Middle Rio Grande Watershed (map by author)

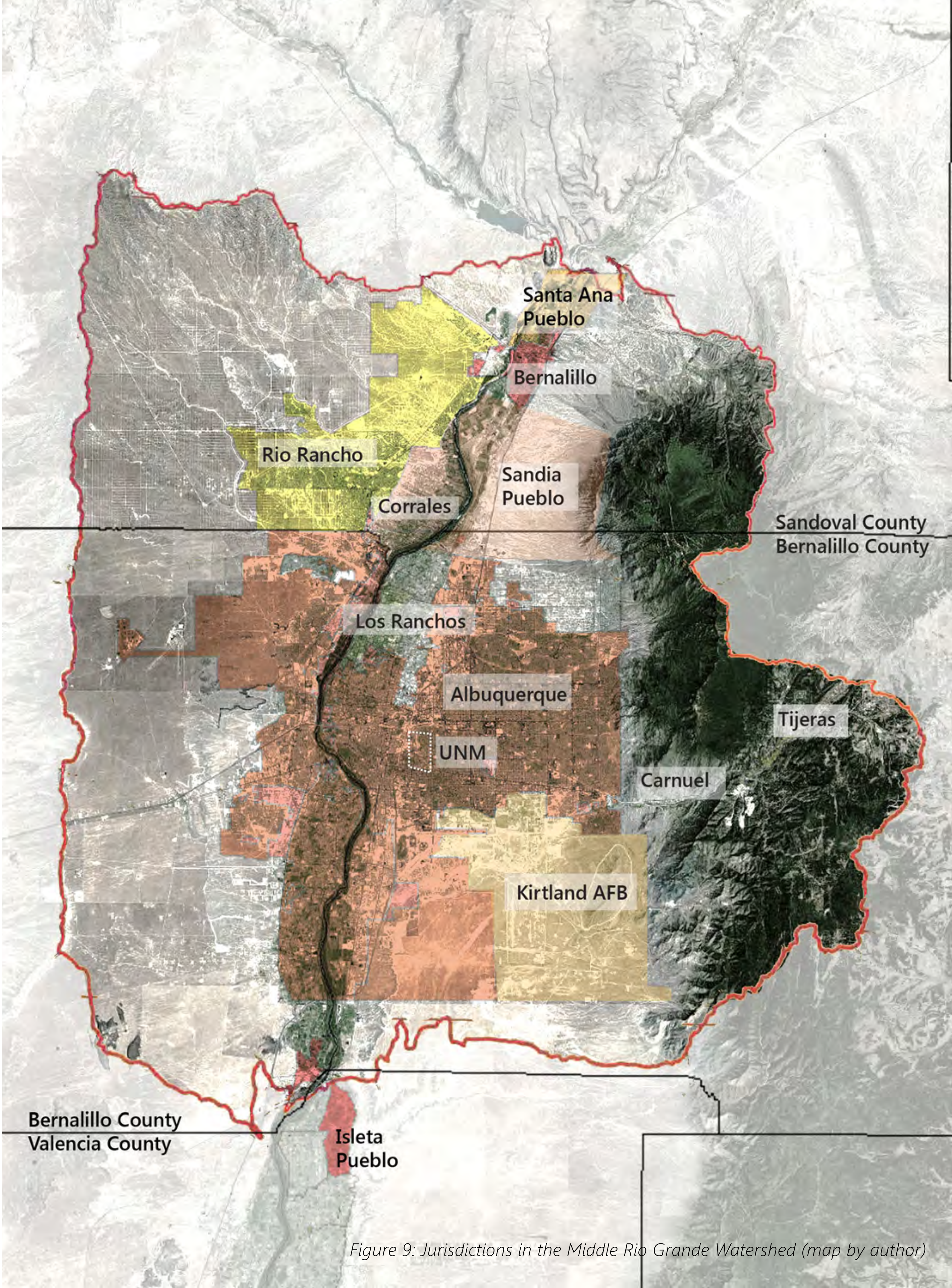


Figure 9: Jurisdictions in the Middle Rio Grande Watershed (map by author)

Background Summary

Green Infrastructure is a new term for an ancient idea. For millennia, humans have known that survival depends on effective management of freshwater resources. Working with natural water systems yields healthy crops, plentiful hunting and fishing, flood-free homes, and clean drinking water. However, this balance was disrupted by nineteenth century industrial revolution ideology which sought control of systems (including water systems) for maximum efficiency, commodification, and profit.

Particularly in the infrastructure boom following the Second World War, the quest for efficiency and control led to the containment of stormwater in concrete pipes and channels. This approach concentrates pollutants and increases flow velocity, both of which cause significant damage to natural waterways. Stormwater was, and often still is, seen as a danger to be mitigated. While industrialization ideology and practices have led to remarkable benefits for some people, they have also created toxic soils and water that can no longer support life, have contributed to increased flood risk, and have made many urban areas unhealthy places to live.

Green infrastructure practices seek to reconnect water to the land, use natural systems to filter pollutants and decrease velocity, and create a healthy environment for humans and other species. In the last ten years, these benefits have been documented and demonstrated in many U.S. cities, especially in Philadelphia, Seattle, and Portland. In these cities, green infrastructure has been accepted as a more cost-effective way of managing stormwater than grey infrastructure, while also providing additional environmental benefits. However, acceptance and implementation of green infrastructure have been slower in arid and semi-arid regions of the United States. San Diego, Los Angeles, Tucson, Phoenix, Flagstaff, Eastern Washington, and Denver are among the semi-arid locales that have developed guides to Low Impact Development (LID), including construction details and ordinances requiring the use of GI practices. Albuquerque, New Mexico, has not yet developed a cohesive system of GI use, but would benefit greatly from systematic implementation. This review describes successful semi-arid specific green infrastructure practices and suggests how they might be better incorporated into the Middle Rio Grande Valley.

DEFINITIONS

The Pima County and City of Tucson Low Impact Development and Green Infrastructure Guidance Manual (2015, ix) defines Low Impact Development as, "an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features and minimizing effective imperviousness to create functional and appealing site drainage that treats stormwater as a resource rather than a waste product." The same source defines green infrastructure as, "an adaptable term used to describe an array of products, technologies, and practices that use natural systems—or engineered systems that mimic natural processes—to enhance overall environmental quality and provide utility services including capturing, cleaning, and infiltrating stormwater; creating wildlife habitat; shading and cooling streets and buildings; and calming traffic. As a general principle, GI techniques use soils and vegetation to infiltrate, evapotranspirate, and/or recycle stormwater runoff" (viii). In other words, LID is the general principle, GI is the specific practice.

Green Stormwater Infrastructure (GSI) is a parallel term to Green Infrastructure and can be used interchangeably.[1] Grey infrastructure, in contrast to GSI and LID, is designed to carry storm water off a site as quickly as possible through concrete or metal pipes and channels. Hybrid infrastructure uses both green and grey infrastructure. GSI Best Management Practices (BMPs) are specific human-made structures that slow, filter, soak, or store stormwater rather than directing it off-site as fast as possible. Examples of GSI BMPs are bioinfiltration cells, stormwater planter boxes, permeable pavement, infiltration trenches, infiltration galleries, gabions, cisterns, vegetated buffers, dry wells, vegetated roofs, bioswales, tree trenches and pits, soil sponges, terraces, sand filters, and rain gardens. In semi-rural and rural areas, BMPs may also be rock structure restoration strategies such as Zuni Bowls, Media Lunas, and One-Rock Dams, and erosion control strategies such as imprinting.

Albuquerque's unique geographic and climatic conditions create a place that is classified as both arid and semi-arid. The lower elevations along the river and first terrace receive less than ten inches of annual rainfall on average, which classifies them as arid. The Northeast Heights, West Mesa, and Foothills areas of the city receive over ten inches of rainfall a year, so they are classified as semi-arid.

GENERAL BENEFITS OF GSI

GSI practices offer numerous and interconnected benefits (see figure 14). These benefits are well-documented and extensive (examples include McDonald 2016, 3, EPA 2010, 3 and EPA 2016, 2). They are summarized here to reinforce the potential to be gained by implementation: Infiltration of storm water improves water quality, reduces peak storm flows, and increases groundwater recharge. Reduced peak storm flows in turn reduce flooding which protects homes and lives. Reduced peak flow volume entering waterways decreases erosion and sedimentation that would otherwise damage habitat and water quality. Additionally, if GSI structures direct stormwater to planted areas, less potable water is need for irrigation, which supports water conservation. Increased vegetative cover provides wildlife habitat, a more beautiful city, and, if water is directed to trees, shade. More shade increases the lifespan of concrete and asphalt, reduces energy use for surrounding buildings, provides enjoyable pedestrian and bicycle paths, increases property values, and counteracts the urban heat island effect. Lower temperatures improve human health, including a decrease in respiratory illnesses. Trees also reduce particulate matter in the air, which improves air quality and also improves human health.

Allowing stormwater to infiltrate into the ground improves soil health through the development of microbial and fungal communities. Healthy soil

[1] The author prefers GSI because it more clearly describes which specific infrastructure is green. This terminology is used by the Philadelphia Water Department and the National Association of City Transportation Officials

bacteria filter chemical pollutants, digest biological contaminants, and improve plant growth. Plants and soil filter sediment and attached pollutants. Improved soil health and vegetation also provide opportunities for carbon sequestration, which improves human health outcomes. The size and placement of GSI structures can calm traffic, protect bike lanes, provide recreation opportunities, and create green space. The construction and maintenance of GSI can bring together communities and provide specialized jobs. The presence of GSI in a city has the potential to reconnect humans with the natural environment, which has positive psychological effects and can inspire people to take better care of natural resources. All of these benefits combine to create safer, healthier, more enjoyable places to live for all inhabitants of a community.

In addition to providing the above-listed advantages, in temperate areas with combined sewer systems[2] such as Seattle, Portland, and Philadelphia, GSI practice has been accepted and refined as a way to decrease infrastructure costs and the hazards of sewer overflows. Because the contemporary practice of GSI was developed in these non-arid areas, its application in arid and semi-arid areas remains less researched and less understood (Stone 2012, Lee and Fisher 2016). This lack of understanding contributes to the misperception that LID does not work in arid or semi-arid environment, and is not needed. However, there is significant research indicating the opposite.

IMPORTANCE OF GSI IN ARID AND SEMI-ARID CLIMATES

GSI strategies have a critical role to play in arid and semi-arid environments. Arid and semi-arid climates are more ecologically sensitive and therefore more easily disturbed by changes such as development and climate change. Findings from a recent computer-based modeling study for Salt-Lake City (semi-arid climate) showed that the modeled water budget was more affected by development in semi-arid areas than in humid areas, and that GSI interventions were more effective in restoring the natural hydrology in semi-arid areas than in comparable studies of wetter climates (Feng Burian Pomeroy 2016). Another study on active rainwater harvesting found that runoff volume reduction potentials were higher in cities in dry climates than in temperate cities (Lee and Fisher 2016).

GSI practices also have a unique and important role to play in improving the water quality of dry climates. The West and Southwest regions of the United States have intense precipitation events, higher runoff due to sparse vegetation and low organic content in soils, and longer periods of time between rainfall. High runoff velocity from heavy rains disturbs already fragile arid soils and carries sediment (Lee and Fisher 2016). High volumes of runoff sometimes overwhelm insufficient grey-infrastructure systems, which can lead to flooding. The extended time periods between events allow pollutants and sediment to accumulate, so that when precipitation does occur it carries a heavier load of mobile solutes (Jiang Yuan Piza 2015, Stone 2012). It is clear that precipitation and soils in the

[2] Combined sewer systems use the same pipes to transport both sewage and stormwater to a common treatment plant. If this system becomes overwhelmed by stormwater volume, a combination of sewage and stormwater is released from outfalls, typically into nearby streams and rivers.

West and Southwest, if unwisely managed, present stormwater-associated risks not present in other areas of the U.S.

The fact that the Western U.S. has followed a development pattern with a high ratio of impermeable surfaces exacerbates the challenges presented by infrequent and intense rainfall. Due to lower population and land values, most Western cities cover square miles with roads and parking lots on which pollutants often have months to accumulate. This pattern is exaggerated in Albuquerque. A study investigating changes in land cover use between 2006 and 2009 in 20 U.S. cities found that Albuquerque had one of the three greatest increases in impervious surfaces, measured both by hectares per year and per capita (Nowak and Greenfield 2012, 27). This disproportionately high ratio of impermeable surface cover stores pollutants and generates even higher volumes of runoff in already intense events. The combination of precipitation and development patterns causes chemical and physical damage to already fragile soils, arroyos, streams, and rivers.

In addition to providing a surface for pollutant accumulation and runoff intensification, roads and parking lots attract and retain heat. Retained heat causes the Urban Heat Island Effect, in which the temperature in urban areas is five to ten degrees (F) hotter than surrounding areas. Increased temperatures cause increased energy consumption for cooling, increased incidence of respiratory illnesses, decreased recreation and physical activity, and an otherwise unpleasant living environment.

The Urban Heat Island Effect (UHIE) is likely to increase in coming years with already-documented climate changes. According to a 2014 USGS published report (in EPA 2016 a, 4), "By mid-century, in Bernalillo County, average annual maximum and minimum temperatures are projected to increase by 7.2°F and 6.2°F, respectively, compared to the 1950-2005 baseline period". Annual precipitation may not change significantly, or it may decrease (EPA 2016 b). Either way, increased heat causes increased evapotranspiration and plants will need more water to survive. This could increase need for potable water for irrigation, which would further tax Western cities already struggling with limited water resources. GSI strategies can reduce the use of potable water by directing stormwater to plants in need of irrigation.

Australia, another hotspot of climate change, also experiences a high level of urbanization – one of the highest in the world. These factors combine to create a marked UHIE in which the temperatures in Australia's cities are 10-20°C (18-36°F) above surrounding areas. Because of this intensified experience of the UHIE, a recent article claims, "the primary imperative for road authorities to act has been climate change and its effect on the environment, where the term 'green infrastructure' has appeared increasingly in land management and planning." (Black Tara Pakzad 2016, 1) According to Roy et al (2008), Victoria, Australia mandates that all new developments meet best practices techniques for Water Sensitive Urban Design (the Australian equivalent of LID). As a rapidly urbanizing hotspot of climate change, the Western US may soon share the urgency felt in Australia to address the Urban Heat Island Effect and water supply shortages through better storm water management.

STORMWATER REGULATION IN THE MIDDLE RIO GRANDE VALLEY

In 1987, Congress amended the Clean Water Act to require regulation of stormwater discharges, in addition to the already-regulated industrial facilities and wastewater treatment plants (GAO 2017). The result of this amendment was the National Pollution Discharge Elimination System (NPDES) permit process. Since 1990, NPDES permits have been required for any municipality discharging stormwater into waters of the United States.[3]

Albuquerque sits in central New Mexico, which is the only state in US EPA Region 6 that does not have regulatory primacy. This means that the EPA directly issues NPDES permits in New Mexico, while other states issue their own permits (Maurer 2013). In 2006, the EPA commissioned a review of the NPDES from the National Research Council. Following publication of the report, the EPA selected three pilot sites from across the country to test recommendations from the report. The Middle Rio Grande was selected as one of these sites, and, in December 2014, the EPA issued a watershed-based Municipal Separate Storm Sewer (MS4) permit to entities in the Middle Rio Grande Valley (Holcomb et al 2017). Whereas standard MS4 permits are issued to specific entities that discharge stormwater (such as a city), the watershed-based MS4 permit is issued to all agencies within a geographic area, and requires cooperation among the agencies.

Unlike previous permits, the watershed-based permit requires multi-agency cooperation to improve storm water quality. Due to the unique circumstances in the Middle Rio Grande, these agencies include multiple federal, state, county, municipal, and tribal organizations. Permittees include: The City of Albuquerque, AMAFCA (Albuquerque Metropolitan Arroyo Flood Control Authority), UNM (University of New Mexico), NM DOT (New Mexico Department of Transportation District 3), Bernalillo County, Sandoval County, Village of Corrales, City of Rio Rancho, Village of Los Ranchos de Albuquerque, KAFB (Kirtland Air Force Base), Town of Bernalillo, EXPO (State Fairgrounds/ Expo NM), SSCAFCA (Southern Sandoval County Arroyo Flood Control Authority), ESCAFCA (Eastern Sandoval County Arroyo Flood Control Authority), Sandia Laboratories, Department of Energy (DOE), Pueblo of Sandia, Pueblo of Isleta, Pueblo of Santa Ana (EPA 2014b 6).

Permittees are responsible for monitoring water quality and educating the public on stormwater quality issues. The permit also requires site plans for development to, "include an evaluation of opportunities for use of GI/LID/Sustainable practices and when the opportunity exists, encourage project proponents to incorporate such practices into the site design to mimic the pre-development hydrology of the previously undeveloped site" (EPA 2014b 26). Permittees are responsible for updating codes and manuals and passing new ordinances to ensure that new development and redevelopment includes GSI and LID practices that detain and filter runoff.

[3] The Clean Water Act defines Waters of the United States as any waters which are used for, or could affect, interstate commerce.

For new development, the permit requires capturing the water from a 90th percentile storm event on site, whereas redevelopment requires capture of the 80th percentile storm event. In Albuquerque, this means the first 0.625 inches of rain for the 90th percentile event and 0.48 inches for the 80th percentile event. These amounts are the required treatment volumes set by the EPA for the permit. The goal with these set amounts is to capture the water from the beginning of a storm containing the highest levels of pollutants that have accumulated on roofs, roads, and other surfaces. Capture of the stormwater treatment volume also decreases erosion from peak flows and helps to restore the hydrological balance that existed before development.

The watershed-based MS4 permit was renewed in February 2016 and will expire in 2019. The intent of the watershed-based permit is to reduce compliance costs while also improving water quality and habitat in the Middle Rio Grande (Holcomb et al 2017), which is listed as an impaired waterway.[4] With these required changes to stormwater infrastructure, questions arise regarding New Mexico water law. Per the 1938 Rio Grande Compact, New Mexico is required to maintain a certain level of flow in the Rio Grande for delivery to Texas. There is concern that levels of flow in the Rio Grande could be impacted by implementation of GSI that encourages infiltration and capture of the 90th percentile storm. If implementation were widespread, the amount of water entering concrete pipes and channels that flows directly to the Rio Grande and to Texas could be reduced.

The concern with reduced amounts of runoff flowing to the Rio Grande is largely theoretical, given the fact that urban stormwater runoff from the Albuquerque area accounts for a minimal percentage of the total flow of the Rio Grande (Thomson 2017). Furthermore, runoff entering the Rio Grande from Albuquerque has increased in the last 40 years with the spread of urbanization (Stone 2012). Also, given high rates of evaporation and infiltration in the river, little or none of the water entering the Rio Grande in the MRG Valley will end up in Texas. Despite these facts, there has been a common misconception that GSI practices illegally interfere with the Rio Grande Compact. The Office of the State Engineer (OSE) recently offered helpful clarification regarding this concern.

This clarification came in the form of a document titled "Green Infrastructure Implementation in New Mexico: Frequently Asked Questions and Guidance from NMED and OSE." In this document, the OSE states that acceptable BMPs include any that, "don't retain or impound water for more than 96 hours and that are considered *de minimus* in nature" (Holcomb et al 2017, 5). Additionally, the OSE encourages infiltration for purposes of aquifer or river recharge.

The capture of roof water for on-site irrigation and domestic use is allowed as long the amount captured does not exceed the amount of water that would have run off before development (i.e. no alteration of pre-development hydrology). The OSE does not encourage any practice that promotes evaporation. If water harvested from impermeable surfaces is intended for any use that

[4] The water quality of an impaired waterway does not support designated uses.

qualifies as beneficial use, or if water is retained for more than 96 hours, a water rights appropriation or special permit is required. Given the specific parameters outlined in the Holcomb et al. (2017) document, perhaps the concern and confusion arising at the intersection of GSI practice and New Mexico Water Law will be relieved, and the practice of LID principles as encouraged in the MS4 watershed-based permit can move forward.

CURRENT GSI/LID PRACTICE IN THE MIDDLE RIO GRANDE VALLEY

The watershed-based permit requirements have resulted in steps by permittees to implement GSI/LID. For example, Bernalillo County passed a stormwater quality ordinance in April 2017 that requires GSI/LID to be implemented in new development "wherever practicable," (Bernalillo County 2017). The City of Albuquerque is in the process of updating chapter 22 of its Design Process Manual (DPM) to include diagrams and basic details for a few GSI practices. The City Council is also considering an ordinance requiring Payment in Lieu for developers who cannot or choose not to capture the required treatment volume on-site. The City and County ordinances set up the conditions for enforcement of GSI implementation.

Permittees belong to several groups that meet regularly to address water quality monitoring and education: The Middle Rio Grande Technical Advisory Group, the Middle Rio Grande Stormwater Quality Team, and the Compliance Monitoring Cooperative. These groups are the vehicles through which permittees collaborate to initiate and evaluate efforts to improve the quality of water flowing to the Rio Grande. The Middle Rio Grande Urban Waters Federal Partnership also facilitates collaboration for improved water quality in the Rio Grande. One of 19 such EPA- led groups in the U.S., membership includes some of the permittees as well as federal, state, and tribal entities who are not regulated by the permit. This partnership has been involved in projects such as the establishment of the Valle de Oro National Wildlife Refuge in 2012 (which will have a large green stormwater infrastructure component).

Although not necessarily for permit compliance reasons, the Albuquerque Bernalillo County Water Utility Authority (ABCWUA) has led a very successful incentive program encouraging residential rainwater harvesting and conservation. Southern Sandoval County Arroyo and Flood Control Authority (SSCAFCA) has constructed several projects employing GSI strategies. These projects include the SSCAFCA building, the Lower Montoyas Arroyo, and the Bosque de Bernalillo Water Quality Feature. The Albuquerque Metropolitan Arroyo and Flood Control Authority (AMAFCA) has constructed a stormwater quality and capture project in Hahn Arroyo and assisted with the technical design for the Imperial Building, among other projects.

The 2012 update of the National Pollution Discharge and Elimination System Manual for Construction and Industrial Activities used by the New Mexico Department of Transportation, Bernalillo County, SSCAFCA, AMAFCA, the Cities of Albuquerque and Rio Rancho, UNM, and the New Mexico Environment Department is perhaps the closest document to a regional LID guide. In addition to explanations of regulatory procedure, it contains design guidelines for site planning, construction, and post-construction practices. It also includes fact sheets for a variety of BMPs to control erosion, sediment, and pollution discharge (NM DOT 2012).

There are many other non-permittee organizations involved in promoting sustainable stormwater management. The Xeriscape Council organizes annual Land and Water Summit conferences on issues of water management, bringing in experts from around the country. Querencia Green, a community outreach program, operates, designs and installs GSI community demonstration projects. The New Mexico Water Collaborative, a non-profit organization, has also been part of several water conservation and reclamation projects around Albuquerque and serves as a resource center on water issues. Adaptive Terrain Systems designs and installs GSI and restoration projects around the state and at various project scales.

Ciudad Soil and Water Conservation District (SWCD) is a "political subdivision of the state of New Mexico and promotes the conservation, improvement, and responsible use of the natural resources on the rural and urban lands within its boundaries" (Ciudad SWCD 2017). Ciudad SWCD partners with organizations, including Bernalillo County, The Nature Conservancy, Adaptive Terrain Systems, and the New Mexico Water Collaborative, to support GSI projects. The many governmental and non-governmental groups involved in GSI and LID practice in the Rio Grande are making steady progress toward widespread implementation, but there is still room for improvement.

BARRIERS TO GSI LID IMPLEMENTATION

In 2010, Katherine Labadie held focus groups with many water system professionals in Albuquerque for her master's thesis titled, "Identifying Barriers to Low Impact Development and Green Infrastructure in the Albuquerque Area." From these focus groups, Labadie found many reasons for the lack of GSI/LID practice. Some of these reasons, such as water rights law and state policy, are no longer barriers. As mentioned above, development standards and ordinances are changing to include GSI/LID. However, many barriers that existed in 2010 still exist today. For example, the low price of municipal water discourages conservation based only on economic reasons.

Another economic issue identified was the lack of funding, either through incentives or expanded stormwater budgets. Labadie (2010 3) also found "skepticism from engineers and developers related to LID/GI techniques," and, "a lack of knowledge on how to design, construct, fund, and maintain these techniques, as well as major knowledge gaps related to how they function in an arid climate". Based on these findings, Labadie made six recommendations: "Promoting communication and collaboration, conducting outreach and education, identifying local knowledge and efforts, utilizing outside knowledge, taking the initiative to lead in this effort, and taking a multifaceted approach to implementing LID/GI" (2010 3).

In 2012, Mark Stone, Ph. D. civil and environmental engineering, and Asako Stone, Ph.D. psychology, completed a study for the Mid Rio Grande

Stormwater Quality Team (a group composed of MS4 permittees) on BMP suitability for the Albuquerque area and perceptions of the Rio Grande. The report addresses Labadie's recommendations for conducting outreach and education and explored BMPs that are best-suited for Albuquerque's unique hydrology. Stone and Stone found that most BMPs developed in humid areas can be adapted to semi-arid practice, although BMPs relying on vegetation may be less suitable due to irrigation needs. However, the necessary adaptations have yet to be clarified. Stone notes that one of the most significant challenges to transportation-specific GSI BMPs is the training of construction workers and inspectors. For BMPs that capture sediment, proper installation and maintenance are critical - without them, failure is highly likely.

Regarding perception of the Rio Grande, Stone and Stone found that general awareness about water resources in Albuquerque (including stormwater and drinking water) are positively correlated with conservation behaviors. The study also found that long-time residents and people who use the Rio Grande for recreation tend to be more knowledgeable about water resource issues in Albuquerque. The authors recommend focusing education and outreach efforts on new residents, as well as encouraging recreation along the Rio Grande.

As a follow up to Labadie's study and a requirement of the watershed-based MS4 permit, Bernalillo County commissioned Sites Southwest Landscape Architecture and Planning and Weston Engineering to complete a 2017 study on impediments to LID. The findings were similar many of Labadie's conclusions; There remain concerns about liability, applicability, and suitability of GSI in Albuquerque, perceived regulation, cost, and permitting concerns in the development community, and a need for clear design and maintenance standards. As recommended by Labadie, the study used outside knowledge in the form of consultation with several peer communities which included Tucson, San Diego, and Denver.

In seeking outside knowledge, Tucson seems to be the most relevant. Although it has much warmer winters, and different cultural, legal, and regulatory environments, Tucson is the city with the most similar climate, precipitation, and urbanization pattern to Albuquerque that also has a well-developed system of GSI practice.

According to permaculture designer Brad Lancaster (2017), a Tucson resident and leader in the field of water harvesting and management, Tucson's path to widespread implementation began with demonstration projects that proved GSI works. Supporters then worked to make GSI practices legal, then incentivized them, then made them legally mandated. This trajectory seems to be reversed in Albuquerque. Because Albuquerque has the watershed-based MS4 permit regulations and direct EPA oversight, there is already a mandate without widespread acceptance of functionality.

GSI practices are already legal in New Mexico, as previously discussed. Incentives remain inconsistent: apart from the water conservation incentives through the Albuquerque Bernalillo

County Water Utility Authority (ABCWUA), there haven't been incentives for choosing green over grey infrastructure. According to Labadie's research (2010) as well as the author's own experiences, there remains significant skepticism among engineers and developers regarding the effectiveness and cost benefits of GSI. Although the legality and mandate for practice are already in place, Albuquerque has yet to prove that GSI works, and needs to expand incentivization. A unique regulatory environment is resulting in a different path to widespread LID practice for the Albuquerque Area.

What can be found in Tucson is a wealth of demonstrations and organizations who research the efficacy of GSI in semi-arid climates with intense precipitation patterns. Although there have been attempts to communicate this information to practitioners and policy makers in Albuquerque, it has yet to have a transformative effect on water infrastructure in the Middle Rio Grande. Between 2010 and 2013, the Albuquerque group Arid LID led a series of workshops and trainings, many in partnership with organizations in Tucson. The New Mexico Chapter of the American Association of Landscape Architects (NMASLA) participated in and contributed to these trainings, which brought momentum for widespread use of green infrastructure in the Albuquerque area. However, this momentum did not last. Arid LID disbanded, the NMASLA shifted focus to pollinators (a critical and related issue), and the fragmented practice of GSI resumed. In the last year, there has been a movement to revive Arid LID[5]. The new iteration is again building a network of communication, collaboration, education, outreach, and initiative recommended by Labadie.

Implementation of GSI/LID has been slow in many other places, too. After decades of research demonstrating why GSI is a superior practice, there is now research investigating why GSI is still not mandatory and accepted everywhere. Two of these studies reveal challenges similar to those faced in Albuquerque. In Australia, Roy et al (2008) cite fragmentation of watershed management responsibility as one issue that is particularly applicable to Albuquerque: "In addition to spatial fragmentation that occurs when a watershed is shared among multiple governing jurisdictions, various components of the urban water cycle (municipal water, stormwater, surface water) may be managed separately, leading to limited integration of water resources management" (348).

While some municipalities have one water department (such as Philadelphia), Albuquerque has separate entities for water treatment and delivery, stormwater, flooding, planning approval, and acequia use and maintenance, not to mention the multiple State and Federal agencies, Pueblos, and municipalities all inhabiting the same area. Although the watershed-based permit addresses this fragmentation, having a high number of involved agencies creates a communication hurdle. Roy et al reinforce several of Labadie's findings, including a lack of funding and effective market incentives, uncertainties in performance and cost, and resistance to change.

[5] The author is a member of the revived Arid LID Coalition.

In September 2017, the United States Government Accountability Office (GAO) released a report on the effectiveness of the EPA's efforts at encouraging the use of GSI to decrease pollution in surface water in the U.S. The GAO interviewed members of 31 randomly-selected municipalities and the EPA to identify barriers to GSI implementation and opportunities for improvement. The report found that although the EPA began encouraging the use of GSI practices to meet water-quality mandates in 2007, there has only been an increase in familiarity with GSI and not the hoped-for increase in use. The municipalities surveyed cited, "developing a capital expenditure estimate, developing an operation and maintenance cost estimate, and designing and engineering a project" (GAO 2017 19) as the aspects of green infrastructure that are more challenging than grey infrastructure and inhibit widespread practice of GSI.

As part of efforts to shift from education and familiarity to actual practice, the GAO report recommends that the EPA will facilitate more productive collaborations among municipal agencies if they, "document their agreement on how they will collaborate, such as in a memorandum of understanding" (GAO 2017 34). The GAO offered the chart below (figure 10) as a concrete set of suggestions for interagency collaboration, culminating with a document outlining agreed-upon roles in collaboration.

Another recent study, by Dhakal and Chevalier (2017), reviewed existing research and literature in addition to EPA case studies of ten cities to investigate policy barriers to GSI implementation. Some of the findings echo Roy et al (2008) and Labadie (2010): "the adoption of GI appears risky to the municipal staff, policy makers, and public, discouraging them

Table 1: Key Issues to Consider for Implementing Interagency Collaborative Mechanisms

Key issues	Key considerations
Outcomes and accountability	Have short-term and long-term outcomes been clearly defined? Is there a way to track and monitor their progress?
Bridging organizational cultures	What are the missions and organizational cultures of the participating agencies? Have agencies agreed on common terminology and definitions?
Leadership	How will leadership be sustained over the long term? If leadership is shared, have roles and responsibilities been clearly identified and agreed upon?
Clarity of roles and responsibilities	Have participating agencies clarified roles and responsibilities?
Participants	Have all relevant participants been included? Do they have the ability to commit resources for their agency?
Resources	How will the collaborative mechanism be funded and staffed? Have online collaboration tools been developed?
Written guidance and agreements	If appropriate, have participating agencies documented their agreement regarding how they will be collaborating? Have they developed ways to continually update and monitor these agreements?

Source: GAO. | GAO-17-750

Figure 10: Table of Findings and Recommendations (GAO 2017)

to embrace the technology" and that "reluctance persists due to the unawareness among the public about how the gray systems are environmentally inappropriate and how GI manages stormwater sustainably" (2017 175). In addition to low municipal water costs preventing motivation to change, this article also mentions that most ecosystem services do not have a monetary value, or that value is difficult to ascertain. Interestingly, the article notes that GSI is a decentralized system, managing water on-site rather than directing to large channels or detention ponds. This decentralized system exists at odds with a highly centralized government system that developed along with the gray infrastructure system. A shift to GSI would challenge both infrastructure and government systems, and the authors suggest that, "neighborhood-level governance could be appropriate for GI" (2017 178)[6] . Dhakal and Chevalier (2017) address specific mechanisms for funding, liability reduction, and education before concluding, "Social acceptance is arguably the most decisive driver of a technology as well as the most effective addresser of its impediments," and that, "In addition to social acceptance, the availability of expertise, skilled personnel, champions, and leaders are of paramount importance for driving GI implementation" (2017 180).

Although Tucson was not studied in the Dhakal and Chevalier article, this last recommendation aligns with the implementation of GSI in Tucson. Brad Lancaster championed the beginning of GSI implementation in Tucson, and had the expertise to back it up. The Watershed Management Group (WMG), founded by several students from the University of Arizona, brought skilled personnel, leaders, and a community focus that built social acceptance of GSI. Today, the WMG provides education, research, demonstration, community outreach, as well as designing and installing residential and commercial GSI projects as a licensed contractor. It has worked closely with Pima County and the City of Tucson to develop ordinances and regulations mandating the use of GSI.

CONCLUSION

Given the sum of positive benefits to be gained by implementation of GSI and the directive of the watershed-based MS4 permit, the Middle Rio Grande Valley has a clear mandate to move forward with widespread practice of these systems.

The literature reviewed in this chapter dispels many misconceptions regarding the practice of GSI in New Mexico. Research has shown that urbanization has a disproportionate effect on fragile semi-arid ecosystems, that GSI contains the possibility of rebuilding ecological integrity, and that Albuquerque is rapidly adding impervious cover. Semi-arid GSI does require adaptation of practices developed in humid areas, but it has been shown to work in semi-arid places, including Tucson and San Diego. The New Mexico Office of the State Engineer has clarified that GSI practice is legal in the state. The EPA-issued watershed-based MS4 permit carries clear direction to use GSI to clean stormwater flowing to the Rio Grande, and local policy supports this direction. There is support among MS4 permittees as well as designers and

[6] This system could be similar to the acequia management governance established in the towns of Northern New Mexico during the Spanish Colonial period in which small communities elected a mayor domo and three commissioners to direct the distribution and maintenance of the irrigation ditches (Wilson 2017). Acequias, or unlined irrigation channels, could be considered green stormwater infrastructure as they do allow water to infiltrate and enhance groundwater recharge.

non-governmental groups for the implementation of GSI at a broader scale. GSI returns many more benefits than grey infrastructure, including reduction of the urban heat island effect, recharge of groundwater resources, filtration of pollutants, creation of habitat, and reconnection of urban residents to their environment.

GSI is significantly more difficult to design than grey infrastructure because it is decentralized and specific to both site and region. Decentralization creates challenges in calculating the flood risk reduction needed for public infrastructure. However, the significant advantages to be gained merit the effort and investment needed to overcome barriers to implementation.

As one group of researchers concluded (in Black et al 2016 2), "The way we manage urban water, particularly urban storm water, influences almost every aspect of our urban environment and quality of life. Water is an essential element of place making, both in maintaining, enhancing the environmental values of surrounding waterways and in the amenity and cultural connection of the place." The widespread use of GSI to improve the health of the Rio Grande strengthens the relationship between residents and the river, which is the geographic and cultural heart of the Valley. Green stormwater infrastructure holds enormous potential to make New Mexico's Middle Rio Grande Valley a healthier place for all.

KEY POINTS FOR BACKGROUND SUMMARY

- GSI has an important role to play in improving water quality and ecosystem health in semi-arid places.
- Stormwater regulation and management in the MRG Valley is a complex situation involving multiple entities at local, county, state, federal, and tribal levels.
- The watershed-based MS4 permit is a strong driver for widespread implementation of GSI.
- Most infiltration-based GSI practices are legal according to the Office of the State Engineer and the New Mexico Environment Department.
- Current barriers to widespread implementation of GSI include lack of incentives for use, low cost of water, uncertainty and skepticism regarding the cost, performance, and liability issues of GSI, lack of clear design and maintenance standards, and need for training, education, and outreach.
- Although GSI practice in the MRG Valley is not yet widespread, there is a wealth of local knowledge as well as resources from other semi-arid areas to guide future implementation..

Part Two: General Considerations

- Green stormwater infrastructure has been practiced in the MRG Valley for thousands of years. Indigenous people and then Spanish settlers worked with hydrological conditions to farm successfully and maintain year-round access to clean drinking water. Many of these practices continue today in certain places. However, the contemporary practice of GSI in the MRG Valley is not yet routine. Agreement on many topics must be reached for the change to be ideologically and technically possible. Questions about the general application of green stormwater infrastructure include:
- Why should stormwater infrastructure change?
- How can GSI address water quality permit requirements?
- How can stormwater infrastructure support healthier trees?
- What volume and intensity of rain should structures be able to handle? What should the design storm criteria be?
- What are the best materials to use for bioinfiltration?
- What information should be collected in the site analysis process and applied to design?

Answers to these questions are organized into general considerations that form a foundation of GSI practice in the Middle Rio Grande Watershed.

Pollutant Reduction

The Rio Grande is the geographic and cultural heart of the Albuquerque area. It is fundamental to the identity of the valley as well as being an important source of drinking water for the city. Despite this significance, contamination from stormwater runoff weakens the health and function of the Rio Grande. Runoff from developed areas contains pollutants that contaminate waterways such as rivers, streams, and arroyos. Pollutants prevent waterways from providing healthy habitat and recreation opportunities, including swimming, fishing and boating. Outdoor recreation along the river is important to the economy and sense of place for the Albuquerque area.

The EPA-issued stormwater discharge permit (MS4 permit) for the MRG watershed is an effort to improve the health of the river. This permit is currently the most significant driver for a change from grey to green infrastructure in the MRG Valley. It is important for all involved professionals (including non-water quality professionals), policy makers, and the public to have a basic understanding of the permit and how it supports the practice of GSI.

In cities such as Albuquerque, where sewage and stormwater use different systems, Municipal Separate Storm Sewer System (MS4) permits are designed to control and minimize the release of pollutants into waterways in order to protect habitat, recreation, and economic and cultural opportunities. Any governmental entity, such as a city or county, that releases stormwater into a waterway classified as a 'Water of the U.S.'[1] must have a permit. Private organizations are regulated by the government entity in which they operate, or by other, more specialized EPA permits.

The United States EPA issues permits for all MS4 entities in New Mexico. Usually, permits are issued to each specific entity that discharges stormwater. However, in 2014, the EPA issued a pilot watershed-based permit to all entities within the Middle Rio Grande Valley. The two designated Waters of the U.S. in the permit are the Rio Grande and the Tijeras Arroyo/Creek. The MRG Valley is one of three pilot programs in the country, and the only one currently functioning successfully (Glass 2018). It is hoped that the watershed-based permit will be more effective in improving water quality and habitat while reducing compliance costs through collaboration among the permittees (Holcomb et al 2017). Permittees are also required to educate and involve the public on water quality issues. There are 14 permittees who are required to cooperate on the development, implementation, and enforcement of programs that improve the cleanliness of water flowing to the Rio Grande.

MS4 permits require reduction of specific non-point source pollutants[2] in waterways. The EPA makes the logical assumption that a reduction in runoff will prevent contaminant from reaching waterways. In semi-arid areas, it is especially important to capture the water that carries pollutants from surfaces, because infrequent rain means that pollutants accumulate for months before being washed off. This first rinse of runoff is known as the 'first flush'. The concentration of pollutants is much higher in first flush events in dry areas than the concentration in more temperate areas (Jiang Yuan Piza 2015).

[1] The Clean Water Act defines Waters of the United States as any waters which are used for or could affect interstate commerce.

[2] Non-point source pollution does not have one identifiable source, such as an industrial plant. Rather, it comes from diffuse sources such as cars, pets, and fertilizers, and is picked up by stormwater and carried to waterways.

The objective of the MRG MS4 permit is to ensure capture of the first flush from every storm. The EPA quantifies the amount of the first flush with the 'required treatment volume,' which for the MRG MS4 permit is the runoff from every storm that produces a rain volume less than or equal to the 90th percentile storm event (approximately 0.6 inches of rain, according to an analysis of historical local rainfall events).

The watershed-based permit for the MRG Valley encourages the use of GSI to capture or filter pollutants from the required treatment volume. Pollutants of concern vary with land use and environmental factors, and are unique to each waterway. For the Middle Rio Grande, the especially damaging pollutants identified by the NMED (2016) are *E. coli* bacteria, temperature, polychlorinated biphenyls (PCBs), and gross alpha emitters. Substances that reduce dissolved oxygen have been of concern for the MRG in the past, are still of concern in the Tijeras Arroyo, and are regulated by the Endangered Species Act section of the MS4 permit. Gross pollutants and floatables (trash) are also a problem for the Rio Grande. The causes of each of these pollutants, as well as the treatments processes, are discussed individually below. In general, infiltration-based GSI practices with a pretreatment device for sedimentation and biological activity of plants and soil will treat all of these pollutants.

E.coli

E. coli, a bacterium found in the fecal matter of warm-blooded animals, is the primary pollutant in the Middle Rio Grande. *E. coli* is not a pathogen, but indicates the potential presence of other bacterial species that may pose a danger to humans in contact with infected water (Glass 2018). In 2005, a microbial source tracking estimated which warm-blooded animals are contributing *E. coli* to the MRG (See figure 11 below). Primary sources were identified as birds, domestic dogs and human beings, all of which can harbor and excrete pathogenic microorganisms. Humans can prevent *E. coli* from entering waterways by maintaining sewer and on-site septic systems, and by cleaning up after pets.

If deprived of food, water, and warm temperatures, *E. coli* will eventually die (the process of desiccation). The exact time it takes for populations to die depends on the number of bacteria and on conditions. However, if provided a nice warm place to live with plenty of food, such as the shallow

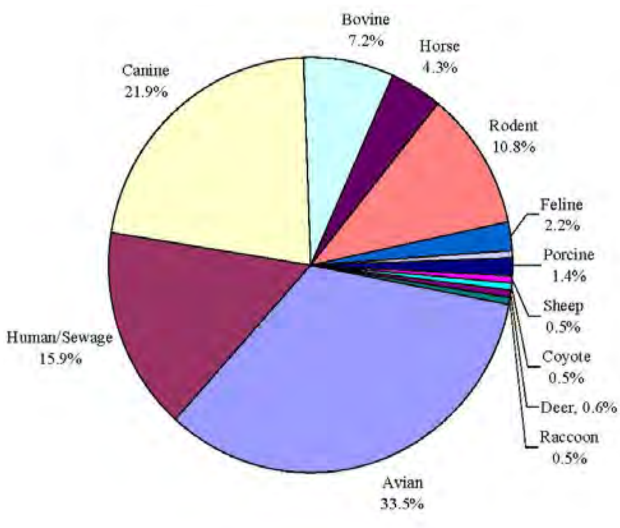


Figure 11: Sources of E.coli in the Entire MRG Study Area Using Ribotyping (Parsons Water and Infrastructure 2005)

waters along the banks of the Rio Grande, E. coli may reproduce. A study is currently underway by Ciudad Soil and Water Conservation District, with funding from the EPA through NMED, to evaluate the potential for *E. coli* to reproduce in Rio Grande sediments (Glass 2018).

Like many pollutants, *E. coli* attaches to larger sediment particles that are held in solution in stormwater. Sediment particles can be organic or inorganic (such as sand or minerals). In order for *E. coli* to be treated, these sediment particles must be trapped. This can be done through two processes: sedimentation, which allows particles to settle out of water, or filtration by straining the particles out of water. Removal of particles through sedimentation is often accomplished with a pre-treatment area where runoff is slowed and particles can settle out. The particles that settle out are confined to one place for easier removal, such as in a concrete forebay, rip rap area, or vegetated filter strip.

Particles not removed in sedimentation are filtered as water soaks into soil (Gulliver et al 2010). Bacteria such as *E. coli* are filtered in the top 1-2 inches of soil. For this reason, green stormwater infrastructure practices involving infiltration, such as flow-through planters, bioswales, and bioinfiltration basins have all been shown to have high pathogen and bacteria removal (County of San Diego 2014). Additionally, exposure to sunlight in the mulch layer of bioretention features can decrease bacterial counts (EPA 2014 a).

Another treatment for *E. coli* in surface water is filtration through a medium containing a certain species of fungi that will capture and eat *E. coli* (the process of predation). In a study done in the University of New Mexico Civil Engineering Department, mycofilters (in this case, burlap bags filled with barley straw inoculated with *P. ostreatus*) were shown to remove 97-98% of *E. coli* in at the surface of contaminated water (Martinez 2016). This study was conducted in a pond-like setting, and could be applicable to detention ponds or perhaps the shallow waters along the banks of the Rio Grande.

TEMPERATURE

The elevated temperature of stormwater runoff is a thermal pollutant. As runoff flows over hard surfaces such as roofs, concrete, and asphalt, it collects stored heat. When warmer water enters a river, it increases the temperature of the river, which is unhealthy for native species adapted to specific temperature ranges.

Reducing the extent of impervious surfaces is the first way to reduce the temperature of runoff. Vegetated permeable surfaces produce very little thermal pollution while pavement produces the most (Gulliver et al 2010). Providing shade is another way to keep surfaces cool and reduce the amount of heat that can be transferred to runoff. Infiltration is also an effective intervention, because as stormwater soaks into soil and then perhaps into groundwater, it transfers heat to the soil rather than transferring heat to the river. Infiltration-based GSI practices that include shade-providing vegetation meet all of these treatment recommendations.

POLYCHLORINATED BIPHENYLS

Polychlorinated biphenyls, or PCBs, are a group of tasteless and odorless human-made chemicals. Although their manufacture was banned in 1979, they are still found in many materials produced before that time. Polychlorinated biphenyls remain a significant pollutant because they persist in the environment for many years. They accumulate in the food chain and affect mammalian skin, endocrine, digestive, and reproductive systems, as well as potentially causing cancer (ATSDR 2014). PCBs have been found in the tissues of fish in the Rio Grande during routine NMED water quality surveys. Although PCBs break down very slowly, they can be consolidated in places that minimize their consumption by humans and other mammals.

Like *E. coli*, PCBs attach to sediment particles that are held in solution in stormwater. PCBs are a chemical pollutant, but to prevent PCBs from flowing to the river the particles to which they are attached must be physically trapped through the processes of sedimentation and filtration. Sediment trapped in a pretreatment area can be cleaned out as necessary, and attached PCBs will be prevented from entering the aquatic food chain. PCB concentrations in removed sediment are typically below levels requiring hazardous waste treatment and can be brought to a landfill (Glass 2018). Particles that are not trapped in the pretreatment area will be filtered in the top 2 to 8 inches of mulch and soil in an infiltration area (County of San Diego 2014), which also prevents them from entering the aquatic food chain.

OXYGEN DEPLETING SUBSTANCES

Dissolved oxygen in waterways is needed for aquatic organisms to breathe. Certain conditions and substances reduce amounts of dissolved oxygen; higher elevations, slower and calmer water movement, and warmer temperatures all contribute to lower levels of dissolved oxygen. Clearly, rivers have fixed elevations, but humans are the cause of reduced flows in the Rio Grande as well as higher temperatures through thermal loading.

Substances such as nutrients and organics (fertilizer, yard waste, and vegetable oils) are carried into stormwater to the river, where they consume dissolved oxygen, leaving less (or none) for the fish, insects, and plants that need dissolved oxygen to live. Humans can prevent these substances from entering waterways by proper disposal at a municipal treatment facility. However, if they do enter stormwater, GSI practices are an important treatment tool.

Organic substances and nutrients can be broken down by bacterial processes in healthy soil or taken up in plant roots as nitrogen. Green stormwater infrastructure practices that involve any form of bioinfiltration in a swale, basin, or planter box, create conditions in which healthy soil bacteria and plants can break down and use organics and nutrients before they end up in the river. If stormwater flows to GSI structures instead of directly into the river, substances that use dissolved oxygen are biologically processed before they contribute to an unhealthy ecosystem.

TRASH

In 2005, between 8 and 15 cubic feet of gross pollutants and floatables (trash) per acre were removed from arroyos and the Rio Grande (ASCG 2005). As seen in figure 12, plastics and cigarette butts were especially prevalent in the 9 sites in AMAFCA drainages that were part of the study.

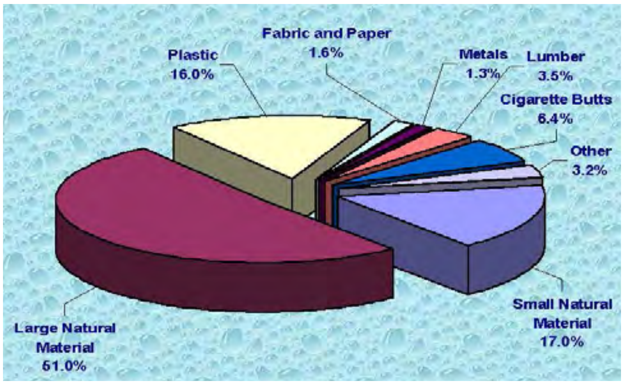


Figure 12: Debris Type by Volume (ASCG)

In the same study, it was also found that piles of trash in arroyos trapped and concentrated other pollutants which were eventually released when stormwater flowed through the trash. Like nutrients and organics, gross pollutants can be most easily remedied by proper disposal in a trash receptacle. However, if not properly disposed of, green stormwater infrastructure practices can trap trash before it impacts arroyos or the river.

Pretreatment devices, located where water enters a structure, trap sediment and trash. If used for filtering trash, pretreatment devices such as screens have the disadvantage of clogging and preventing water from entering a basin or swale. Water backing up behind a screen can cause flooding. Certain plants, including willows and grasses, are ideal for trapping trash and are also flexible enough to allow water to continue to flow through. The use of riparian vegetation to trap trash in stormwater flows has been implemented by the Southern Sandoval County Arroyo Flood Control Authority in their recently-completed Lower Montoyas Arroyo project.

GSI structures that fill with trash and aren't regularly cleaned become public eyesores. As GSI structures are integrated into residential and commercial areas, they tend to be more visible than arroyos or the river, which also accumulate trash. For GSI to be both effective at trash collection and a positively accepted practice, regular maintenance is critical. Municipal departments, already stretched for funding, cannot necessarily meet these maintenance requirements. Individuals, neighborhood organizations, and private groups have an opportunity to keep GSI structures clean and functioning.

GROSS ALPHA EMITTERS

Gross alpha emitters, which are types of radioactive or unstable elements, are associated with certain geologic types or can be human-generated. They are mostly a concern in the northern part of the watershed, in and around Rio Rancho. Their likely source is the volcanos on the Western edge of the watershed. Gross alpha emitters attach to sediment particles, so they can be trapped through sedimentation of heavier particles and filtration of smaller particles as water infiltrates into soil.

The range of treatment processes offered through GSI addresses the stormwater pollution requirements of the MS4 permit. In particular, infiltration-based GSI practices with pretreatment areas capture sediment and pollutants that attach to sediment (such as *E. coli*, PCBs, and gross alpha emitters), as well as reducing thermal loading and processing oxygen-depleting substances. Through chemical and biological processes in healthy soils and plants, infiltration-based GSI practices can also process other pollutants that are present in developed areas, including hydrocarbons and heavy metals.

KEY POINTS FOR POLLUTION REDUCTION:

- The Rio Grande is critical to the identity, history, and culture of Central New Mexico, as well as an important source of drinking water. The health of the community depends on the health of the river.
- Pollutants carried in stormwater compromise the health of the Rio Grande.
- The EPA-issued, watershed-based stormwater discharge permit (MS4 permit) exists to improve the health of the river by reducing contamination from pollutants in stormwater . It mandates capture of the most polluted first rinse of runoff.
- Six pollutants are especially problematic for the Middle Rio Grande: *E. coli*, temperature, polychlorinated biphenyls (PCBs), gross alpha emitters, oxygen-depleting substances, and trash.
- GSI features treat all of these pollutants through pretreatment devices, and infiltration and filtration processes that rely on healthy soil and plants.

POLLUTANT	PREVENTION	TREATMENT PROCESS	GSI PRACTICE
E. coli	Septic system maintenance, picking up pet waste	Dessication, filtration, sedimentation, exposure to sunlight, predation	Filtration through soil, exposure to sunlight in mulch layer, sediment trap
Temperature	Minimize impervious surfaces, maximize shade	Heat transfer to soil	Infiltration, shade from trees and shrubs
Polychlorinated biphenyls (PCBs)	None (banned in 1979)	Capture through filtration and sedimentation (not treatment, but prevents PCBs from entering waterway)	Sediment trap, filtration through mulch and soil
Oxygen-depleting substances	Proper disposal of fertilizers, yard waste, fats, and greases, reduction of thermal load	Biological degradation, uptake into plants	Pretreatment, infiltration in healthy soils, plant growth
Trash	Proper disposal, especially of cigarette butts and plastics	Filtration	Pretreatment, filtration through vegetation
Gross Alpha Emitters	None (probable source is volcanoes)	Sedimentation and filtration	Sediment trap, infiltration

Figure 13: Prevention and Treatment of Key Pollutants in the MRG Watershed (figure by author)

Climate Adaptation

Most residents of the Middle Rio Grande (MRG) Valley love its climate. People may have even chosen to live in the MRG Valley because of its climate. Aside from spring winds, a week or two of intense summer heat, and a handful of frigid and wet winter days, Albuquerque weather delights its residents.

Yet, as any long-time resident of the Middle Rio Grande (MRG) Valley can tell you, the climate has changed in recent years. Instead of spring arriving in May following one last late April storm, temperatures begin climbing in March or even February. Instead of late afternoon monsoon rains in July and August, the rains might come in June or October, and at midnight instead of 3:00 pm, or not at all. Instead of a week or two of over 100-degree temperatures in late June, there might be 8 weeks of 100-degree temperatures in July and August. Instead of snow falling in December and January, there might be no precipitation at all, or perhaps a bit of light rain.

These trends are expected to continue, with average maximum and minimum temperatures in Bernalillo County expected to rise 7.2 and 6.2 degrees Fahrenheit by 2050 (USGS in EPA 2016 a). Annual precipitation may decrease, and droughts are predicted to be more severe (EPA 2016 b).

Changes in climate affect the health of people, plants, and animals in the MRG Valley. Higher temperatures are dangerous for humans (EPA 2016 b). They decrease the livability of the city environment and amplify the Urban Heat Island Effect (UHIE, see background summary for explanation). They also increase the amount of water lost to evaporation and transpiration, making it more challenging for plants and soil to stay alive. In the mountains of Southern Colorado and Northern New Mexico, which are the headwaters of the Rio Grande, longer springs and hotter summers lead to decreased snow pack, higher evaporation rates, and longer fire seasons. Decreased snowpack and forest fires jeopardize the ability of mountain ecosystems to keep the Rio Grande flowing, and occasionally clog the river with charcoal and ash. As an important source of potable water for the MRG Valley, the health of the city depends on the health of the river.[1]

To those who are attached to this area of the world, the experienced and envisioned loss of landscapes and ways of life are quite troubling. However, as ecosystem engineers, people can change the way we do things to mitigate hotter temperatures, keep neighborhoods safe from floods, and support the viability of the plants and soil on which we depend. Three key practices of green stormwater infrastructure can address multiple challenges presented by current and predicted climate changes.

PRACTICE ONE: ALLOW WATER TO COLLECT AND INFILTRATE

Water falling from the sky needs to be able to collect in shallow basins and infiltrate into the soil. Water held deeper in the soil is available for plants, which increases plant health while also decreasing potable water use. With increased temperatures, evapotranspiration and irrigation needs also

[1] The Albuquerque Bernalillo County Water Utility Authority(ABCWUA) recognizes the importance of the river, and is taking proactive steps to contribute to watershed health in the Northern mountains while also exploring other means by which to protect potable water sources, including underground storage and groundwater recharge.

increase; more water is and will be needed to keep plants alive. Given the precarious situation of the forests of the northern mountains and the Rio Grande, it is wise to reduce potable water use wherever possible.

Infiltration basins and swales of various sizes provide places where water can soak into uncompacted soil. This allows soil moisture to be maintained much deeper in the soil profile (Kauffman Stropki Mundt 2017). Soil moisture helps to build soil health, and healthy soils can absorb more water than parched, hydrophobic soils. In less frequent but possibly more intense storms, it is advantageous for soil to be able to quickly absorb large amounts of water. The absorbent properties of soil can be increased further with organic mulches and subsurface gravel storage layers. It is critical for designers, engineers, and planners to include space for basins and swales in new and re development, especially in Albuquerque, where the creation of impervious surfaces outpaces most other cities (Nowak and Greenfield 2012).

Allowing water to soak into the soil provides plants access to deep water sources in the long and hot periods between storms. Water in the soil at least 18 inches below ground (in the B horizon) is safe from increasing evaporation rates at the surface, especially if the surface is protected with shredded wood mulch (Kauffman Stropki Mundt 2017). Specialized irrigation methods, although more expensive, are also available to deliver water deeper in the soil where it is protected from evaporation.

In certain areas, such as along arroyos, it is possible for stormwater infiltration to recharge groundwater levels. Groundwater provides an alternative to pumping water from the unpredictable flows of the Rio Grande so it is important for long-term water security to recharge groundwater.

PRACTICE TWO: INVEST IN HEALTHY, DROUGHT ADAPTED TREES AND PLANTS

The urban heat island effect means that increased
The urban heat island effect means that increased
temperatures occur where there is more asphalt, concrete, and buildings. Trees provide shade for hard surfaces and buildings, and prevent the absorption of heat. Shade keeps air temperatures lower, people healthier, and decreases energy use from air conditioning. Reduction in energy use contributes to reduction in water use at power generation sites outside the MRG watershed.

Shrubs and grasses keep the ground surface around trees cooler, which in turn improves tree health. Although the shade and cooling benefit from shrubs and grasses is not as significant as that of trees, it does contribute to a more livable place. Shrubs and grasses provide bird and pollinator habitat and add aesthetic value to the landscape.

Plant roots, especially tree roots, pull water from the soil and build soil structure, increasing the absorbency of healthy soil. Pore space created by roots maintains the infiltration ability of soil. In combination with the volume of temporary surface water storage space in basins, absorbent roots and soils help to reduce flood risk inherent in infrequent but intense storms. Plant leaves and needles also intercept rain water, decreasing runoff that can lead to flooding. In the absence of healthy plants and soils, there is higher runoff from intense storms, causing increased flood risk.

Healthy trees, plants, and soils also sequester carbon and intercept air pollution, mitigating the climate effects and human health impacts of burning fossil fuels.

Trees, of course, require a significant investment of resources and water for establishment of healthy roots, so it is critical to select species that are adapted to intense heat, temperature variation, and long dry periods (see Appendix A). To adapt to earlier springs and longer, hotter summers, planting should occur in the fall so that seedlings have several months of root development to support the plant during the many hot, dry months (Kauffman Stropki Mundt 2017).

PRACTICE THREE: USE SOFT MATERIALS TO MANAGE STORMWATER

Soft materials, such as soil, mulch, rocks, and plants, provide important flexibility in responding to changes in both precipitation and development patterns (Brooks and Young 2018). It is much easier to adjust capacity of features with soft materials than concrete structures, which may prove to be either obsolete or insufficient in the coming decades. When infrastructure is kept above ground, visible, and involves plants, people are more likely to recognize the function of infrastructure and notice changes in weather and climate. Keeping people connected to infrastructure, resources, and place can increase the likelihood of concern for environmental health. In a 2013 study done by The Urban Land Institute, it was determined that, "[a]nother aim of having Singapore residents experience nature as an integral part of their lives is to encourage them to value, and as a result, take better care of the environment and the city's limited natural resources" (in Black Tara Pakzad 2016 4). Above-ground GSI practices have an additional advantage of being easier to maintain and less expensive than below-ground GSI practices (such as infiltration trenches or galleries).

While the changing climate presents a possible future in which the Middle Rio Grande Valley is significantly less hospitable to human, plant, and soil life, there is a possibility to adapt water management methods to promote plant and soil life that can protect humans from increased temperatures and more intense precipitation. A few simple, research-based methods hold the key to a healthier future.

KEY POINTS FOR CLIMATE ADAPTATION:

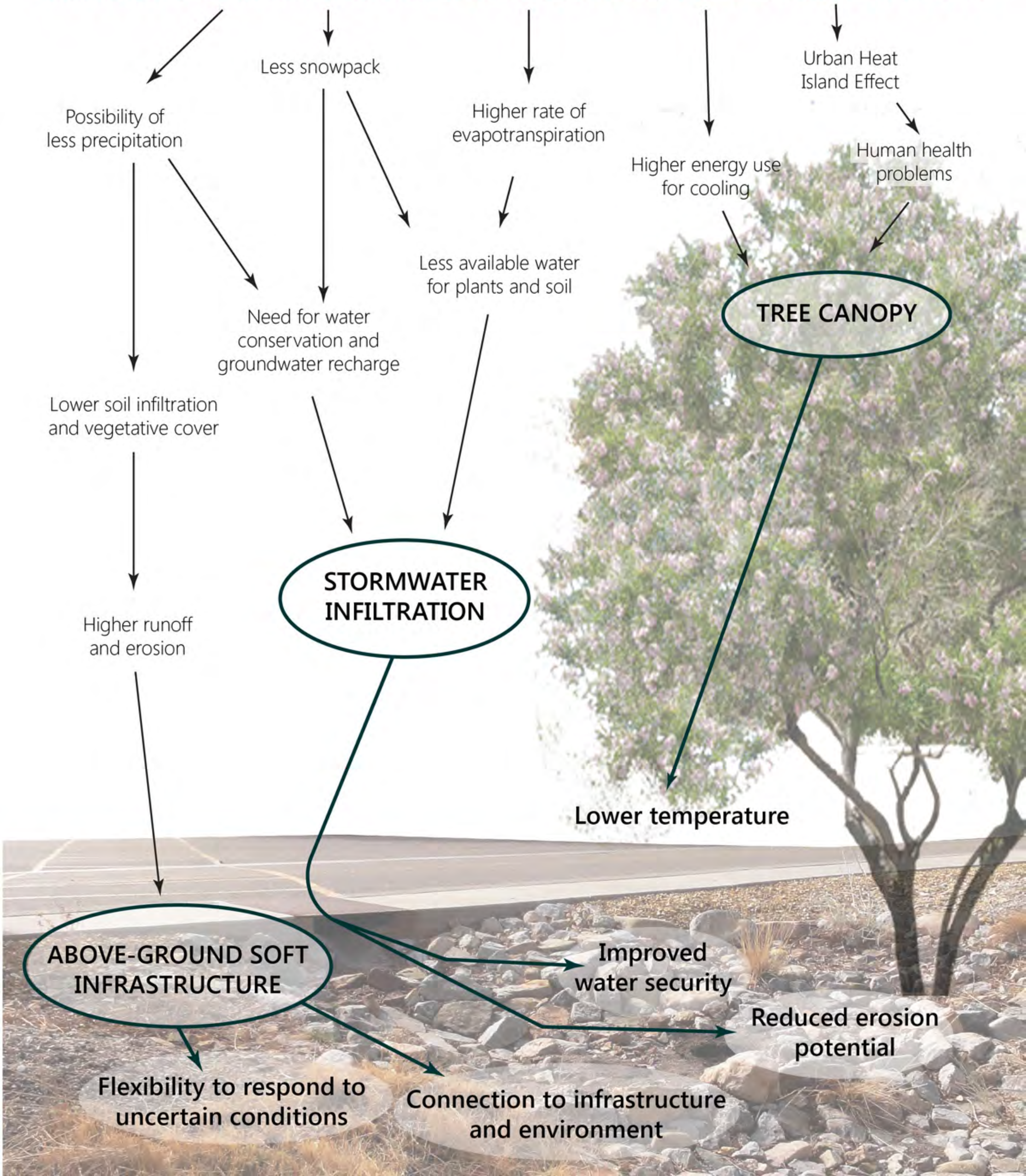
- The MRG Valley is becoming warmer, and precipitation less predictable. These changes have been recorded are expected to increase in coming years.
- Higher temperatures have negative effects on the health of people, plants, and animals. Temperatures are even higher in urban areas where concrete, asphalt, and buildings absorb and release heat. This is known as the urban heat island effect (UHIE).
- Unpredictable precipitation jeopardizes water supply for people, plants, and animals.

Three aspects of GSI respond to these changes:

- **INFILTRATION**: GSI features that allow stormwater to infiltrate deep into the ground improve soil health and tree and plant resiliency, decrease potable water use for irrigation, and can recharge groundwater in certain places.
- **TREE CANOPY:** GSI helps to build a healthy tree canopy, which counteracts the UHIE, makes people healthier, decreases energy uses, sequesters air pollution and carbon, and provides habitat.
- **FLEXIBILITY:** GSI features constructed above ground and without concrete provide flexibility in responding to changes as well as a visible connection to changes in climate.

Figure 14: Climate Change Effects and Interventions (figure by author)

WARMER TEMPERATURES AND UNPREDICTABLE PRECIPITATION



Stormwater and Tree Canopy

A healthy tree canopy is the primary antidote to the urban heat island effect. On a scorching summer day, relief provided by shade is invaluable. Trees filter and trap contaminants, and reduce runoff through root uptake and interception. Trees also improve human health, sequester carbon, provide habitat, increase property values and reduce energy consumption for cooling buildings. It has been estimated that urban trees in Albuquerque provide $8.97 million dollars per year in combined benefits for pollution removal, carbon sequestration, carbon avoidance, energy savings, and stormwater avoidance, and have a collective standing value of $1.93 billion dollars (Project Desert Canopy 2017). Trees are a living and economical solution to the many challenges of a changing climate.

However, the Middle Rio Grande Valley is not exactly an inviting place for trees to grow. Apart from the river valley and mountains, there are only three species of native trees: Honey mesquite (*Prosopis glandulosa*), Desert willow (*Chilopsis linearis*) and One-seed Juniper (*Juniperus monsperma*). Most of the MRG Valley consists of shrub and grassland; in order for tree species to survive and thrive here, they cannot be an afterthought. If trees are not prioritized, they will not survive. In fact, a recent study showed a 2.7% loss of tree canopy Albuquerque between 2006 and 2009, among the three highest losses in the study, measured by both total hectares and per capita. Of the 20 cities studied, only Houston and New Orleans lost more tree canopy than Albuquerque (Nowak and Greenfield 2012). Careful and deliberate attention must be paid to creating conditions for healthy tree growth, including access to stormwater.

Trees with a 30-foot diameter need at least 1,000 cubic feet of uncompacted soil or bioretention soil media[1] to develop a strong root system (EPA 2013). In tight urban conditions, this volume of soil can be provided through technologies such as structural soil, permeable pavement, and suspended pavement. According to the EPA report "Stormwater to Street Trees" (2013), trees planted under suspended pavement outperform trees planted in structural soil. The Ultra Urban Green Infrastructure Guidelines recommend compacting soil or bioretention media beneath trees to 85-90%, and soil around trees to 70% to prevent excessive settling (City and County of Denver 2015). They also recommend a minimum width of 9 feet uncompacted soil. Of this 9-foot width, four feet can be provided under suspended pavement or provided through structural soil, while a minimum of 5 feet must be at the surface.

As with all green stormwater infrastructure practices, utilities, soil properties, and depth to water table must be considered in planting trees. Roots may interfere with underground utilities, requiring relocation of either the utilities or the tree. Existing soil must be stable even when saturated, and have sufficient infiltration rates to prevent tree roots from drowning. If infiltration rates are insufficient to prevent tree roots from drowning, an underdrain connected to another infiltration area or to an existing storm sewer can be used to evacuate excess water.

If there is enough space at the base of a tree, planting shrubs and grasses offers several advantages. Plants under a tree shade the surface

[1] Bioretention soil media is a mix of organics and sand designed for high infiltration rates, pollutant filtration, and plant growth.

and keep tree roots cool; they also provide additional pollution filtration and improve soil structure. Plants at the base of a tree can dissuade people from walking near the tree, and are an alternative to 8-12-inch rock or tree grates that are often used for this purpose. Both rocks and tree grates are less aesthetically pleasing, absorb and release heat, and do not cool tree roots like shrubs and grasses do. However, both plants and rocks do protect the tree from human damage and protect the soil from compaction. Compacted soil cannot infiltrate stormwater or support healthy root function. City of Denver staff have observed "that trees surrounded by other vegetation are more frequently watered by nearby residents" (City of Denver 2015 62), indicating a higher level of concern and care for trees with plants at their base rather than a grate or rocks.

Stormwater can flow to tree roots either through curb inlets or underground storage and conveyance systems, which are more expensive and harder to maintain. Sediment should be filtered before entering the tree pit or trench so that it does not clog the pore space in soil, decreasing infiltration rates and root health. Sediment can be trapped above ground with a forebay[2] where sediment can settle out, or below ground with a sand or fine gravel filter. It is important that stormwater flowing to an area planted with trees does not contain road salts that can kill roots and soil microbes. As the MRG Valley experiences reduced snowfall as a result of warmer temperatures, this is a less important concern.

Allowing stormwater to infiltrate deeply into the soil benefits both the tree and plants around the tree. If provided uncompacted soil and deep watering (either through irrigation or stormwater), roots of drought-adapted trees can easily grow 25 feet down into the ground, while roots closer to the surface access air and collect water from smaller precipitation events or poorly-designed irrigation. Unlined tree trenches and pits allow deep root growth. Many trees and shrubs transfer water from lower in the soil to the drier surface, providing an irrigation system for smaller plants (Houdeshel et al 2012).

While almost all trees in semi-arid areas require supplemental irrigation to establish a healthy and resilient root system, it is possible for established trees to survive only on stormwater runoff. However, it is difficult to say exactly how much impervious surface area is needed to generate sufficient runoff to support the irrigation needs of a tree. This question has been explored in two other semi-arid places, Denver, Colorado, and Pima County, Arizona, that also receive precipitation in late summer and early fall, like Albuquerque.

The City and County of Denver calculate that runoff from approximately 1,500 square feet of impervious surface should be provided per street tree to satisfy water quality requirements (City and County of Denver 2015 61). No additional irrigation guidelines are given. Denver averages a little over 14 inches of annual precipitation to Albuquerque's 8.67 inches, and lower temperatures mean lower evapotranspiration which means more precipitation is available for tree function than would exist in Albuquerque, so runoff from a greater amount of

[2] A forebay is an area where sediment can settle and be trapped before water flows to an infiltration structure.

impervious area would be needed to meet a tree's water needs in the MRG Valley.

Using information on estimated evapotranspiration and precipitation in March (the last month before a long period without precipitation), the calculation for surface area to plant canopy size in the *Pima County GI LID Manual* (2014) estimates that a desert-adapted tree with a 17.8-foot canopy radius would require runoff from 3,300 square feet of impervious surface to meet irrigation needs. The author is not aware of any desert-adapted plants that have a 17.8-foot canopy radius, so this method of calculation may need to be adjusted to account for maximum canopy size of desert-adapted plants. Tucson averages slightly more than 11 inches of annual precipitation and has higher temperatures and evapotranspiration rates than Albuquerque, so Tucson's estimate of 3,300 square feet is more relevant than Denver's 1,500 square feet.

In considering tree species, a bigger, denser canopy offers more stormwater benefits (EPA 2013), but adaptations to drought and wind and habitat benefit are also important considerations. Any tree with invasive potential should be avoided. According to Greg McPherson, research forester with the USDA Forest Service, unpredictable and extreme changes in climate make it even more important to plant a diversity of species in order to have a stable canopy (McPherson 2017). He also recommends gradually shifting the palette of trees to those adapted to future rather than current climate. For Albuquerque, this means that tree species should be selected from a place like El Paso, Texas, where temperatures are 6-8 degrees Fahrenheit warmer.

Through careful species selection, access to plenty of uncompacted soil, and stormwater saturation, the tree canopy of the Central New Mexico could become more robust and provide invaluable benefits to residents, now and into the future.

KEY POINTS FOR STORMWATER AND TREE CANOPY:

- Trees provide beautiful and cost-effective protection from heat, pollution, and flooding.
- In the MRG watershed, careful and deliberate attention must be paid to creating favorable conditions for healthy trees and selecting drought-adapted species.
- Trees planted in GSI features are healthier because they are watered deeply by stormwater, which also decreases potable water use.
- Wherever possible, shrubs, flowers, and grasses should be planted around trees.
- A tree with a 30-foot diameter canopy needs at least 1,000 cubic feet of uncompacted soil.

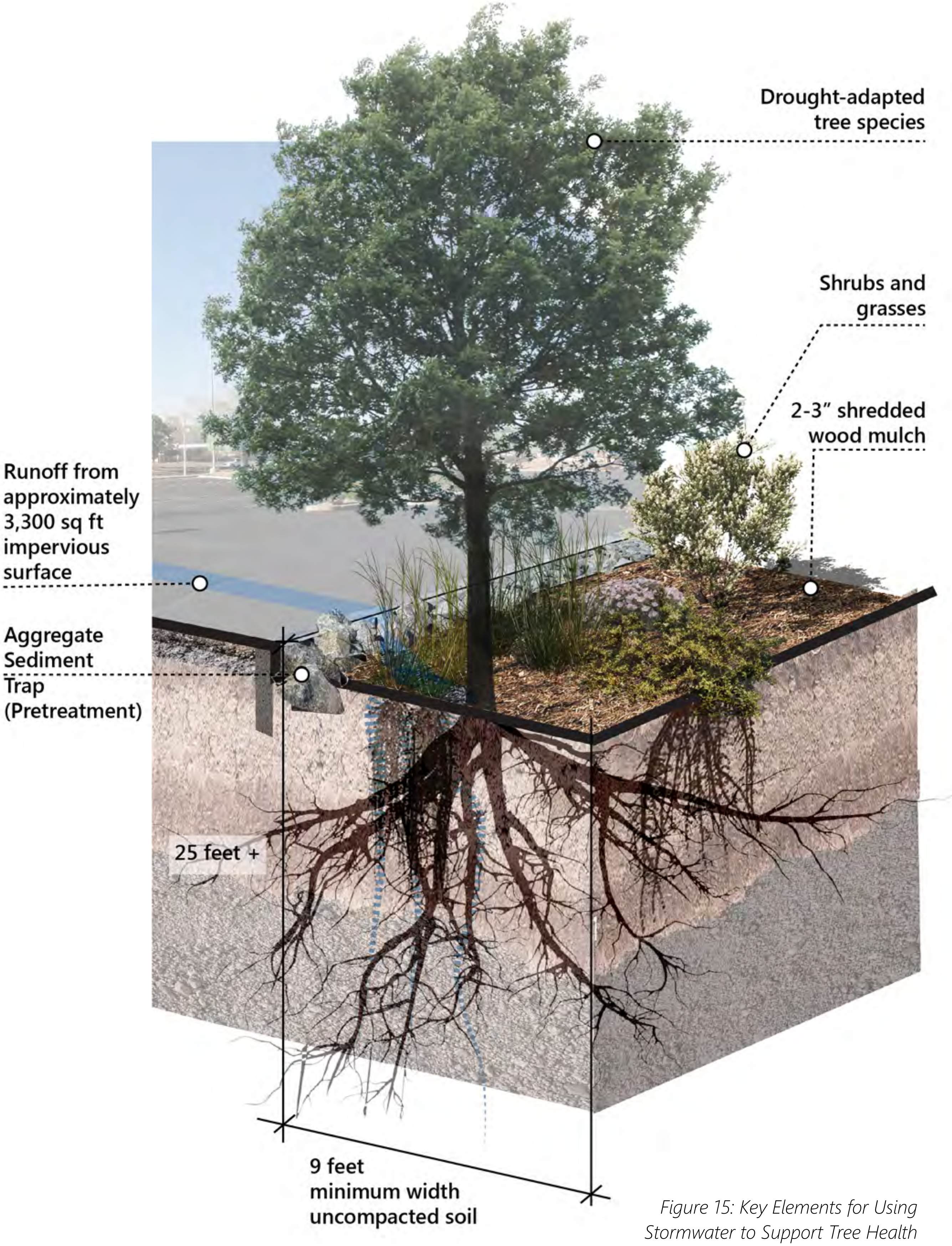


Figure 15: Key Elements for Using Stormwater to Support Tree Health (figure by author)

Bioinfiltration Sizing and Material

Any casual observer of semi-arid landscapes has noticed that wherever a little extra water collects, something will grow. A remarkably small increase in available water provided to drought-adapted plants causes a response. The technical term for deliberately improving soil conditions, creating a place for stormwater to collect and soak in, and plants to grow, is called bioinfiltration. The biological components are healthy soil and plants, and the water collection brings the infiltration component. Bioinfiltration practices provide a wide range of benefits that include the physical, chemical, and biological treatment of pollutants, carbon sequestration, enhanced vegetative growth providing shade, cooler temperatures, habitat, improved soil moisture and water storage for plant resiliency during dry periods, and increased infiltration capacity reducing flood risk.

Infiltration practices alone (such as an infiltration trench or dry pond), or filtration practices alone (such as a lined planter box) do provide benefits, and are ideal for sites with certain constraints. But the combination of biological components (plants and mulches) and deep infiltration provides the most water quality benefits. Bioinfiltration cells have been shown to have high levels of filtration for heavy metals, total suspended solids, sediment, bacteria, oil and grease, and hydrocarbons (EPA 2016, County of San Diego 2014, Jiang, Yuan, Piza 2015). Healthy soil and plants are the most effective tools in treating runoff, so they should always be prioritized in GSI design.

Bioinfiltration practices can be applied in a variety of GSI structures. Linear bioinfiltration features that convey water are known as bioswales, while temporary ponding areas are known as bioinfiltration basins. Both vary in size and shape. Raingardens and stormwater tree trenches are specific types of bioinfiltration practices. As long as a practice includes deliberate improvement of soil health with the addition of organic material, plants, and water collection that infiltrates within 96 hours, bioinfiltration is at work.

According to the EPA watershed-based MS4 permit, government entities must ensure that runoff from public and private development treats runoff on-site. If used for this purpose, bioinfiltration structures must be sized to capture runoff from the 80th or 90th percentile storm event (required treatment volume), depending on whether the site is being redeveloped or developed. Roughly speaking, the first half inch of rain must either be captured and infiltrated on-site, or be filtered through a GSI structure before being discharged. To size a bioinfiltration feature, the designer must calculate the runoff from impervious surfaces such as roads, roofs, and parking lots, then ensure that basin volume and infiltration rates match the runoff volume. For example, a 200-square foot basin with a 1-foot depth would provide 200 cubic feet of basin volume. The designer also must verify that the infiltration rates of the subsoil are at least 0.3 inches per hour (County of Los Angeles 2014), which corresponds to soil hydrologic groups A and B. To provide adequate contact time for soil microbes to degrade pollutants, infiltration rates should not exceed 2 inches per hour (County of San Diego 2014).

The City of Albuquerque Development Process Manual (Chapter 22) specifies that detention basin depth cannot exceed 18 inches, or protective fencing would be required. The 18-inch basin depth limit is standard in GSI LID manuals from semi-arid places. An average depth of 9 inches is recommended in San Diego County, although any depth between 6 inches and 18 inches is acceptable (2014). The basin depth cannot exceed the required drainage time, which can be between 12 and 96 hours. For example, if the saturated infiltration rate is 0.3 inches per hour, in 48 hours 14.4 inches of water would infiltrate, so basin depth could not exceed 14 inches. Per New Mexico water law, basins must drain within 96 hours unless water rights are available, but for mosquito control and plant health, drainage within 48 hours is recommended.

The second factor in sizing a bioinfiltration feature is flood risk reduction, which depends on the hydrology of the site. In New Mexico, as in most of the southwestern United States, the majority of annual precipitation comes in late summer and early fall in the form of monsoon rains. These rain storms tend to be brief and intense. Although the intensity of the storm is not generally greater than storms in say, Kansas, due to high impervious surfaces, hydrophobic soils, and low vegetative cover, rain becomes runoff faster and at higher rates than in more temperate places. When intense rain quickly becomes runoff, flash floods occur. Any water infrastructure, including GSI, "must be capable of receiving flashy events without notice" (Stone 2012).

Bioinfiltration structures can account for flashy events in several ways. They can provide temporary storage volume on the surface or below ground; a subsurface gravel layer can create room for greater water volumes, which can then slowly infiltrate into the subsoil. Infiltration rates of surface soil can be improved with the addition of organic mulch and plants, which means that greater volumes of water can soak in more quickly. Soil amendments should be used with caution, because when not well integrated with hydrophobic subsoils, they quickly become saturated and the extra weight can cause them to slide. Finally, if infiltration rates and temporary storage are insufficient for flood risk reduction purposes, bioinfiltration features should at least be protected against damage during a flash flood and have a bypass or overflow system.

Site and budget constraints are also factors in sizing bioinfiltration features. In tight urban conditions, small spaces must be able to hold or infiltrate greater quantities of water due to larger areas of impervious surface. This can be accomplished through the following measures: careful engineering of poured concrete side walls, 2 feet to 4 feet of engineered bioretention soil media (with infiltration rates of up to 6 inches per hour), and underdrains that collect excess water at depth and carry it to an existing storm sewer pipe. These options were considered for the Imperial Building in downtown Albuquerque (EPA 2014a), and would be appropriate for other Downtown, Nob Hill, or Uptown locations, but are expensive and would not be needed for most other parts of the Middle Rio Grande Valley. If a budget allows for improved infiltration rates, even at sites without the pressure of high density development, the addition of a subsurface gravel storage layer can improve plant resiliency by encouraging deeper infiltration of larger volumes of water (Houdeshel et al 2012). Void space in the gravel layer can be protected with choke layers of sand and small aggregate instead of geotextile fabric (see figure 21). Geotextile fabric inhibits the deep growth of plant roots and does not encourage plant resiliency.

In areas with good subsoil infiltration rates and sufficient available space (which is most of the Middle Rio Grande Valley), the most cost-effective bioinfiltration construction option is to excavate a basin or swale (while taking precautions not to compact soil which ruins infiltration rates), create armored pretreatment and overflow areas, add plants, then add 2-3 inches of shredded wood mulch. This option avoids the added expense of subsurface storage, specialized soil mixes, and plumbing, but does require more space due to lower infiltration rates and only surface storage. Soil health is improved with the addition of shredded wood mulch. If soil is compacted, it must be ripped to at least 12 inches before installing the bioinfiltration feature (City of Tucson 2005).

	Net Present Values – Median (50th Percentile)								
	Costs		Benefits						
	CapEx Cost	O&M Costs	Flood Risk Reduction	Property Value Uplift	Heat Mortality Risk Reduction	Reduced CO_2 Emissions	Reduced Other Costs	Direct Financial NPV	**Total SNPV**
Bioretention	($2,096)	($377)	$169	$49	$515	$0	$0	($2,473)	**($1,740)**
Pervious Pavers	($2,496)	($834)	$168	$51	$513	$0	$0	($3,330)	**($2,597)**
Detention Basin / Extended Detention	($1,215)	($194)	$234	$50	$514	$0	$0	($1,409)	**($612)**
Water Harvesting Basin*	($132)	($7)	$200	$52	$518	$0	$0	($139)	**$631**
Cistern	($2,685)	$0	$95	$0	$0	$0	$448	($2,685)	**($2,142)**
Xeriscape Swale	($383)	($173)	$159	$51	$512	$0	$0	($556)	**$167**
Infiltration Trench	($701)	($167)	$200	$50	$515	$0	$0	($868)	**($102)**
Pavement	($10,817)	$0	($424)	$0	$0	$0	$0	($10,817)	**($11,241)**
Concrete	($14,106)	$0	($379)	$0	$0	($1,346)	$0	($14,106)	**($15,831)**
	*Entered as Infiltration Basin								

Figure 16: Summary Results fo Individual GSI/LID Features (per 1,000 sq ft) - Median Results (Stantec)

The chart in figure 16, from a study completed by Stantec Engineering and Design and Impact Infrastructure, LLC for the *Pima County and City of Tucson GI LID Manual* (2014 Appendix F), shows the net benefits provided by water harvesting basins and xeriscape swales.

To further improve infiltration rates, and soil and plant health, soil sponges can be added to basins and swales (see figure 20). Soil sponges are an easy, low-cost way to improve the performance of bioinfiltration features. Soil sponges are excavated cylinders 1' wide and 2' deep that are then filled with equal proportions of non-composted wood mulch, pumice, and composted overs (the parts of compost that are larger than ¾ inches). The composted overs inoculate the soil with micro-organisms while the wood mulch and pumice provide additional pore space for water to fill up the cylinder. The beneficial effects of concentrated water and microorganisms radiate out from the cylinder (Brooks and Young 2018).

The velocity of water flowing into a basin or swale should be dissipated to prevent erosion. A pretreatment device can reduce velocity and trap sediment. If not collected and removed, sediment can clog soil pore space in basins and prevent infiltration. At a concentrated inlet such as a curb cut, pretreatment can be done with aggregate, pieces of broken concrete, or a small concrete basin called a forebay. If there is a concern that large rocks in the pretreatment device will be displaced or used to cause damage, the rocks can be cemented in place. If water flows into the basin or swale as sheet flow, a level spreader can be used to dissipate volume. If a pretreatment area is not provided, eventually sediment and cigarette butts will accumulate in the basin (see figure 17 below), which will decrease infiltration rates and could eventually block the inlet.

Figure 17: Sediment Accumulation in Infiltration Area, Albuquerque, NM (photo by author)

Additionally, the slopes of basins and swales should not exceed 3 feet of horizontal rise for every 1 foot of vertical rise (a 3:1 slope), and should be protected from erosion with 8-12-inch crushed aggregate or broken concrete. Aggregate or broken concrete can also be used for the energy dissipation at the inlet and overflow. If there is a concern about erosion behind the aggregate on side slopes, and if revegetation is not possible, geotextile fabric can be used. However, this is a rare case in which geotextile fabric should be used in green stormwater infrastructure.

Although geotextile fabric is favored by many for its purported reduction in maintenance, in most situations it creates more problems that it solves. In addition to being unnecessary for weed prevention, geotextile fabric is only permeable when saturated and therefore prevents rainfall from small precipitation events (which is most precipitation events in the MRG) from reaching soil and plant roots. It may also prevent gas exchange needed for soil to sequester carbon. For these reasons, the *Ultra Urban Green Infrastructure Guidelines* prohibit use of weed block fabric (City and County of Denver 2015).

No lining should be used in bioinfiltration basins or swales, unless it is necessary to site a bioinfiltration feature within 10 feet of a building or basement, or if groundwater contamination is a concern. Linings prevent the deep roots of healthy drought-adapted plants growth and access to water in the subsoil (Houdeshel et al 2012).

Geotextile fabric used under rock mulch is another common practice that is not recommended. Rocks do not add organic material to the soil and therefore do not contribute to pollutant treatment that is so

Figure 18: Rock-lined Basin Stained by Runoff After One Year, Albuquerque, NM (photo by author)

important in GSI features. Rocks can be unsightly when stained by runoff that contains oils and hydrocarbons (See figure 18 below). While leaf litter that falls on wood mulch is virtually unnoticeable, leaf litter on rocks requires maintenance, which usually involves a gas-powered leaf blower, which creates pollution. Eventually, rocks fill with dirt, and weeds grow above the geotextile fabric. Then, the geotextile fabric and rocks are usually brought to the landfill.

Two to three inches of shredded wood mulch is a preferable groundcover to rocks. In addition to suppressing weed growth, it locks together and doesn't blow away or float away as easily as other organic mulches such as straw, pecan shells, or chipped wood mulch. If invasive species on site or nearby must be removed, including Siberian Elm (*Ulmus pumila*), Tree of Heaven (*Ailanthus altissima*), Russian Olive (*Eleagnus angustifolia*), or Salt Cedar (*Tamarix spp*.), they can be shredded and re-used on-site as mulch (Brooks and Young 2018).

If an on-site source for mulch is not available, both the *County of Los Angeles LID Standards Manual* (2014) and the *Eastern Washington LID Guidance Manual* (2013) recommend shredded and aged mulch because it is less likely to float. If rocks are used in or around a bioinfiltration feature, they must be washed clean, for small particles in crusher fines or decomposed granite can clog soil pore space and decrease infiltration rates (City of Tucson 2005). Wood mulch depth of over 3 inches can inhibit gas exchange between soil and air.

The export of nutrients and organics (which deplete dissolved oxygen in the Rio Grande) from bioinfiltration structures has been observed (Jiang Yuan Piza 2015). This possibility can be reduced by trapping organic debris at the outlet, and by limiting the amount of nitrogen and amendments added to the soil during construction of the bioinfiltration feature. Although GSI guides in temperate areas recommend adding topsoil to improve soil and plant health in bioinfiltration features, wood mulch is sufficient when planting drought-adapted species.

By following these recommendations, the benefits and safety of regionally-specific bioinfiltration features can be maximized while minimizing cost of installation and maintenance.

Figure 19: Basins with Wood Mulch and Plants, Tucson, AZ (photo by author)

KEY POINTS FOR BIOINFILTRATION SIZING AND MATERIALS:

- Bioinfiltration builds healthy plants and soil to treat and infiltrate stormwater runoff.
- Bioinfiltration offers the most benefits of any GSI practice, including treating pollution, reducing flood risk, recharging groundwater (depending on location), sequestering carbon, and providing shade, beauty, and habitat.
- Basic components of bioinfiltration systems include:
  - -A pretreatment device for sediment capture (concrete or rock)
  - -Shredded wood mulch
  - -Rocks to protect areas of higher velocity flow
  - -Carefully selected trees and plants
- Sizing and materials for bioinfiltration basins are flexible and can accommodate a variety of projects and budgets.
- The success of bioinfiltration features depends on uncompacted soils with infiltration rates between 0.3 inches and 2.0 inches per hour.
- Soil sponges are cost-effective and proven method to increase infiltration rates, soil health, and plant resiliency in a bioinfiltration basin or swale.
- Basins and swales should drain within 48 hours

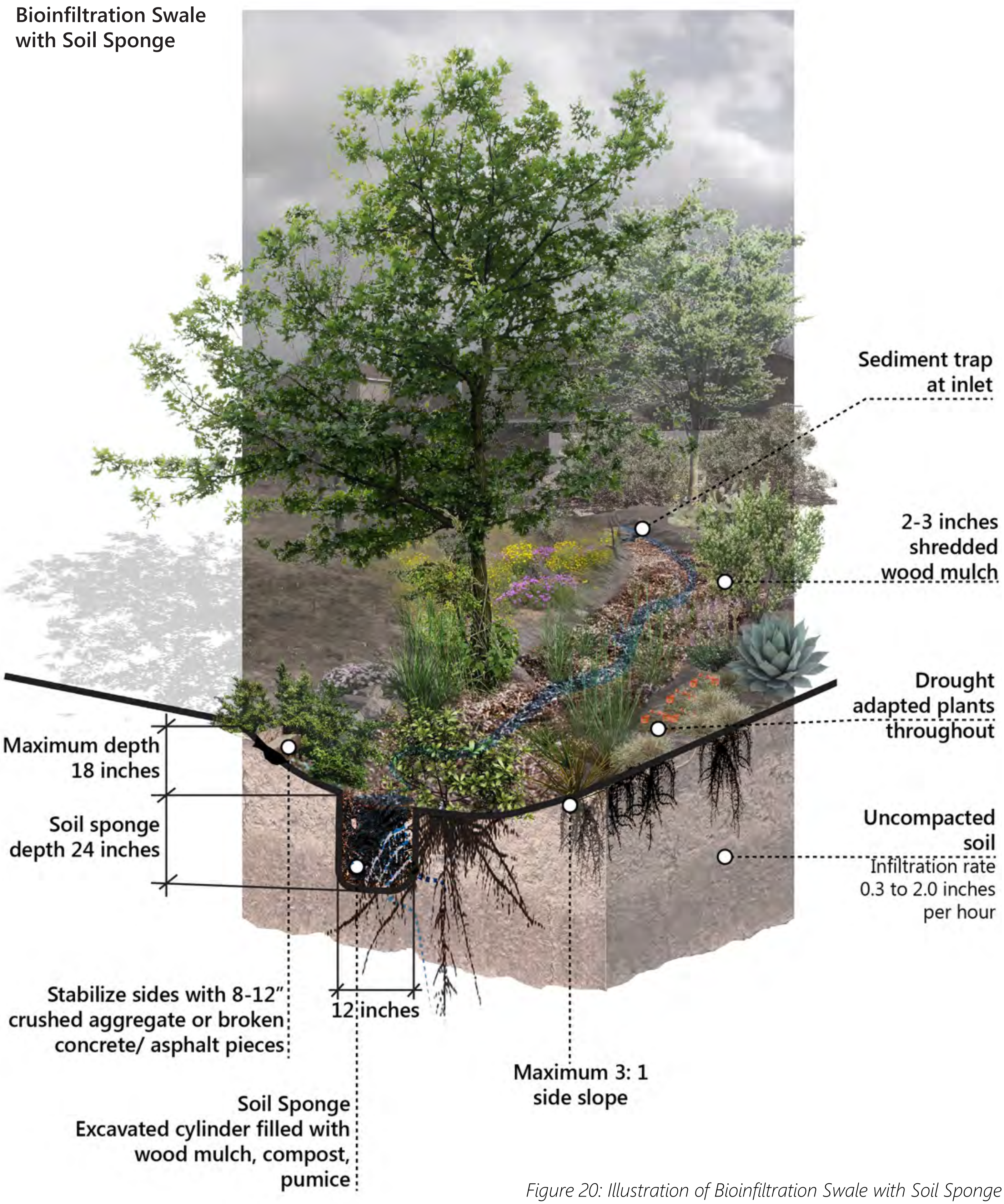


Figure 20: Illustration of Bioinfiltration Swale with Soil Sponge (figure by author)

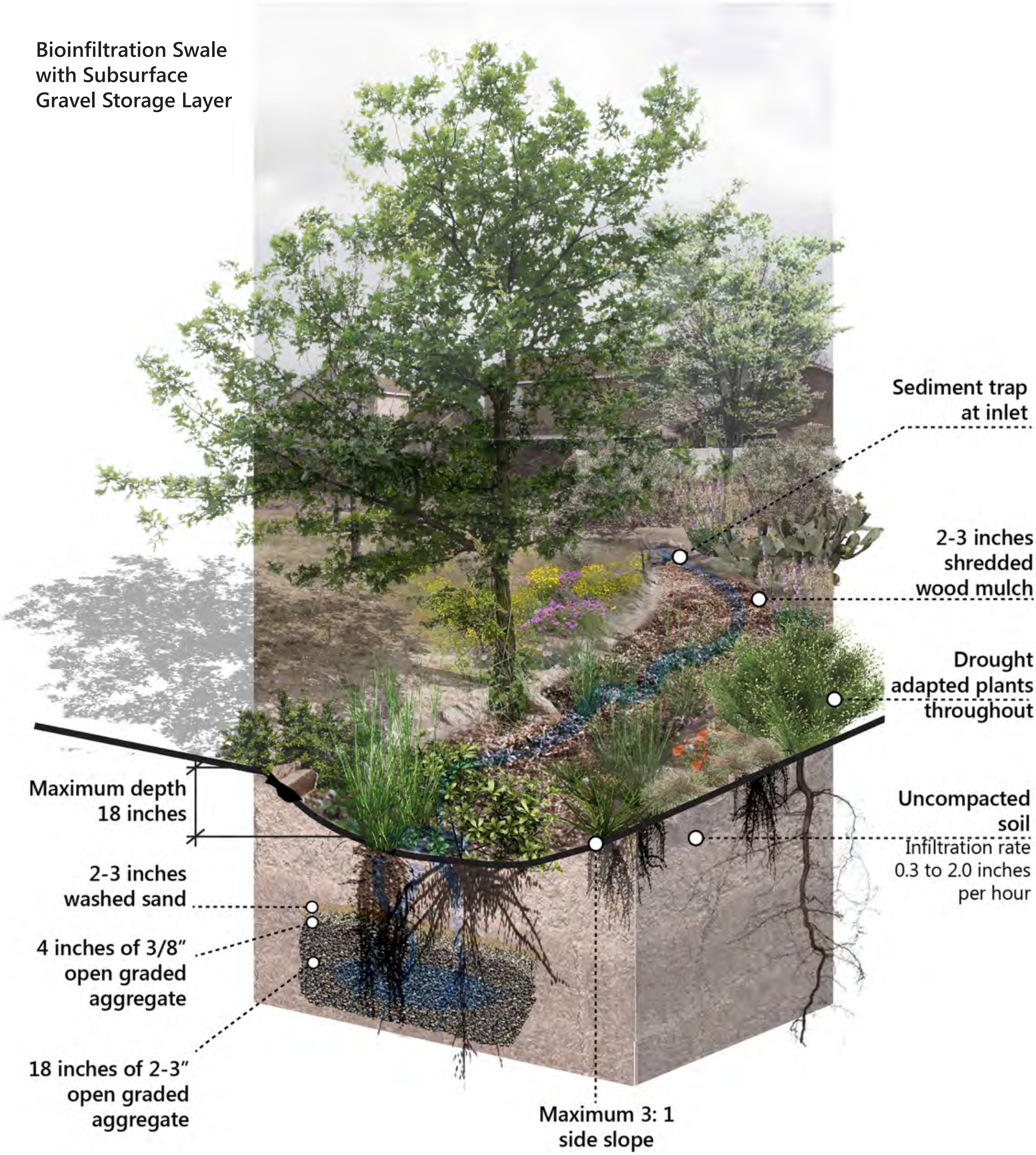


Figure 21: Illustration of Bioinfiltration Swale with Underground Gravel Storage Layer (figure by author)

Plant Selection and Irrigation

Plants in GSI features are an important part of an engineered system and must be carefully selected and maintained for the feature to function. Pore space and organic material created by plant roots maintains and improves infiltration rates. Without plants, the shade and habitat benefits of GSI feature are nonexistent. Plants make GSI features more aesthetically attractive and regionally unique, which increases public acceptance.

Green stormwater infrastructure, especially in New Mexico, requires that plants survive challenging conditions and provide a variety of services. Plant roots are expected to stabilize soil against water movement and erosion, while the above-ground parts are exposed to intense sun, drying winds, and hard freezes. Plants in the bottom of basins and swales must be adapted to both temporary inundation and drought, but never be invasive. All plants must be commercially available or at least easy to propagate. Sourcing plants from high desert suppliers is critical if plants are to thrive in the harsh conditions of the MRG Valley. The dual function of GSI as stormwater management and as habitat requires that plants provide food and shelter for pollinators and birds. In the MRG Valley, a variety of elevations and biomes means that plants for one GSI site may be inappropriate for another site a mile away.

Five categories of transects, or areas of similar elevation and climate, run north south through the Middle Rio Grande watershed[1]: The West Mesa (west of Coors Blvd); the Valley (between Coors and Edith); the East Mesa (from Edith to Juan Tabo); the Foothills (from Juan Tabo to the National Forest); and the East Mountains (along highway 14) (fig 23). These transects each receive significantly different amounts of precipitation and have different high and low temperature averages.

Within all transects, four general biome categories are recognized for simplified plant selection. Two biomes are urban and two are non-urban. Within urbanized areas, the two biomes are Urban Ephemeral Riparian, which is the biome in and around unpaved arroyos, and Urban Desert Grassland Shrubland. The word 'urban' describes places that have more impervious surface than permeable surface, and applies to most of Albuquerque and Rio Rancho. In the non-urban places, the two primary biomes are Shrub Desert Grassland, and Riparian. Riparian biomes occur along acequias, ditches, the Rio Grande and Tijeras Creek, while other areas can generally be classified as Shrub Desert Grassland. Non-urban locations include the East Mountains, North Albuquerque Acres, the North and South Valleys, and other areas of unincorporated Bernalillo County.

Due to water conservation goals, plants must be able to live without irrigation once established, and therefore must be drought-adapted. In the MRG Valley, under normal precipitation conditions, plants may become established after three years of irrigation, while under drought conditions, five years of irrigation are required (Phillips 2018). This recommendation is similar to the City of Tucson's guidelines for two to five years of establishment irrigation (2013). These time periods coincide with the average life span of inexpensive drip irrigation; if drip irrigation is used for establishment, the timing

[1] For further explanation of the elevations and transects of the MRG Valley, see the introduction to the *Bernalillo County Water Conservation Standards/Guidelines* developed by Sites Southwest Landscape Architecture.

of system failure and the end of establishment irrigation may be the same. Trees require 8 – 13 years of establishment irrigation, and may require continued irrigation, depending on species and site factors such as reflected heat and exposure to wind.

It is important to note that by not overwatering plants or watering beyond establishment period, plant growth and production of leaf litter will not be excessive, which means less pruning and maintenance. While in some conditions tree species may not need irrigation beyond establishment, trees merit continued, efficient irrigation because of the multitude of benefits they return to the community.

Selecting at least three species within each plant category (tree, shrub, perennial, grass), makes it more likely that even in the event of extreme drought or insect infestation, some species will live (County of Los Angeles 2014). Species diversity is also critical for habitat benefit. Maintenance and inspection of plants in a GSI feature must be more careful than standard landscapes because GSI plants have an important infrastructural role to play, not just an aesthetic one.

Fall planting is preferred as it gives plants five to six months for root growth before temperatures and winds stress new seedlings (Kauffman Stropki Mundt 2017), and makes it less likely that new plants or seeds are washed away by intense summer storms. Seeds can be used in and around GSI features, but there is a risk that they will wash away in a storm (City of Tucson 2005). Mulch should be kept at least 4 inches away from the base of new plants.

The City of Tucson Active Practice Guidelines for Green Streets (2013) require a minimum of 25% vegetative cover and 25% tree canopy cover (at maturity) for bioinfiltration basins. This semi-arid specific planting density should be followed instead of guidelines for the East Coast which preference full vegetative cover such as grass-covered bioswales (Maurer 2013).

Unlined arroyos are important for both infiltration and large-scale conveyance of stormwater, and should include plants. However, plants selection for unlined arroyos has unique design requirements. Due to large-scale removal of sediment with machines, trees should not be planted in the inundation zone of arroyos and sediment basins. Shrubs, grasses, and perennials may be planted in the inundation zone. Although they may be damaged with routine maintenance, many shrubs are tough and will regrow. It is important to consult with an engineer when selecting plants for an arroyo to ensure that flood control requirements are not negatively impacted by the inclusion of plants.

Trees and shrubs listed in Appendix A meet the conditions described above, and were chosen for the hotter, drier climate of the future but also for cold hardiness. Although not included in this list, future research could address plant tolerance for mineral salts and phytoremediation (pollutant treatment) benefits that could further enhance the treatment capabilities of GSI practices.

KEY POINTS FOR PLANT SELECTION AND IRRIGATION:

- All plants for GSI features must: :
  - -Survive without irrigation after a 3-5-year establishment period (longer for trees)
  - -Stabilize soils
  - -Tolerate heat, drought, and freezing temperatures
  - -Be non-invasive
- Elevation varies within the MRG watershed, which effects plant species. The right plants must be selected for the project location and transect (West Mesa, Valley, East Mesa, Foothills, East Mountains).
- Plant species in GSI features along arroyos and creeks are different from plant species in other areas. This difference needs to be accounted for by selecting plants from the right biome.
- In GSI features, plants may be best suited to grow at the bottom of a basin or swale (inundation zone), along the sides (transition zone), or at the top (high ground).
- Plant in the fall (October and November) to promote root establishment and minimize irrigation.

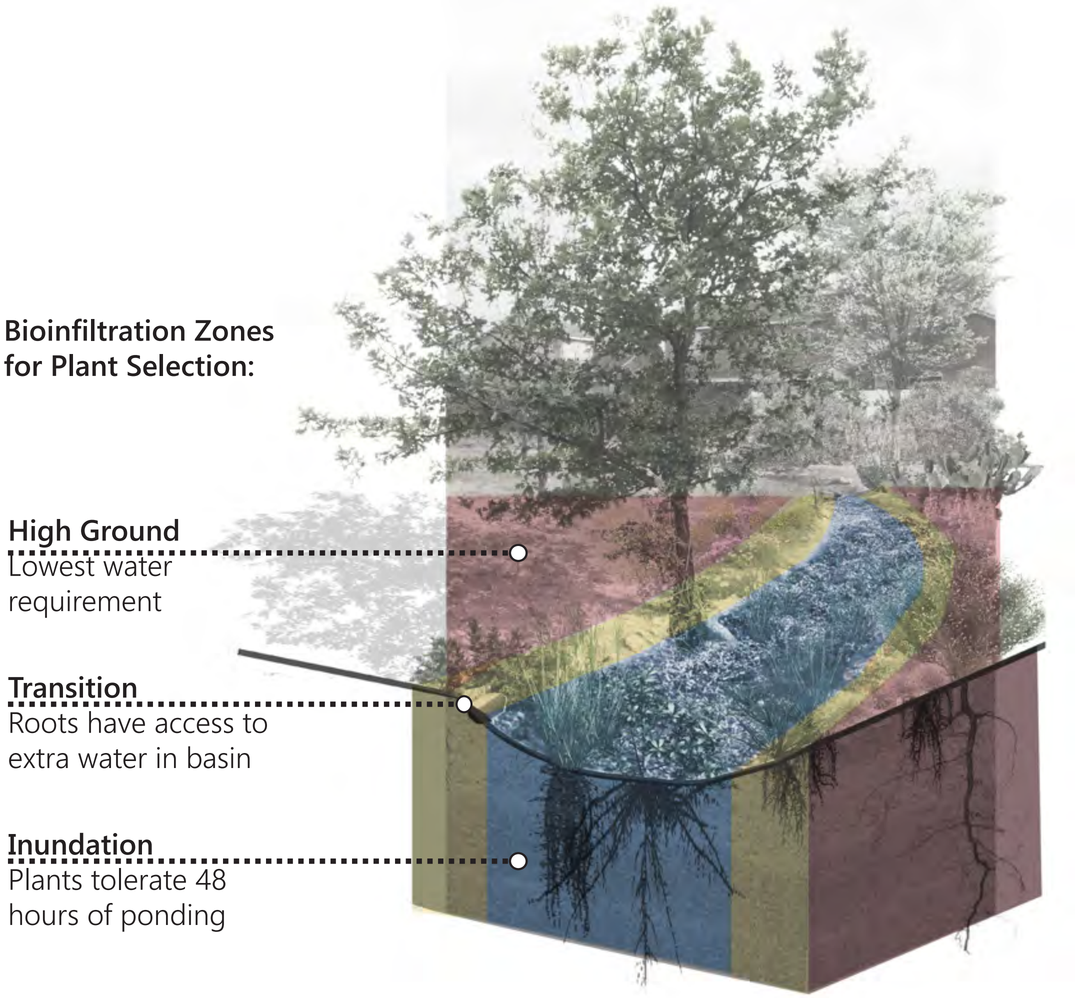


Figure 22: Bioinfiltration Zones for Plant Selection (figure by author)

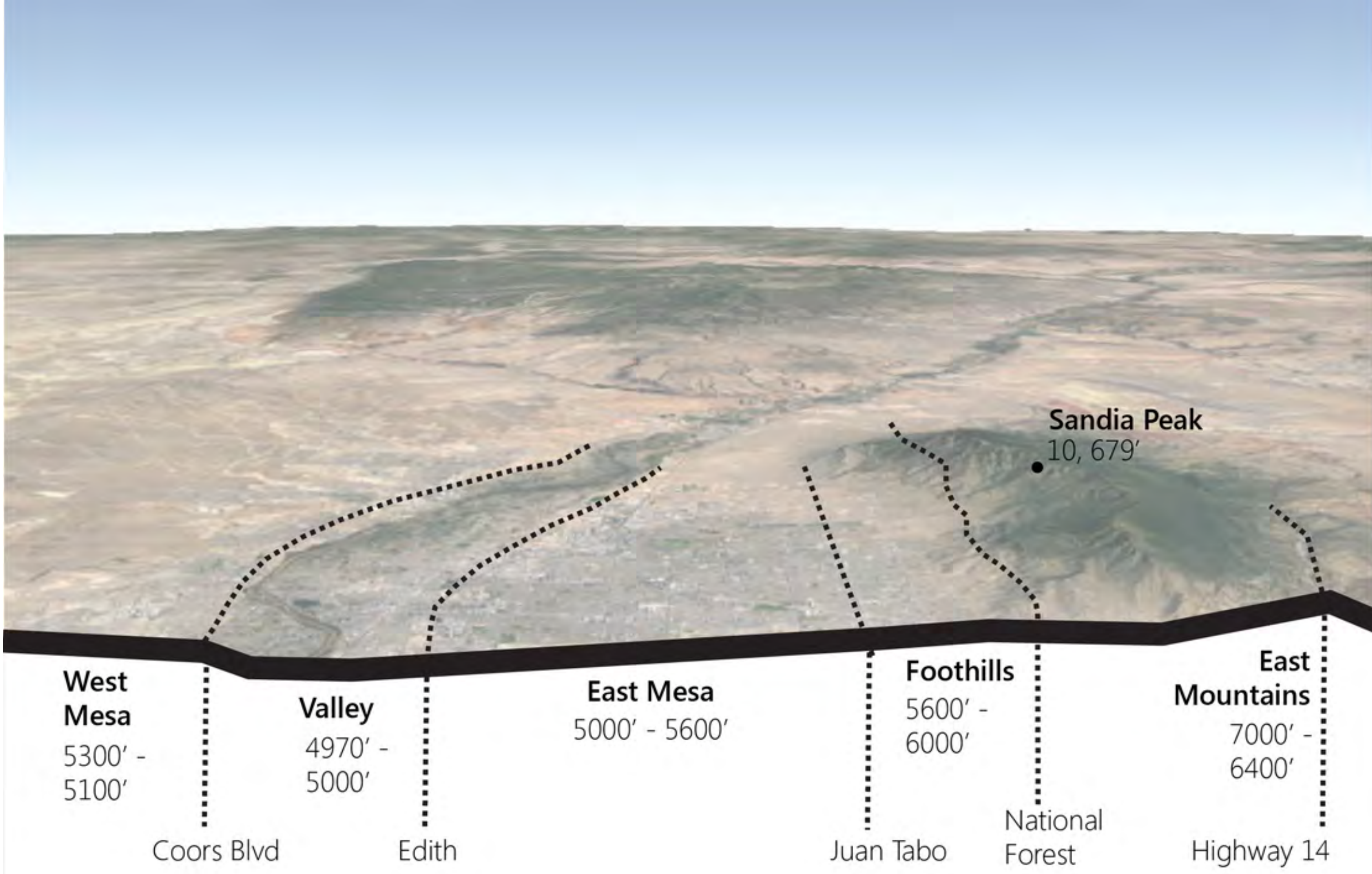


Figure 23: Five Transects for Plant Selection in the MRG Watershed (figure by author)

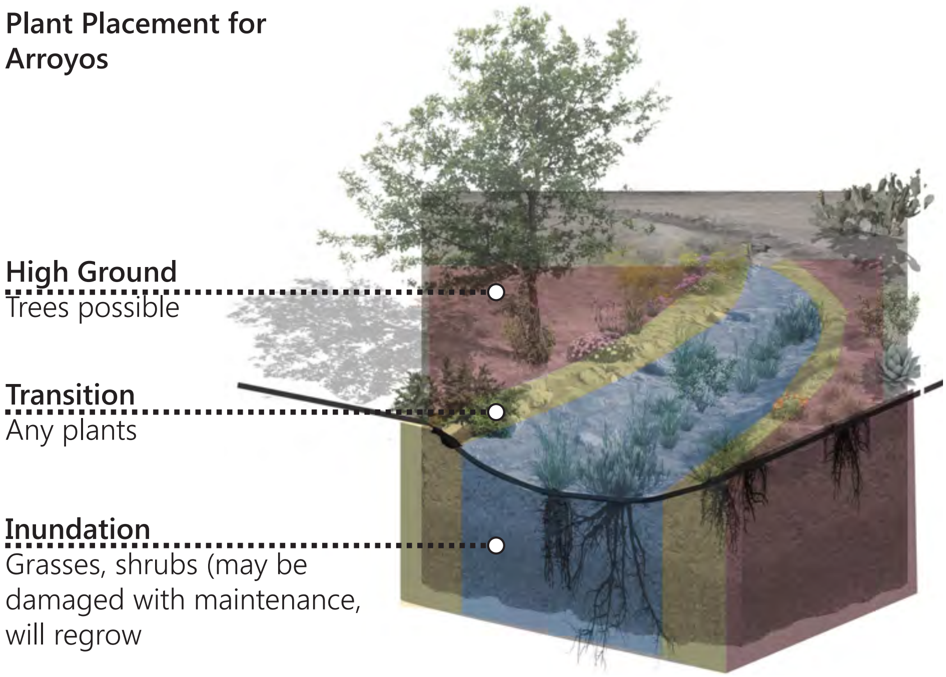


Figure 24: Plant Placement by Bioinfiltration Zone for Arroyos (figure by author)

Flood Control and Design Storm

Newcomers to the Middle Rio Grande Valley and the Southwest may be alarmed by dramatic summer storms and flash flood warnings. The sudden arrival of dark clouds, bursts of thunder and lighting, and sheets of rain are quite unlike the character of storms in other places. Although the rate of inches per hour (intensity) of rain is the same or less than many other places in the country, due to comparatively sparse vegetative cover and hydrophobic soils, rainfall quickly becomes runoff and can then become a flash flood (Stone 2012). Large areas of human-made impervious surfaces exacerbate these issues and are greater in Albuquerque than in many other cities (Nowak and Greenfield 2012). For professionals working in stormwater infrastructure, calculating flood risk is imperative for public safety.

If green stormwater infrastructure is to be considered part of stormwater infrastructure rather than an additional requirement for water quality, engineers must be able to evaluate its effect on flood risk reduction using an accepted method. Otherwise, local code requirements for flood risk reduction must be met entirely by grey infrastructure, making GSI an added expense rather than a multi-functional part of the stormwater drainage system. An accepted method does not yet exist for the Middle Rio Grande Valley, but it does in Pima County, Arizona.

Before reviewing the methods used in Pima County, the following is a summary of how the intensity and depth of rainfall from storm events are categorized. For flood-risk reduction purposes, the Federal Emergency Management Agency (FEMA) classifies storm events based on two factors, recurrence interval and duration of storm. For example, the 100-year, 24-hour storm is a storm event with a 1% chance of occurring in any given year and has a 24-hour duration (once every 100 years is a 1% chance per year). The duration is an important component for flood safety because it considers the intensity of the storm event.

For water quality purposes, the EPA classifies storm events by looking at the number and depth of storm events over a 24-hour period regardless of intensity.[1] This method requires analysis of historical rainfall data that can be used to determine the percentage of rainfall events below a certain depth. The 90th percentile storm has a rainfall depth statistically exceeded by 10% of storms. It is important to understand the different methods used by FEMA and the EPA to avoid confusion of storm classification as it relates to the design of GSI as both water quantity and quality features.

When designing infrastructure, whether concrete pipes or infiltration basins, there must be an agreed-upon amount of volume and flow from a specific storm frequency, intensity, and volume for which the structure will work. This is known as the design storm. To design for flood risk, the *City of Albuquerque Development Process Manual* (DPM) design storm is the 100-year, 6-hour event. In the University of New Mexico area, this is about 2.3 inches of rain in 6 hours.

The Pima County and City of Tucson GI LID Manual, a non-regulatory guide for neighborhood-scale development, recommends designing stormwater

[1] The Rainfall Frequency Spectrum method was used to determine the water quality storm for the Middle Rio Grande (Tetra Tech 2015).

infrastructure for the 98th percentile event, which, in the Tucson area, is about 1.5 inches of rain. Rain in a 99th percentile storm in Tucson (comparable to a 100-year storm) amounts to about 3.0 inches. The reasoning for flood risk reduction is that if green stormwater infrastructure can safely detain 1.5 inches of rain, the calculated flood risk for the 100-year event (3.0 inches of rain) would be reduced by half.

The Pima County Stormwater Detention and Retention Manual, a regulatory guide for private development, has a more involved procedure. The designer must calculate the post-development runoff volume and peak discharge for 2, 10, and 100-year events. Then the total volume of water harvesting basins is calculated and compared to the volume of the runoff volume for each storm (2, 10, and 100 year). This ratio is then put into an equation to find what is called the 'Stormwater Harvesting Factor,' which is then used to find the peak discharge reduction for flood risk control.

These methods used in Pima County seem to be based strictly on the volume provided by infiltration basins. However, if a structure includes temporary subsurface storage in either engineered bioretention soil media or a gravel storage layer, the volume of soil or gravel multiplied by the porosity of the media (indicating the amount of void space) provides quantifiable additional storage volume (County of San Diego 2014). For example, if the gravel storage layer has the standard 40% pore space[2] and a total volume of 1,000 cubic feet, an additional 400 cubic feet of water storage can be added to the total volume for flood risk reduction purposes. Infiltration rate may provide an additional flood risk reduction benefit, and this possibility should be evaluated within the specific soil and hydrology parameters of the MRG watershed.

In addition to design storms for flood risk reduction, there are design storms for water quality. For purposes of water quality, the goal is to capture the runoff that carries the highest concentrations of pollutants from freshly-rinsed roofs, roads, and parking lots. If this runoff is captured on a site, runoff from a site more closely resembles hydrologic patterns before impervious surfaces were added.

Permit requirements include specific depths of rainfall that must be captured (stormwater quality treatment volumes) to restore the pre-development hydrology of a site. According to the watershed-based MS4 permit, new development must treat all water from the 90th percentile storm, while redevelopment must treat all water from the 80th percentile storm. In EPA-commissioned studies, the engineering firm Tetra Tech found these amounts to be 0.615 inches and 0.48 inches, respectively, for Albuquerque (Tetra Tech 2015), although other methods of calculation produce difference amounts.

The *COA DPM* proposed revisions recommend GSI and LID components integrate both water quality and flood control whenever possible. Herein lies a clear advantage of GSI: it can simultaneously address water quality and quantity (and provide a host of other benefits) in a way that grey

[2] The porosity for standard engineered bioretention soil media is also 0.40 (Washington Department of Ecology 2015). .

infrastructure cannot. To design for the multiple advantageous capabilities of GSI, more than one design storm must be considered — the water quality event and the flood event. The *COA DPM* also requires the 10-year storm to be evaluated for purposes of erosion and sediment control on slopes and in open channels. *The Eastern Washington LID Guidance Manual* (2014) requires calculation of the 10-year, 24-hour storm for a combination of flow control and water quality. These requirements match closely with the *Pima County Stormwater Detention and Retention Manual* requirements to calculate performance for 2, 10, and 100-year events.

If a site does not have space to allow for GSI to address flood risk reduction in a significant way, the structure must at least be protected from the intensity of a 100-year event. The County of San Diego, for example, requires that GSI treat rainfall from the 85th percentile event while also addressing potential scouring and erosion from the 100-year event. The *COA DPM* specifies that for detention ponds, the design storm must be greater than or equal to the time it takes for the water to leave the pond (either through infiltration or release through an outlet), but must also safely convey the 100-year event. Proposed revisions to the DPM require that a bypass be provided for overflow in events larger than the water quality storm.

GSI features are decentralized, and making these extensive calculations could be significantly more time consuming than calculations for sizing pipe diameters or detention ponds. GSI calculations could be simplified by finding a unit rate for an identifiable feature, and then multiplying this unit rate by the number of features present at a site. For example, if a bioinfiltration basin has 100 cubic feet of temporary surface storage and another 100 cubic feet of temporary subsurface storage, then total flood risk reduction benefit of 200 cubic feet could be multiplied by the number of similar basins sited throughout a parking lot or along a road. This modular way of approaching GSI benefit provides a compromise between the decentralized nature of GSI and the need for large-scale flood risk reduction calculation.

Addressing the technical considerations of how to calculate flood risk reduction and which design storms to use are important steps in finding watershed-wide agreement on how to include GSI in the design of safe, integrated, and beneficial management of stormwater.

KEY POINTS FOR FLOOD RISK REDUCTION AND DESIGN STORM:

- For GSI features, peak flow and volume calculations should address these storms:

  80th or 90th percentile storm events for water quality (EPA-determined)

  10-year storm for erosion and sediment control (only for channels and slopes)

  100-year, 6-hour storm for flood risk (FEMA- determined)

- All GSI features must be protected against damage from flash floods.
- In order to be considered an integral and contributing part of the water infrastructure, GSI features must have a quantifiable contribution to flood risk reduction beyond the water quality benefits associated with GSI/LID.
- Flood risk reduction can be calculated by using the following factors:

  The volume of temporary surface storage

  The volume of temporary subsurface storage (a function of volume + porosity)

- Volume calculations for decentralized GSI features can be streamlined by finding a unit benefit per feature and multiplying by the number of features.

Site Analysis and Planning

In many ways, analyzing a site for the purpose of GSI construction is very similar to analyzing a site for any other construction project: Information must be collected regarding existing topography, utilities, soil types, buildings, zoning, circulation, master plans, and local land use and design standards including set-backs, road widths, open-space requirements. For all water infrastructure systems, including GSI, collecting hydrological information is critical, and should include the contributing drainage area and land uses and covers, precipitation frequency and quantity, existing onsite drainage, points of on-site and off-site discharge, areas of erosion and sedimentation, the name of the receiving waterway (such as the Rio Grande or Tijeras Creek), as well as any areas prone to flooding.

The site analysis information that is unique to GSI generally relates to conserving existing ecological advantages, integrating stormwater treatment into the site plan at every step, decreasing impervious surfaces, using all permeable areas for infiltration, and maximizing the benefits of the project including the provision of shade, habitat, aesthetic value, groundwater recharge, water conservation, and maintaining cultural resources and viewsheds. Regarding the MS4 permit, it is important to note whether the site is a new development or redevelopment, and the correct regulations followed (see 'Design Storm' section).

General low impact development (LID) principles incorporated into GSI design for both new and redevelopment include protecting existing site features such as riparian areas, other habitat, trees, and healthy soils, creating (or protecting) buffers along waterways, and not disrupting erodible slopes. The site analysis process must include identification of these features so that they can be preserved in planning and construction phases.

Unlike grey infrastructure, GSI often includes plant material, so not only must existing plants be inventoried, but local landscape requirements and water sources for irrigation must be considered. Water conservation is an important aspect of LID, so when considering a site for GSI construction it is helpful to not only consider the amount of surface runoff available for plants and infiltration, but to also consider the availability of other non-potable water sources that could be used for irrigation, such as nuisance flows[1] or reclaimed water.

As previously discussed, GSI features must treat pollutants, and if possible address flooding concerns. Certain GSI structures are better able to handle large volumes of water for flood control, such as infiltration galleries and trenches. Both of these practices provide below-ground water storage in void spaces between gravel before water eventually infiltrates, but do not provide the water quality and cooling benefits of features with healthy soil and plants.

The depth to groundwater is an important factor in site analysis. Although more research on groundwater contamination through infiltration is needed (Lee and Fisher 2016), there is widespread concern that shallow groundwater tables may be contaminated if pollutant-laden stormwater is allowed to infiltrate. The New Mexico Environment Department (NMED) protects groundwater from possible contamination by permitting 'Class V Injection Wells', which are infiltration features

[1] Nuisance flow, also known as dry weather flow or fugitive flow, is the water going through a storm sewer system when there is no precipitation. Although there is no single source of nuisance flow water, it can accumulate from inefficient, irrigation, car washing, etc. This is a potential source of non-potable water for irrigation that needs further testing and demonstration.

deeper than they are wide or long. GSI and LID guides reviewed for this thesis recommend that groundwater tables are at least 5-10 feet below an infiltration feature. In the MRG Valley, shallow groundwater tables may be a concern along the river. Soil stability when saturated and infiltration rates must be also studied.

Site analysis can also reveal opportunities for additional environmental benefits. When analyzing a site, the designer should assess possibilities for draining stormwater to existing trees (while protecting their root systems) or finding places where new trees might benefit from runoff while shading buildings or hard surfaces. Wildlife habitat can be addressed by examining existing species, possibility for wildlife corridors, and unmet wildlife needs that could be provided through proposed GSI. The tree and shrub list in Appendix A provides examples of plants to be used for bird and pollinator benefit.

The Bernalillo County Greenprint maps, developed in partnership with the Trust for Public Land, are a major resource for identifying locations of endangered or threatened species, as well as sites for potential groundwater recharge, heat island effect, and conservation priority. This data set should be consulted on all development projects within the county. These maps also make it possible to prioritize and site GSI projects within a larger system. If the practice of GSI is to have system-wide benefits, it must be systematically implemented. If GSI implementation is isolated and inconsistent, benefits will be limited.

Social and organizational information is another important part of site analysis, especially in the MRG Valley where there is a long history of human settlement and strong cultural connections to water and to the river. Existing cultural resources need to be included in water infrastructure planning, including acequias and agricultural areas. Also, the long-term performance of GSI depends on maintenance, which, in certain areas, could be provided by residents, neighborhood associations, or civic groups. Human resources such as these should be investigated and analyzed during the site analysis process.

Safety concerns are also essential, including keeping pond depths less than 18 inches, protecting against floods, and preventing standing water that would allow mosquitoes to breed. The designer must also consider the potential need for maintenance access as well as the selection of building materials that will not negatively impact water quality. For example, materials such as pressure-treated wood and galvanized metal release contaminants that are released into runoff (County of Los Angeles 2014).

Infiltration structures should not be used within 10’ of building foundations, unless lined with an impermeable layer. Infiltration should also not be used where it could destabilize contaminants at brownfield sites. The jet fuel spill that has contaminated groundwater under Kirtland Air Force Base and surrounding neighborhoods may be such sites. These sites require additional specialized treatment outside the scope of this thesis.

The site analysis and planning process for GSI is more involved than for standard infrastructure or construction projects, but its many benefits are numerous and invaluable. Training and resource materials will be needed for professionals in the MRG Valley regarding site analysis and planning processes. Cost is another factor to be considered in the site analysis and planning process and will need to be developed as GSI practice moves forward in the MRG Valley.

See Appendix B for a list of considerations for incorporating GSI into site analysis and planning.

KEY POINTS FOR SITE ANALYSIS AND PLANNING:

- Only use impervious surface if absolutely necessary, and interrupt large impervious areas with permeable surfaces.
- Use all permeable surfaces for infiltration.
- Identify and preserve permeable and stable soils, existing drainage and buffers, and habitat
- Use the Bernalillo County Greenprint maps to identify opportunities to address the urban heat island effect, recharge groundwater, support community conservation priorities, and connect wildlife habitat.
- Find opportunities to connect to human and cultural resources and non-potable water sources.
- For the most cost effective results, begin planning for on-site stormwater treatment in the earliest planning stages, and involve all related disciplines (engineers, landscape architects, architects, etc.).

Part Three: Conditions and Example

Background and general considerations presented in Parts One and Two create the foundation for LID and GSI practice in the MRG watershed. Part Three will present the application of these concepts in three conditions found throughout the watershed: unstable slopes, parking lots, and roof downspouts. The process for selecting these conditions included consideration of three factors: water quality impact, professional recommendations, and applicability across the watershed. Because the watershed-based Municipal Separate Storm Sewer (MS4) permit is the primary driver for water infrastructure change in the Middle Rio Grande (MRG) Valley, the conditions of the permit will be used as a baseline for water quality requirements. Recommendations and advice from local practitioners and regulators were collected through interviews. It was found to be essential that each condition be applicable to both urban and rural settings as the MRG Valley contains large areas of each. It is also important to have a number of surface stormwater flow patterns represented in order to analyze a range of applicable interventions.

In all conditions, application of low impact development (LID) and watershed management principles in the planning stages of a development project reduces the need for large on-site structures for stormwater management. These principles include: maintaining existing site drainage patterns, slowing and soaking surface flow wherever possible, keeping water high on the watershed for as long as possible, and conserving existing soil and vegetation. Recent revisions to the *City of Albuquerque Design Process Manual, Chapter 22*, recommend addressing stormwater management early in a design process to better address water quality and minimize "less desirable treatment strategies" (COA 2014 Revision 101). In particular, changes in grading design and soil protection during construction do not add expense but can be the difference between possible or cost-prohibitive incorporation of GSI.

The practices suggested in this section are the most effective and least expensive if included in an integrated site plan prioritizing LID and stormwater quality. In existing development, these practices can often be applied as retrofits.

Condition One: Unstable Slopes

Unstable slopes contribute sediment to stormwater and reduce safety and accessibility of nearby sidewalks. Combined with geologic and hydrologic conditions characteristics of semi-arid areas, unstable slopes result in erosion which is a major concern in semi-arid regions. Erosion also releases sediment, to which many chemical and biological pollutants attach and are carried to waterways. The EPA-issued MS4 permit specifies that the City of Albuquerque, AMAFCA, and Bernalillo County "implement a strategy to identify and eliminate controllable sources of PCBs (polychlorinated biphenyls) that cause or contribute to exceedances of applicable water quality standards." (EPA 2014b 13). As an insoluble pollutant, PCBs attach to sediment particles, which means that reducing sediment load in stormwater can also reduce PCBs. The Endangered Species Act Requirements of the MS4 permit call for reduction in pollutant loads associated with sediment (EPA 2014b 22). Addressing the condition of unstable slopes has the potential to address both PCBs and the Endangered Species Act requirements by reducing transport of sediment from slopes.

In an earlier report done by the author for the Bernalillo County Transportation Planning Department on use of green stormwater infrastructure, transportation planner Julie Luna identified unstable slopes as a primary concern of the county. Luna provided several photos of sites in the county where erosion from unstable slopes causes slippery surfaces and decreased sidewalk accessibility.

As seen in figures 25 and 26, topographical changes in the MRG Valley coupled with highly erodible soils make slope stabilization difficult. Hydrologic patterns typical of semi-arid places exacerbate this problem. Like San Diego County, another semi-arid place, the Middle Rio Grande Valley experiences storms that often result in flashy, high peak-flow rates of storm runoff (San Diego County 2014 16). Due to this pattern, "[t]he design

Figures 25 and 26: Eroding Slopes on Blake Road West of Coors Blvd (photos by Julie Luna) of LID features used in San Diego County must account for the high-intensity storms to provide for. . . appropriate erosion prevention" (San Diego County 2014 16). This attention to erosion prevention is equally important in New Mexico, where stable slopes are needed in stream and arroyo banks, new development, and places where ineffective measures were initially employed.

The goal of slope stabilization methods within the framework of GSI is permanent stability of the slope through enhanced soil structure and vegetation. Stability is much easier to achieve if additional runoff is kept off the slope. The idea is fundamental to general watershed management: Keep water as high on the watershed as possible to prevent damaging effects of increased volume and velocity downstream (Lancaster 2013). If sheet flow cannot be infiltrated before flowing down a slope, it should be spread out to prevent the formation of erosion-accelerating channels. A strip of gravel running along the top of the slope will suffice to spread and slow sheet flow. Upstream runoff that cannot be spread or infiltrated may need to be directed to a drain flowing to an infiltration basin or swale at the base of the slope.

Flow calculations, soil type, and measure of steepness are the primary factors influencing what practices can be applied to unstable slopes. Soils that are shallow, sandy, or rocky are especially prone to erosion and have more limited possibilities for stabilization. The steepness of a slope can be described in a ratio or a percentage. For example, a 3:1 slope has three units of horizontal change for every one unit of vertical change; 3:1 slope could also be described as a 33% slope. A 2:1 slope rises one unit for every two units of horizontal run and could also be described as a 50% slope.

SLOPES 3:1 AND LESS

Vegetated slopes filter pollutants and decrease the amount of runoff. However, slopes cause increased runoff velocity which means that, even with vegetation, there will be runoff at the toe (base) of a slope during heavy rain. Additional infiltration at the base of slopes should always be considered.

Slopes between 15% and 33% (less than a 3:1 slope) can be stabilized with wattles, seeding, mulching, and earthworks, which all slow and capture water as it falls on or flows over the ground. Wattles, which look like long snakes, can be made from a variety of materials. The interior of a wattle can be straw, compost, or material that has been grubbed from a site ('Live Wattles'). The exterior can be a biodegradable netting or fabric. Placed on-contour, wattles serve as berms, slowing water and creating areas for moisture and organic material to collect and for plants to grow. They also filter sediment, oil and grease, and trash (NM DOT 2012).

The NM DOT has tested and refined seed lists of native plants for five climate-based districts in New Mexico, as well as soil preparation and mulch guidelines, including slope stabilization (Gisler 2018). These guidelines could be adopted for slope stabilization in the MRG watershed, whether adjacent to state highways or not.

The *NM DOT NPDES Manual* recommends use of mulch alone if seed germination is unlikely. On slopes less than 2:1, mulch can be mechanically crimped or anchored into the soil to prevent it from blowing away (NM DOT 2012). Mulch can also be held in place by biodegradable tackifiers or nets. Mulch options, for use with or without seed, include weed-free hay or straw, shredded wood mulch, and small aggregate. Gravel over 1 inch in size has been shown to inhibit vegetative growth (Gisler 2018). Erosion control mats, made from biodegradable material such as coconut fiber or straw, can hold seeds and soil in place until roots and soil structure are developed. Tackifier, a sticky substance that is sometimes made from guar gum, performs the same function.

Earthworks for use on slopes less than 3:1 include on-contour swales and eyebrow micro-basins, both of which collect water into depressions where it can infiltrate. On-contour swales run parallel to contour lines and perpendicular to the flow of water, and slow rather than convey water. The spacing of these swales depends on the exact slope and soil type, although on-contour swales are not recommended for shallow, sandy, or rocky soils (Sites Southwest 2011).

Eyebrow micro-basins provide a protected and slow path for water to flow down a slope from basin to basin. Basins located near existing vegetation support expanded root growth which anchors the plant and holds soil in place. Soil sponges and mulch should be used in micro-basins and on-contour swales. Trees, grasses, and shrubs with deep or fibrous roots can be planted in basins and swales for long-term soil stability. The canopy areas of trees and shrubs intercept rainfall which decreases the amount of water reaching the surface and therefore also decreases erosion. Planting plans for slopes should consider that plants at the top of a slope will receive less runoff while plants at the base will receive additional runoff from the slope.

On-contour swales and micro-basins for slopes are not recommended where stormwater quality flows (flow resulting 0.5 inches of precipitation) will exceed 1.5 feet per second. The overflow points for both types of earthworks must be reinforced with large rock (4-inch minimum) to protect from erosion where water flow is concentrated.

SLOPES OVER 3:1

On slopes steeper than 3:1, wattles can be used to create terraces that result in flat areas where water and soil will not run off. Seeding can also work to control erosion on slopes exceeding 3:1. On these steeper slopes, before seeding, the *NM DOT NPDES Manual* recommends grooving soil on-contour, 2 to 4 inches deep and 4 to 10 inches apart, also known as 'surface roughening.' Imprinting is another method of surface roughening that creates waffle-like depressions in which water collects and seeds germinate. The *NM DOT NPDES Manual* recommends imprinting in combination with seeding and mulching for slopes greater than 3:1, unless rocky or sandy soils are present (2012). However, the *Bernalillo County Water Conservation Guidelines* (Sites SW 2014) discourage use of imprinting where slope exceeds 2% (which is almost flat).

Rip rap (8-12-inch aggregate) can be used to achieve stability and some filtration of pollutants if water supply or project timing do not allow for establishment of vegetation on slopes greater than 3:1. On slopes between 3:1 and 1.5:1, the *Pima County Detention and Retention Manual* (2015) recommends hand-placed rip-rap on geotextile fabric. Geotextile fabric under rip rap prevents soil from eroding behind the rip-rap and causing a rock slide. However, like other rock mulches, rip-rap on a slope can eventually fill with dirt and require replacement (see figure 25). Geotextile fabric should not be used if stabilization through revegetation is possible as it impedes root growth.

Fiberschines are an option for stabilizing steep arroyo or stream banks. Also known as biologs, fibershines are a roll of biodegradable material (such as coconut fiber or small branches) staked into the unstable bank, preferably with a wooden stake or live willow cutting. The roll of material traps sediment which builds up the bank. Fiberschines prevent nutrients, oils, and greases from entering the arroyo or stream (NM DOT 2012). If a site is being cleared of vegetation or invasive species, branches can be woven into logs for use in fiberschines (Brooks 2018). Plants, such as willows, can grow through and around fibershines and provide bank stabilization as the fiberschine biodegrades.

Gabions, wire frames filled with large aggregate, are popular slope stabilization devices. If expertly installed, gabions can successfully stabilize a slope and provide an aesthetically attractive element in landscapes. However, if they don't provide sufficient coverage of the eroding area, or if they are shallowly anchored, gabions can exacerbate erosion and require removal.

The Pima County Detention and Retention Manual calls for retention walls, concrete, or mortared rip-rap on slopes of or exceeding 1:1. Although these are not GSI practices, infiltration at the top and bottom of these structures should still be considered.

During construction, all GSI features must be protected from runoff, or reinstalled if damaged by a big storm. Runoff can temporarily be routed around a slope to prevent damage. Using tracked rather than wheeled vehicles limits soil compaction and maintains infiltration rates. As with all GSI practices, success of erosion control measures is only possible if care is taken to prevent soil from compaction during construction.

After construction, slope stabilization features should be inspected after all storms of 0.5 inches or greater (NM DOT 2012), and if necessary, repaired or adjusted. Plants may need to be pruned or replaced, and berms rebuilt or armored. Regular trash collection prevents possible blockages to runoff flow which can increase erosion. Mulch will need to be added every 2-3 years, or as it biodegrades. The tops of berms can serve as access paths for regular maintenance without destabilizing slopes.

KEY POINTS FOR UNSTABLE SLOPES:

- Unstable slopes can cause safety and accessibility issues and contribute sediment to stormwater.
- Intense storms, erodible soils, and elevation changes make erosion a significant problem in the MRG watershed.
- Infiltrate water at the top and bottom of slopes to minimize damage on and below the slope.
- Slopes less than 3:1 can be stabilized with seeding, mulches, erosion control blankets, earthworks, and wattles.
- Slopes greater than 3:1 can be stabilized with terracing, fiberschines, seeding with surface roughening, and, if necessary, rip-rap over geotextile fabric.

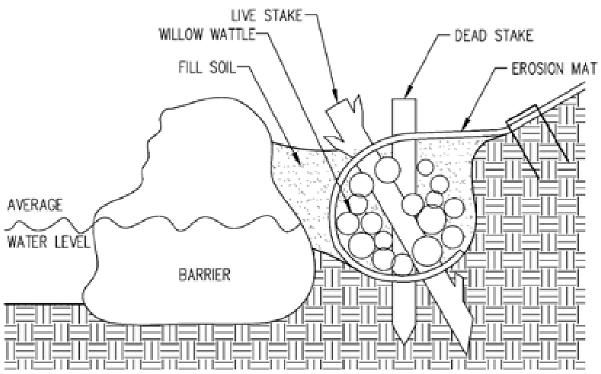


Figure 27: Detail of a Fiberschine (NM DOT)

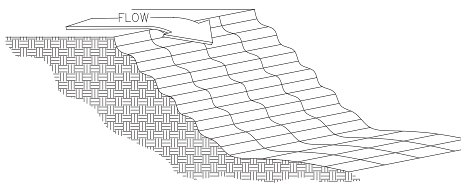


Figure 28: Diagram of Surface Roughening (NM DOT)

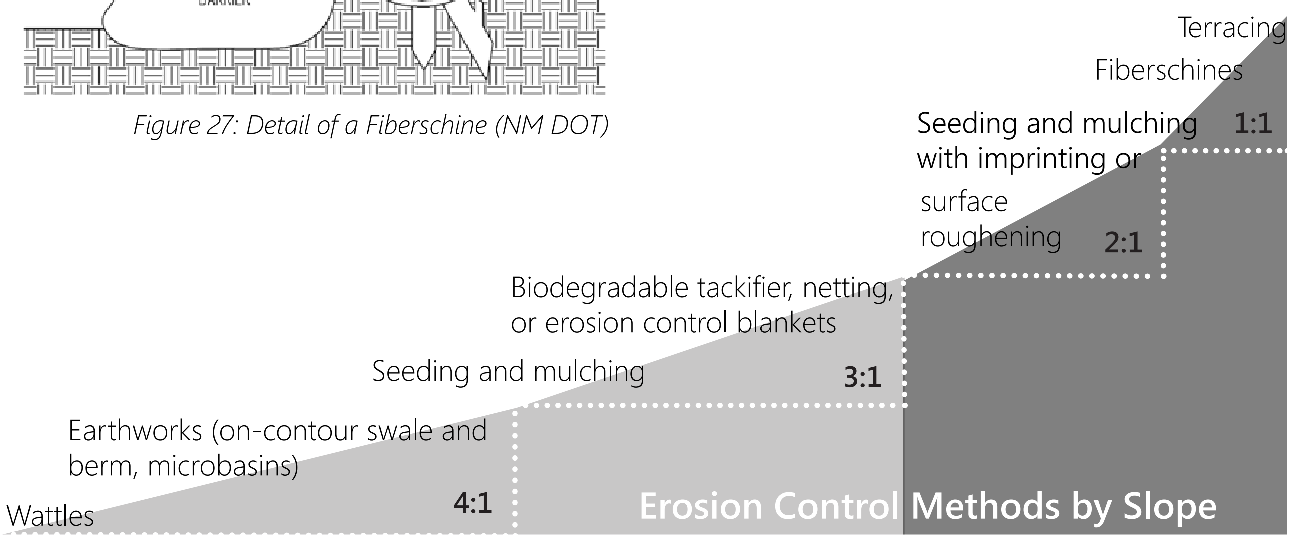


Figure 29: Erosion Control Methods Organized by Slope (figure by author)

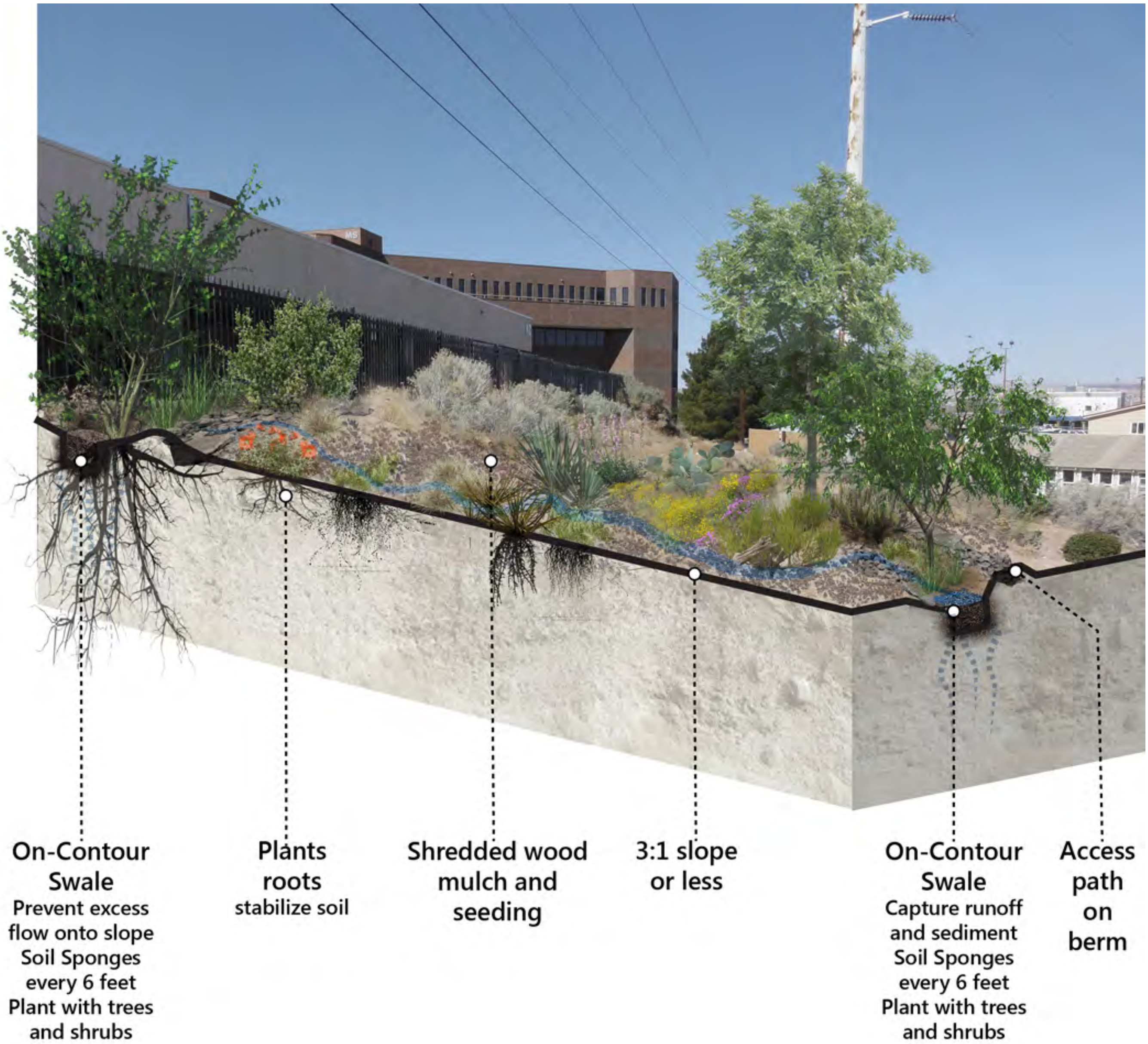


Figure 30: Illustration of Slope Stabilization Methods (figure by author)

Condition Two: Roof Runoff

Like vehicular surfaces, rooftops make up a significant percentage of impervious surfaces in both urban and rural settings, and therefore represent a significant opportunity to reimagine stormwater management. A 2012 study found that buildings cover 12.5% of surfaces within Albuquerque (Nowak and Greenfield 2012).

Roof runoff generally exits the roof surface at a limited number of points, which makes it a source of runoff that is easy to intercept and filter. Roof runoff represents a concentrated pattern of flow unlike the other two conditions, which have diffuse surface flows. Concentrated flows are typically managed with some sort of conveyance practice, an important element of stormwater management that can be explored further at a small scale.

According to the 2016 EPA Technical Assistance report for the Imperial Building at Second Street and Silver in Albuquerque, "[r]ooftop runoff tends to have relatively low levels of physical and chemical pollutants, but elevated microbial counts are typical" (EPA 2016b 8-9). Avian waste is the likely source of these microbial counts. According to a 2005 microbial source tracking report for the MRG, bird waste is a significant source of *E. coli* in the Rio Grande (see Figure 11).

As with all GSI projects, managing roof runoff with GSI is more effective if addressed in the site planning phase of a project, and if there is early cooperation among engineers, architects, and landscape architects. A building's location on a site, its roof slope and direction, and its drainage points can make the process of infiltration easier or unmanageable. In commercial areas, often roof runoff is directed to the back of the building to a utility alley. This is really a missed opportunity to use roof water to irrigate trees and plants in the front of the building, making the business more inviting to potential customers. This opportunity should be considered during planning stages, or if gutters or drainage are being redone.

Infiltration is the primary goal in most GSI features. However, infiltration within 10 feet of a building foundation is not recommended because water can seep into any cracks in the foundation and eventually destabilize the building. Although infiltration is still the end goal in managing roof runoff, the first goal is to convey runoff to a safe distance from the foundation.

Roof runoff, especially on larger buildings, leaves the roof surface at concentrated points such as canales[1], gutter downspouts, or drains. Each of these present an opportunity to make water infrastructure visible and add sculptural effects. Because of the drop from roof surface to ground surface, roof runoff carries more gravitational energy than other runoff conditions, which can be incorporated into sculpture, but if not managed, can also cause damage. Concentrated, high velocity flows entering conveyance swales or channels cause scouring and erosion and increase sediment load in the water. In order to avoid this problem, roof runoff must first encounter a device to dissipate energy and spread the flow. On the ground, this device can be a splash block/pad, or large rocks. These devices are similar to pretreatment devices for parking lots, but because roof runoff does

[1] Canales are openings in the parapet to allow for roof drainage. They are common in adobe-style flat-roofed buildings.

not contain large amounts of sediment, energy dissipation is the goal rather than sedimentation.

Locating the device at the base of downspouts or drains is easy, but with canales it is more challenging due to variable velocity of water leaving the roof. Water could trickle out of a canale if there is a little rain, or jet from a canale during a large storm. An energy dissipation device at the base of a canale should be sufficiently wide to accommodate a range of possible runoff landing points.

Once concentrated flow has been dissipated and spread, it can enter a conveyance swale. In most swales, some infiltration and filtration would be encouraged. However, because infiltration is problematic near buildings, conveyances from roof downspouts may be lined with geotextile fabric and mulched with large aggregate, both of which are not recommended for bioinfiltration. Vegetated swales are not recommended because they allow for infiltration. Cobble swales, already a ubiquitous feature in xeriscapes, are ideally suited to convey water away from buildings with minimal infiltration. However, cobble swales should be only as long as needed to bring water a safe distance from the building, and should terminate in a bioinfiltration area.

As with bioinfiltration areas, the depth of the conveyance swale should not exceed 18 inches. Both the *Bernalillo County Water Conservation Guidelines* and the *NM DOT NPDES Manual* recommend a 6-inch freeboard within conveyance swales. Freeboard is the distance between the top of water flow in a flood and the top of the berm containing the flow, and is a safety factor to prevent overflow from the sides of the swale. The freeboard requirement means that the water depth in the swale during a 100-year, 6-hour event should be one foot or less. The width of the swale depends on the anticipated peak flow volume from the roof and the cross-sectional area needed to accommodate peak flow. *The City of Albuquerque Development Process Manual* requires side slopes in open channels have a 3:1 ratio or less, which also influences the cross-sectional area.

Longitudinal slope recommendations are given for vegetated swales, and start at a minimum of 0.5% (Pima County 2015) or 2% (Sites Southwest 2011). Maximum longitudinal slope for vegetated swales ranges from 4% (San Diego County 2014) to 6% (Los Angeles County 2014, Sites Southwest 2011). Peak flows should be less than 5 feet per second (Sites SW 2011). However, because rock-lined swales dissipate additional energy from water, slopes and peak flows may actually be slightly higher than what is recommended for vegetated swales.

Check dams[2], widely recommended as a method to limit slopes and reduce erosion and sediment transport in vegetated swales with slopes exceeding 2.5%, often inadvertently increase scouring and velocity below the dam, as well as scouring and erosion where the dam meets the banks (Fleming 2017, Brooks and Young 2018). For this reason, check dams are not a recommended practice.

Instead of check dams, a preferred method for reducing slopes within conveyance swales is to

[2] Check dams are small dam-like devices meant to slow the flow of water in a channel, but not stop it.

use curves to increase the length of the swale and create a meandering path. Curves also act to decrease velocity of flow, but may require additional armoring to absorb the impact of flow velocity as it hits the turn. If the path of a swale is straight rather than meandering, additional energy dissipation may be needed at the swale outlet/basin inlet to prevent scouring.

The bioinfiltration basin at the end of the swale must be a minimum of 10 feet from the building foundation. As the primary contaminant in roof runoff is *E. coli*, infiltration or sedimentation is needed to remove the bacteria from runoff. However, *E. coli* is not taken up into the edible parts of plants, so trees and shrubs producing edible fruits and berries may be safely planted in and around basins receiving roof runoff. Using roof runoff to irrigate food crops contributes to much-needed food security, and can provide economic opportunities. However, it is not recommended to plant crops such as spinach, lettuce, or chard whose edible parts are in contact with possibly contaminated water.

Planting deciduous trees in or around bioinfiltration basins on the East, West, or South sides of a building ensures that roof runoff supports tree growth, which keeps the building cooler during the summer and lowers energy use. Deciduous trees allow winter sun to heat the building, which also lowers energy use. Evergreen trees should be planted on the North side only. If planted on other sides, evergreen trees can block winter sun from reaching the building, which can increase energy use to heat the building in the winter.

The bioinfiltration area must have a protected overflow leading to either another swale or basin, or to an impervious surface leading to a storm drain. See 'Bioinfiltration Materials and Sizing' section for further information.

Sediment and trash are not significant concerns in roof runoff management, so maintenance is more straightforward as compared to parking lots. Typical maintenance includes verifying that roof runoff is successfully entering and flowing through the swale as well as checking for erosion or blockages in the swale and at the overflow. These inspections should occur after storms of 0.5 inches of precipitation or more (NM DOT 2012). Plants will require light pruning annually, and replacement as needed; Mulch should be added every two to three years.

KEY POINTS FOR ROOF RUNOFF:

- Roof runoff contains *E. coli*, but is a resource for irrigating trees and plants.
- Sculptural downspouts can increase visibility of stormwater and add aesthetic interest.
- Roof runoff should be conveyed to a bioinfiltration basin or swale sited at least 10 feet away from the building foundation.
- Deciduous trees planted in a bioinfiltration basin on the south, east, or west sides of a building provide shade, reduce energy use for cooling, and counteract the UHIE.

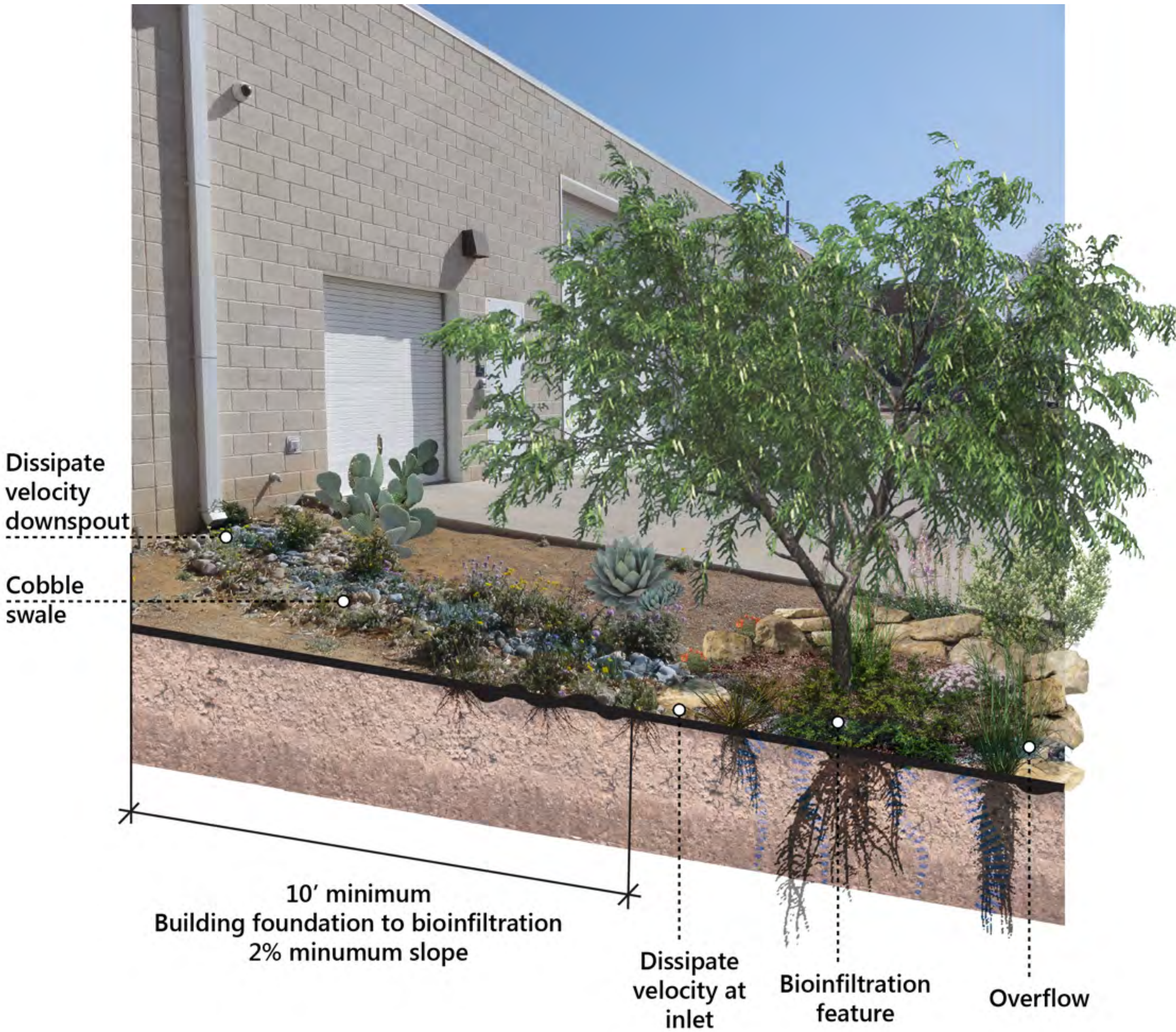


Figure 31: Illustration of Conveyance and Bioinfiltration for Roof Runoff (figure by author)

Condition Three: Parking Lots

Vehicular surfaces, including parking lots, are a large proportion of total impervious surfaces in developed places, but are of particular concern in Western cities with development patterns defined by sprawl and reliance on personal vehicles. Generally constructed of asphalt or concrete, these surfaces retain and slowly release heat, contributing to the urban heat island effect (UHIE). In industrial and commercial areas, parking lots are the single greatest land use (County of San Diego 2014). An analysis of aerial photos from 2009 showed that 14.9% of Albuquerque's surface area was covered by parking lots, driveways, and sidewalks. This category of impervious cover is greater than either roads or buildings (Nowak and Greenfield 2012).

Roads and parking lots collect pollutants, including sediment, hydrocarbons, heavy metals, thermal loads, pesticides and fertilizer, pet waste, and trash. Of these elements, sediment, thermal loads, fertilizer (an oxygen-depleting substance), pet waste (source of E. coli), and trash are required to be controlled by the MS4 permit.

Patrick Chavez, stormwater quality engineer with AMAFCA, recommended selecting parking lots as a condition for this thesis as they are frequently a missed opportunity for green stormwater infrastructure (Chavez 2018). Chavez also suggested that parking lot interventions might be more quickly applied than road interventions because they generally have one private owner whereas roads fall under the jurisdiction of several entities and usually require lengthy processes for any protocol changes.

In 2010, Katherine Labadie's research in the Albuquerque area identified 'Harvesting parking lot runoff' as the most recommended technique by the panel of professionals who were interviewed. This finding indicates favorable possibility for widespread implementation of GSI in this condition.

Data and demonstration projects are needed to provide compelling evidence of local GSI effectiveness and counteract ongoing GSI skepticism. Easily quantifiable runoff from parking lots could make for efficient data collection projects in contrast to roads, which often have unclear watershed boundaries. Parking lots also offer reasonable public visibility for GSI interventions.

Several new parking lots constructed in the Albuquerque include runoff capture in basins and swales (see figure 18). While it is encouraging to see that permit requirements are influencing development, the next step is to ensure that interventions use safe guidelines to provide the desired water quality improvement, and have an acceptable return on investment. Parking lots are opportunity to explore possibilities for best practices that may be applied immediately.

Non-structural practices involving planning and policy should first be considered when designing stormwater-smart parking lots. Of course, LID principles should be practiced wherever possible, including conservation of existing drainage patterns, areas of permeable soil, and valuable vegetation. Incorporation of these principles requires cooperation among landscape architects, engineers, and architects in the initial stages of a project.

Often parking lots are designed for times of heaviest use, resulting in excessive numbers of parking stalls and expanses of asphalt. Parking ratios, or the number of parking spaces required per municipal code, should be reevaluated to mandate the least number of spaces. If overflow parking is needed, it can be constructed with permeable materials such as gravel or pavers. Creating incentives for shared use can also limit the size of parking lots. Shared use parking is possible when adjacent organizations have different hours of peak demand. For example, a church and school could share parking; a church needs parking on evenings and weekends while a school requires weekday parking.

Reconsidered parking lot layouts can also reduce the amount of asphalt needed. Diagonal parking stalls with one-way aisles require 5-10% less surface area than traditional perpendicular parking stalls with two-way aisles (Washington Department of Ecology 2013).

Incorporating permeable areas into parking lots is critical, as large impervious surfaces generate high volumes and velocity of contaminated runoff. Breaking up large impervious areas into smaller areas separated by permeable spaces, such as pervious paving or infiltration areas, keeps runoff in smaller, more manageable quantities.

Permeable paving materials are ideal for parking lots with limited speeds and wear. Suitable materials include permeable concrete, asphalt, pavers, or gravel, which is prevented from compaction with open-cell support system. They can be used in the entire lot, in low spots needing additional drainage, in overflow parking spaces, or for pedestrian walkways within parking lots. Standards can require that in lots, a certain percentage of permeable paving should be incorporated. Permeable paving has been shown to have high removal rates of sediment and heavy metals, and medium removal rates for pathogens, oil, and grease (County of San Diego 2014).

Infiltration areas in parking lots require a few key components. Among them, site grading that directs runoff to infiltration areas and allowing runoff to access infiltration basins or swales. Grading does not involve any additional cost but does require integrated site planning. Installing tire barriers and flush curbs instead of barrier curbs allows runoff to sheet flow into an infiltration area. Slotted curbs allow water to enter infiltration areas at select points and with concentrated velocity. For slotted curbs, *The County of Los Angeles LID Standards Manual* (2014) recommends 11-inch-wide inlets at least every 6 feet. There needs to be a 2-inch drop between the edge of the flush curb or curb inlet and the pretreatment device. This drop causes a slight increase in runoff velocity which keeps the inlet clear of small debris.

There are two common pretreatment materials for infiltration basins: aggregate and vegetation. If runoff enters an infiltration basin through sheet flow, a gravel level spreader will be needed to dissipate velocity, prevent erosive channels from forming, and collect particles through sedimentation. This spreader should be a 12-inch wide, 6-inch deep aggregate strip bordering the edge of the parking lot (County of Los Angeles 2014). If runoff is concentrated at curb inlets, a forebay made from concrete or large aggregate can accomplish the same objectives.

A vegetated buffer strip is an additional pretreatment option that can filter trash, heavy metals, and additional sediment and attached pollutants through filtration (County of San Diego 2014). Vegetated buffer strips are only appropriate if slopes are between 2% and 4%, and if at least a 4-foot strip of space is available. Two inches of compost can be tilled into the top 6 inches of uncompacted soil to give seeds or plants an advantageous start, and allow for greater plant density and enhanced filtration.

After flowing through the gravel, and possibly a vegetated buffer strip, parking lot runoff should enter an infiltration basin or swale. The configuration and material of the infiltration area depends on available space, volume of water that must be treated or detained to meet water quality and flood risk reduction goals, project budget, and maintenance that can be provided. This area can be only for infiltration, such as an infiltration trench (also known as French drain) filled with rocks, or it can be a bioinfiltration feature with the additional pollutant treatment, shade, and habitat benefits provided by plants and soil. The materials of the bioinfiltration feature can be as simple as mulch and plants, include soil sponges or a gravel storage layer, or, if space is limited, bioretention soil media.

Bioinfiltration structures can be located in parking islands, between rows of stalls, or at the perimeter of a parking lot. They should incorporate trees to the greatest extent possible to shade heat-retaining asphalt as well as provide shade for vehicles. Large shade trees increase the visibility of bioinfiltration structures because of their physical size, and because people are drawn to shade in hot places. Adding pedestrian walkways under trees further increases the visibility of GSI features, and provides improved safety and comfort. Surface treatments such as paint or mosaics can also be used to draw public attention to the presence of GSI. Signage furthers the benefits of visibility by educating the public on the existence and benefits of bioinfiltration.

Signage also communicates the function of bioinfiltration areas to property owners and maintenance crews. New owners or maintenance crews may see the bioinfiltration area as a standard landscape with aesthetic value only, not an important piece of infrastructure. If the bioinfiltration area is subsequently altered, or filled to create additional parking spaces, flooding and water quality issues will result. There are several anecdotal instances of successful GSI interventions in the MRG Valley successfully resolving flooding issues before being inadvertently destroyed by maintenance crews or homeowners who were not aware of their function. Needless to say, the function was learned too late when flooding returned.

Bioinfiltration features in parking lots must be protected from foot traffic, which causes soil compaction and plant damage. These actions decrease infiltration rates of soil and the function of the structure. Protection from compaction can be accomplished through strategically placed boulders, small fences, or dense planting (if runoff volume is sufficient to irrigate dense planting). Large aggregate can also be used; people don't like walking on 8-12-inch cobble, but rock does not contribute to improved soil and plant health.

Bioinfiltration basins need an overflow channel to the street, or an underdrain connected to the storm sewer system. Overflows must be protected against erosion.

Trash must be regularly removed from bioinfiltration features, along with weeds until desired vegetation is established. Inlets and overflows should be checked for clogging and erosion after storms of 0.5 inches of rainfall or more. Plants will need annual pruning, and may need occasional replacement. Plants will only need irrigation for the establishment period, and should not be fertilized after planting. Shredded wood mulch will need to be added every 2-3 years as it biodegrades. Gravel or concrete pretreatment require cleaning when they fill with sediment. If permeable pavement is used, it will require annual vacuuming with a vactor truck to remove accumulated sediment from the pore spaces of the pavement. If the pavement is not vacuumed, pore spaces will clog and permeability will decrease.

KEY POINTS FOR PARKING LOTS:

- Parking lots contribute to the urban heat island effect and are a source of *E. coli*, trash, sediment, thermal load, hydrocarbons, heavy metals, and oxygen-depleting substances.
- Minimize the use of impervious material by designing parking lots with the following: one-way aisles and diagonal parking, requiring the least number of spaces, and creating incentives for shared parking.
- Interrupt impervious surfaces with pervious areas such as permeable pavement or bioinfiltration basins and swales.
- Use flush or slotted curbs to allow runoff to enter bioinfiltration areas.
- Support tree growth to provide shade. Protect trees from cars and people.

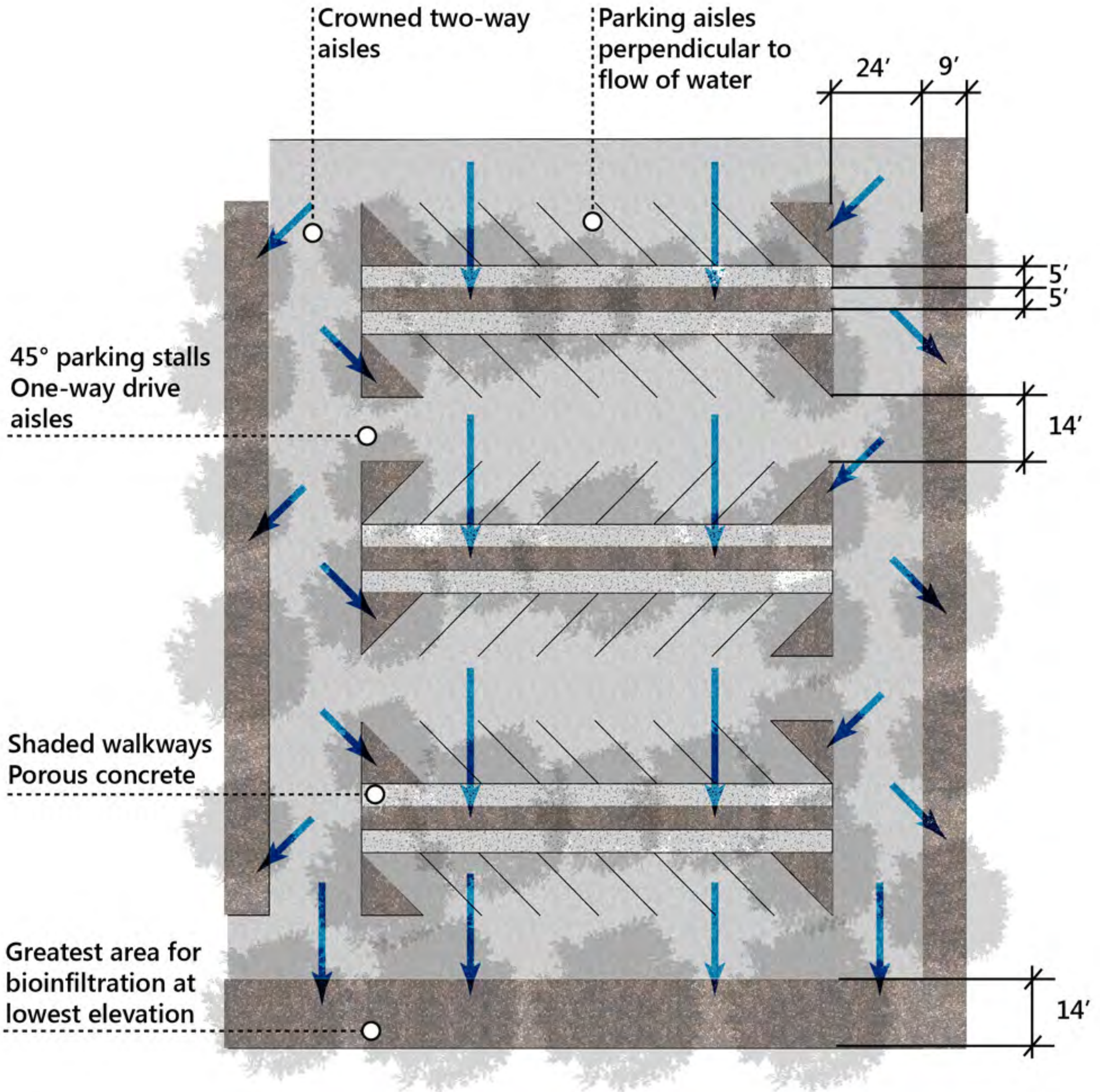


Figure 32: Illustration of Recommended Parking Lot Configuration and Dimensions (figure by author)

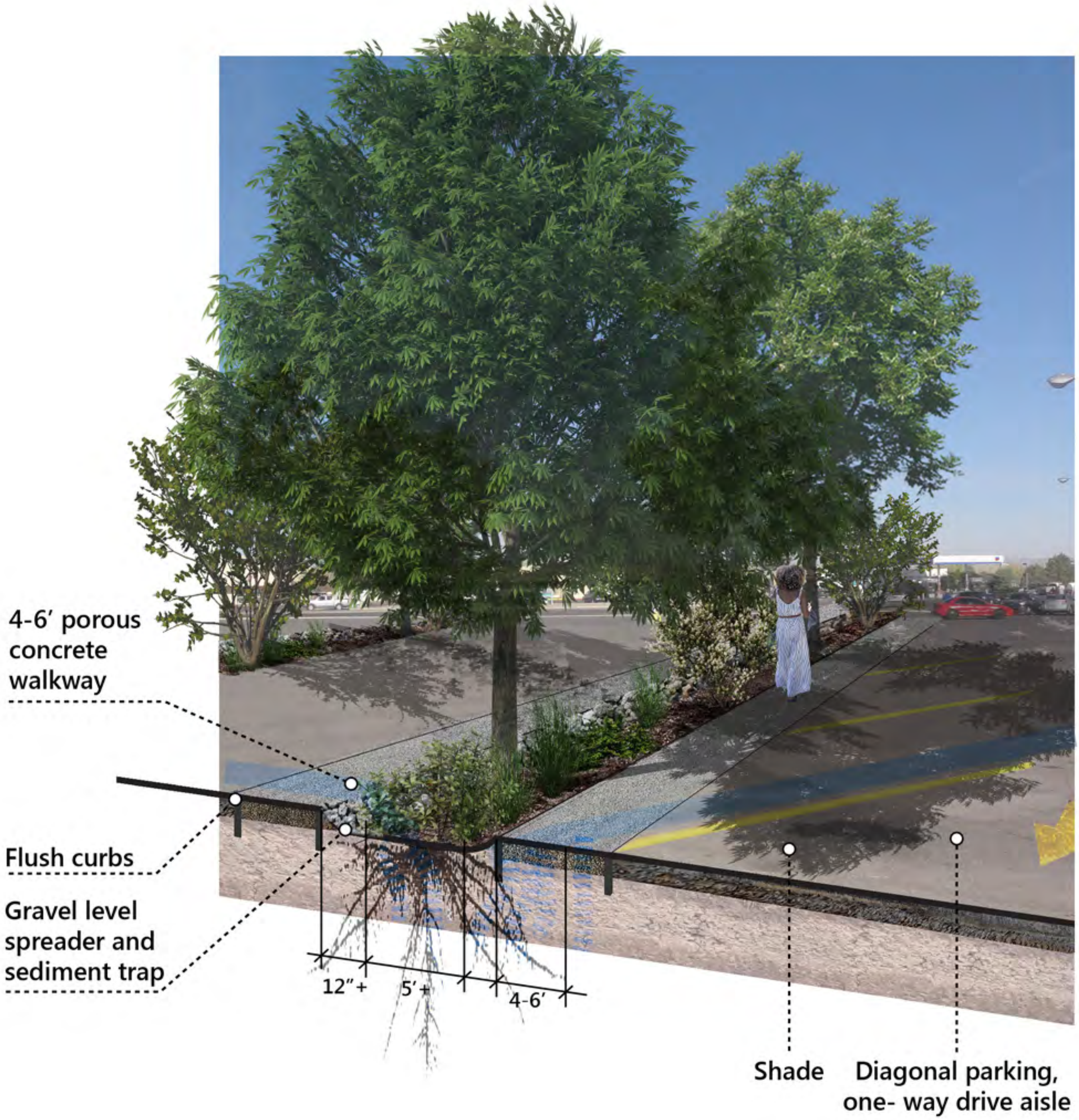


Figure 33: Illustration of Recommended Elements and Materials for Parking Lots (figure by author)

GSI Demonstration Site

Research findings were applied to a test site within the MRG watershed on the main campus of Central New Mexico Community College (CNM). CNM has a designated sustainability project manager within the physical plant department, as well as a program encouraging instructors to use the campus as a living lab. These programs allowed the author to engage in a cooperative process, have access to physical plant department records, and create the possibility for future student involvement with the proposed designs.

Figure 34: Site Location (figure by author)

Molly Blumhoefer, the sustainability project manager at CNM, suggested an area on the main campus that encompasses all three types of conditions researched for this thesis: a parking lot, roof drains, and an unstable slope located on and around Ken Chappy Hall.

Ken Chappy Hall (KC Hall) is on the southern half of the CNM main campus, and includes a parking lot to the east, part of the roof runoff from the building, and an unstable slope just north of the building. Drains for roof and parking lot runoff are connected to the same storm sewer pipe which exits to a concrete valley gutter before flowing directly onto University Boulevard (see figure 36). There is no treatment or infiltration provided for the water from the storm drain. After entering University Blvd, water flows to Avenida Cesar Chavez and then to the South Diversion channel, an unlined arroyo that connects with a concrete-lined section of Tijeras Arroyo, before flowing to the Rio Grande.

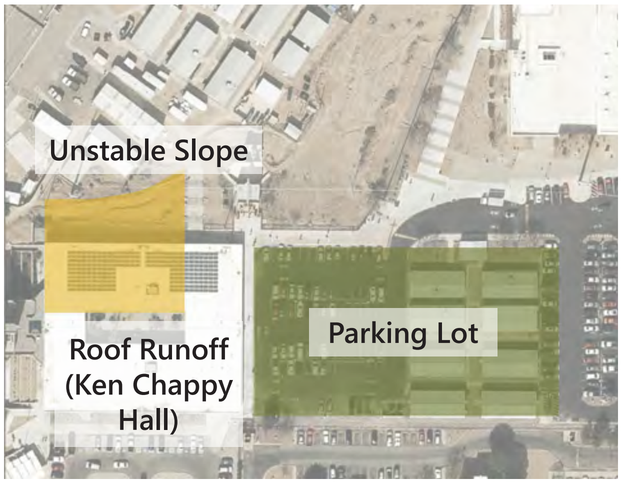


Figure 35: Three Conditions of Site (figure by author)

Figure 36: Site Drainage to Univ. Blvd (figure by author)

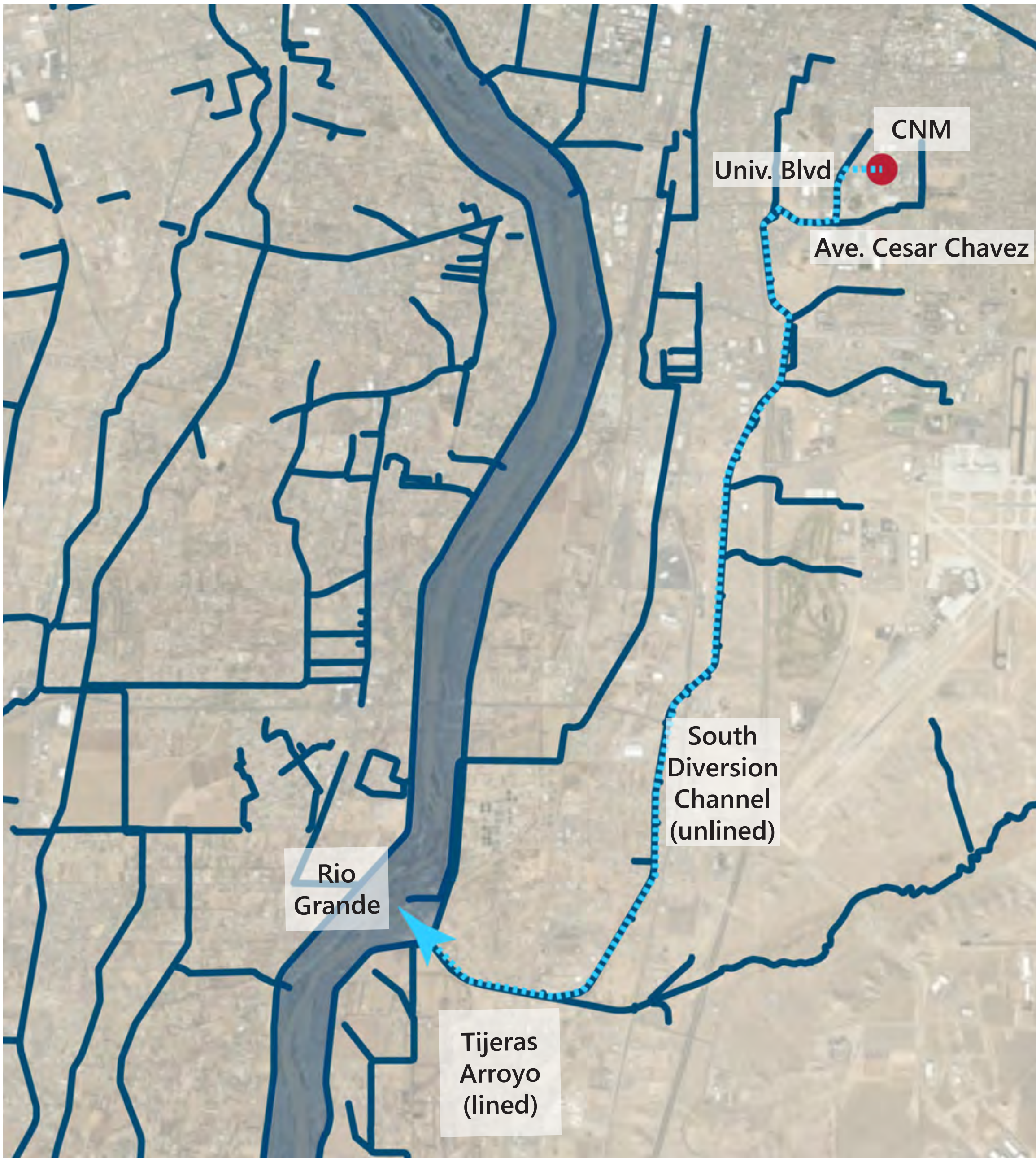


Figure 37: Runoff Flow Path to Rio Grande (figure by author)

SITE ANALYSIS

Parking Lot

The area of the parking lot draining to the storm sewer inlet closest to KC hall covers approximately 52,000 square feet, including parking lot islands (50,400 square feet without the islands). The parking lot was renovated and expanded in 2017 and included the construction of 7 parking lot islands, 5 of which have the potential to intercept and treat water that would otherwise flow directly to the storm sewer inlet. Four of these 5 islands include one 24" curb inlet to collect stormwater. The landscaped area within the islands is recessed 6 to 8 inches to allow for ponding. The islands are landscaped with geotextile fabric, one-inch aggregate, drought-tolerant shrubs (Including *Dasylirion wheeleri*, *Ericameria larcifolia*, and *Hesperaloe parviflora*), and one or two trees each (*Fraxinus* and similar). Plants within the islands are irrigated. The area of the parking lot draining to the drop inlet slopes down from east to west, with slopes ranging from approximately 2% to 6%. A trench drain runs along the lowest (western) edge of the parking lot and is connected to the drop inlet for the storm sewer. This parking lot probably contains typical parking lot pollutants, including *E. coli*, heavy metals, hydrocarbons, thermal pollution, cigarette butts (floatables), and sediment.

Figure 38: Recently Constructed Parking Lot Island with One Curb Inlet (photo by author)

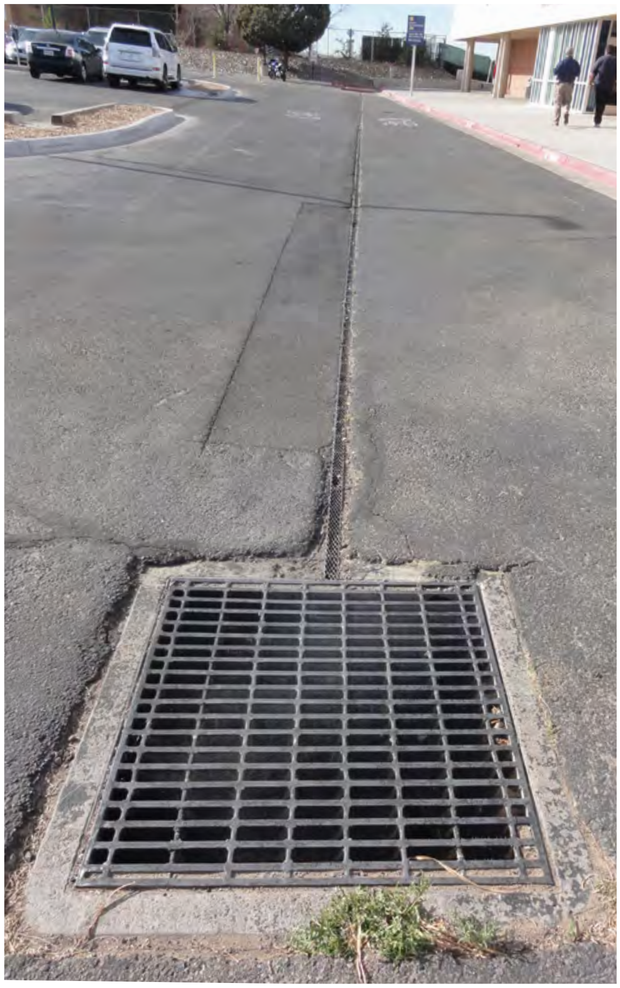
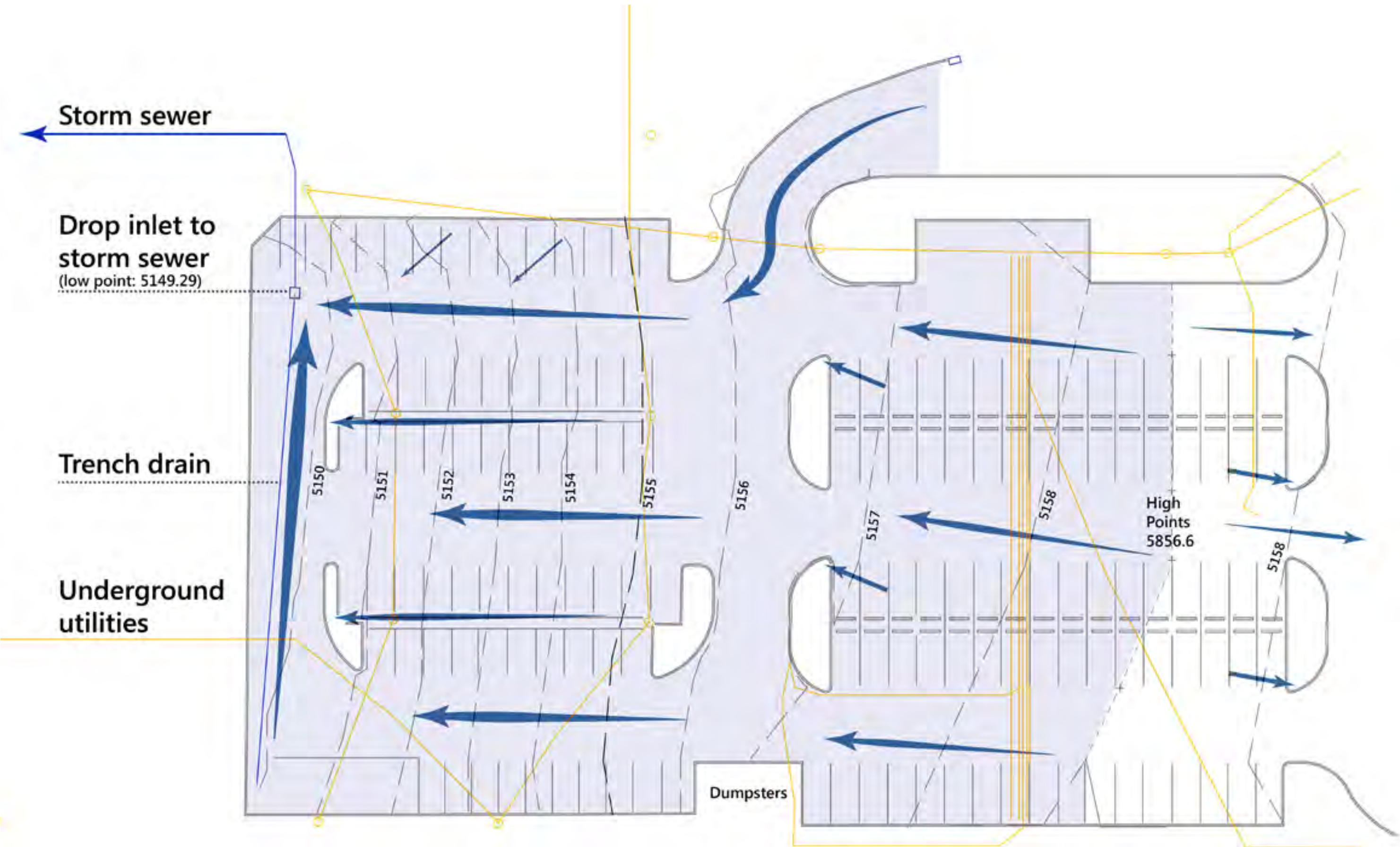


Figure 39: Trench Drain and Drop Inlet in Parking Lot (photo by author)



Stormwater Quality Volume Calculation:

Runoff coefficient → (0.95); 80th percentile rainfall depth (ft) → (0.48"/12")

(50,400 sq ft asphalt) (0.95) (0.48"/12") = 1915 cubic feet of runoff (14,300 gallons)

OR 1,516 cubic feet of runoff (11,341 gallons) if using 0.1" initial abstraction

Figure 40: Existing Parking Lot Drainage Diagram and Calculations (figure by author)

Roof Runoff

KC Hall has a white membrane roof with a photovoltaic array on the north half of the roof. Raised separators divide the roof into quarters, with each quarter having four 6-8-inch drains directly connected to the storm sewer. The roof surface around each drain is slightly recessed to collect water, has a basket filter, and is located next to a canale. Water that does not flow into the drain flows out of the canale and onto the ground below. The amount of runoff leaving through the canale is variable, and depends on storm intensity and the condition of the basket drains, which can become clogged with debris. Erosion below 2 of the 4 canales on the north side of the building indicate that 2 canales are regularly discharging runoff. Aggregate swales have recently been built under these two canales to address erosion (see figure 42). The maintenance department would prefer a smooth walking surface instead of aggregate. After flowing through the swale, runoff is discharged onto an unstable slope where it cuts channels into the slope. Roof runoff typically has elevated level of bacteria (such as *E. coli*) and thermal pollution.

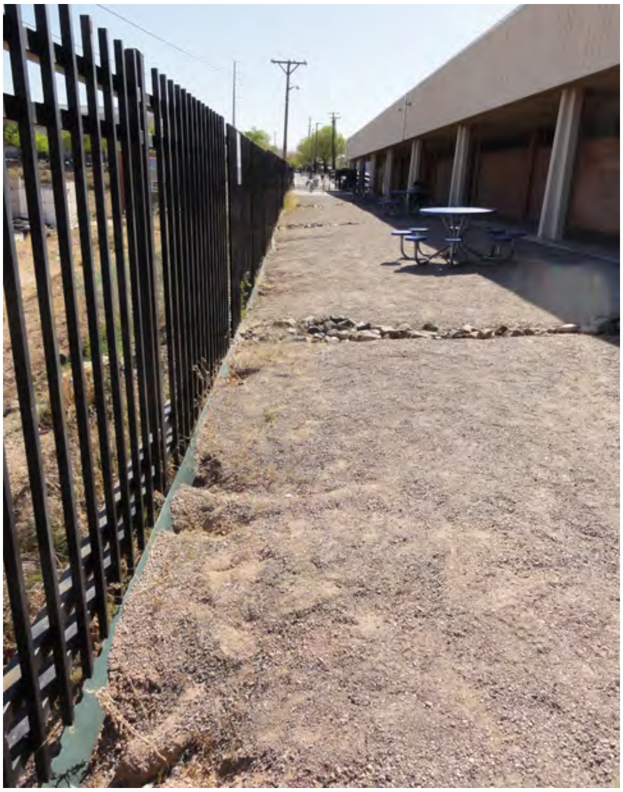


Figure 41: Erosion Along Length of Fence (photo by author)

Figure 42: Aggregate Under Canale (photo by author)

Unstable Slope

The unstable slope begins 17 feet north of the edge of the KC Hall roof and drops down into an area where portable classrooms and large equipment storage are located. The areas receiving runoff from canales show the most severe channels, although runoff from the packed crusher fine area between the KC roof and the beginning of the slope cause erosion along the length of the slope. Steel edging has been placed to try and control this issue.

Mid-way down the slope, a large berm has been added to direct runoff away from a portable building. The berm directs water to an area for ponding at the base of the slope, where it sits until it evaporates, usually after a week or so. Sediment from the slope washes onto stairs and a walkway.

The west end of the slope is much steeper than the east end. According to a 1995 land survey, the west end of the slope has a 37% slope (greater than 3:1), while the east end has a 25% slope (less than 3:1). Mild slopes at the east end appear stable, although there is significant undercutting along the concrete walkway and steps. Four patches of mature Chamisa (*Ericameria nauseosus*) and Four-wing Saltbush (*Atriplex canescens*) appear to be stabilizing a few areas of the slope, although most of the slope is bare. The soil appears to be sand and gravelly clay.

Greenprint maps show several interesting considerations for the CNM site. The unstable slope is identified as having a moderate goal of water quality protection and is a high priority area for protecting permeable soils. Most of CNM campus south of Coal Ave has a moderate need for access to outdoor spaces, which can be provided in the area between KC Hall and the slope. The parking lot area and KC Hall roof has a moderate severity of urban heat island effect (UHIE), which can be addressed through additional shade. This rating also indicates additional need to treat runoff for thermal loading.

Figure 43: Channels Cutting into Steepest End of Slope (photo by author)

Figure 44: Erosion Undercutting Walkway On Slope (photo by author)

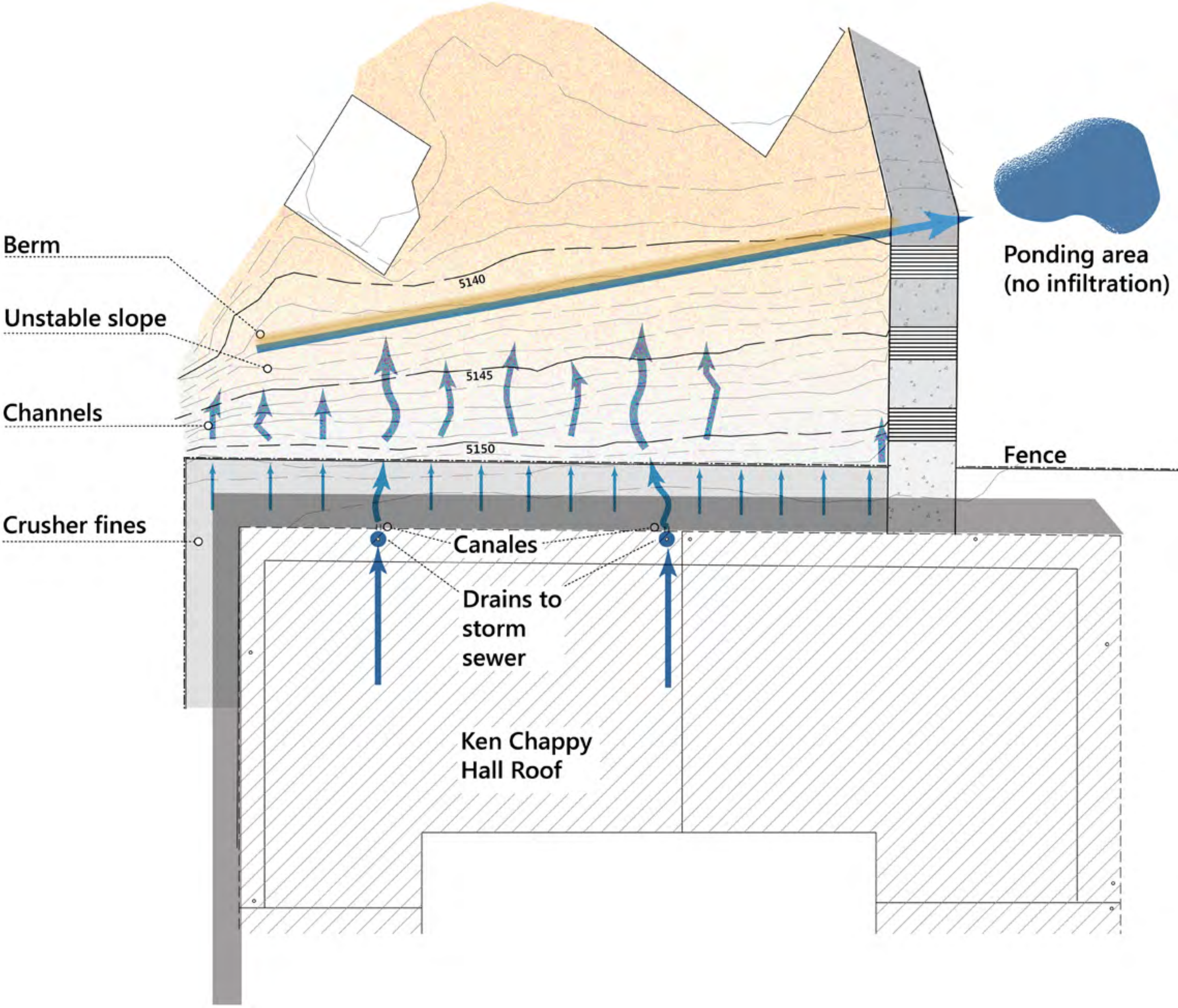


Figure 45: Existing Roof and Slope Conditions and Drainage (figure by author)

DESIGN RECOMMENDATIONS

Parking Lot

According to the watershed MS4 permit, redevelopment projects, including this parking lot, should be designed to capture and treat runoff from the 80th percentile storm on site. For the MRG watershed, the 80th percentile storm has 0.48 inches of rainfall depth. For 50,400 square feet of asphalt (see figure 40), this amounts to approximately 1900 cubic feet of runoff, assuming a runoff coefficient of 0.95 for asphalt. If the existing parking islands fill to capacity, they have a combined potential to treat 270 cubic feet of runoff. This means that an additional 1630 cubic feet of water should be treated.

However, the parking lot, having been recently expanded, is not likely to have major renovations in the near future. Although it would be ideal to change the orientation and grading of the parking lot so that parking aisles and infiltration areas are perpendicular to the flow of water for interruption and capture of runoff (see figure 32), it is more realistic to make minor adjustments. The first and easiest adjustment is to cut additional curb inlets on each island. Twenty-four inches is a generous width to accept runoff flow, but each island should have 11-inch inlets every six feet on the side of the island receiving runoff (County of LA 2014). This will ensure that the existing parking islands fill to capacity.

Another easy adjustment is to add pre-treatment area at each inlet to trap sediment and small trash. Without a pre-treatment area, the basins will eventually fill with sediment and have greatly reduced infiltration rates. Sediment should also be vacuumed from the pre-treatment area as it fills. This regular maintenance is also needed to prevent a mound of sediment from building at each inlet, which could prevent the flow of water into the basin.

The depth of the existing basins, as well as locations of existing trees and shrubs, is ideal. Water quality treatment in the parking islands could be further improved by the removal of geotextile fabric, in order for contaminated runoff to have direct contact with beneficial soil microorganisms. Precipitation from small storms could also infiltrate, rather than be absorbed by the geotextile fabric. Rock mulch in the bottom of each basin should be replaced with shredded wood mulch to increase soil health and water quality treatment. Additional grasses and shrubs could be planted to discourage traffic across the islands and improve infiltration rates and pollutant treatment. Observation during a storm may show that basin depths in the western-most islands need to be lowered to prevent runoff from immediately overflowing the lower curb.

Most of the runoff from the 50,400 square feet of asphalt draining to the storm drain inlet will not flow through a parking lot island, but it will flow to the existing trench drain at the lowest side of the lot. If this trench drain were replaced with a strip of 740 square feet of permeable concrete or pavers, much of the runoff would be treated. Permeable paving has been shown to have high removal rates of sediment and heavy metals, and medium removal rates for pathogens, oil, and grease (County of San Diego 2014).

An underdrain beneath the porous concrete could then collect the treated water and carry it to the storm drain. The permeable pavement area would need to be vacuumed with a vactor truck annually to prevent it from clogging with sediment.

A 740- square-foot permeable pavement strip in place of the trench drain could meet some of this need. If the existing drop inlet were surrounded with a raised asphalt ring to direct water to the permeable pavement rather than directly into the inlet, perhaps 6 inches of infiltration could be assumed. This would give the permeable pavement a 320-cubic foot treatment benefit.

The addition of three tree pits, at 46 square feet each, with a 12-inch ponding depth, would increase treatment capacity by 138 cu ft while counteracting the Urban Heat Island Effect. Existing asphalt would have to be sawcut, and compacted subsoil ripped to at least 36 inches to allow for infiltration and plant growth. Suspended paving in the parking spaces (125 square feet per space) around the tree pits would provide the needed volume of uncompacted soil for tree growth. Permeable paving could be used over the suspended paving system, but because the slope in this area is 6%, water will quickly runoff before infiltrating (2% is the maximum recommended slope for permeable pavement). Valley gutters cut into the existing asphalt would direct first flush and low flows to the tree pits, and also serve to slow traffic.

These interventions would help the parking lot come closer to water quality compliance. However, at least 10,000 square feet of additional permeable surface would be needed for full permit compliance, and to take full advantage of stormwater as a resource for creating a comfortable, healthy, beautiful environment.

Roof Runoff

Due to the placement and condition of the drains on the KC Hall roof that are connected to the storm sewer, it is difficult to calculate how much runoff exits the roof through the canales on the north side of the building. However, it is clear that enough water is leaving the roof to cause erosion immediately below each canale and on the nearby slope. There is a 17-foot strip of packed crusher fines between the covered walkway and the fence at the top of the slope. This space is an ideal location to use GSI to create an inviting place for students to congregate, which would address the moderate need for access to outdoor spaces. A linear bioinfiltration swale just inside the fence would capture runoff from both the roof and the crusher fine area, and could provide water for vegetation. This swale would solve the erosion problem near the fence, and would significantly reduce erosion on the slope below.

Aggregate swales under the canales could be replaced with concrete valley gutters for a smooth walking surface. The end of the gutter directly under the canale must be flared to capture splash. Arcs of broken asphalt (perhaps removed from the parking lot) would spread the concentrated flow from the gutters while also dividing the space into smaller outdoor lounge rooms. Soil sponges

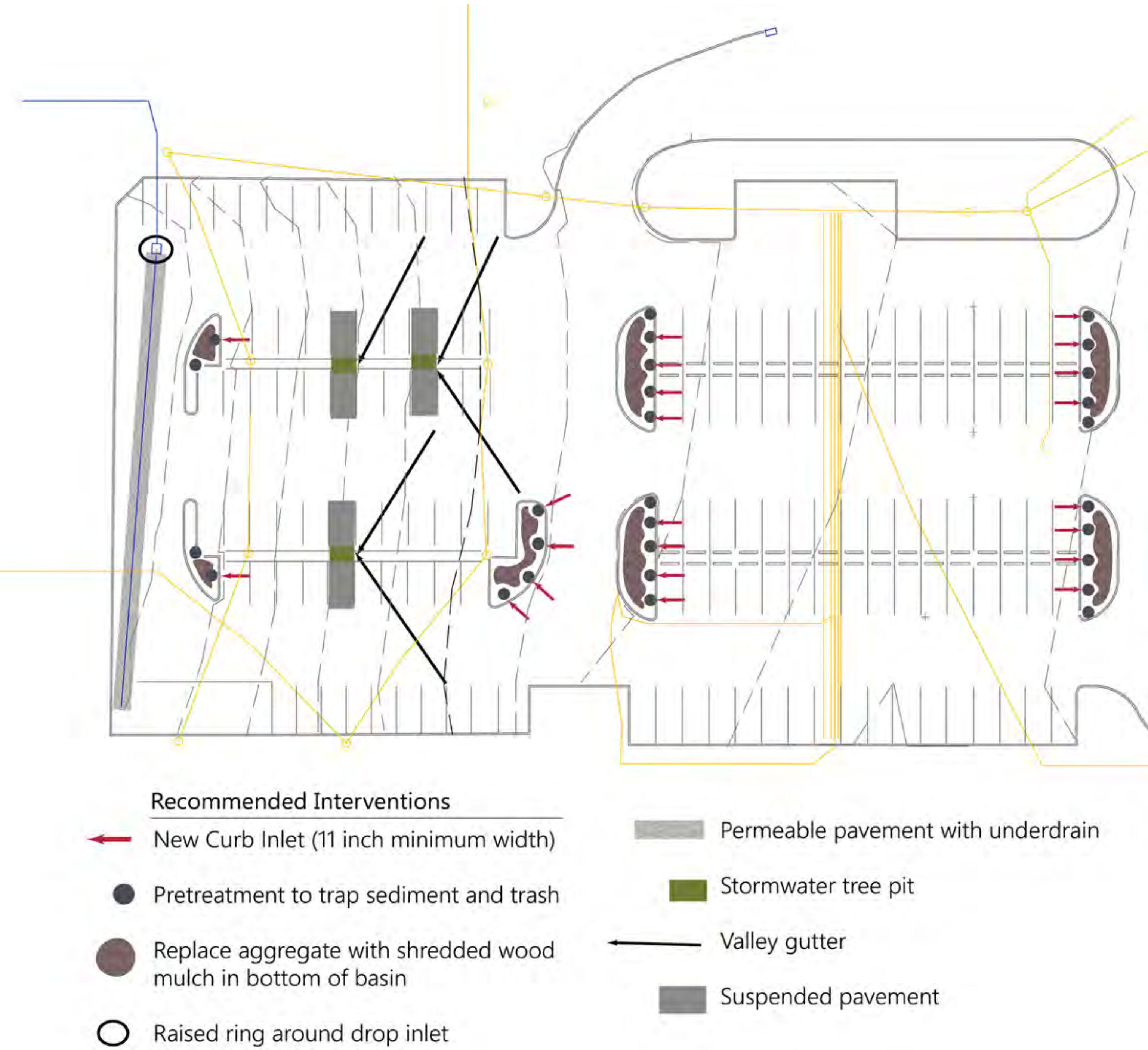


Figure 46: Recommended Parking Lot Interventions (figure by author)

spaced approximately every six feet in the swale will increase infiltration rates and plant health. An approximately 1% slope from west to east will ensure drainage toward the east end of the swale in intense storms, but not prevent infiltration. Multiple overflow points at the east end of the swale will release water to a secondary swale on the slope, and then to the most stable area of the slope, in the most extreme events. Attention should be paid to keep overflow points away from the walkway to prevent undercutting.

When the roof basket drains are clean, it is likely that the first flush of water containing the most E. coli and thermal load goes directly to the storm sewer. Instead, the lower 2 to 3 inches of the basket drains could be sealed so that the first flush goes through the canales and the basket drains only accept water if the roof begins filling. Another possibility is to divert first flush water as it exits the storm sewer, before it reaches University Blvd. There is a detention area adjacent to the valley gutter where the storm sewer pipe discharges water. A low flow diversion connected to a slope drain (with a splash block at the outlet) could deliver water to the base of the detention pond without causing erosion on the sloped sides. The basin should be adjusted to promote infiltration, including the removal of gravel and filter fabric and the addition of shredded wood mulch and plants.

Slope

Once runoff from the roof and crusher fine area is prevented from flowing onto the slope, there will be an immediate decrease in erosion. A swale on-contour at the top of the slope would catch any overflow from the linear swale in the crusher fine area. Below this initial swale, most of the slope is less than 3:1, and would be stabilized with seeding and mulching. On the west end of the slope where the grade is steeper, on-contour surface roughening may be needed, as well as light grading. Across the slope, biodegradable tackifier or netting could be used to hold seeds and mulch in place. Temporary irrigation would be needed to germinate the seeds. Night time temperatures at the time of seeding should be at least 50 degrees (F) to allow warm season grasses to germinate. The New Mexico Department of Transportation has a native seed mix designed for central New Mexico that could be used.

The existing rills and the undercutting along the walkway would need to be filled and lightly compacted before seeding and mulching. Soil from the existing berm could be used to fill rills, and to decrease the steep slope at the west end of the slope. A much smaller berm and swale in approximately the same location will catch flow at the base of the slope before it washes over the walkway and to the ponding area. The addition of desert willow or mesquite trees in the swale would screen the utility area for most of the year. Soil sponges should be added to every 6 feet in all swales to immediately improve infiltration. If these methods are shown to work on one part of the slope, they could be applied to the rest of the slope to the north and east of KC Hall.

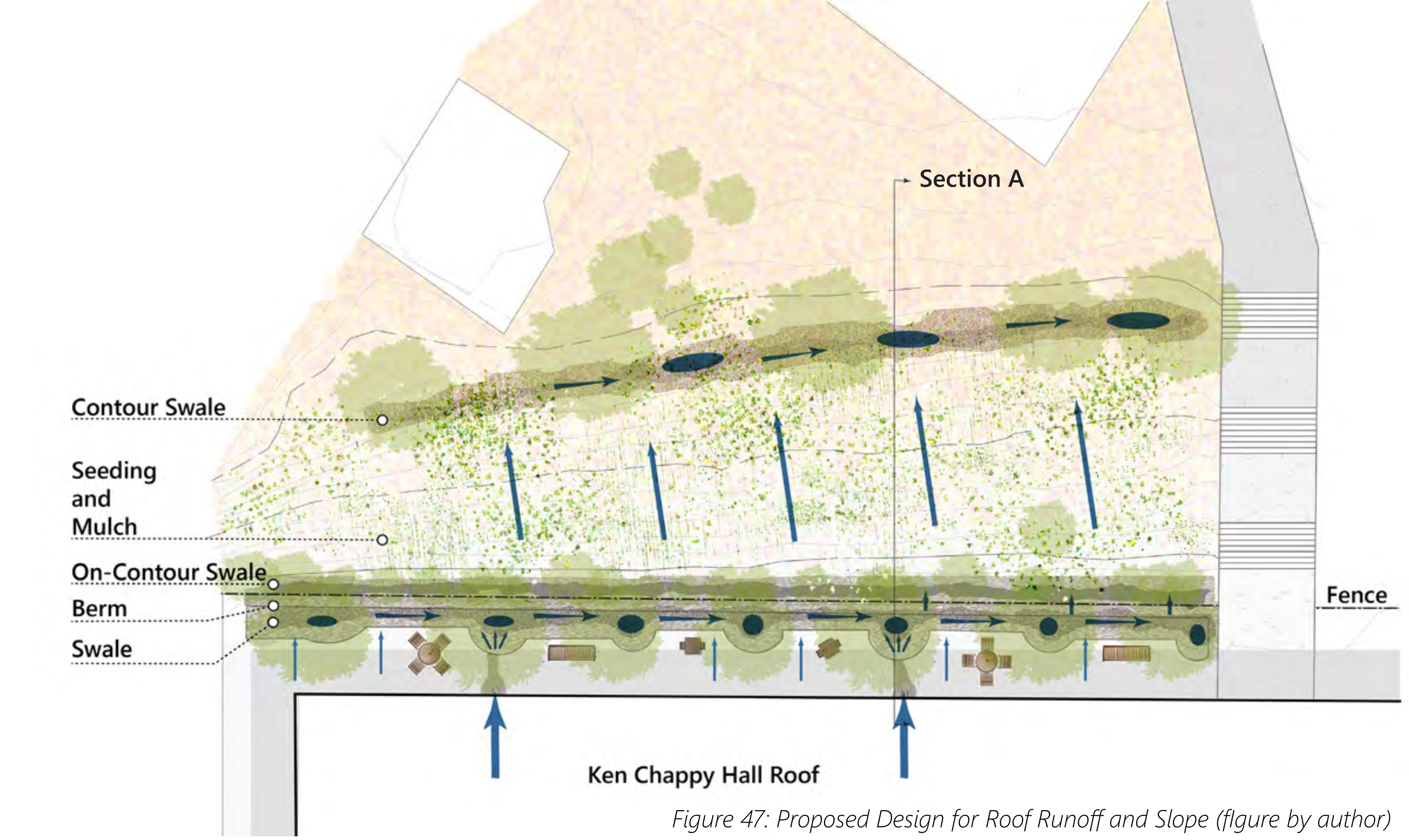


Figure 47: Proposed Design for Roof Runoff and Slope (figure by author)

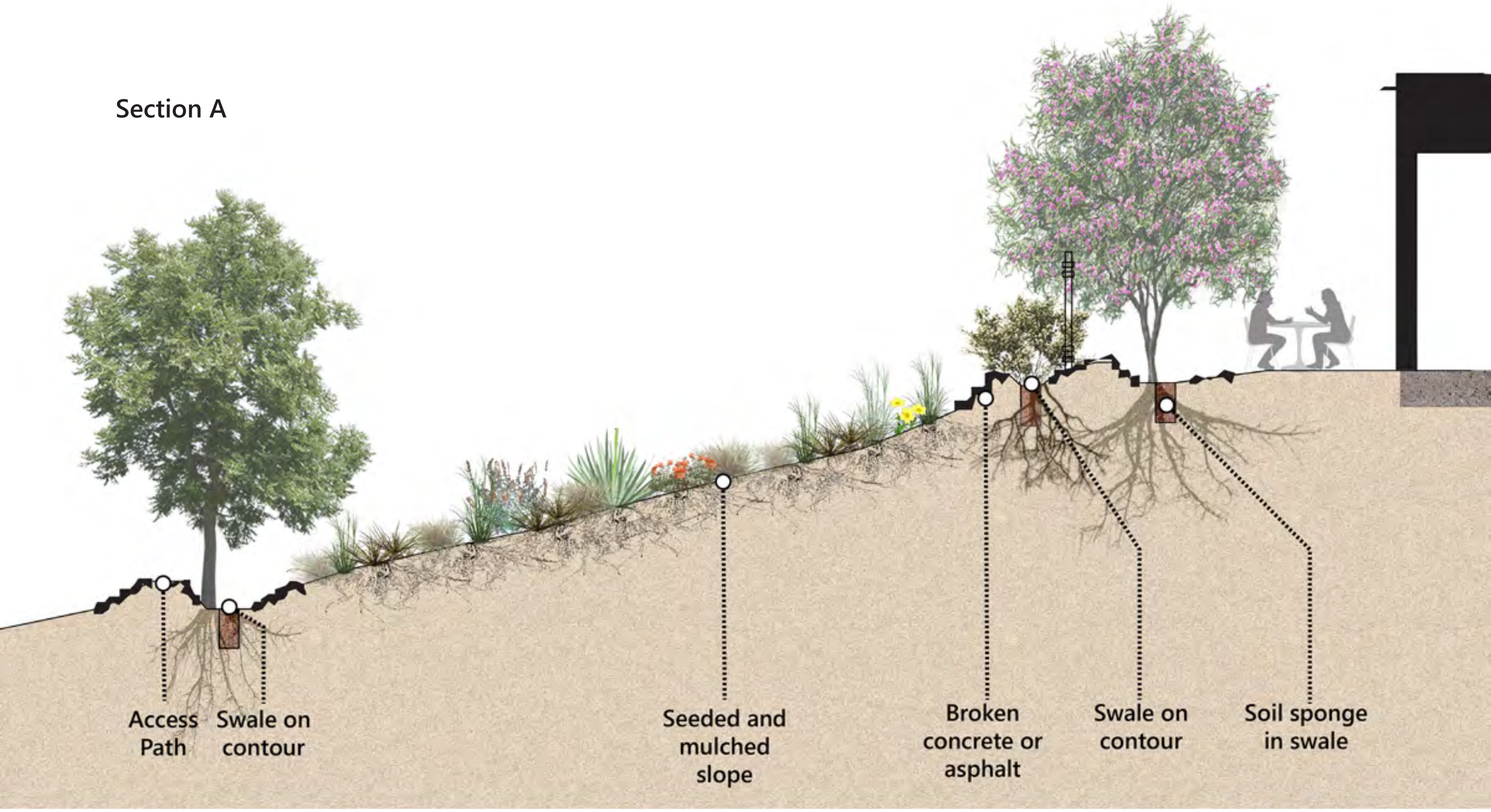


Figure 48: Section A Through Proposed Design for Roof Runoff and Slope (figure by author)

Figure 49: Perspective Rendering of Outdoor Lounge Area Along Bioinfiltration Swale (figure by author)

Monitoring

There are several opportunities for CNM students to engage with water treatment in the proposed design as part of the 'Campus as a Living Lab' program. The most important step would be to set up a precipitation monitoring system. Rainfall in the MRG Valley is highly variable, and what is recorded at the official monitoring station at the Albuquerque Sunport 2.5 miles away from CNM can be very different than precipitation on this site.

In the parking lot, students could first monitor whether or not water is entering the parking islands through existing curb inlets. Observation of runoff during a storm could provide information on where to best place additional inlets, and whether those inlets should be angled to receive runoff. Students could also collect and categorize the type of trash being trapped in the pre-treatment area of inlets, as well as monitoring the rate of accumulation of sediment at the inlet. This would help maintenance crews to know how frequently to vacuum the pre-treatment areas. Although it would be more difficult, students could monitor runoff from the parking lot (either entering the islands or the storm sewer) for the presence of *E. coli*, heavy metals, PCBs, etc.

Students could also develop a test retrofit of one parking island while leaving a similar island as a control. The test island could have additional curb cuts installed, gravel and weed block fabric removed in the basin and replaced with shredded wood mulch, and additional plants added. The test island could be monitored for soil moisture, weed growth, plant health, and sediment and trash capture.

If the basket drains on the roof are sealed at the base, students could monitor the first flush of roof runoff flowing from the canales for E. coli and temperature, as well as volume of flow. Being able to match the volume of flow with on-site storm data would enable the swale to be more accurately sized for design storm volumes. If the swale were built and planted with trees and shrubs from the plant list in Appendix A, students would have the opportunity to observe plant health and learn about native and drought adapted plants. The slope could be monitored for signs of channel formation, and for sediment washing onto the walkway. If the slope were seeded, students could take photos of the slope in mid-April, early August, and October to explore how plant species, distribution, and density is correlated with precipitation timing and intensity.

If possible, water flowing into the storm sewer from the trench drain could be monitored for pollutants (such as E. coli, heavy metals, etc). This data would provide a baseline of contamination by which to measure the effectiveness of a strip of permeable pavement. After construction, water leaving the underdrain could be monitored instead of the trench drain. Water quality monitoring could also be conducted at the drop inlet to measure the effect of changes to the parking lot islands or addition of bioinfiltration areas. Potential educational opportunities would be another layer of benefits for this already high-visibility GSI demonstration site.

Conclusion

The topics and suggestions presented in this thesis offer a synthesis of information needed for expanded GSI practice in the Middle Rio Grande Valley. However, there remains a significant amount of information to gather and develop if GSI is to become common practice in the watershed. Development of this information through an inclusive and collaborative process would be a most efficient and effective way to bring lasting change, and could be collected into a GSI/LID guide.

It is possible the that Middle Rio Grande watershed could have one GSI/LID guide that covers all projects and development within the watershed. Consistency provided by use of one guide across the watershed would make expectations clear to developers, and streamline the training of involved professionals.

The development of a watershed-based GSI guide would put in place documented mechanisms of collaboration that could be critical in responding to future threats and challenges. The global struggle with water security (including in Cape Town, South Africa) is a reminder that cooperation within a watershed may be the key to continued urban habitation.

The incorporation of GSI into the public right-of-way in and along streets, which was not addressed in this thesis, would be best handled through a watershed-based guide. There are many uses and functions that coexist in the right of way; adding GSI to this list requires detailed and nuanced negotiation of physical and jurisdictional overlaps.

These are a few additional topics that would need to be agreed upon by all permittees for the development of a guide:

- Methods of practice, including a protocol for assessing flood risk reduction provided by GSI features
- Precise costs for material, construction, and maintenance
- Standard specifications and details

The cost of GSI is always a primary consideration. This thesis addresses cost in a general sense, but precise information on the costs of installation and maintenance are locally-specific. In addition to upfront costs, there are many methods by which to conduct analyses of cost-benefit and return on investment. The City of Philadelphia found support for widespread use of GSI by emphasizing the 'Triple Bottom Line' method, that is, including economic, social, and environmental benefits in the evaluation of GSI. While these calculations are important, it is equally important to consider the future economic consequences of a failure to act. In coastal areas, such as New York City and Boston, severe storms and sea level rise have driven increased interest in GSI as a way to keep cities and towns habitable, not only because GSI is cost-effective. In the Western United States, water scarcity, fire, flooding, and erosion threaten cities and towns. The upfront cost of addressing these threats may be inconsequential compared to the ultimate cost of procrastination.

Like any large-scale change, investment is needed to demonstrate new ways of doing things. Involved professionals (landscape architects and designers, architects, engineers, planners, hydrologists, contractors, developers, etc), regulatory personnel, maintenance crews, and inspectors would all need training in GSI. This training would involve not only changes in process and practice, but also a shift in paradigm from uni-functional infrastructure to multi-functional infrastructure, and from discrete objectives to broad consideration of an entire system.

The importance of cooperation in water management in New Mexico is not new. Indigenous Pueblo people have engaged in this practice for millennia. Today, the Pueblos are leaders in acting on ecological imperative — they donate water rights to keep the river flowing, and fund much of the conservation and research work that is needed for watershed health. Five hundred years ago, Spanish settlers began practicing local, water-focused governance centered around acequias. Today, acequia communities continue to facilitate water management and education across property lines. The unique cultures of New Mexico have provided and continue to be a source of critical values, actions, and information that could strengthen the widespread practice of GSI.

The practice of GSI could be further improved and grounded in place through the development of a regional GSI aesthetic. The materials used in GSI, namely plants, mulch, and rocks, can be placed in a haphazard way, or in a way that emphasizes their visibility, function, and experience through deliberate juxtaposition of soft materials adjacent to hardscape. Developing a regional aesthetic would increase public buy-in and help create a MRG-specific GSI identity.

A few components of GSI practice in the Albuquerque area could be easily and immediately improved. Very few GSI features built in the last 5 years have pretreatment areas or devices. This means that features are likely to clog with sediment and trash, and infiltration rates will eventually decline. Use of pretreatment devices, combined with regular removal of collected sediment and trash, is fundamental to the long-term performance of GSI practices.

Many existing GSI features in Albuquerque do not include plants. Lack of vegetation in GSI features, such as in rock swales, jeopardizes the long-term infiltration rates of the structure, decreases pollutant filtration ability, and is a missed opportunity to provide much-needed shade, habitat, and aesthetic improvement. While plants do require irrigation for establishment and some maintenance, they are a critical part of the function and benefit of GSI practice.

There are still aspects of GSI that are not well understood in semi-arid climates, such as the potential contamination of groundwater by infiltrated stormwater (Lee and Fisher 2016). Monitoring and documentation of new and existing projects in the MRG Valley could contribute to a better understanding of GSI, while also countering the skepticism regarding the effectiveness of GSI in semi-arid climates. As mentioned in the section on parking lots, documentation and signage are also critical for communicating the function of GSI features that could be mistaken for aesthetic rather than infrastructural projects, and mistakenly destroyed.

Whether through the creation of a GSI LID manual for the entire watershed, or through continued efforts by organizations and individuals, the expanded practice of GSI depends on a weaving together of many strands: unique climatic, cultural, legal, and regulatory factors, expertise from a multitude of professions and traditions, and relevant knowledge from other semi-arid places. The creation of this web must find a working balance between the inherent complexity of GSI and the standardization that is a reality of governmental systems. This infrastructure system can only grow from human connections. GSI is a method to revive the land by reconnecting it with water, but also requires people to connect to the land and to each other.

Figure 50: Bioinfiltration Basin, Tucson (photo by author)

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Appendix A:
Tree and Shrub Lists By Transect

WEST MESA

Botanical Name	Common Name	Mature Size (Height x Spread)	Biome			
			Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
TREES						
Acacia syn Senegalia greggii	Catclaw acacia	10' x15'	X	X	X	X
Celtis laevigata/reticulata	Netleaf/Canyon hackberry	25' x 25'	X	X	X	X
Cercis mexicana	Mexican redbud	20' x 15'	X	X		X
Chilopsis linearis	Desert willow	20' x 25'	X	X	X	X
Crataegus ambigua	Russian hawthorn	15' x 20'	X			X
Juniperus monosperma	One-seed juniper	15' x 20'		X	X	
Pinus eldarica	Afghan pine	40' x 20'	X	X		
Pinus pinea	Italian stone pine	60' x 50'	X			
Pistacia chinensis	Chinese pistache	40' x 20'	X			X
Prosopis glandulosa	Honey mesquite	25' x 30'	X	X	X	X
Prosopis pubescens	Screwbean mesquite	20' x 20'	X	X	X	X
Quercus fusiformis	Escarpment live oak	25' x 30'	X			X
Rhus lanceolata	Praire flameleaf sumac	15' x 20'	X			X
Robinia pseudoacacia	Black locust	40' x 25'	X	X	X	X
Sapindus saponaria var. drummondii	Western soapberry	30' x 30'	X			X
Ulmus parvifolia (and	Lacebark elm	40' x 30'	X			X
Vitex agnus castus	Chaste tree	20' x 20'	X			X
Zyzyphus jujuba	Jujube	25' x 25'	X	X	X	X

More testing is needed on *Gymnocladus dioica* (questionable drought tolerance) and *Ulmus propinqua* (potentially invasive).

Several additional trees were considered for this list and not included because of concerns with heat and/or drought tolerance: *Celtis*

Botanical Name	Common Name	Mature Size (Height x Spread)	Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
SHRUBS						
Anisacanthus wrightii	Desert honeysuckle	5' x 4'	X	X	X	X
Arctostaphylos x coloradoensis	Chieftain or Panchito manzanita	2' x 4'	X	X	X	
Artemisia filifolia	Sand sage	4' x 4'	X	X	X	
Artemisia frigida	Fringed sage	1' x 1'	X	X	X	
Atriplex canescens	Four-winged saltbush	5' x 7'			X	X
Baccharis salicifolia	Seep willow/ mulefat	8' x 6'	X			X

	Bioinfiltration Zone			Wildlife		Evergreen/ Semi-	Notes
	Inundation	Transition	High Ground	Pollinator	Bird		
	X	X		X	X		Fast grower, good barrier plant
	X	X		X	X		Small red fruits in fall
	X	X		X			Bright pink blooms in early spring
		X	X	X	X		Blooms summer and fall
	X			X	X		
		X	X		X	E	Only use female of species
		X			X	E	
		X			X	E	
	X	X			X		
	X	X	X	X	X		Yellow flowers in summer
	X	X	X	X	X		
	X	X		X	X	E	Texas native
	X			X	X		White flowers in summer, good fall color, fast growing, can form thickets
	X	X		X	X		White flowers in late spring, fixes nitrogen
	X	X		X			Slow grower, white flowers in summer followed by inedible yellow berries
	X	X		X	X		Non-invasive, elm beetle resistant
	X	X		X			
	X	X	X	X	X		Thicket-forming barrier plant

occidentalis, Gleditsia triacanthos, Juglans major and nigra, Prunus cistena, Quercus buckleyi.

	X	X		X	X		bright red/orange flowers in early summer and when well watered
		X		X	X	E	Requires good drainage
		X	X		X	E	Requires good drainage, only give one year establishment irrigation
	X	X	X		X	E	Establishes well from seed
			X		X	E	Allergen-producing, use sparingly, will reseed, salt tolerant
	X	X		X		SE	sticky foliage, pinkish flowers

Botanical Name	Common Name	Mature Size (Height x Spread)	Biome			
			Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
Buddleia marrubifolia	Wooly butterfly bush	4' x 4'	X	X	X	X
Caesalpinia giliesii	Yellow bird of paradise	5' x 5'	X	X	X	X
Caryopteris x clandonensis	Blue mist spirea	4' x 4'	X	X	X	X
Cercocarpus breviflorus	Hairy mountain mahogany	10' x 8'	X	X		X
Cercocarpus ledifolius	Curlleaf mountain mahogany	10' x 12'	X	X		X
Chamaebatiaria millefolium	Fernbush	6' x 8'	X	X	X	X
Chrysactinia mexicana	Damianita	1' x 2'		X	X	
Dalea frutescens	Black dalea	2' x 4'	X	X	X	X
Ephedra nevadensis	Nevada jointfir	4' x 4'	X	X	X	
Ephedra viridis	Green ephedra	5' x 5'	X	X	X	
Ericameria larcifolia	Turpentine bush	3' x 4'	X	X	X	
Ericameria nauseosa	Chamisa/ Rabbitbrush	5' x 8'	X	X	X	
Eriogonum fasciculatum	Flat-top buckwheat	1' x 2'	X	X	X	
Eriogonum wrightii	Wright's buckwheat	1' x 2'	X	X	X	
Fallugia paradoxa	Apache plume	6' x 7'	X	X	X	X
Forestiera neomexicana	New Mexico olive	12' x 12'	X	X		X
Larrea tridentata	Creosote bush	6' x 8'	X	X	X	
Lycium andersonii	Anderson wolfberry	6' x 6'	X	X	X	X
Mahonia haematocarpa	Red mahonia/ barberry	6' x 5'	X	X	X	X
Parryella filifolia	Dune broom	3' x 4'		X	X	
Prunus americana	Wild plum	10' x 10'	X			X
Prunus besseyi	Western sand cherry	5' x 5'	X	X	X	X
Prunus virginiana var melanocarpa	Western choke cherry	10' x 10'	X	X		X
Purshia mexicana	Cliff rose	8' x 8'	X	X	X	
Rhus microphylla	Littleleaf sumac	8' x 9'	X	X	X	X
Rhus trilobata	Three leaf sumac	6' x 6'	X	X	X	X
Salvia chamaedryoides	Mexican blue sage	1' x 2'	X	X		
Salvia greggii	Autumn or Cherry sage	2' x 3'	X	X	X	X
Vauquelinia californica ssp	Arizona rosewood	12' x 10'	X	X		

	Bioinfiltration Zone			Wildlife		Evergreen/ Semi-	Notes
	Inundation	Transition	High Ground	Pollinator	Bird		
	possible	X		X	X	SE	
		X	X	X	X		
	X	X		X			
		X		X	X	E	Slow growing
		X		X	X	E	Slow growing
	X	X		X	X		
		X	X	X		E	
	X	X		X			
		X	X	X	X	E	
		X	X	X	X	E	
	X	X	X	X		E	Yellow flowers in fall
		X	X	X	X	E	Use sparingly, flowers have foul odor
		X	X	X	X		
		X	X	X	X		
	X	X	X	X	X	SE	
	X	X		X	X		
		X	X	X	X	E	Yellow flowers in spring and winter
	X	X	X	X	X	E	Salt tolerant
	X	X	X	X	X	E	Yellow flowers in spring followed by red berries
		X	X	X	X		Slope stabilizer, easy to grow from seed, not currently available but easy to propogate
	X			X	X		
		X	X	X	X		
	X			X	X		Local provenance critical
		X	X	X	X	E	Fragrant
	X	X	X	X	X		
	X	X	X	X	X		
		X		X		SE	Does well in clay
	X	X		X	X	SE	Brittle
	X	X	X	X	X	E	Does well with high winds

VALLEY

Botanical Name	Common Name	Mature Size (Height x Spread)	Biome			
			Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
TREES						
Acacia syn Senegalia greggii	Catclaw acacia	10' x15'	X	X	X	X
Celtis laevigata/reticulata	Netleaf/Canyon hackberry	25' x 25'	X	X	X	X
Cercis mexicana	Mexican redbud	20' x 15'	X	X		X
Chilopsis linearis	Desert willow	20' x 25'	X	X	X	X
Crataegus ambigua	Russian hawthorn	15' x 20'	X			X
Juniperus monosperma	One-seed juniper	15' x 20'		X	X	
Pinus eldarica	Afghan pine	40' x 20'	X	X		
Pinus pinea	Italian stone pine	60' x 50'	X			
Pistacia chinensis	Chinese pistache	40' x 20'	X			X
Populus deltoides var. wislizeni	Rio Grande cottonwood	50' x 60'				X
Prosopis glandulosa	Honey mesquite	25' x 30'	X	X	X	X
Prosopis pubescens	Screwbean mesquite	20' x 20'	X	X	X	X
Quercus fusiformis	Escarpment live oak	25' x 30'	X			X
Quercus gambelii	Gambel oak	25' x 25'	X			X
Quercus muhlenbergii	Chinquapin oak	40' x 50'	X			X
Rhus lanceolata	Praire flameleaf sumac	15' x 20'	X			X
Robinia pseudoacacia	Black locust	40' x 25'	X	X	X	X
Sapindus saponaria var. drummondii	Western soapberry	30' x 30'	X			X
Styphnolobium japonicum	Japanese pagoda tree	35' x 25'	X			X
Ulmus parvifolia (and	Lacebark elm	40' x 30'	X			X
Vitex agnus castus	Chaste tree	20' x 20'	X			X
Zyzyphus jujuba	Jujube	25' x 25'	X	X	X	X

More testing is needed on *Gymnocladus dioica* (questionable drought tolerance) and *Ulmus propinqua* (potentially invasive).

Several additional trees were considered for this list and not included because of concerns with heat and/or drought tolerance: *Celtis*

Botanical Name	Common Name	Mature Size (Height x Spread)	Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
SHRUBS						
Amorpha fruticosa	False indigo	10' x 10'	X			X
Anisacanthus wrightii	Desert honeysuckle	5' x 4'	X	X	X	X

	Bioinfiltration Zone			Wildlife		Evergreen/ Semi-	Notes
	Inundation	Transition	High Ground	Pollinator	Bird		
	X	X		X	X		Fast grower, good barrier plant
	X	X		X	X		Small red fruits in fall
	X	X		X			Bright pink blooms in early spring
		X	X	X	X		Blooms summer and fall
	X			X	X		
		X	X		X	E	Only use female of species
		X			X	E	
		X			X	E	
	X	X			X		
	X	X		X	X		Premier wildlife habitat
	X	X	X	X	X		Yellow flowers in summer
	X	X	X	X	X		
	X	X		X	X	E	Texas native
	X	X		X	X		
	X	X		X	X		Texas native
	X			X	X		White flowers in summer, good fall color, fast growing, can form thickets
	X	X		X	X		White flowers in late spring, fixes nitrogen
	X	X		X			Slow grower, white flowers in summer followed by inedible yellow berries
	X	X			X		White flowers in summer
	X	X		X	X		Non-invasive, elm beetle resistant
	X	X		X			
	X	X	X	X	X		Thicket-forming barrier plant

occidentalis, Gleditsia triacanthos, Juglans major and nigra, Prunus cistena, Quercus buckleyi.

		X		X			Dark purple/orange flowers
	X	X		X	X		Bright red/orange flowers in early summer and when well watered

Botanical Name	Common Name	Mature Size (Height x Spread)	Biome			
			Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
Arctostaphylos x coloradoensis	Chieftain or Panchito manzanita	2' x 4'	X	X	X	
Artemisia filifolia	Sand sage	4' x 4'	X	X	X	
Artemisia frigida	Fringed sage	1' x 1'	X	X	X	
Atriplex canescens	Four-winged saltbush	5' x 7'			X	X
Baccharis salicifolia	Seep willow/ Mulefat	8' x 6'	X			X
Buddleia marrubifolia	Wooly butterfly bush	4' x 4'	X	X	X	X
Caesalpinia giliesii	Yellow bird of paradise	5' x 5'	X	X	X	X
Caryopteris x clandonensis	Blue mist spirea	4' x 4'	X	X	X	X
Cercocarpus breviflorus	Hairy mountain mahogany	10' x 8'	X	X		X
Cercocarpus ledifolius	Curlleaf mountain mahogany	10' x 12'	X	X		X
Chamaebatiaria millefolium	Fernbush	6' x 8'	X	X	X	X
Chrysactinia mexicana	Damianita	1' x 2'		X	X	
Dalea frutescens	Black dalea	2' x 4'	X	X	X	X
Ephedra nevadensis	Nevada jointfir	4' x 4'	X	X	X	
Ephedra viridis	Green ephedra	5' x 5'	X	X	X	
Ericameria larcifolia	Turpentine bush	3' x 4'	X	X	X	
Ericameria nauseosa	Chamisa/ Rabbitbrush	5' x 8'	X	X	X	
Eriogonum fasciculatum	Flat-top buckwheat	1' x 2'	X	X	X	
Eriogonum wrightii	Wright's buckwheat	1' x 2'	X	X	X	
Fallugia paradoxa	Apache plume	6' x 7'	X	X	X	X
Forestiera neomexicana	New Mexico olive	12' x 12'	X	X		X
Larrea tridentata	Creosote bush	6' x 8'	X	X	X	
Lycium andersonii	Anderson wolfberry	6' x 6'	X	X	X	X
Mahonia haematocarpa	Red mahonia/ barberry	6' x 5'	X	X	X	X
Prunus americana	Wild plum	10' x 10'	X			X
Prunus besseyi	Western sand cherry	5' x 5'	X	X	X	X
Prunus virginiana var melanocarpa	Western choke cherry	10' x 10'	X	X		X
Purshia mexicana	Cliff rose	8' x 8'	X	X	X	

	Bioinfiltration Zone			Wildlife		Evergreen/ Semi-	Notes
	Inundation	Transition	High Ground	Pollinator	Bird		
		X		X	X	E	Requires good drainage
		X	X		X	E	Requires good drainage, only give one year establishment irrigation
	X	X	X		X	E	Establishes well from seed
			X		X	E	Allergen-producing, use sparingly, will reseed, salt tolerant
	X	X		X		SE	Sticky foliage, pinkish flowers
	possible	X		X	X	SE	
		X	X	X	X		
	X	X		X			
		X		X	X	E	Slow growing
		X		X	X	E	Slow growing
	X	X		X	X		
		X	X	X		E	
	X	X		X			
		X	X	X	X	E	
		X	X	X	X	E	
	X	X	X	X		E	Yellow flowers in fall
		X	X	X	X	E	Use sparingly, flowers have foul odor
		X	X	X	X		
		X	X	X	X		
	X	X	X	X	X	SE	
	X	X		X	X		
		X	X	X	X	E	Yellow flowers in spring and winter
	X	X	X	X	X	E	Salt tolerant
	X	X	X	X	X	E	Yellow flowers in spring followed by red berries
	X	X		X	X		
		X	X	X	X		
	X	X		X	X		Local provenance critical
		X	X	X	X	E	Fragrant

EAST MESA

Botanical Name	Common Name	Mature Size (Height x Spread)	Biome			
			Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
TREES						
Acacia syn Senegalia greggii	Catclaw acacia	10' x 15'	X	X	X	X
Celtis laevigata/reticulata	Netleaf/ Canyon hackberry	25' x 25'	X	X	X	X
Cercis mexicana	Mexican redbud	20' x 15'	X	X		X
Chilopsis linearis	Desert willow	20' x 25'	X	X	X	X
Crataegus ambigua	Russian hawthorn	15' x 20'	X			X
Juniperus monosperma	One-seed juniper	15' x 20'		X	X	
Pinus eldarica	Afghan pine	40' x 20'	X	possible		
Pinus pinea	Italian stone pine	60' x 50'	X			
Pistacia chinensis	Chinese pistache	40' x 20'	X			X
Prosopis glandulosa	Honey mesquite	25' x 30'	X	X	X	X
Prosopis pubescens	Screwbean mesquite	20' x 20'	X	X	X	X
Quercus fusiformis	Escarpment live oak	25' x 30'	X			X
Quercus muhlenbergii	Chinquapin oak	40' x 50'	X			X
Rhus lanceolata	Praire flameleaf sumac	15' x 20'	X			X
Robinia pseudoacacia	Black locust	40' x 25'	X	X	X	X
Sapindus saponaria var. drummondii	Western soapberry	30' x 30'	X			X
Ulmus parvifolia (and hybrids)	Lacebark elm	40' x 30'	X			X
Vitex agnus castus	Chaste tree	20' x 20'	X			X
Zyzyphus jujuba	Jujube	25' x 25'	X	X	X	X
More testing is needed on *Gymnocladus dioica* (questionable drought tolerance) and *Ulmus propinqua* (potentially invasive).						
Several additional trees were considered for this list and not included because of concerns with heat and/or drought tolerance: *Celtis oc*						
SHRUBS						
Anisacanthus wrightii	Desert honeysuckle	5' x 4'	X	X	X	X
Arctostaphylos x coloradoensis	Chieftain or Panchito manzanita	2' x 4'	X	X	X	
Artemisia filifolia	Sand sage	4' x 4'	X	X	X	
Artemisia frigida	Fringed sage	1' x 1'	X	X	X	
Atriplex canescens	Four-winged saltbush	5' x 7'			X	X
Baccharis salicifolia	Seep willow/ Mulefat	8' x 6'	X			X
Buddleia marrubifolia	Wooly butterfly bush	4' x 4'	X	X	X	X

Bioinfiltration Zone			Wildlife		Evergreen/ Semi	Notes
Inundation	Transition	High Ground	Pollinator	Bird		
X	X		X	X		Fast grower, good barrier plant
X	X		X	X		Small red fruits in fall
X	X		X			Bright pink blooms in early spring
	X	X	X	X		Blooms summer and fall
X			X	X		
	X	X		X	E	Only use female of species
	X			X	E	
	X			X	E	
X	X			X		
X	X	X	X	X		Yellow flowers in summer
X	X	X	X	X		
X	X		X	X	E	Texas native
X	X		X	X		Texas native
X			X	X		White flowers in summer, good fall color, fast growing, can form thickets
X	X		X	X		White flowers in late spring, fixes nitrogen
X	X		X			Slow grower, white flowers in summer followed by inedible yellow berries
X	X		X	X		Non-invasive, elm beetle resistant
X	X		X			
X	X	X	X	X		Thicket-forming barrier plant

cidentalis, Gleditsia triacanthos, Juglans major and nigra, Prunus cistena, Quercus buckleyi.

Inundation	Transition	High Ground	Pollinator	Bird	Evergreen/ Semi	Notes
X	X		X	X		Bright red/orange flowers in early summer and when well watered
	X		X	X	E	Requires good drainage
	X	X		X	E	Requires good drainage, only give one year establishment irrigation
X	X	X		X	E	Establishes well from seed
		X		X	E	Allergen-producing, use sparingly, will reseed, salt tolerant
X	X		X		SE	Sticky foliage, pinkish flowers
possible	X		X	X	SE	

Botanical Name	Common Name	Mature Size (Height x Spread)	Biome			
			Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
Caesalpinia giliesii	Yellow Bird of Paradise	5' x 5'	X	X	X	X
Caryopteris x clandonensis	Blue Mist Spirea	4' x 4'	X	X	X	X
Cercocarpus breviflorus	Hairy mountain mahogany	10' x 8'	X	X		X
Cercocarpus ledifolius	Curlleaf mountain mahogany	10' x 12'	X	X		X
Chamaebatiaria millefolium	Fernbush	6' x 8'	X	X	X	X
Chrysactinia mexicana	Damianita	1' x 2'		X	X	
Dalea frutescens	Black dalea	2' x 4'	X	X	X	X
Ephedra nevadensis	Nevada jointfir	4' x 4'	X	X	X	
Ephedra viridis	Green ephedra	5 x 5'	X	X	X	
Ericameria larcifolia	Turpentine bush	3' x 4'	X	X	X	
Ericameria nauseosa	Chamisa/ Rabbitbrush	5' x 8'	X	X	X	
Eriogonum fasciculatum	Flat-top buckwheat	1' x 2'	X	X	X	
Eriogonum wrightii	Wright's buckwheat	1' x 2'	X	X	X	
Fallugia paradoxa	Apache plume	6' x 7'	X	X	X	X
Forestiera neomexicana	New Mexico olive	12' x 12'	X	X		X
Larrea tridentata	Creosote bush	6' x 8'	X	X	X	
Lycium andersonii	Anderson wolfberry	6' x 6'	X	X	X	X
Mahonia haematocarpa	Red mahonia/ barberry	6' x 5'	X	X	X	X
Parryella filifolia	Dune broom	3' x 4'		X	X	
Prunus besseyi	Western sand cherry	5' x 5'	X	X	X	X
Prunus virginiana var melanocarpa	Western choke cherry	10' x 10'	X	X		X
Purshia mexicana	Cliff rose	8' x 8'	X	X	X	
Rhus glabra cismontana	Compact smooth sumac	5' x 7'	X	X		X
Rhus microphylla	Littleleaf sumac	8' x 9'	X	X	X	X
Rhus trilobata	Three leaf sumac	6' x 6'	X	X	X	X
Salvia chamaedryoides	Mexican blue sage	1' x 2'	X	X		
Salvia greggii	Autumn or Cherry sage	2' x 3'	X	X	X	X
Vauquelinia californica ssp	Arizona rosewood	12' x 10'	X	X		

	Bioinfiltration Zone			Wildlife		Evergreen/ Semi	Notes
	Inundation	Transition	High Ground	Pollinator	Bird		
		X	X	X	X		
	X	X		X			
		X		X	X	E	Slow growing
		X		X	X	E	Slow growing
	X	X		X	X		
		X	X	X		E	
	X	X		X			
		X	X	X	X	E	
		X	X	X	X	E	
	X	X	X	X		E	Yellow flowers in fall
		X	X	X	X	E	Use sparingly, flowers have foul odor
		X	X	X	X		
		X	X	X	X		
	X	X	X	X	X	SE	
	X	X		X	X		
		X	X	X	X	E	Yellow flowers in spring and winter
	X	X	X	X	X	E	Salt tolerant
	X	X	X	X	X	E	Yellow flowers in spring followed by red berries
		X	X	X	X		Slope stabilizer, easy to grow from seed, not currently available but easy to propogate
		X	X	X	X		
	X			X	X		Local provenance critical
		X	X	X	X	E	Fragrant
	X	X		X	X		Soil stabilizer
	X	X	X	X	X		
	X	X	X	X	X		
		X		X		SE	Does well in clay
	X	X		X	X	SE	Brittle
	X	X	X	X	X	E	Does well with high winds

FOOTHILLS

Botanical Name	Common Name	Mature Size (Height x Spread)	Biome			
			Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
T R E E S						
Celtis laevigata/reticulata	Netleaf/Canyon hackberry	25' x 25'	X	X	X	X
Cercis mexicana	Mexican redbud	20' x 15'	X	X		X
Chilopsis linearis	Desert willow	20' x 25'	X	X	X	X
Crataegus ambigua	Russian hawthorn	15' x 20'	X			X
Juniperus monosperma	One-seed juniper	15' x 20'		X	X	
Pinus eldarica	Afghan pine	40' x 20'	X	possible		
Pinus pinea	Italian stone pine	60' x 50'	X			
Pistacia chinensis	Chinese pistache	40' x 20'	X			X
Prosopis glandulosa	Honey mesquite	25' x 30'	X	X	X	X
Prosopis pubescens	Screwbean mesquite	20' x 20'	X	X	X	X
Quercus fusiformis	Escarpment live oak	25' x 30'	X			X
Quercus gambelii	Gambel oak	25' x 25'	X			X
Quercus muhlenbergii	Chinquapin oak	40' x 50'	X			X
Quercus turbinella	Scrub live oak	18' x 20'	X			X
Rhus lanceolata	Praire flameleaf sumac	15' x 20'	X			X
Robinia pseudoacacia	Black locust	40' x 25'	X	X	X	X
Sapindus saponaria var. drummondii	Western soapberry	30' x 30'	X			X
Ulmus parvifolia (and	Lacebark elm	40' x 30'	X			X
Vitex agnus castus	Chaste tree	20' x 20'	X			X
Zyzyphus jujuba	Jujube	25' x 25'	X	X	X	X

More testing is needed on *Gymnocladus dioica* (questionable drought tolerance) and *Ulmus propinqua* (potentially invasive).

Several additional trees were considered for this list and not included because of concerns with heat and/or drought tolerance: *Celtis o*

Botanical Name	Common Name	Mature Size (Height x Spread)	Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
S H R U B S						
Amorpha fruticosa	False indigo	10' x 10'	X			X
Anisacanthus wrightii	Desert honeysuckle	5' x 4'	X	X	X	X
Arctostaphylos x coloradoensis	Chieftain or Panchito manzanita	2' x 4'	X	X	X	
Artemisia filifolia	Sand sage	4' x 4'	X	X	X	
Artemisia frigida	Fringed sage	1' x 1'	X	X	X	

Bioinfiltration Zone			Wildlife		Evergreen/ Semi-	Notes
Inundation	Transition	High Ground	Pollinator	Bird		
X	X		X	X		Small red fruits in fall
X	X		X			Bright pink blooms in early spring
	X	X	X	X		Blooms summer and fall
X			X	X		
	X	X		X	E	Only use female of species
	X			X	E	
	X			X	E	
X	X			X		
X	X	X	X	X		Yellow flowers in summer
X	X	X	X	X		
X	X		X	X	E	Texas native
X	X		X	X		
X	X		X	X		Texas native
X	X		X	X	E	
X			X	X		White flowers in summer, good fall color, fast growing, can form thickets
X	X		X	X		White flowers in late spring, fixes nitrogen
X	X		X			Slow grower, white flowers in summer followed by inedible yellow berries
X	X		X	X		Non-invasive, elm beetle resistant
X	X		X			
X	X	X	X	X		Thicket-forming barrier plant

ccidentalis, Gleditsia triacanthos, Juglans major and nigra, Prunus cistena, Quercus buckleyi.

	X		X			Dark purple/orange flowers
X	X		X	X		Bright red/orange flowers in early summer and when well watered
	X	X	X	X	E	Requires good drainage
	X	X		X	E	Requires good drainage, only give one year establishment irrigation
X	X	X		X	E	Establishes well from seed

Botanical Name	Common Name	Mature Size (Height x Spread)	Biome			
			Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
Atriplex canescens	Four-winged saltbush	5' x 7'			X	X
Baccharis salicifolia	Seep willow/ Mulefat	8' x 6'	X			X
Buddleia marrubifolia	Wooly butterfly bush	4' x 4'	X	X	X	X
Caesalpinia giliesii	Yellow bird of paradise	5' x 5'	X	X	X	X
Caryopteris x clandonensis	Blue mist spirea	4' x 4'	X	X	X	X
Cercocarpus breviflorus	Hairy mountain mahogany	10' x 8'	X	X		X
Cercocarpus ledifolius	Curlleaf mountain mahogany	10' x 12'	X	X		X
Chamaebatiaria millefolium	Fernbush	6' x 8'	X	X	X	X
Chrysactinia mexicana	Damianita	1' x 2'		X	X	
Dalea frutescens	Black dalea	2' x 4'	X	X	X	X
Ephedra nevadensis	Nevada jointfir	4' x 4'	X	X	X	
Ephedra viridis	Green ephedra	5' x 5'	X	X	X	
Ericameria larcifolia	Turpentine bush	3' x 4'	X	X	X	
Ericameria nauseosa	Chamisa/ Rabbitbrush	5' x 8'	X	X	X	
Eriogonum fasciculatum	Flat-top buckwheat	1' x 2'	X	X	X	
Eriogonum wrightii	Wright's buckwheat	1' x 2'	X	X	X	
Fallugia paradoxa	Apache plume	6' x 7'	X	X	X	X
Forestiera neomexicana	New Mexico olive	12' x 12'	X	X		X
Larrea tridentata	Creosote bush	6' x 8'	X	X	X	
Lycium andersonii	Anderson wolfberry	6' x 6'	X	X	X	X
Mahonia haematocarpa	Red mahonia/ barberry	6' x 5'	X	X	X	X
Parryella filifolia	Dune broom	3' x 4'		X	X	
Prunus americana	Wild plum	10' x 10'	X			X
Prunus besseyi	Western sand cherry	5' x 5'	X	X	X	X
Prunus virginiana var melanocarpa	Western choke cherry	10' x 10'	X	X		X
Purshia mexicana	Cliff rose	8' x 8'	X	X	X	
Rhus glabra cismontana	Compact smooth sumac	5' x 7'	X	X		X
Rhus microphylla	Littleleaf sumac	8' x 9'	X	X	X	X

	Bioinfiltration Zone			Wildlife		Evergreen/ Semi-	Notes
	Inundation	Transition	High Ground	Pollinator	Bird		
			X		X	E	Allergen-producing, use sparingly, will reseed, salt tolerant
	X	X		X		SE	Sticky foliage, pinkish flowers
	possible	X		X	X	SE	
		X	X	X	X		
	X	X		X			
		X	X	X	X	E	Slow growing
		X	X	X	X	E	Slow growing
	X	X		X	X		
		X	X	X		E	
	X	X		X			
		X	X	X	X	E	
		X	X	X	X	E	
	X	X	X	X		E	Yellow flowers in fall
		X	X	X	X	E	Use sparingly, flowers have foul odor
		X	X	X	X		
		X	X	X	X		
	X	X	X	X	X	SE	
	X	X		X	X		
		X	X	X	X	E	Yellow flowers in spring and winter
	X	X	X	X	X	E	Salt tolerant
	X	X	X	X	X	E	Yellow flowers in spring followed by red berries
		X	X	X	X		Slope stabilizer, easy to grow from seed, not currently available but easy to propogate
	X	X		X	X		
		X	X	X	X		
	X			X	X		Local provenance critical
		X	X	X	X	E	Fragrant
	X	X		X	X		Soil stabilizer
	X	X	X	X	X		

EAST MOUNTAINS

Botanical Name	Common Name	Mature Size (Height x Spread)	Biome			
			Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
TREES						
Celtis laevigata/reticulata	Netleaf/Canyon hackberry	25' x 25'	X	X	X	X
Cercis mexicana	Mexican redbud	20' x 15'	X	X		X
Juniperus monosperma	One-seed juniper	15' x 20'		X	X	
Pistacia chinensis	Chinese pistache	40' x 20'	X			X
Populus deltoides var. wislizeni	Rio Grande cottonwood	50' x 60'				X
Prosopis pubescens	Screwbean mesquite	20' x 20'	X	X	X	X
Quercus gambelii	Gambel oak	25' x 25'	X			X
Quercus muhlenbergii	Chinquapin oak	40' x 50'	X			X
Quercus turbinella	Scrub live oak	18' x 20'	X			X
Rhus lanceolata	Praire flameleaf sumac	15' x 20'	X			X
Robinia pseudoacacia	Black locust	40' x 25'	X	X	X	X
Sapindus saponaria var. drummondii	Western soapberry	30' x 30'	X			X
Styphnolobium japonicum	Japanese pagoda tree	35' x 25'	X			X
Ulmus parvifolia (and	Lacebark elm	40' x 30'	X			X
Zyzyphus jujuba	Jujube	25' x 25'	X	X	X	X

More testing is needed on *Gymnocladus dioica* (questionable drought tolerance) and *Ulmus propinqua* (potentially invasive).

Several additional trees were considered for this list and not included because of concerns with heat and/or drought tolerance: *Celtis o*

Botanical Name	Common Name	Mature Size (Height x Spread)	Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
SHRUBS						
Amorpha fruticosa	False indigo	10' x 10'	X			X
Arctostaphylos x coloradoensis	Chieftain or Panchito manzanita	2' x 4'	X	X	X	
Artemisia filifolia	Sand sage	4' x 4'	X	X	X	
Artemisia frigida	Fringed sage	1' x 1'	X	X	X	
Atriplex canescens	Four-winged saltbush	5' x 7'			X	X
Caryopteris x clandonensis	Blue mist spirea	4' x 4'	X	X	X	X
Cercocarpus breviflorus	Hairy mountain mahogany	10' x 8'	X	X		X

Bioinfiltration Zone			Wildlife		Evergreen/ Semi-	Notes
Inundation	Transition	High Ground	Pollinator	Bird		
X	X		X	X		Small red fruits in fall
X	X		X			Bright pink blooms in early spring
	X	X		X	E	Only use female of species
X	X			X		
X	X		X	X		Premier wildlife habitat
X	X	X	X	X		
X	X		X	X		
X	X		X	X		Texas native
X	X		X	X	E	
X			X	X		White flowers in summer, good fall color, fast growing, can form thickets
X	X		X	X		White flowers in late spring, fixes nitrogen
X	X		X			Slow grower, white flowers in summer followed by inedible yellow berries
X	X			X		White flowers in summer
X	X		X	X		Non-invasive, elm beetle resistant
X	X	X	X	X		Thicket-forming barrier plant
ccidentalis, Gleditsia triacanthos, Juglans major and nigra, Prunus cistena, Quercus buckleyi.						
	X		X			Dark purple/orange flowers
	X	X	X	X	E	Requires good drainage
	X	X		X	E	Requires good drainage, only give one year establishment irrigation
X	X	X		X	E	Establishes well from seed
		X		X	E	Allergen-producing, use sparingly, will reseed, salt tolerant
X	X		X			
	X	X	X	X	E	Slow growing

Botanical Name	Common Name	Mature Size (Height x Spread)	Biome			
			Urban Ephemeral Riparian	Urban Grassland/ Shrubland	Shrub Desert Grassland	Riparian
Caesalpinia giliesii	Yellow Bird of Paradise	5' x 5'	X	X	X	X
Caryopteris x clandonensis	Blue Mist Spirea	4' x 4'	X	X	X	X
Cercocarpus breviflorus	Hairy mountain mahogany	10' x 8'	X	X		X
Cercocarpus ledifolius	Curlleaf mountain mahogany	10' x 12'	X	X		X
Chamaebatiaria millefolium	Fernbush	6' x 8'	X	X	X	X
Chrysactinia mexicana	Damianita	1' x 2'		X	X	
Dalea frutescens	Black dalea	2' x 4'	X	X	X	X
Ephedra nevadensis	Nevada jointfir	4' x 4'	X	X	X	
Ephedra viridis	Green ephedra	5 x 5'	X	X	X	
Ericameria larcifolia	Turpentine bush	3' x 4'	X	X	X	
Ericameria nauseosa	Chamisa/ Rabbitbrush	5' x 8'	X	X	X	
Eriogonum fasciculatum	Flat-top buckwheat	1' x 2'	X	X	X	
Eriogonum wrightii	Wright's buckwheat	1' x 2'	X	X	X	
Fallugia paradoxa	Apache plume	6' x 7'	X	X	X	X
Forestiera neomexicana	New Mexico olive	12' x 12'	X	X		X
Larrea tridentata	Creosote bush	6' x 8'	X	X	X	
Lycium andersonii	Anderson wolfberry	6' x 6'	X	X	X	X
Mahonia haematocarpa	Red mahonia/ barberry	6' x 5'	X	X	X	X
Parryella filifolia	Dune broom	3' x 4'		X	X	
Prunus besseyi	Western sand cherry	5' x 5'	X	X	X	X
Prunus virginiana var melanocarpa	Western choke cherry	10' x 10'	X	X		X
Purshia mexicana	Cliff rose	8' x 8'	X	X	X	
Rhus glabra cismontana	Compact smooth sumac	5' x 7'	X	X		X
Rhus microphylla	Littleleaf sumac	8' x 9'	X	X	X	X
Rhus trilobata	Three leaf sumac	6' x 6'	X	X	X	X
Salvia chamaedryoides	Mexican blue sage	1' x 2'	X	X		
Salvia greggii	Autumn or Cherry sage	2' x 3'	X	X	X	X
Vauquelinia californica ssp	Arizona rosewood	12' x 10'	X	X		

	Bioinfiltration Zone			Wildlife		Evergreen/ Semi	Notes
	Inundation	Transition	High Ground	Pollinator	Bird		
		X	X	X	X		
	X	X		X			
		X		X	X	E	Slow growing
		X		X	X	E	Slow growing
	X	X		X	X		
		X	X	X		E	
	X	X		X			
		X	X	X	X	E	
		X	X	X	X	E	
	X	X	X	X		E	Yellow flowers in fall
		X	X	X	X	E	Use sparingly, flowers have foul odor
		X	X	X	X		
		X	X	X	X		
	X	X	X	X	X	SE	
	X	X		X	X		
		X	X	X	X	E	Yellow flowers in spring and winter
	X	X	X	X	X	E	Salt tolerant
	X	X	X	X	X	E	Yellow flowers in spring followed by red berries
		X	X	X	X		Slope stabilizer, easy to grow from seed, not currently available but easy to propogate
		X	X	X	X		
	X			X	X		Local provenance critical
		X	X	X	X	E	Fragrant
	X	X		X	X		Soil stabilizer
	X	X	X	X	X		
	X	X	X	X	X		
		X		X		SE	Does well in clay
	X	X		X	X	SE	Brittle
	X	X	X	X	X	E	Does well with high winds

Appendix B:
Site Analysis and Planning Charts

Analysis	Planning
Development	
New development	Runoff from 90th percentile storm treated on-site, integrate stormwater management into every aspect of site planning
Redevelopment	Runoff from 80th percentile storm treated on site, creatively find ways to maximize bioinfiltration
Topography	
Slopes	Protect or avoid slopes over 3:1 if possible
Areas of erosion or deposition	Apply erosion control methods
Existing drainages	Keep natural on-site drainages if possible, stabilize if necessary
Low points	Ensure adequate infiltration at low points
Exposure to wind and sun	Select vegetation accordingly
Areas of shade	Consider potential ice formation
Hydrology	
Existing drainages	Keep existing drainages if possible
Flow from off-site	Keep water as high as possible
Dishcharge points	Spread flow to minimize erosion
Existing riparian or wetland areas	Protect these areas during construction
Contributing drainage area and land uses	Calculate water treatment volume, consider how runoff be directed to plants and trees
Flood control requirements	Calculate and providestorage needed (to drain within 96 hours)
Percent impervious surfaces	Consider how to break up or reduce areas of impervious surfaces
Percent vegetated surfaces	Consider how to increase vegetated area and use all vegetated areas for bioinfiltration
Nearby non-potable water source	Use non-potable water for irrigation, if available
Water Quality	
Type of land use and development	Select GSI practices that have demonstrated ability to treat pollutants in stormwater
Gas station, auto care, restaurant, industrial area	Additional requirements for treatment prior to discharge
Brownfield (heavily contaminated site)	Infiltration not recommended

Analysis	Planning
Vegetation	
Existing species and condition	Use for erosion control, protect during construction
Invasive species	Remove invasive species, including chipping or cutting for on-site reuse
Threatened or endangered species	Protect or transplant during construction
Mature trees and species	Make every effort to protect
Existing or potential microclimates	Select vegetation accordingly
Geotechnical	
Hydrologic group	If A or B, infiltration recommended, test imported and existing soils, protect from compaction
Infiltration rates	At least 0.3"/hour for infiltration
Depth to groundwater	At least 5' below basin for infiltration
Stability when saturated	If soil unstable, avoid infiltration
Areas of permeable soils	Protect during construction, use for infiltration
Areas of erodible soils	Stabilize all soils
Areas of stable but erodible soils	Protect during construction
Other geohazards	
Wildlife	
Existing species	Protect and expand habitat
Threatened or endangered species	See ESA requirements
Potential for wildlife corridor creation or connection	Consult Greenprint maps, provide habitat
Utilities	
Easements	Use caution when siting GSI in easements
Utility locations	Site trees and infiltration away from utilities
Location of nearby supply wells	Infiltration not recommended within 100' of supply well
Design standards	
Set-backs	
Minimum road widths	Use minimum widths to reduce impervious surfaces
Open space requirements	Combine open space and GSI
Historic buildings or landscapes	Respect historic areas
Landscape requirements	Incorporate landscape requirements into GSI

Analysis	Planning
Access and Circulation	
Existing ingress and egress	Ensure visibility if siting GSI near ingress and egress
Road classifications	Road classification affects right-of-way distances and possible space for GSI
Master plans affecting site	Incoporate GSI into master plan
Pedestrian access	Site GSI features to encourage pedestrian
Bike access	and bike use
Bernalillo County Greenprint Maps	
Potential for groundwater recharge	Prioritize infiltration
Conservation priority	Maximize pervious areas
Urban Heat Island severity	Prioritize trees if in an UHI area
Structures	
Location of building or wall foundations	Infiltration not recommended within 10' of building foundation
Building and wall heights	Consider potential shadows or microclimates
Building heating and cooling use	Consider possibility to reduce energy use through trees
Reflected heat from buldings or walls	Select vegetation accordingly, provide additional irrigation
Human Resouces	
Existing cultural resources	Protect and enhance cultural resources
Existing neighborhood or civic groups	Evaluate group interest in GSI maintenance
Important viewsheds	Protect viewsheds
Desired use (program)	Maxmize potential enjoyment/use