Stormwater Best Management Practices (BMPs) for Sturgis, SD

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1. Executive Summary

With recent development in Sturgis, SD, much of the land surface has become impervious, making the city susceptible to flooding. The businesses on Lazelle Street are an example of this. This increased urbanization is a concern because it leads to increased runoff, impacting water quantity and water quality. In particular, runoff can cause property damage, erode and pollute streams, and overload sewer systems. Furthermore, runoff can transmit environmentally harmful pollutants such as oil from cars and trucks; sand, gravel, and salt from snow operations; sediment from soil erosion; animal waste; and trash.

This guide's purpose will be to assist the city, landowners, and small businesses in selecting appropriate green infrastructure to reduce their contribution to urban runoff.

Many of the street examples are for cities of a larger size. However, some of the ideas can be incorporated into future projects.

2. Introduction

This chapter provides an overview of why stormwater management is important and an introduction to its solutions. We first discuss how urbanization increases runoff, the problems associated with flooding, and its relation to Sturgis, SD. Then, we discuss the differences between "gray" and "green" infrastructure and delve into the pros and cons of green infrastructure based on their environmental, economic, and community impacts.

2.1. Why Stormwater is Important

According to the Environmental Protection Agency, modifications to the land surface caused by man-made construction are the primary cause of stormwater runoff. Urbanization changes how water moves through the environment by the construction of impervious surfaces such as asphalt and concrete pavements, compaction of soil, and removal of vegetation. These changes reduce interception, evapotranspiration, and infiltration of water, resulting in higher runoff. Figure 2-1 shows how urbanization increases the percentage of impervious surfaces, reducing infiltration, and therefore increasing runoff (EPA, 2007).

The effect of increased runoff is an increase in frequency, duration, and severity of flooding. These changes to the rate and volume of runoff can cause changes to the geomorphology of streams, rivers, ravines, and drainage ways. Such changes include stream widening and bank erosion; degradation of the riparian zone of streams and rivers, which is vital to ecosystems; and an increase in the floodplain elevation, meaning areas that may have previously been considered safe are now at risk of flooding. ("Overview of basic stormwater concepts," Minnesota Stormwater Manual, 2020)

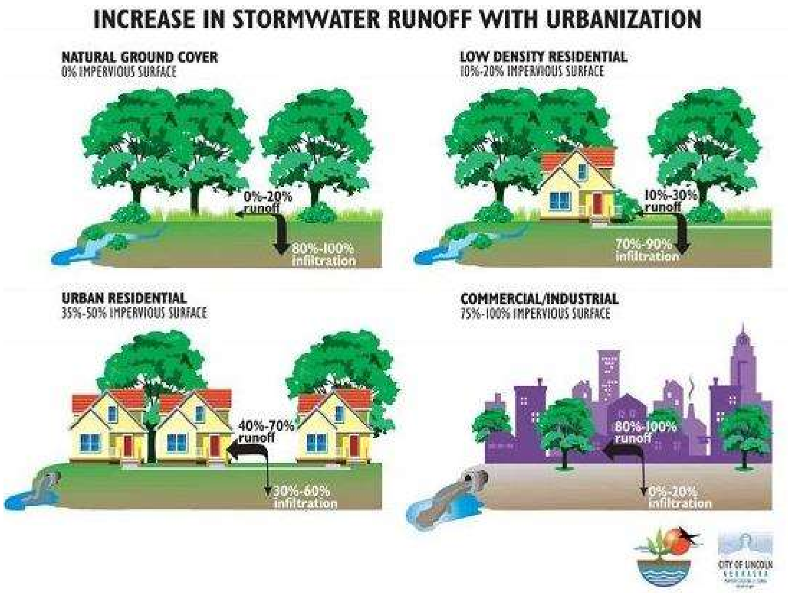

Figure 2-1: Urbanization increases stormwater runoff. (City of Lincoln, NE, 2020)

2.2. Urbanization and Flood Risk in Sturgis

According to the Federal Emergency Management Agency's (FEMA) National Flood Hazard Map, 20% of land inside Sturgis is located within a Special Flood Hazard Area, and a significant percentage is in the 100-year floodplain, as shown in Figure 2-2 below. The flood risk in Sturgis threatens economic and environmental damage in the form of property damage to citizens and business owners, pollution of streams, and degradation of stream channels. For solutions, flood risk can be mitigated with effective stormwater management by using a combination of gray and green infrastructure, discussed next.

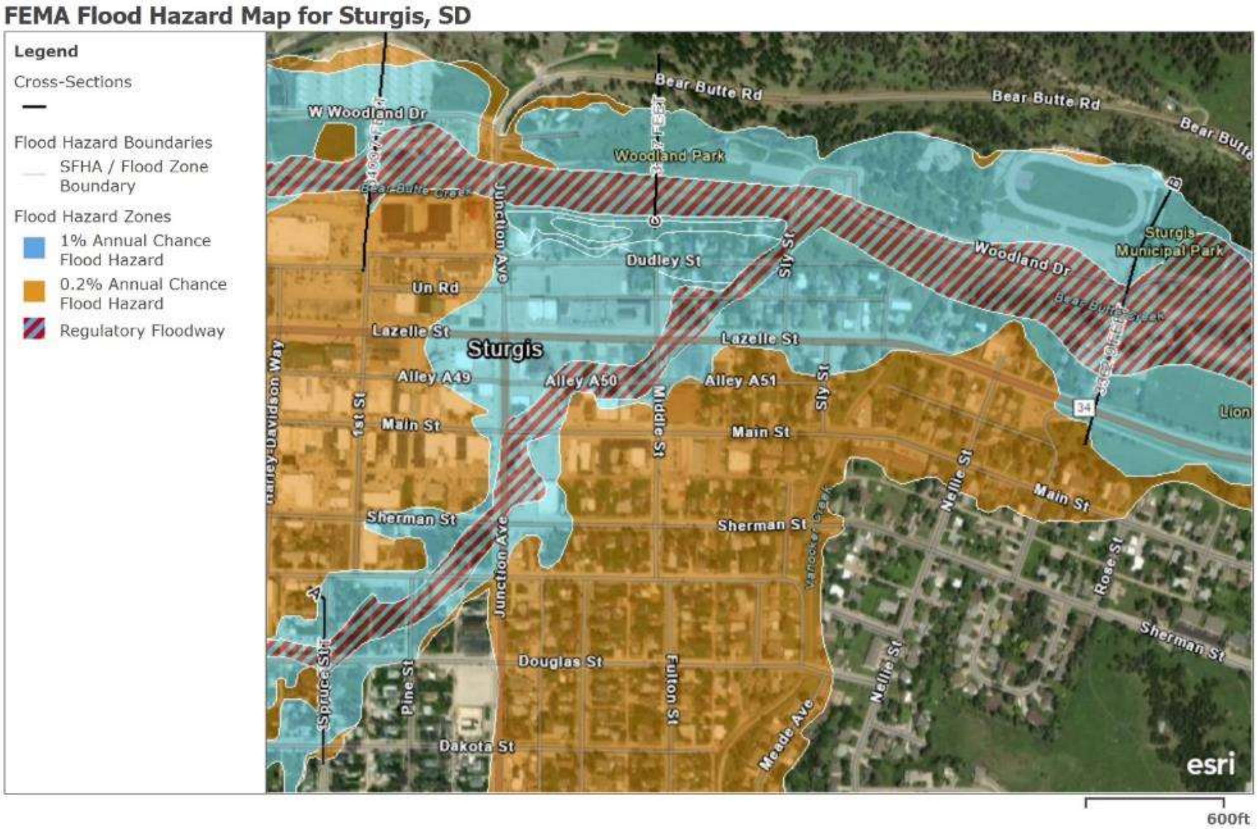

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Figure 2-2: FEMA Flood Hazard Map for Sturgis, SD showing the annual chance of flood hazards (FEMA, 2011)

2.3. What is Gray and Green Infrastructure?

Gray Infrastructure

Gray infrastructure refers to engineered systems which capture and convey runoff, such as gutters, storm sewers, tunnels, culverts, and related systems. According to the EPA, conventional gray infrastructure practices typically focus on addressing peak flow rate and suspended solids concentrations. However, gray infrastructure may leave increased stormwater volume and runoff rates unaddressed, which cause stream erosion. Furthermore, conventional practices cannot treat runoff pollutants such as nutrients, pathogens, and metals. (EPA, 2007)

Green Infrastructure

Green infrastructure uses natural systems such as soils, trees, and vegetation to promote infiltration, evapotranspiration, and recycling of stormwater runoff. By intercepting stormwater runoff at the source, green infrastructure can address issues gray infrastructure cannot, such as stormwater volume, runoff rates, and pollutant loading. If utilized, green infrastructure can be a cost-effective way to complement existing gray infrastructure systems and provide environmental, economic, and community benefits. Green and gray Infrastructure aren't necessarily one or the other and instead lie somewhere on a spectrum as shown in Figure 2-3.

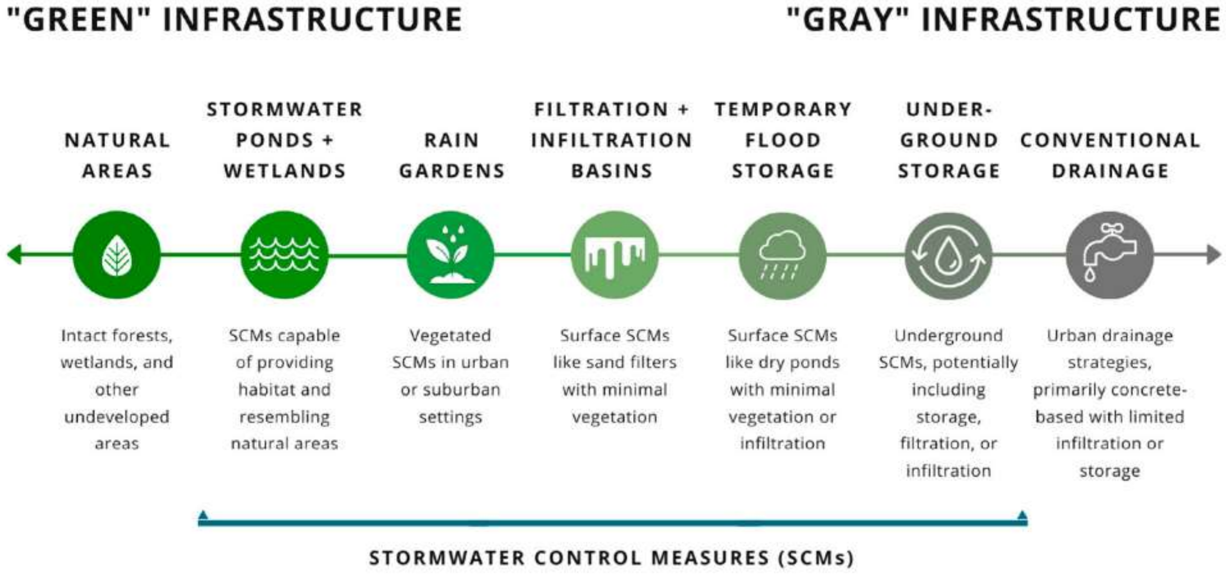


Figure 2-3: Spectrum of green vs gray infrastructure BMPs. (Taguchi et al., 2020)

Implementing Green Infrastructure

Green infrastructure is effective in urbanized areas with high-density development and can be integrated into existing features including streets, parking lots, and public recreational areas such as parks and sports complexes The EPA highlights the following scenarios as great opportunities to implement green infrastructure:

- "Repairing, resurfacing, or replacing roadways and parking lots"
- "Repairing or replacing damaged sidewalks and curbs"
- "Upgrading or replacing utilities in the public right-of-way (e.g., sanitary sewer systems, storm sewer systems, drinking water supply lines)"
- "Redeveloping vacant or abandoned properties"
("Why You Should Consider Green Stormwater Infrastructure for Your Community", 2019)

Examples of gray and green infrastructure are shown in Figure 2-4.

Figure 2-4: (A) Storm drain (City of Portland, 2012), (B) Culvert ("Grading a Culvert"), (C) Green roof (City of Portland, 2012), (D) Curb extension bioretention cell (NACTO, 2017).

2.4. Benefits of Green Infrastructure

With the importance of proper stormwater management in mind, the benefits of green infrastructure will be discussed, with an emphasis on its environmental, economic, and community impacts.

2.4.1. Environmental Benefits

Runoff Reduction

The conventional approach to stormwater management tends to relocate the problem to downstream communities by increasing their flows and total discharges from storm events. Green infrastructure utilizes infiltration, evapotranspiration, and rainfall capture, to capture smaller events and restore the hydrologic function of the watershed itself. Green infrastructure is most effective at managing localized flooding, but it can also reduce the impact of flooding events at the watershed level. (Odefey, et al., 2012)

Pollutant Reduction

Pollutants transported by runoff are a significant source of contamination in drinking water supplies, recreational waters, and productive fishing areas. Green infrastructure can reduce pollutant concentrations directly, by plant absorption, or indirectly, by reducing combined sewer overflows. Combined sewer systems collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe, which is then transported to a wastewater treatment plant. When combined sewers overflow, the untreated sewage, which may contain industrial waste, toxic materials, and debris, gets discharged directly into streams, as shown in Figure 2-5. (Odefey, et al., 2012)

Stream Erosion Reduction

Frequent flooding caused by smaller storm events increases channel and bank erosion, potentially threatening roads, bridges, and other public infrastructure. These food events are often caused by 0.5-year and 1.5-year storm events, with the cumulative impact potentially being greater than one-time larger floods. According to FEMA, up to 25% of economic losses resulting from flooding occur due to these cumulative impacts. (Odefey, et al., 2012)

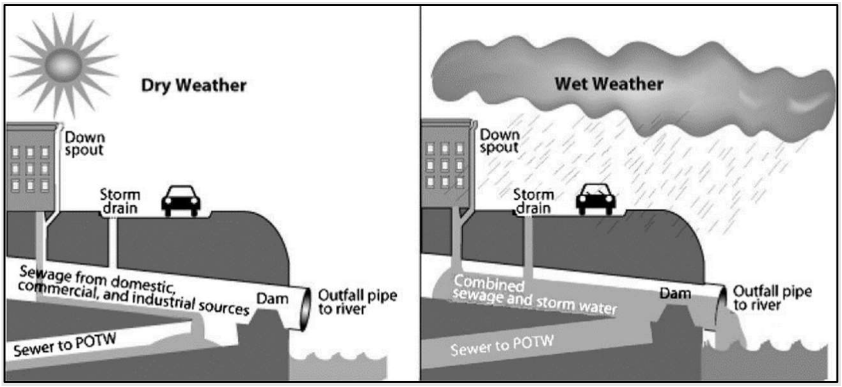


Figure 2-5: Runoff can overwhelm the capacity of combined sewers. (Odefey et al., 2012)

2.4.2. Economic Benefits

Capital Cost Reduction

In many cases, low impact development is more cost-effective at stormwater management than conventional gray infrastructure. In 2007, the EPA conducted a report analyzing 17 case studies of developments using Low Impact Development (LID) practices and their effects on project cost and environmental performance. In the 16 out of 17 cases, project costs were significantly reduced, with capital cost savings ranging from 15 to 80 percent, shown in Table 2-1. Cost reductions were attributed to factors such as reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping. (EPA, 2007)

Positive Return on Investment

Green infrastructure such as tree parks has also been shown to provide a positive return on investment. In 2005, a study published in the Journal of Forestry analyzed the effects of tree parks in five US cities, Fort Collins, CO; Cheyenne, WY; Bismarck, ND; Berkeley, CA, and Glendale, AZ. Cities spent $13-65 annually per tree, gaining economic benefits of $31 to $89 per tree, meaning that for every dollar invested, cities received $1.37 to $3.09 in return. (McPherson et al., 2005)

Table 2-1: Case studies comparing cost between conventional and LID stormwater management approaches. (EPA, 2007)

Project	Conventional Development Cost	LID Cost	Cost Difference	Cost Reduction
2nd Avenue SEA Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Bloedel Donovan Park	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Garden Valley	$324,400	$260,700	$63,700	20%
Kensington estates	$765,700	$1,502,900	-$737,200	-96%
Laurel Springs	$1,654,021	$1,149,552	$504,469	30%
Mill Creel	$12,510	$9,099	$3,411	27%
Prairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	$2,700,650	$461,510	15%

Energy Demand Reduction

Street trees and green roofs can also mitigate the urban heat island effect and lower surface and air temperatures. Shaded surfaces may be 20–45°F cooler than unshaded surfaces, reducing electricity costs for cooling in the summer. Added tree shade can also slow the deterioration of street pavement and reduce maintenance costs. Furthermore, trees and vegetation can reduce wind speeds, slowing heat loss in the winter Table 2-2 gives potential annual electricity savings with strategically placed trees on residential yards. (EPA, “Heat Islands,” 2019)

Flood Damage Mitigation

By reducing peak flows and total runoff, green infrastructure can also reduce flooding and property damage. FEMA estimated in 2005 that in the US, flooding causes $1 billion in damages annually with 25% of damages linked to stormwater (FEMA, 2005). By preventing floods, the capital costs and operation and maintenance costs of stormwater can be reduced. Furthermore, because green infrastructure reduces stream erosion, costs for cleanups and stream restoration may also be avoided. (EPA, 2007)

Property Value Increase

Another potential benefit of green spaces for cities is it increases real estate value and property tax revenue. Studies have found that trees and vegetative landscaping can increase residential property values from 3% to 10% and increase retail & commercial property values from 7% to 23%. However, the city should also consider the potential strain this may cause for low-income residents and assess whether increasing property value is a positive or negative impact for each site proposed. (Wolf, 2005)

Table 2-2: Annual electricity savings due to trees strategically planted in residential yards, averaged across 40-year life of a tree. (Clements, 2013)

Table 1. Annual electricity savings due to trees strategically planted in residential yards, averaged across 40-year life of tree

	Opposite west-facing wall		Opposite south-facing wall		Opposite east-facing wall	
	Energy savings (kWh/yr)	**$ savings**	**Energy savings (KWh/yr)**	**$ savings**	**Energy savings (kWh/yr)**	**$ savings**
Small tree: Crab apple (22 ft. tall, 21-ft. spread)	96	$9.59	54	$5.39	68	$6.79
Medium tree: Red oak (40 ft. tall, 27-ft. spread)	191	$19.08	99	$9.89	131	$13.09
Large tree: Hackberry (47 ft. tall, 37-ft. spread)	268	$26.77	189	$18.88	206	$20.58

Sources: McPherson et al. 2006, EIA 2013a, b.

2.4.3. Community Benefits

Adding green infrastructure to streets can offer numerous community benefits, including improving public health, reducing stress, and encouraging physical activity (Tzoulas, 2007). Studies have also indicated that natural features and open spaces in residential areas contribute to residents' feeling of attachment to the community and other residents (Kim and Kaplan, 2004). Furthermore, the community benefits of green streets apply to many types of residents in cities.

Green infrastructure must be designed to allow city crews and utility companies the ability to perform routine or emergency maintenance for sewers, subsurface utilities, etc.

3. BMP Descriptions

This chapter provides descriptions of stormwater BMPs and their advantages and disadvantages.

3.1. Bioretention

Bioretention systems as seen in Figure 3-1 are vegetated, shallow landscaped areas that capture and temporarily store stormwater runoff. This runoff is absorbed by the vegetation, engineered soil media, and microorganisms. These systems typically consist of a pretreatment facility, surface ponding area, surface cover, bioretention soil media, underdrain, and an overflow outlet, elements which are discussed further in the next chapter. There also are two different types of systems, online and offline. Online systems allow all flow from the drainage area to flow into the bioretention area and allows the excess flow to flow through a facility and exit through an overflow structure or weir without being treated. Offline systems split the runoff so that the design flow enters the bioretention area and larger flow bypass the facility. These systems are often cut into the curb of a street or parking lot for the inlet of the system. Offline systems are typically preferred for bioretention systems since the overflow facility in online systems can be overwhelmed and require maintenance.

Advantages

Bioretention systems are advantageous because they are easy to integrate into parking lot islands, roadway medians, and rights-of-way along roads since it is not limited to a specific shape. Depending on site characteristics, bioretention areas can be designed to provide runoff reduction, pollutant treatment, and/or flood control. Bioretention systems are better suited for sites with a drainage area of 2.5 acres or less, while any less than 1 acre would be better suited for rain gardens.

Disadvantages

Disadvantages of bioretention systems include the need for annual removal of sediment build-up, maintenance of vegetation, the need for access to roads, and specialized equipment and training needed in constructing the system. Systems need to be located on relatively flat terrain, and the grade immediately adjacent to the basin (15 to 20 feet) should be between 1 and 5 percent to promote drainage while limiting the potential for erosion.

Figure 3-1: Bioretention cell in Lincoln, NE

Figure 3-2: Bioretention cell in Rapid City, SD

3.2. Rain Garden

Rain gardens are small residential depressions planted with native wetland and prairie vegetation, where sheet flow and runoff collect and infiltrates These systems are easy to plan and build, can improve water quality by filtering pollutants from stormwater, are effective at reducing runoff volumes, and are aesthetically pleasing. Rain gardens should be placed so their well overflow path does not interfere with adjoining property drainage patterns. Rain gardens should also be placed away from areas where ponded water may create problems for surrounding vegetation or land use. Rain gardens are typically integrated into residential yards and community common areas as shown in Figure 3-2.

Advantages

The advantages of rain gardens are the low to medium costs (depending on the size), the low to medium cost of maintenance (depending on the size), the ease of building, and the improvement in water quality.

Disadvantages

Some disadvantages of rain gardens include the need to irrigate to maintain vegetation during dry periods and the annual maintenance to maintain vegetation and aesthetics.

Figure 3-2: Rain gardens in Lincoln, NE

3.3. Infiltration Planter

Infiltration planters as seen in Figure 3-3 are raised structural planting beds that can filter and infiltrate runoff from surrounding parking lots, sidewalks, or rooftops. These systems work well at the individual residential, commercial, residential, or governmental parcel scales. They can be installed in a variety of sizes and styles, providing a variety of looks for each locations' need. Infiltration planters can also integrate a variety of plants catering to the needs of each location and maintenance availability.

Advantages

Advantages of infiltration planters are their ability to filter out pollutants, infiltrate runoff to reduce flow rates and volumes, and flexible usage in areas with limited space. This system can be used as part of a traditional landscaping plan and should reduce the amount of watering needed to maintain landscaping. The removal of sediments and pollutants for this system is high, often exceeding 80 percent.

Disadvantages

Some disadvantages, however, include high maintenance for keeping the system unclogged with debris, limited capability to reduce significant amounts of runoff based on receiving area, and require a minimum of three feet of permeable medium between the bottom of the growing medium and the water table.

Figure 3-3: Infiltration Basin utilizing native plants and decorative boulders

3.4. Green Roof

Green roofs, as shown in Figure 3-4 consist of placing layers of plants and rooting medium over a traditional roofing system. They are grouped into two categories: extensive and intensive. Extensive roofs are lightweight systems of manufactured root medium which typically have low plant diversity, are easily incorporated into conventional building construction, and require little maintenance. Intensive roofs use a deep rooting medium such as topsoil and can incorporate a wide variety of plants but require special considerations due to higher roof loading and greater maintenance.

Advantages

The advantages of extensive green roofs are their low maintenance, low weight, ability to reduce summer cooling costs, and ability to slow stormwater runoff. Extensive green roof systems provide insulation for the roof, extend the life of the roof, and reduces the impervious area for the property.

The advantages of intensive green roof systems are similar to that of an extensive green roof system. Intensive systems provide greater plant diversity, better aesthetics, and potential access for recreation. Similar to extensive green roofs, this system slows stormwater runoff, allows for a larger detention capacity, and reduces the impervious area for the property.

Disadvantages

One disadvantage of extensive green roof systems is that they can be unattractive to some during the winter. Green roof systems are also very expensive to implement on existing structures and are often not feasible for property owners. Furthermore, limited types of plants can be used, and native species may not be possible.

Intensive green roof systems have disadvantages as well, including a greater roof load causing higher design loads, expensive design and construction, and the need to implement an irrigation and drainage system. They also require higher maintenance and are a potential fire hazard during dormant seasons, especially with native plant species.

Figure 3-4: (Left) Green roof in Denver, CO. (Right) Montana State Fund building in Helena, MT. (EPA, 2020)

3.5. Retention Ponds

Retention ponds function by incorporating ponds or lakes into a stormwater treatment system. An example of how they can be implemented can be seen in Figure 3-5. The primary pollutant removal mechanism in retention ponds is sedimentation. Since wet ponds have the capability of removing soluble pollutants, they are suitable for sites where nutrient or pollutant loads are expected to be high.

Advantages

The advantages of retention ponds are their runoff control, creation of habitat for wildlife, aesthetic appearance, and encouragement of community recreation facilities. They also may require less maintenance if natural vegetation is used along the banks.

Disadvantages

Retention pond disadvantages include reducing the amount of developable land, requiring approval from dam safety authorities, requiring maintenance at regular intervals to remove sediments deposited in the base of the pond, and potential wildlife issues. If not maintained properly, ponds can become overgrown and become a nuisance due to mosquitos, odors, duckweed cover, or harmful algal blooms that can kill pets (Taguchi et al., 2020). Stormwater ponds can also have negative impacts on property values and raise safety concerns for residents.

With these potential concerns in mind, retention ponds must be coupled with regular inspections, maintenance, and monitoring. One way to encourage this is by making maintenance simple and inexpensive. By using pretreatment practices that capture a large fraction of suspended solids, leaves, and trash, maintenance can be done more easily.

Figure 3-5: (A) City Park in Denver, CO. (B) A shopping center in Denver, CO. (EPA, 2020)

3.6. Pervious Pavements

Pervious pavements, also known as permeable pavement, allows precipitation to infiltrate vertical pore spaces in the paving material. A breakdown of how these systems work is shown in Figure 0-1 and Figure 3-6. This paving material is constructed of brick, concrete, asphalt, plastic, rock, and/or gravel. Permeable pavement can also achieve a removal rate of over 80 percent for sediment and other pollutants.

Advantages

The main advantage of pervious pavements is that it's suitable for a wide variety of scales, including trails, overflow parking lots, and light traffic roadways. They also can reduce runoff volumes and impervious surface area. Depending on the pavement system, it may provide pollutant filtering.

Disadvantages

Some disadvantages of pervious pavement are the amount of maintenance needed. This could become costly if the pavement becomes clogged with sediment and no longer allows infiltration. Certain types of pervious pavement types have a high potential for failure unless properly designed, constructed, and maintained. Restricting pervious pavement to areas with relatively low traffic volumes and relatively light vehicles will increase its lifespan.

Figure 3-6: (A) Denver, CO. (B) Woodlawn Cemetery in Sioux Falls, SD. (C) Fort Collins, CO. (D) Western Dakota Tech in Rapid City, SD (EPA, 2020)

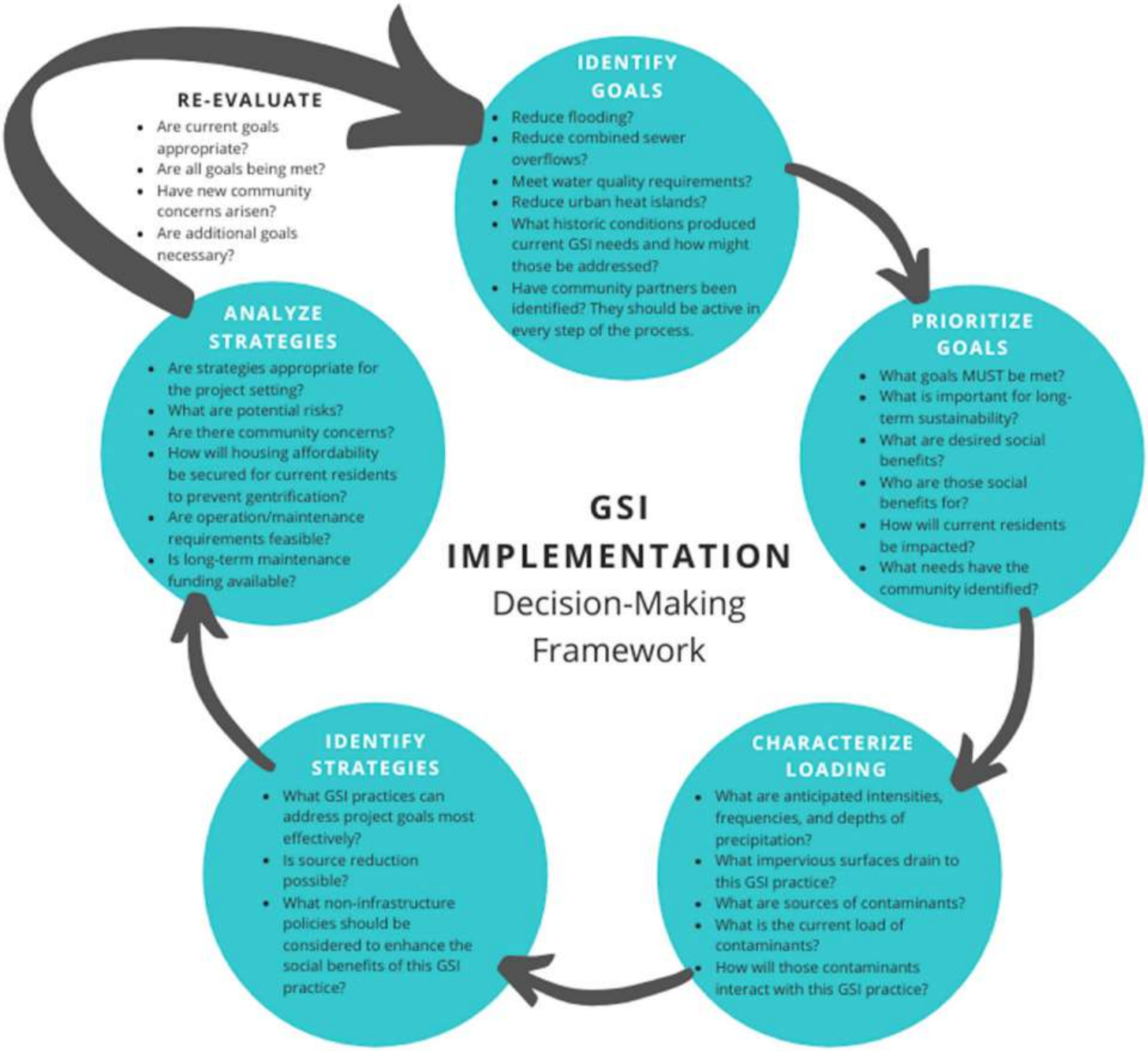
4. BMP Selection

This chapter discusses the many different factors associated with BMP selection, including site characteristics, treatment objectives, aesthetics, and cost. Each site may have different conditions and objectives, so each site may have unique solutions. Furthermore, there may be multiple solutions for each site which may combine multiple BMPs to meet the treatment objectives. The following section provides an overview of factors to consider when selecting BMPs, but it is not exhaustive.

4.1. BMP Selection Framework

A publication from the University of Minnesota outlines a framework for implementing green infrastructure which involves prioritizing project goals while remaining considerate of the broader context around the project and how different social groups may be impacted. To summarize the framework, the steps are listed below and in Figure 4-1.

1. **Identify Goals** – “Reduce flooding? Reduce combined sewer overflows? Meet water quality requirements? What historic conditions produced the need for green infrastructure and how may they be addressed?”
2. **Prioritize Goals** – “What goals MUST be met? How will current residents be impacted? What needs have the community identified?”
3. **Characterize Loading** – “What are anticipated intensities, frequencies, and depths of precipitation? What impervious surfaces drain to the BMP practice? What are the sources and loading of contaminants, and how will they interact with the BMP?”
4. **Identify Strategies** – “Which BMPs can address project goals most effectively? Are source reduction or pollution prevention opportunities available?”
5. **Analyze Strategies** – “Are strategies appropriate for the project setting? What are potential risks? Are there community concerns? Are operation/maintenance requirements feasible?”
6. **Re-evaluate** – “Are current goals appropriate? Are all goals being met? Have new community concerns arisen? Are additional goals necessary?”
   (Taguchi, 2020)



IDENTIFY GOALS

- Reduce flooding?
- Reduce combined sewer overflows?
- Meet water quality requirements?
- Reduce urban heat islands?
- What historic conditions produced current GSI needs and how might those be addressed?
- Have community partners been identified? They should be active in every step of the process.

PRIORITIZE GOALS

- What goals MUST be met?
- What is important for long-term sustainability?
- What are desired social benefits?
- Who are those social benefits for?
- How will current residents be impacted?
- What needs have the community identified?

CHARACTERIZE LOADING

- What are anticipated intensities, frequencies, and depths of precipitation?
- What impervious surfaces drain to this GSI practice?
- What are sources of contaminants?
- What is the current load of contaminants?
- How will those contaminants interact with this GSI practice?

IDENTIFY STRATEGIES

- What GSI practices can address project goals most effectively?
- Is source reduction possible?
- What non-infrastructure policies should be considered to enhance the social benefits of this GSI practice?

ANALYZE STRATEGIES

- Are strategies appropriate for the project setting?
- What are potential risks?
- Are there community concerns?
- How will housing affordability be secured for current residents to prevent gentrification?
- Are operation/maintenance requirements feasible?
- Is long-term maintenance funding available?

RE-EVALUATE

- Are current goals appropriate?
- Are all goals being met?
- Have new community concerns arisen?
- Are additional goals necessary?

Figure 4-1: Decision-making framework for equitably and effectively implementing green stormwater infrastructure (GSI) (Taguchi, 2020)

4.2. BMP Selection Tools

The EPA has developed several tools to assist users in implementing green infrastructure. These tools can help users locate information related to green infrastructure, identify suitable BMP locations, identify if they can meet stormwater retention targets, screen BMPs for cost-effectiveness, quantify BMP treatment effectiveness, and assist in planning stormwater infrastructure. For non-technical readers, be on the lookout for other tools online, as they may simplify the selection and design process.

- **Green Infrastructure Wizard (GIWiz)** – Interactive web application which provides users with EPA tools and resources related to green infrastructure.
- **EPA Best Management Practices (BMPs) Siting Tool** – "Identifies potential suitable locations/areas for implementing different types of BMPs or low impact development (LID) controls. Supports selecting locations that meet criteria such as drainage area; slope; hydrological soil group; groundwater table depth; and road, stream, and building buffers."
- **National Stormwater Calculator (SWC)** – "Informs site developers on how well they can meet a desired stormwater retention target with and without the use of green infrastructure. Estimates the annual amount of stormwater runoff from a specific location in the United States based on local soil conditions, land cover, and historic rainfall records."
- **Watershed Management Optimization Support Tool (WMOST)** – "Screens a wide range of practices across their watershed or jurisdiction for cost-effectiveness and environmental and economic sustainability."
- **Visualizing Ecosystems for Land Management Assessment (VELMA) Model** – "Quantifies the effectiveness of natural and engineered green infrastructure management practices for reducing nonpoint sources of nutrients and contaminants in streams, estuaries, and groundwater."
- **Green Infrastructure Flexible Model (GIFMod)** – "Evaluates the performance of urban stormwater and agricultural green infrastructure practices."
- **Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) Tool** – "Uses a life cycle cost framework to support feasibility and planning of stormwater infrastructure. It helps stormwater professionals, community planners, and local decision makers understand and weigh the estimated costs, reductions in runoff and pollutant loads, and co-benefits of various planning scenarios as they consider stormwater management projects."
- **Storm Water Management Model (SWMM)** – "Used for large-scale planning, analysis, and design related to stormwater runoff, combined and sanitary sewers, and other drainage systems."
  ("Green Infrastructure Modeling Toolkit", 2020)

4.3. Factors to consider when selecting BMPs

This section provides an overview of factors to consider in BMP selection but is not exhaustive. Careful consideration of the factors is important because improper BMP selection can lead to adverse resource impacts, tension with community members, and wasted time and money. Effective selection, however, can bring a multitude of environmental, economic, and community benefits. A summary of the factors to consider when selecting BMPs is provided below.

1. **Pollution Prevention Opportunities** – Assess if opportunities are available to reduce the production of pollutants which can be transported by runoff, reducing the treatment requirements of BMPs.
2. **Better Site Design** – Assess if the site can be redesigned to minimize runoff and reduce the size requirements of BMPs.
3. **Climate and Terrain Conditions** – Assess the influence of factors such as annual precipitation, temperate, and changing climate conditions on BMPs proposed for the site.
4. **Stormwater Treatment Suitability** – Assess the level of treatment required to manage storm events for the site. Different BMPs are effective over different ranges of storm events.
5. **Site Physical Feasibility** – Assess factors such as the geography, soil types, available area, contaminants, and environmental or infrastructure restrictions of the site.
6. **Community and Environmental Factors** – Assess factors such as the cost, maintenance requirements, aesthetics, community acceptance, and potential harms or nuisances of proposed BMPs.
   ("Process for selecting Best Management Practices," Minnesota Stormwater Manual).

Additionally, the Minnesota Stormwater Manual provides some general principles for stormwater management, which are provided below.

- Preventing runoff from being produced in the first place reduces the need for stormwater management.
- Proper maintenance will provide the best performance and prolong the lifespan for BMPs.
- Effective design and construction can reduce the maintenance required for BMP functioning.
- The less active management the BMP requires, the better.
- Designs should consider all impacts, including environmental impacts, health and human safety, maintenance, and cost.
  ("Overview of basic stormwater concepts," Minnesota Stormwater Manual, 2020)

4.3.1. Pollution Prevention Opportunities

Depending on the site, opportunities may be available to reduce the production of pollutants at the site level, reducing the potential size and treatment requirements for proposed BMPs. If there are no pollutants of concern at the site, this step may not be applicable.

Some municipal pollution prevention practices and the level of pollutant control offered are shown in Table 4-1. For more information on each control strategy, consult the Urban Subwatershed Restoration Manual and the Minnesota Stormwater Manual's page on Pollution Prevention.

Table 4-1: Municipal pollution prevention practices and level of pollutant control offered. (Scheuler et al., 2005)

	Stormwater Pollutants Controlled						
Practice	**Sediment**	**Nutrients**	**Metals**	**Trash**	**Oil**	**Toxins**	**Bacteria**
Temp. Construction Sediment Control	High	Medium	Low	Low	None	None	None
Wind Erosion Control	High	Medium	Low	Low	None	None	None
Streambank Stabilization	High	Medium	None	None	None	None	None
Material Storage Control	High	Medium	Medium	None	High	High	None
Better Street and Parking Lot Cleaning	High	Medium	Medium	Medium	Medium	Low	None
Proper Vehicle Management	High	High	High	Medium	High	High	None
Storm Sewer System Maintenance	High	Medium	Low	Medium	None	None	None
Better Turf Management	Medium	High	None	None	None	High	None
Better Street and Parking Lot Deicing	Medium	Low	Low	None	None	High	None
Dumpster and Landfill Management	Low	Medium	Medium	High	Medium	High	High
Sanitary Sewer System Maintenance	Low	High	None	None	None	Low	High
Proper Pool Discharge	None	None	None	None	None	High	None
Litter and Animal Waste Control	None	High	None	High	None	None	High

4.3.2. Better Site Design

The goal of better site design is to mitigate the effects of urbanization during the planning phase of development. If the site's hydrologic condition and natural areas are protected, less stormwater management will be required later on. While not all better site design techniques apply to every development or retrofitting site, the goal is to apply as many as possible to maximize stormwater reduction benefits. This way, costs can be saved up-front by reducing the necessity for BMPs. Some examples of better site design practices are shown below. For more specific guidance on better site design strategies, consult the Minnesota Stormwater Manual page on Better Site Design.

- **Preserving natural areas**:
    - Natural area conservation
    - Site reforestation
    - Stream buffers
    - Open space design
    - Reduce paved areas and compacted soils
- **Disconnecting and distributing runoff**:
    - Soil compost amendments
    - Disconnection of surface impervious cover
    - Rooftop disconnection
    - Grass channels
    - Stormwater landscaping
- **Reducing impervious cover in site design:**
    - Narrower streets
    - Slimmer sidewalks
    - Smaller cul-de-sacs
    - Shorter driveways
    - Smaller parking lots

("Better Site Design," Minnesota Stormwater Manual, 2019)

4.3.3. Climate and Weather

Sturgis, SD is in Environmental Protection Agency (EPA) Region 8, which is a semi-arid climate facing rapid freeze/thaw cycles and intermittent/unpredictable rainfall patterns (Lee and Schumer, 2016). Special considerations to make for the cold climate of this region are discussed in Table 4-2. Also, if infrastructure has an expected lifespan of 30 years or more, changing climate conditions may need to be considered, as it may affect the long-term functionality of BMPs. (de Mooy et al., 2016)

Table 4-2: BMP Design challenges of cold climates. (Caraco and Claytor, 2005)

Cold Climate Characteristics	BMP Design Challenge
Cold temperature	• Ice formation on permanent pools • Reduced biological activity • Reduced oxygen levels during ice cover • Reduced settling velocities
Deep frost line	• Pipe freezing • Reduced soil infiltration • Frost heaving
Short growing season	• Reduced time period to establish vegetation • Selection of appropriate plant species for cold climates
Significant snowfall	• High runoff volumes during snowmelt and rain-on-snow • High pollutant loads during Spring melt • Road salts and deicers may affect water quality and plant health • Snow may affect BMP storage capabilities

4.3.4. Stormwater Treatment Suitability

Treatment requirements for a given site are typically based on local regulations or ordinances. If none exist, the BMP designer may need to use their judgment to determine the appropriate design storm. The Minnesota Stormwater Manual uses the following unified criteria to define treatment requirements for different storm types, described below and in Table 4-3, which helps assess the level of treatment required to manage storm events for a given site. In general, the Green infrastructure is typically best suited to manage runoff for frequent, smaller storm events in the range of 1-2 inches over 24 hours. It's also important to note that different BMPs are effective over different ranges of storm events, shown in Table 4-3 and Figure 4-2.

1. **Recharge**
   - Targets rainfall events that create little or no runoff but produce much of the annual groundwater recharge at the site
   - Goal: Retain or treat runoff from first 1.0" fall on site
2. **Water Quality** (85th percentile storm)
   - Targets rainfall events that deliver the majority of the stormwater pollutants at the site
   - Goal: Detain and remove 80% TSS from the first 1.2" of runoff from impervious area
3. **Channel Protection** (1-year 24-hour storm)
   - Targets storms that generate bankful and sub-bankful floods in the stream that cause channel enlargement
   - Goal: Detain runoff from the 1-yr 24-hr storm for 24 hours
4. **Overbank Floods** (Varies between 5-, 10- and 25-year storm)
   - Targets large and infrequent storm events that spill over to floodplain and cause damage to infrastructure
   - Goal: Control peak discharge for 5-, 10-, or 25-year storm
5. **Extreme Storms** (100-year storm)
   - Controls the largest, least frequent, and most catastrophic floods that threaten property and public safety
   - Goal: Safety convey the 100-yr storm and evaluate effects on storm system and downstream areas
     ("Unified Sizing Criteria," Minnesota Stormwater Manual, 2019)

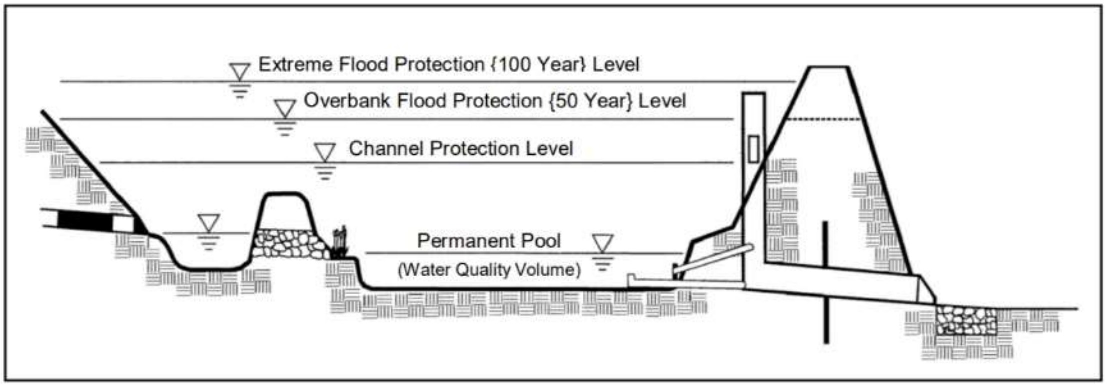


Figure 4-2: Level of stormwater treatment required for different unified sizing criteria. (Columbia County Stormwater Manual, 2009)

Table 4-3: BMP suitability for different unified sizing criteria. ("BMP Suitability," Minnesota Stormwater Manual, 2015)

BMP group	Recharge[a]	Water quality[a]	Channel protection[a]	Peak discharge[a]	Hot spot runoff
Bioretention	Varies	Yes	Possible[b]	No	Yes. (Needs underdrain)
Filtration - media	No	Yes	No	No	Yes
Filtration - vegetative	Varies[c]	Yes	Possible[b]	No	Yes
Infiltration trench	Yes	Yes	No	No	No
Infiltration basin	Yes	Yes	Yes	Yes	No
Stormwater ponds	No[d]	Yes	Yes	Yes	Yes
Constructed wetlands	Varies[d]	Yes	Yes	Yes	Yes. (Needs pre-treatment)
Supplemental BMPs	Varies	No[b]	Possible[b]	No	No[e]

[a] See section on unified sizing criteria for more information
[b] Can be incorporated into the structural control in certain situations
[c] May be provided by infiltration
[d] When impermeable liners are required or pool intercepts groundwater
[e] Can be included as part of the treatment train

4.3.5. Site Physical Characteristics

A summary of site physical characteristics to consider include:

- **Geography** – available area, drainage features, adjacent waterways, slope
- **Soil types** – infiltration rate, storage capacity, moisture content
- **Contaminants** – pollutant treatment objectives, any remediation required before BMP implementation
- **Utilities** – location of above and underground utilities, such as electricity transmission, gas lines, water/sewer lines, which may limit or affect
  (de Mooy et al., 2016)

Available Area

A common issue for cities when implementing BMPs is space constraints, and streets may need to be retrofitted or reconstructed to implement stormwater BMPs. Different BMPs are also best suited for different scales shown in Table 4-4, Table 4-5, and Figure 4-3. Steps to take when developing a preliminary site layout include:

- **Assess the site's existing infrastructure.**
    - Site grading (existing and proposed topography)
    - Roads
    - Buildings
    - Utilities (water, sewer, gas, etc.)
    - Recreational areas (parks, trails, etc.)
    - Parcel Boundaries
- **Assess if portions of the site should be protected.**
    - Natural wetlands
    - Floodplains
    - Steep slopes
    - Wildlife habitats
    - Open spaces
    - Streams and riparian areas
    - Soils with high infiltration rates
    - Aquifers and their recharge areas.
- **Strategically locate BMPs.**
    - Select areas that promote greater infiltration
    - Seek ways to reallocate existing space, such as overly wide streets, underutilized parking space, or sites for permeable pavement.
    - Assess opportunities to improve safety, pedestrian access, or transit operation. There may be opportunities to address other concerns while designing for green infrastructure.

  (Montana Department of Environmental Quality, 2017)

Soil Types

Different BMPs are suitable for different soil infiltration rates. For example, low infiltration rates are preferred for ponds and wetlands, but not suitable for bioretention designs. For initial estimations, soil information can be found from the Natural Resources Conservation Service (NRCS) Web Soil Survey.

- **Group A**: “Low runoff potential, high infiltration rate, well-drained sands, and gravels”
- **Group B**: “Moderate infiltration rate, well-drained sandy loam and fine to coarse gravels”
- **Group C**: “Slow infiltration rate, silty loam and moderately fine to fine texture types”
- **Group D**: “High runoff potential, slow infiltration rate, clay, and soils with high water table” (Montana Department of Environmental Quality, 2017)

Contributing Drainage Area

Contributing drainage area is defined as the total area, including pervious and impervious surfaces contributing to a BMP. This factor is screened because different BMPs are optimal under certain drainage area sizes. If the drainage area of the site exceeds the maximum for the BMP, designers can consider using multiple smaller BMPs of the same type.

Depth to Bedrock and Water Table

Shallow water tables and bedrock limits the depth of BMPs, reduces the potential for subsurface infiltration, may cause maintenance concerns, and potential contamination of groundwater. Initial estimations of depth to groundwater can be done using the NRCS Web Soil Survey, local records, or historic data. (Montana Department of Environmental Quality, 2017)

Karst Geology

Karst is a landscape formed by the dissolution of soluble bedrock such as limestone or dolomite. Karst geology is a concern because they are often associated with sinkholes, springs, caves, and a highly irregular soil-rock interface. BMPs that store or infiltrate runoff have the potential to create sinkholes and produce groundwater contamination. Before BMP implementation, site investigations should be conducted to determine if karst poses a potential hazard. (Montana Department of Environmental Quality, 2017)

Sensitive Receiving Waterbodies

It is also important to assess the nature and regulatory status of waters that will receive runoff from the BMP site. If the site drains to a sensitive lake, drinking supply aquifer, wetland, or other protected water bodies, there may be certain restrictions or special treatment requirements for BMPs. Consult state and local regulations to identify potential areas of concern.

Table 4-4: Physical feasibility of BMPs at different scales. Adapted from (City of Lincoln, NE, 2020)

	Level				
BMP Name	**District**	**Neighborhood**	**Block**	**Residential Parcel**	**Commercial/ Government Parcel**
Bioretention	X	x	x	x	x
Retention Pond	x	x	x		x
Extended Detention Basin	x	x	x		x
Vegetated Buffer	x	x	x	x	x
Grassed Swale	x	x	x	x	x
Green Roof				x	x
Infiltration Basin	x	x	x		x
Infiltration Planter				x	x
Infiltration Trench			x	x	x
Permeable Pavement		x	x	x	x
Rain Barrel & Cistern				x	x
Rain Garden		x	x	x	x
Urban Forest	x	x	x	x	x
Vegetated Bioswale	x	x	x	x	x

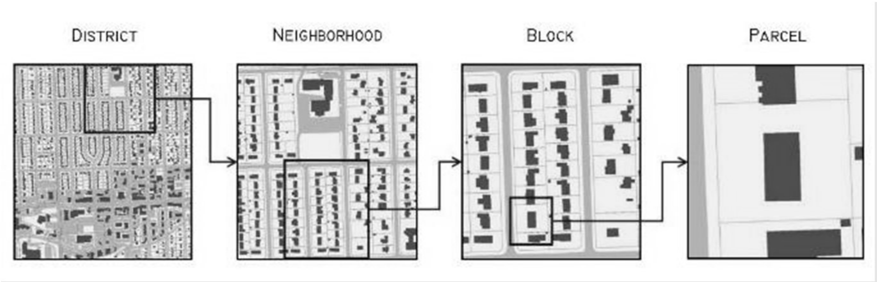


Figure 4-3: Municipal size scales. (City of Lincoln, NE, 2020)

Table 4-5: Factors defining physical feasibility for BMPs. Adapted from ("BMP Selection Based on Physical Feasibility, Minnesota Stormwater Manual, 2019")

BMP group	Surface area[a]	Drainage area	Soil infiltration rate	Head	Separation from bedrock	Depth to seasonally high-water table	Maximum slope[c]
Bioretention	7-10%; Minimum 200 ft^2	5 acre maximum; 0.5-2.0 acre preferred	Any soil; use underdrain for C and D soils[d]		3 feet	3 feet	20%
Filtration (media)	Negligible, except for access	5 acre maximum; 0.5-2.0 acre preferred	Media part of design[d]	2-6 feet	0 feet if enclosed	3 feet for vegetated; 0 feet if enclosed	20%
Filtration (vegetative)	Varies based on depth	10 acre maximum	Media part of design	2-6 feet	0 feet if enclosed	3 feet for vegetated; 0 feet if enclosed	20%
Infiltration trench	Varies based on depth	5 to 10 acre maximum	Native soils with i >= 0.2 inches/hour	2-12 feet	3 feet	3 feet	15%
Infiltration basin	Varies based on depth	5 to 50 acre maximum	Native soils with i >= 0.2 inches/hour	2-12 feet	3 feet	3 feet	15%
Stormwater ponds	1-3%	10 to 25 acres recommended[b]	A or B soils may require liner	3-10 feet	0 feet (shallow soil limits design)	0 feet (except if hotspot or aquifer)	25%
Constructed wetlands	2-4%	25 acre minimum[b]	A or B soils may require liner	3-10 feet	0 feet	0 feet (except if hotspot or aquifer)	25%

[a] Surface area as a function of contributing surface area, except for ponds and wetlands, where it is a function of the entire drainage area

[b] 10 acres or less may be feasible if groundwater is intercepted and/or if water balance calculations indicate a wet pool can be sustained

[c] Slope is defined as the slope across the proposed location of the practice

[d] Infiltration gallery could be designed to provide limited recharge

4.3.6. Community and Environmental Factors

With proper selection and maintenance, BMPs can offer numerous economic, environmental, and community benefits. However, if improperly maintained, they can become eyesores, breed mosquitos, and cease to function. Community and environmental factors to consider are listed below, Table 4-6 rates each BMP on these criteria, and Figure 4-4 shows an example of how green infrastructure can provide aesthetic improvements to streets.

- **Ease of Maintenance** – All BMPs require a certain level of inspection and maintenance to function properly, but some are easier to maintain than others. The table below rates their ease of maintenance based on, frequency and cost of scheduled maintenance; chronic maintenance problems; reported failure rates, and inspection needs.
- **Community Acceptance** – Community acceptance is a subjective measure that is rated based on market surveys, reported nuisance problems, visual preference, and required vegetation management.
- **Cost** – Table 4-6 compares the construction costs of each BMP. While not included in the table, it's also important to consider the life-cycle costs of BMPs which operation costs, maintenance costs, rehabilitation costs, and potential cost savings.
- **Habitat quality** – With proper installation, landscaping, and vegetative management, BMPs can create a habitat for wildlife and waterfowl. This factor is rated based on the required surface area, water and wetland features, vegetative cover, and buffers.
- **Nuisances** – If BMPs are improperly maintained, they can cause nuisances such as mosquitos, geese, overgrown vegetation, floatable debris, odors, and become an eyesore. ("Process for selecting Best Management Practices," Minnesota Stormwater Manual).

Figure 4-4: Green infrastructure can provide aesthetic improvements to streets. Bioretention and street trees shown in photo are from Vine Street, Seattle, WA (NACTO, 2017)

Table 4-6: Community and environmental factors for BMPs. Adapted from (City of Lincoln, NE, 2020)

BMP Family	BMP List	Ease of Maintenance	Community Acceptance	Wildlife Habitat	Construction Cost
Retention	Wet Pond	Low	High	Medium	Low
	Extended Storage Pond	Low	Medium	Medium	Low
	Wet Vaults	High	High	None	High
Detention	Dry Pond	Medium	Medium	Minor	Low
	Oversized Pipes	Low	High	None	High
	Oil Grid/Separator	High	High	None	High
	Dry Swale	Medium	High	Low	Medium
Infiltration	On-Lot Infiltration	Medium	Medium	Medium	Low
	Infiltration Basin	Medium	Medium	Medium	Medium
	Infiltration Trench	Medium	Medium	None	Medium
Wetland	Stormwater Wetland	Low	High	High	Medium
	Wet Swale	Medium	High	Medium	Low
Filtration	Surface Sand Filters	Medium	Medium	Low	High
	Underground Filters	High	High	None	High
	Bioretention	Medium	Medium	Medium	Medium
	Filter Strips	Low	High	Medium	Low

5. BMP Design Guidance

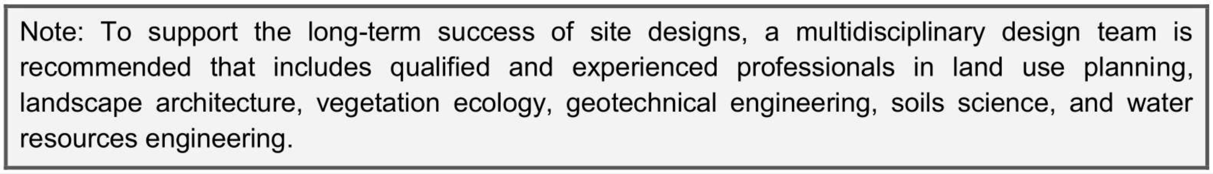
This chapter discusses the approaches and procedures involved in designing effective green infrastructure. Important design elements of BMPs for bioretention cells, green roofs, permeable pavements, and retention ponds are discussed, along with sizing procedures if applicable.

5.1. BMP Design Approach Flowchart

The Montana Department of Environmental Quality has developed a design approach flowchart for the implementation of stormwater BMPs. Outlined are three development phases, which are further explained in Figure 5-2.

1. **Preliminary Design** - Preliminary design involves conducting a site assessment to form decisions about BMP placement and selection, identifying design standards and requirements, developing a preliminary site layout, and conducting a hydrologic analysis to determine delineations of subwatersheds and approximation of impervious areas within them.
2. **BMP Selection and Sizing** – Iterative procedure which factors land use, target pollutants, performance capabilities, and physical site capabilities to determine the most efficient and effective BMP(s) for the site.
3. **Final Design** - The final design should include final siting and sizing, landscaping plans, construction considerations, and operation and maintenance considerations. Before transitioning to the final design phase, coordination with the local jurisdictions is recommended to determine if BMP(s) meet the jurisdiction's design standards and requirements. (Montana Department of Environmental Quality, 2017)

The authors also emphasize the importance of having an experienced and multidisciplinary design team, as indicated in Figure 5-1 to ensure BMP success (Montana Department of Environmental Quality, 2017).



Note: To support the long-term success of site designs, a multidisciplinary design team is recommended that includes qualified and experienced professionals in land use planning, landscape architecture, vegetation ecology, geotechnical engineering, soils science, and water resources engineering.

Figure 5-1: Having a diverse team of experienced professionals is important to ensure BMP success. (Montana Department of Environmental Quality, 2017)

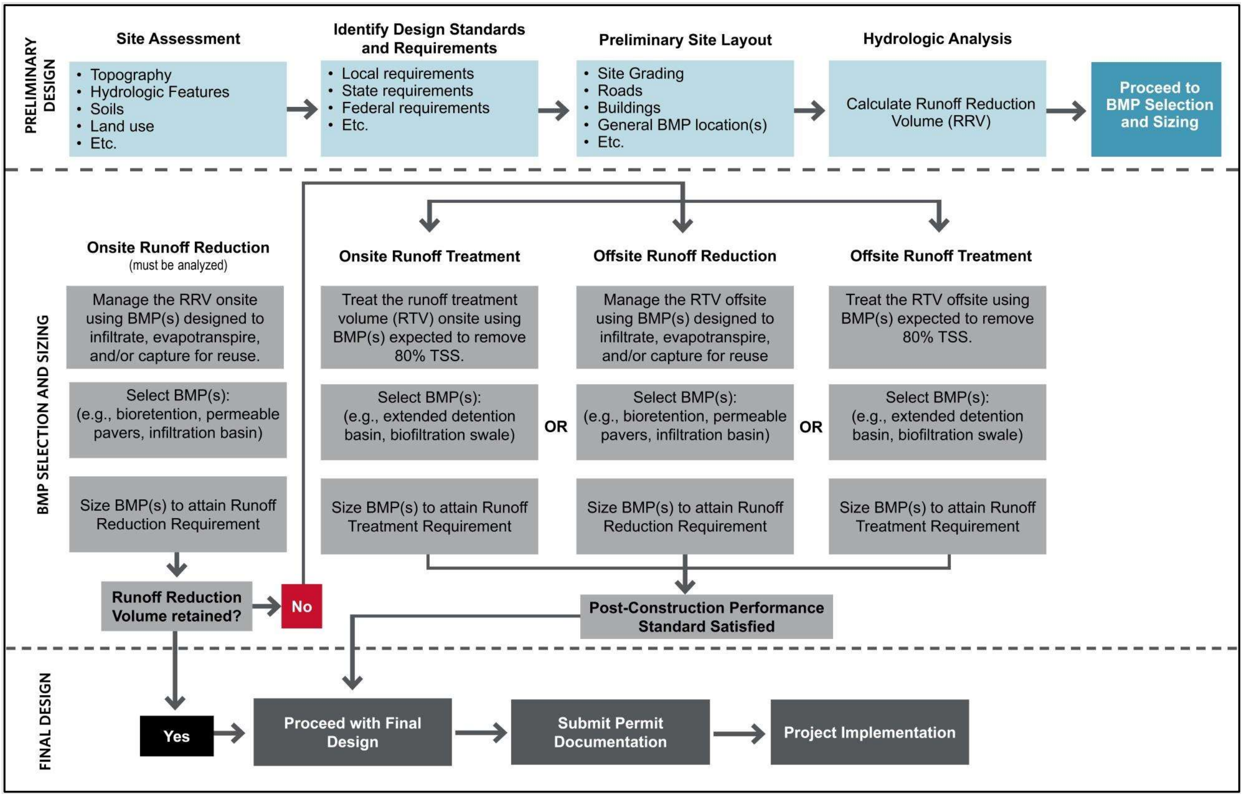


Figure 5-2: BMP design approach flowchart. (Montana Department of Environmental Quality, 2017)

5.2. BMP Design Calculations

The ultimate purpose of stormwater management is to return a developed area to its predeveloped runoff conditions. This section will discuss how to calculate or find common parameters used in BMP design, including rainfall depth, hydraulic conductivity, location of groundwater table, and BMP storage volume. Note that parameters may vary depending on site conditions.

5.2.1. Design Storm

This section will go through an example process of selecting a design storm and associated parameters. The storm drain system is designed for a 10-year storm. For small-scale BMPs, a duration of 15 minutes is required to reach the peak runoff flow rate. With this in mind, a 10-year 15-minute design storm is used. Using Eq 5-1 the intensity of the storm can be found. For that equation, the coefficients a & b can be found using Figure 5-3 & Table 5-1, with d being the duration of the storm in minutes. Table 5-2 shows the storm intensity and coefficients used for a 15-minute 10-year design storm for the city of Sturgis, SD.

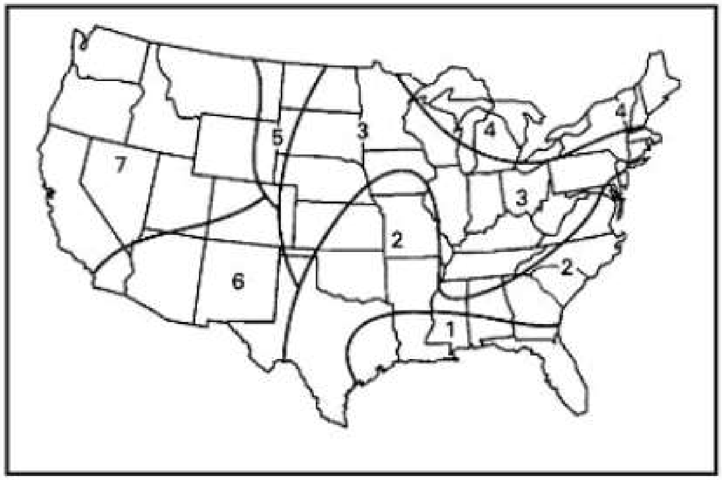
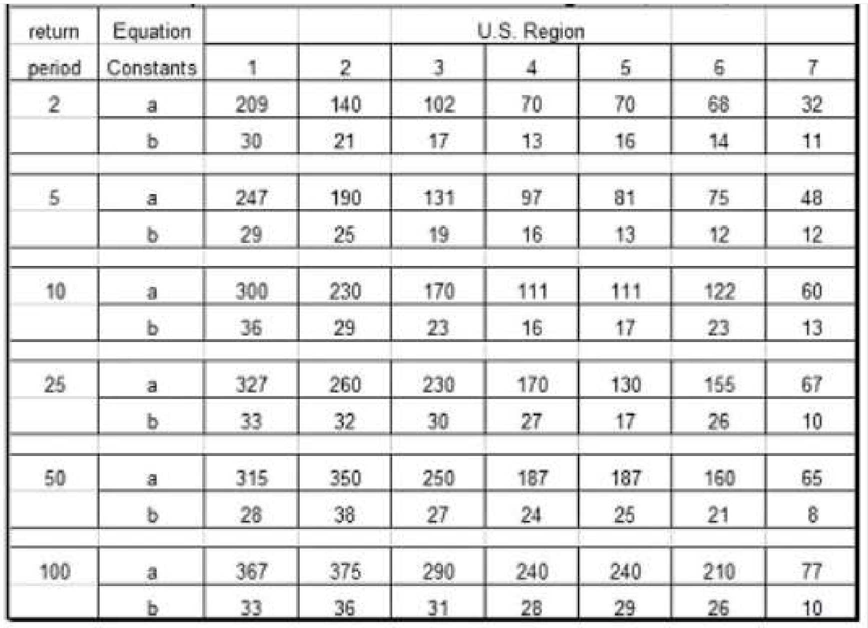


Figure 5-3: Steel Equation US Regions (Engineers Edge)

Table 5-1: Steel Equation Constants (Engineers Edge)



return period	Equation Constants	U.S. Region						
		1	2	3	4	5	6	7
2	a	209	140	102	70	70	68	32
	b	30	21	17	13	16	14	11
5	a	247	190	131	97	81	75	48
	b	29	25	19	16	13	12	12
10	a	300	230	170	111	111	122	60
	b	36	29	23	16	17	23	13
25	a	327	260	230	170	130	155	67
	b	33	32	30	27	17	26	10
50	a	315	350	250	187	187	160	65
	b	28	38	27	24	25	21	8
100	a	367	375	290	240	240	210	77
	b	33	36	31	28	29	26	10

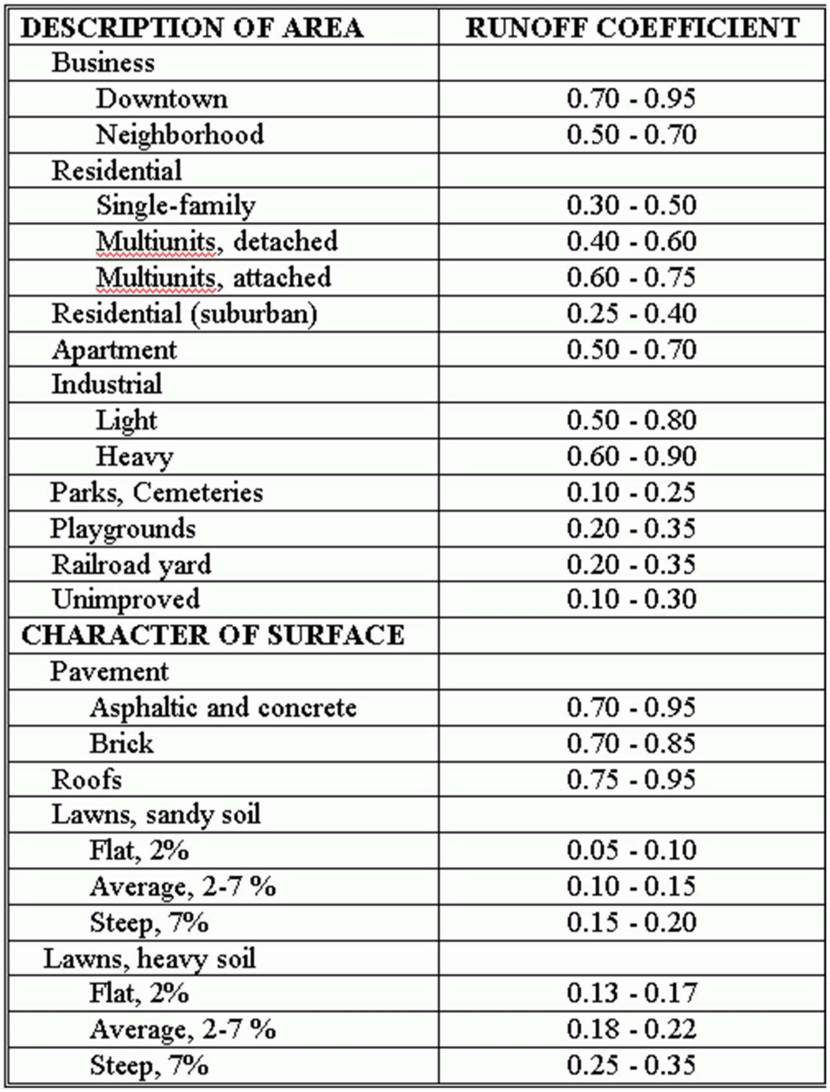
$$I = \frac{a}{d+b} \tag{Eq 5-1}$$

Table 5-2: Steel Coefficients and Calculation

a	111
b	17
d (min)	15
I (in/hr)	3.47

To find the total runoff, the duration of the storm and runoff coefficient are required. The runoff coefficient is included in the equation to account for the rainfall that was absorbed into the ground and deposited into depressions. The runoff coefficient can be found using Table 5-3. For this example, a coefficient is 0.9 was selected. Note that this parameter will vary based on site conditions, and it is up to the BMP designer to use their judgment to determine the most appropriate values. For a conservative design, a higher runoff coefficient may be used. The total runoff is found using Eq 5-2 and Table 5-4 shows the calculations with the given assumptions. For an area with multiple types of land use, a weighted average can be used to find a composite runoff coefficient value.

Table 5-3: Runoff Coefficient Constants (Engineers Edge)



DESCRIPTION OF AREA	RUNOFF COEFFICIENT
Business	
Downtown	0.70 - 0.95
Neighborhood	0.50 - 0.70
Residential	
Single-family	0.30 - 0.50
Multiunits, detached	0.40 - 0.60
Multiunits, attached	0.60 - 0.75
Residential (suburban)	0.25 - 0.40
Apartment	0.50 - 0.70
Industrial	
Light	0.50 - 0.80
Heavy	0.60 - 0.90
Parks, Cemeteries	0.10 - 0.25
Playgrounds	0.20 - 0.35
Railroad yard	0.20 - 0.35
Unimproved	0.10 - 0.30
CHARACTER OF SURFACE	
Pavement	
Asphaltic and concrete	0.70 - 0.95
Brick	0.70 - 0.85
Roofs	0.75 - 0.95
Lawns, sandy soil	
Flat, 2%	0.05 - 0.10
Average, 2-7 %	0.10 - 0.15
Steep, 7%	0.15 - 0.20
Lawns, heavy soil	
Flat, 2%	0.13 - 0.17
Average, 2-7 %	0.18 - 0.22
Steep, 7%	0.25 - 0.35

$$Total\ Runoff\ Depth\ (in) = I * \frac{d}{60} * C \qquad \text{(Eq 5-2)}$$

Table 5-4: Total Runoff Depth Calculation

I (in/hr)	3.47
d (min)	15
C (runoff coefficient)	90%
Total Runoff Depth (in)	.781

5.2.2. Soil Infiltration

Many BMP's utilize rapid infiltration of stormwater to work effectively. However, soil infiltration rates can vary greatly from location to location. The following soil infiltration information was found using WebSoilSurvey, Figure 5-4 shows a map of Sturgis SD overlayed with a map of the top layer of soil in the area, and Table 5-5 can be used to find the type of soil and the hydraulic conductivity.

Table 5-5: Sturgis SD Infiltration Rates (websoilsurvey, 2020)

Map unit symbol	Soil Type	Saturated Hydraulic Conductivity (ft/day)
P014B	Altvan loam, moist, 2 to 6 percent slopes	2.835
P036D	Blackpipe silt loam, moist, 6 to 15 percent slopes	2.551
P124E	Fairburn-Butche complex, 15 to 40 percent slopes	2.551
P194D	Lakoa-Maitland complex, 6 to 25 percent slopes	9.298
P256D	Nevee-Spearfish silt loams, 6 to 20 percent slopes	3.685
P264E	Nihill gravelly loam, moist, 9 to 40 percent slopes	2.551
P324D	Pierre-Fairburn-Ucross complex, moist, 6 to 25 percent slopes	1.559
P324F	Pierre-Fairburn-Ucross complex, moist, 10 to 50 percent slopes	1.559
P342A	Rapidcreek gravelly loam, warm, 1 to 3 percent slopes, occasionally flooded	3.402
P344B	Rapidcreek very cobbly sandy loam, warm, 1 to 6 percent slopes, nonflooded	17.008
P480F	Spearfish-Rock outcrop complex, 10 to 60 percent slopes	2.835
P488A	St. Onge loam, 0 to 2 percent slopes, rarely flooded	2.551
P512B	Thirtynine silt loam, 2 to 6 percent slopes	1.984
P514B	Tilford silt loam, 2 to 6 percent slopes	2.551

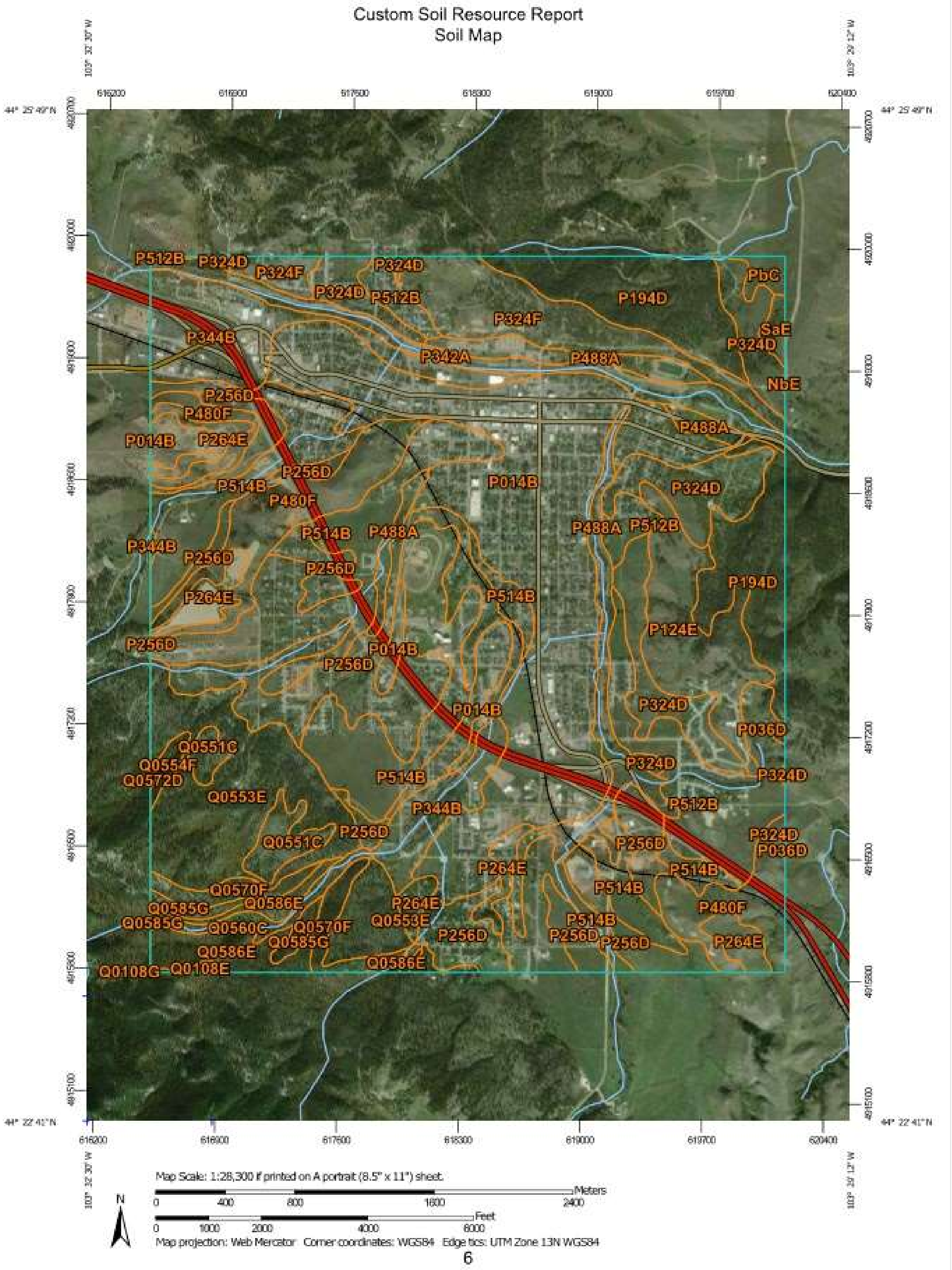


Figure 5-4: Web Soil Survey Hydraulic Conductivity Map (websoilsurvey, 2020)

5.2.3. Groundwater Table

Bioretention, infiltration, and many filtering BMPs require a minimum separation distance between the bottom of the BMP to the groundwater table ("Process for selecting Best Management Practices," Minnesota Stormwater Manual). This is a concern because if the groundwater table is too close/shallow, groundwater contamination can occur (Minnesota Stormwater Manual. "Shallow Groundwater," 2019).

The groundwater table can vary in depth during the year and can be hard to know exactly where it is. For Sturgis SD, the groundwater table can be estimated by using Bear Butte Creek on the north side of town, which serves as a drainage way for heavy rainfall in the hills starting near Deadwood SD. Bear Butte Creek is located on Figure 5-5 with a thick blue line.

Using data collected by USGS, Figure 5-6 shows the average daily streamflow for both Deadwood and Sturgis in 1998 and 2002 (the latest streamflow data for both). There isn't much of a difference between the two stream gauge stations, so by taking the average of both locations it was found that Deadwood had an average of 3.83 cfs while Sturgis had an average of 3.33 cfs. This indicates that the creek loses flow through seepage into the ground, that Bear Butte Creek is a losing stream, and that the groundwater table is below the creek. This is enough room for BMP usage without contaminating the groundwater.

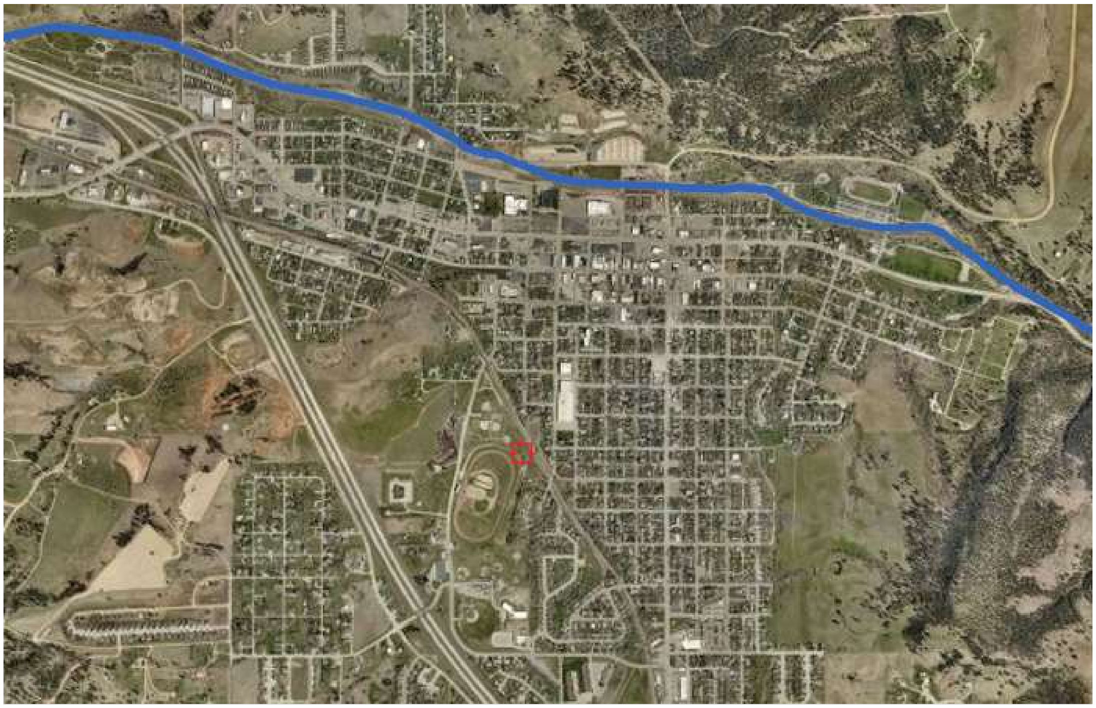


Figure 5-5: Bear Butte Creek Location

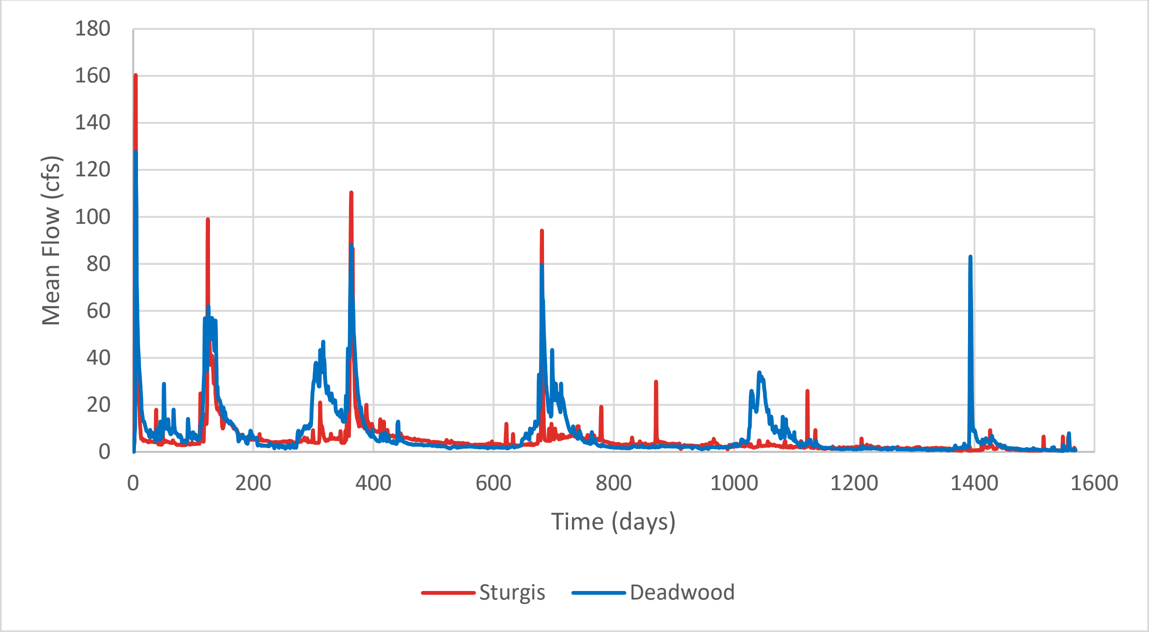


Figure 5-6: Bear Butte Stream Flows (USGS, 2021)

5.3. Bioretention Cells

5.3.1. Design Elements

Before designing bioretention cells a physical feasibility check should be conducted to determine if the proposed location is adequate. A summary of factors to consider is listed below.

Physical Feasibility Check

- **Drainage Area -** Recommended maximum contributing drainage area is 5 acres per cell
- **Site Topography and Slope -** Recommended that slope areas adjacent to the bioretention practice is between 1% and 33%.
- **Soil Type -** Usage of engineered filter media is highly recommended. For soil types HSG C or D, underdrain is highly recommended.
- **Depth to Water Table and Bedrock** - A minimum distance of 3 ft to bedrock and water table is required.
- **Presence of Active Karst -** It is highly recommended to avoid using bioretention in areas with active karst without a geotechnical assessment. An underdrain and impermeable liner may be applicable for some karst areas.
- **Site Location/Minimum Setbacks -** Consult local ordinances for specific requirements. It is highly recommended that bioretention practices are not hydraulically connected to structure foundations or pavement to avoid seepage and frost heave, respectively. If there is a concern for groundwater contamination, groundwater mapping can be conducted to determine possible connections to adjacent groundwater wells. The Minnesota Stormwater Manual provides recommended minimum setbacks as shown in **Table 5-6**.
  Adapted from ("BMP Selection Based on Physical Feasibility, Minnesota Stormwater Manual, 2019")

Table 5-6: Recommended minimum setback requirements for BMPs ("Minimum setback requirements," Minnesota Stormwater Manual, 2020)

Setback from	Minimum Distance [feet]
Property Line	10
Building Foundation*	10
Private Well	50
Septic System Tank/Leach Field	35
* Minimum with slopes directed away from the building.	

Overflow Conveyance

Overflow conveyance is necessary for all bioretention practices in order to safely convey flows that exceed the design capacity. It’s important to provide safe conveyance of larger flows within properly sized pipes, channels, or overland flood routing to a receiving waterbody to minimize risks to public safety and property damage. Figure 5-7 shows an example of an offline and online conveyance system. (Montana Department of Environmental Quality, 2017)

- **Online system** – All runoff from the drainage area flows into the bioretention area. Flows exceeding the design flow exit through an overflow structure or weir without being treated. (Montana Department of Environmental Quality, 2017)
- **Offline system** – Flow is split or diverted upstream so only the design flow enters the bioretention area and larger flows bypass the bioretention cell. This reduces required storage volume, long-term pollutant loading, and association maintenance. (New Jersey Stormwater Best Management Practices Manual, 2009)

Offline systems are preferred over online systems when feasible, especially for bioretention cells with contributing drainage areas greater than 0.5 acres. Large drainage basins can overwhelm or damage bioretention areas in online systems. (Montana Department of Environmental Quality, 2017)

Figure 5-7: Offline conveyance system (left) versus Online conveyance system (right). (Montana Department of Environmental Quality, 2017)

Underdrains and impermeable liners

Determining if underdrains or impermeable liners are required depends on the land use, proximity to adjacent structures, and soil characteristics. For a detailed procedure of the geotechnical investigation required subsurface explorations, consult Urban Storm Drainage Criteria Manual (USDCM) Volume 3 section B-3. See Figure 5-8 for details for no-, partial-, and full-infiltration sections

- **No-infiltration Section** – Contains an underdrain and impermeable liner which prevents infiltration of stormwater into the subgrade soils. Consider using this section if any of the following conditions exist:
    - "The site is a stormwater hotspot (area where land activities generate highly contaminated runoff) and infiltration may result in groundwater contamination."
    - "The site is located over contaminated soils and infiltration may mobilize these contaminants."
    - "The BMP is located over potentially expansive soils or bedrock that could swell from infiltration and potentially damage adjacent structures such as building foundation or pavement"
- **Partial Infiltration Section** – Contains an underdrain but does not contain an impermeable liner, allowing for some infiltration. Stormwater that does not infiltrate is collected and removed by the underdrain.
- **Full Infiltration Section** – Contains neither an underdrain nor an impermeable liner, designed to infiltrate water into the subgrade below.
  (Mile High Flood District, 2010)

Design requirements for under-drain systems in bioretention facilities are outlined below.

- "Slotted PVC pipe diameters from 4 to 8 inches are required."
- "Slots should be cut perpendicular to the length of the pipe at a width of 1/16th of an inch by an inch long. Slots can be on top or bottom of the pipe."
- "Slots should be spaced every ¼ inch down the length of the pipe."
- "The underdrain should be sloped a minimum of .5%."
- "For large bioretention cells a maximum distance of 25 feet is recommended between underdrain pipes."
- "For each underdrain pipe a t section is recommended to allow for insertion of water to clean out the underdrain."
  (Montana Department of Environmental Quality, 2017)

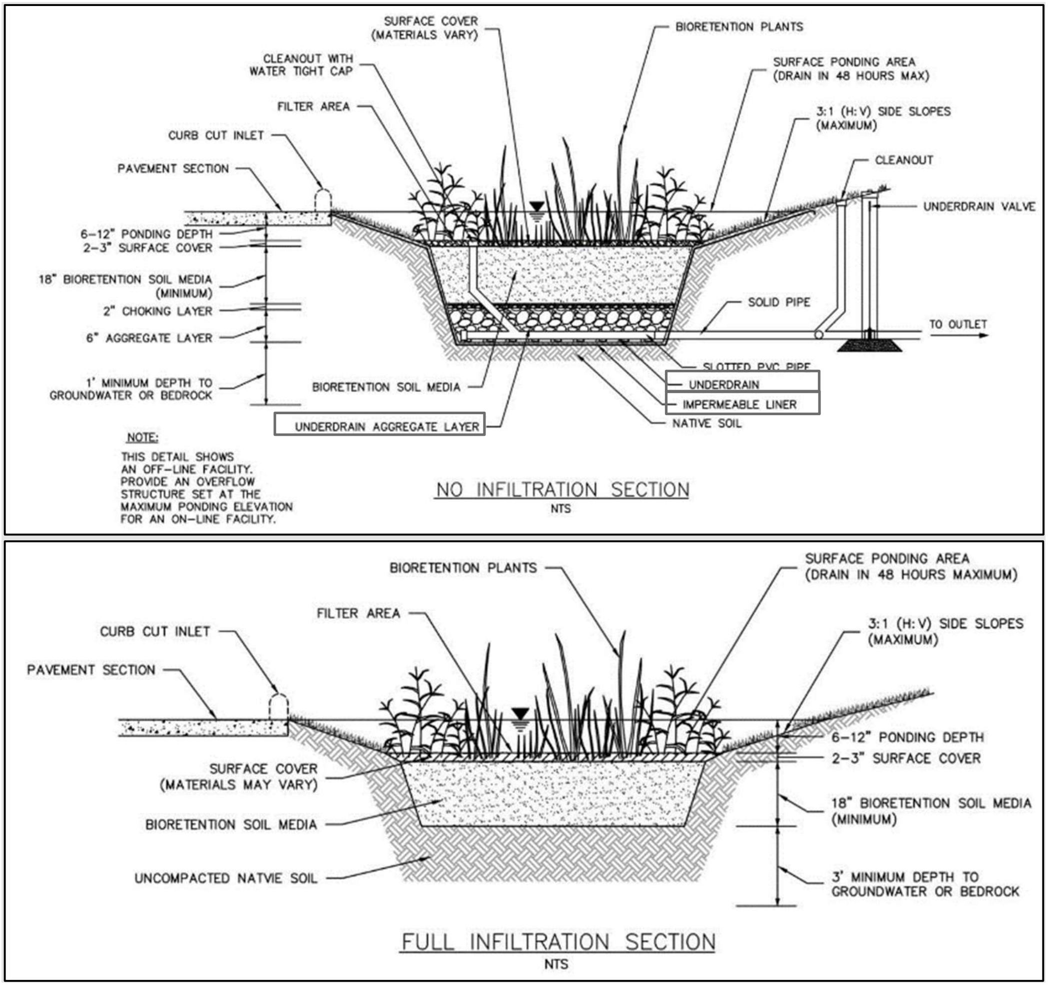


Figure 5-8: No- and full-infiltration sections (Montana Department of Environmental Quality, 2017)

Pretreatment

Pretreatment involves capturing and removing trash and coarse sediment particles from entering the filter area. Usage of pretreatment devices is required to prevent clogging of the filtration system. Areas that receive high sediment loading may have higher pretreatment requirements. Pretreatment devices include vegetated filter strip, vegetated swale, small sedimentation basin (forebay), and water quality inlet (e.g., grit chamber). Some examples of pretreatment are shown in Figure 5-9. Table 5-7 provides an overview of the pros and cons of the three types of pretreatment devices. The Minnesota Stormwater Manual also has a pretreatment practice selection tool that may be of interest to designers.

Figure 5-9: (A) Settling Device as raingarden forebay. (B) Screen. (C) Vegetated Filter Strip. ("Overview and methods of pretreatment," Minnesota Stormwater Manual, 2020)

Table 5-7: Summary of pretreatment characteristics ("Overview and methods of pretreatment," Minnesota Stormwater Manual, 2020).

Pretreatment practice	Mechanism of pollutant removal	Relative pollutant removal	Capital cost	Relative maintenance frequency	Relative maintenance effort	Relative space requirements
Pretreatment settling devices	Screening & settling	Medium	Medium to High	Medium[1]	Low to Medium	Low to Medium
Pretreatment screens	Screening	Low	Low	High	Medium	Low
Pretreatment vegetated filter strips	Screening & Settling	Medium	Low	Low	High	High

5.3.2. Bioretention Design and Sizing Procedure

Bioretention cells are often designed around their storage volume and drainage time. The procedure to calculate these parameters is discussed at the beginning of this chapter.

Storage Depth and Layer Thickness

Before the required storage depth ($D_{s,r}$) can be calculated, the BMP designer should select a bioretention cell area that meets the physical requirements and space limitations of the site. Note that the bioretention cell area does not include the sloped area along the edges of the cell. The equation to calculate the required storage depth is shown in Eq 5-3.

$$D_{s,r}\ (in) = \frac{Total\ Runoff\ Depth\ [ft] \times Drainage\ Area\ [ft^2]}{Bioretention\ Cell\ Area\ [ft^2]} \qquad \text{(Eq 5-3)}$$

The storage depth is separated into 3 different areas depending on the type of bioretention cell. Table 5-8 lists the typical range of thicknesses and porosity for each area. The total storage depth bioretention cell is found using Eq 5-4, which is a summation of all layers that will be in your bioretention cell. The bioretention storage depth (D_s) found here should be greater than or equal to the required storage depth ($D_{s,r}$) calculated in Eq 5-3

Table 5-8: Bioretention Cell Layer Thickness and Porosity for full-infiltration sections (Montana Department of Environmental Quality, 2017)

	Thickness		
	max (in)	min (in)	Porosity (μ)
Surface Ponding Storage	12	0	1
Soil Media Storage	∞	18	0.25
Underdrain Gravel	∞	6	0.4

$$\mathrm{D_s\ (in)} = \Sigma\ (\text{Layer Thickness} \times \mu) \qquad \text{(Eq 5-4)}$$

Drainage Time

Draining the bioretention cell can occur in two forms: by infiltration into the natural ground, by underdrain, or a combination of the two. To find the drainage time (T_d) the saturated hydraulic conductivity (See 5.2.2 Soil Infiltration) and the ponded layer thickness are required. The drainage time can then be calculated using Eq 6-5. A factor of safety of 2 should then be added to the result to ensure a safe drainage time. The maximum drainage time should be no more than 48 hours. If the drainage time is greater than 48 hours, an underdrain is required. (Montana Department of Environmental Quality, 2017).

$$\mathrm{T_d\ (day)} = \frac{\text{Ponded Layer Thickness [ft]} \times 2}{\text{Saturated Hydraulic Conductivity} \left[\frac{\text{ft}}{\text{day}}\right]} \qquad \text{(Eq 5-5)}$$

5.4. Green Roofs

5.4.1. Design Elements

Figure 5-10 shows the elements of a typical green roof, which are described below. For specific design guidance and vegetation suggestions, consult Tolderlund's *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West*.

- **Vegetation** – Factors to consider when selecting plants include:
    - Growth rates
    - Wind resistance
    - Drought tolerance
    - Nutrient requirements
    - Solar exposure
    - Sensitivity to pollution
    - Fire resistance
- **Growing Medium** – The growing medium provides nutrients for growth by using a combination of inorganic matter such as sand, gravel, or lightweight aggregate, and organic matter such as peat, compost, clippings, or worm casting. A typical growing medium for Sturgis's climate is composed of 85-95% expanded shale and 5-15% organic matter.
- **Filter Mat** -The purpose of the filter mat is to keep the growing media and drainage layer separated. This layer will allow water to freely move through but keeping the growing media from clogging the drainage layer.
- **Drainage Layer** – The drainage layer allows adequate moisture to remain and sustain plant life while removing any excess water. Maintenance may be required to remove debris and plant material from the drainage layer to ensure optimal functioning.
- **Insulation Layer** – This layer may be used to prevent heat loss and maintain a consistent soil temperature during the frequent freeze/thaw cycles of Sturgis. They are typically made of polyurethane foam, polystyrene foam, or fiberglass.
- **Root Barrier** - Without the proper protection, the roof could very easily be destroyed by the growth of roots. The root barrier consists of a plastic lining with a minimum thickness of 30 mm and a minimum of 6 inches of overlap between seams.
- **Waterproof Membrane** – This is the final and most critical layer of green roofs, which prevent water from entering the building. Typical materials include PVC and varieties of bituminous materials.
- **Roof Deck** - Here the roofing system begins and is no longer directly a part of the green roof. Note that adding a green roof to a structure can add a load of up to 150 psf to the structure, which may require building renovations.
  Adapted from (Tolderlund, 2010)

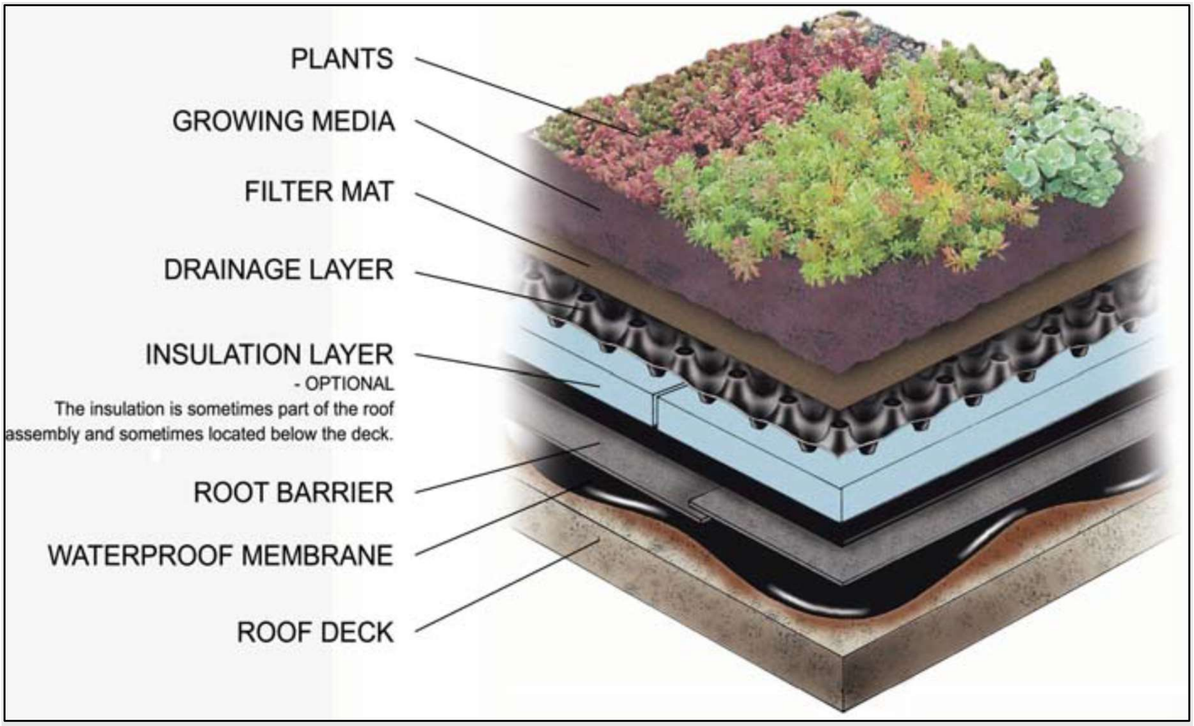


Figure 5-10: Layers of a Green Roof (Tolderlund, 2010)

5.5. Retention Pond

5.5.1. Design Elements

Retention ponds function by capturing the extra runoff slowly releasing it to a desired location. By design, retention ponds will always have standing water. The design elements for retention ponds are described as follows, and Figure 5-11 below shows a typical layout for a retention pond.

- **Treatment pool –** The treatment pool functions by slowing runoff, allowing sediment and debris to deposit by gravity. Note that the depth of the control outlet determines how the treatment pool should be designed. The treatment pool is depicted as the deep-water zone in Figure 5-11.
- **Temporary Storage –** This element functions by capturing excess runoff, storing it, and slowly releasing it over 24 hours. The volume of the temporary storage should by adjusted factor of safety of 2.
- **Inlet and Forebays –** Inlets and forebays direct runoff into the retention pond.
- **Outlet Control Structure –** This structure's purpose is regulating the depth and the outflow of the pond. Control structures can be weirs, spillways, or inverted pipes. The control structure is designed to empty the temporary storage within 24 hours. For large retention ponds, a weir or spillway should be used to ensure that water drains in an appropriate timeframe. For small retention ponds inverted pipe will suffice.
- **Pond Liner –** If the area has a high hydraulic conductivity a clay liner should be added to minimize the infiltration and retain water during droughts. The clay liner should have a minimum height of 18 inches.
  Adapted from (Stormwater Pond Design, Construction and Sedimentation, 2020)

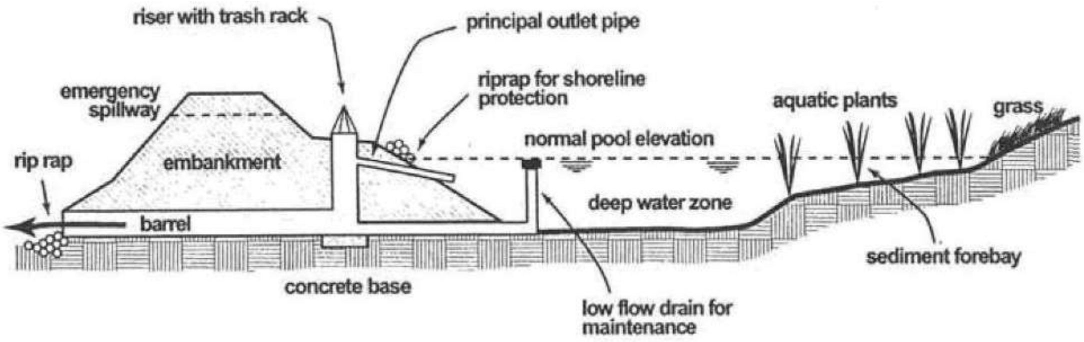


Figure 5-11: Retention Pond Schematic (Stormwater Pond Design, Construction and Sedimentation, 2020)

Excess Runoff Volume & Temporary Storage Depth

The excess runoff volume is found using Eq 5-6 and is a function of the total rainfall depth (See Eq 5-2) and contributing drainage area, which is defined as the total area, including pervious and impervious surfaces that contribute to a BMP. The drainage area can be found using Google maps, Streamstats, or other online resources.

$$Excess\ Runoff\ Volume\ (ft^3) = \frac{Total\ Rainfall\ Depth\ [in] \times Drainage\ Area\ [ft^2] \times 2}{12} \qquad \text{(Eq 5-6)}$$

The temporary storage depth is enclosed by constructed or natural soil banks. If desired, an overflow weir can be added to the pond to maintain a maximum depth. If added, the overflow weir should be located so overflow water drains water away from structures. Eq 5-7 is used to find temporary storage depth.

$$Temporary\ Storage\ Depth\ (ft) = \frac{Excess\ Runoff\ Volume\ [ft^3]}{Treatment\ Pool\ Area\ [ft^2]} \qquad \text{(Eq 5-7)}$$

Weirs & Spillways

In weirs and spillways (Figure 5-12), the maximum flow rate out of the retention pond is calculated using Eq 5-8. This parameter is a function of the rainfall intensity (see Eq 5-1). For this equation, the units of flow rate are [ft^3/s] and 43,200 is a conversion factor used to convert the final result into [ft^3/s].

$$Rain\ Flow\ Rate\ \left(\frac{ft^3}{s}\right) = \frac{I\left[\frac{in}{hr}\right] \times Drainage\ Area\ [ft^2]}{43200} \qquad \textit{(Eq 5-8)}$$

The flow rate of the weir is calculated using (Eq 5-9) and should equal roughly one-third of the rain flow rate to allow for adequate sedimentation time. Note that the height (H) and length (L) are in units of feet.

$$Weir\ Flow\ Rate\ \left(\frac{ft^3}{s}\right) = 3.247LH^{1.48} - \left[\frac{0.566L^{1.9}}{1+(2L^{1.87})}\right]H^{1.9} \qquad \textit{(Eq 5-9)}$$

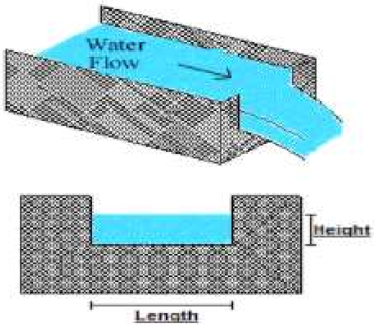


Figure 5-12: Typical Weir/Spillway

Inverted Pipe

The inverted pipe should be designed so that the temporary storage will empty less than 24 hours. The pipe diameter is found using Eq 5-10. The calculated diameter value will likely need to be rounded up to a value that is commonly manufactured and sold on the market. Table 5-9 describes the parameters of the equation and Figure 5-13 shows an example of a typical inverted pipe.

Table 5-9: Inverted Pipe Variable Descriptions

Variable	**Description**	**Units**
t	Total Drainage Time	s
A	Area of Storage Depth	ft^2
C	Orifice Coefficient	
H	Storage Depth	ft
g	Gravity	ft/s^2
D	Pipe Diameter	ft

$$D = \sqrt{\frac{4*A}{\pi} * H * \sqrt{\frac{2}{g}}} \qquad \text{(Eq 5-10)}$$

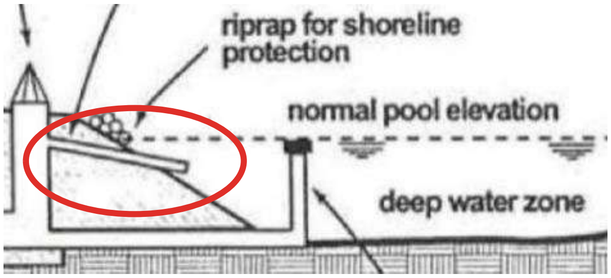


Figure 5-13: Typical Inverted Pipe

5.6. Permeable Pavement

5.6.1. Design Elements

Permeable pavements are a substitute for traditional concrete or asphalt pavement. Permeable pavements excel in parking lots, areas with low traffic speed, and where space is limited. The main factors to consider when choosing permeable pavement are climate, durability, and cost. One major concern to consider is the rapid freeze/thaw cycles in Sturgis which can cause permeable pavements to crack and degrade.

The permeable pavement unit design consists of an array of hollow columns that filled with gravel shown in Figure 5-14. This system can be placed directly over the natural soil with a filter layer to prevent mixing of the soil and gravel layers. The efficiency of permeable pavements depend on how well the stormwater can infiltrate into the soil below, and the following relationship needs to be true for them to be feasible.

$$\text{Saturated Hydraulic Conductivity (in/hr)} \geq \text{Storm Intensity (in/hr)}$$

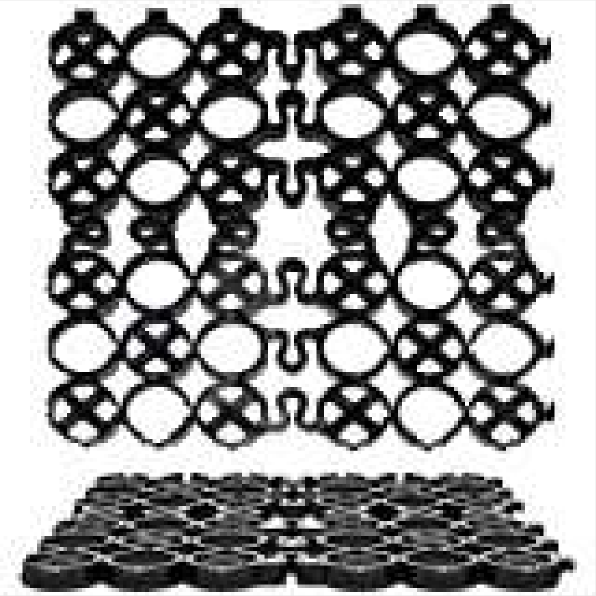


Figure 5-14: Permeable Pavement Array (True Grid Pavers)

6. BMP Maintenance

All stormwater management systems require maintenance. Proper maintenance of BMPs is important to ensure effective functioning of BMPs, protect public safety, and meet legal standards. To maximize the environmental benefits and cost-effectiveness of BMPs, BMPs should be designed with maintenance in mind. The EPA highlights some factors to consider before BMP implementation:

- Type of maintenance to be performed
- Frequency of maintenance and available personnel to perform maintenance
- Cost of component replacement (e.g., plants, shrubs, permeable pavement)
- Sufficient and dedicated funds to cover operation and maintenance activities, including the cost of replacement components
  (“Operation and Maintenance Considerations for Green Infrastructure, 2018)

Developing a Maintenance Plan

It is also important to plan for maintenance and define realistic goals for maintenance. Written plans and procedures for maintenance and accountability are critical to ensure proper long-term maintenance. It should also be identified if inspections and maintenance can be performed with existing staff, if additional staff needs to be hired, if specialized training is needed, or if it is more cost-effective to hire a contractor. (“Operation and Maintenance Considerations for Green Infrastructure, 2018)

Furthermore, it is also important to define the parties responsible for maintaining BMPs. To do this, the Urban Storm Drainage Criteria Manual Volume 3 outlines four potential strategies.

- “Publicly owned BMPs are maintained by the MS4 permittee.”
- “Publicly owned regional drainage facilities located within the UDFCD service area may be maintained by UDFCD when specific maintenance eligibility criteria are met (subject to funding limitations).”
- “Privately owned BMPs typically are maintained by the property owner, homeowner’s association, or property manager.”
- “Privately owned BMPs may be maintained by the MS4 permittee under a written agreement with the owner, with appropriate fees assessed for maintenance services.”
  (Mile High Flood District, 2010)

In the following pages, specific maintenance requirements for bioretention, rain gardens, infiltration planters, green roofs, retention ponds, and permeable pavement will be discussed.

6.1. Bioretention

Bioretention systems need to be inspected on the infiltrating surface at least annually and following any major rain events. Liter and debris need to be removed periodically to ensure clogging is minimized and proper drainage is maintained. When applicable wood mulch should be replaced when needed to keep a depth of approximately three inches. If ponded water is still visible 48hours after a storm event, underdrain locations should be checked and clean of debris.

6.2. Rain Gardens

Rain gardens infiltration surface should be inspected at least once a year or after a major precipitation event to determine if acceptable infiltration is being achieved. Debris and litter should be removed from the infiltrating surface and from the overflow structure to minimize clogging of the media. Weeds should be removed before they flower. The side slopes and grass filter strips should be inspected for evidence of any erosion and fixed immediately.

6.3. Infiltration Planter

Litter and debris in an infiltration planter should be removed to prevent channelization, clogging, and interference with plant growth. Inlets and outlets should be inspected regularly to ensure unrestricted stormwater flow. Mulch should be replaced as needed to keep plant life healthy and filter media (sand or topsoil) should be replaced when native soil is exposed, or erosion channels are forming. Planter walls should be examined for deficiencies, such as rot, cracks, and failure, and should be repaired as needed. Sedimentation build-up of over 2 inches should be removed by hand to minimize damage to vegetation.

6.4. Green roofs

Green roof inspection should be done at least three times per year. Joints, borders, waterproof membrane, or other features that pass through the roof to remove roots should be inspected periodically. Drains should be inspected frequently for vegetation and foreign objects since these must remain permanently accessible. Inspection of rotting plants should be done to remove these plants since they are no longer helpful in the drainage process. In the early Spring of each year, mowing or trimming of plants should be done and weeds should be removed continually. Inspections are the responsibility of the building owner.

6.5. Retention ponds

Retention ponds should be inspected annually with the amount of sediment in any forebays and debris at the outlet structure noted. Debris should be removed regularly; this could include floating debris that could potentially clog the outlet or overflow structure. This BMP should be checked regularly for mosquito breeding signs and treated if found. Removal of sediment from the bottom of the pond may be required every 5 to 10 years to maintain volume and deter algae growth. The inlets and outlets should be checked for material damage, erosion, or undercutting.

6.6. Pervious Pavements

Inspection of pervious pavements should be conducted at least annually; this can be done during a rain event or with a garden hose to ensure that the water is infiltrating the surface. Debris should be removed routinely; a vacuum or regenerative air sweeper will be required to help maintain or restore infiltration. For snow removal plowing is the safest option since adding sand will reduce the infiltration and liquid treatments will not stay at the surface and will be less effective.

7. BMP Costs

Construction Costs

The construction costs presented in Table 7-1 are based on two different measurements. The bioretention cells and retention ponds are based on the volume of water treated while the pervious pavement and green roofs are based on the total area for the BMP. The green roof construction costs only accounted for the green roof itself and not for any additional structural costs to support the system. These costs are averages and are listed primarily to compare between BMPs. Costs may vary widely from site to site.

Table 7-1: BMP Construction Costs

BMP Name	Cost of Water Storage	Cost of BMP Area
Bioretention Cell (Jarrett Albert)	$3 / ft^3$	-
Retention Pond (Naturally Resilient Communities)	$1 / ft^3$	-
Pervious Pavement (Kreuger G.)	-	$4 / ft^2$
Green Roof (EcoGardens)	-	$15 / ft^2$

Maintenance Costs

Similar to construction costs, the annual maintenance costs presented in Table 7-2 are based on the cost of water storage and the cost of BMP area. Again, costs may vary widely from site to site, and the following numbers should be primarily used as initial estimates to compare between BMPs.

Table 7-2: BMP Annual Maintenance Costs

BMP Name	Cost of Water Storage	Cost of BMP Area
Bioretention Cell (Jarrett Allen)	$1.25/ft^3$	-
Retention Pond (Naturally Resilient Communities)	$4/ft^3$	-
Pervious Pavement (Kreuger G.)	-	$0.20/ft^2$
Green Roof (EcoGardens)	-	$1/ft^2$

8. BMP Recommendations

8.1. Urban Streets

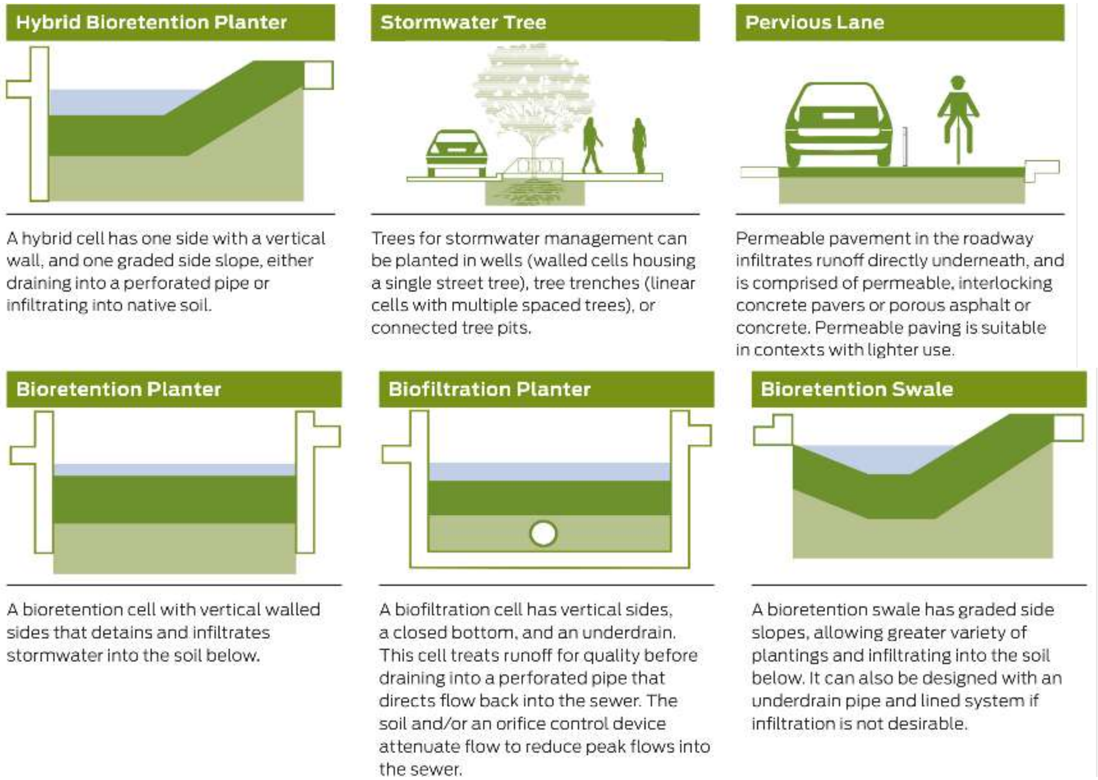
This section provides BMP recommendations for urban streets with a focus on sites where bioretention and pervious pavement practices excel. Recommendations, example street configurations, and diagrams are sourced from the National Association of City Transportation Officials (NACTO) Urban Street Design Guide. The legend and Figure 8-1 below describe the BMPs mentioned in the following recommendations. The following street types will be discussed with BMP recommendations for each.

- Ultra-Urban Street
- Boulevard
- Neighborhood Main Street
- Residential Street
- Commercial Shared Street
- Residential Shared Street
- Green Alley
- Industrial Street
- Intersection

Legend

● Stormwater BMPs with proven success in several North American cities

● Stormwater BMPs which may be successful depending on the site context



A hybrid cell has one side with a vertical wall, and one graded side slope, either draining into a perforated pipe or infiltrating into native soil.

Trees for stormwater management can be planted in wells (walled cells housing a single street tree), tree trenches (linear cells with multiple spaced trees), or connected tree pits.

Permeable pavement in the roadway infiltrates runoff directly underneath, and is comprised of permeable, interlocking concrete pavers or porous asphalt or concrete. Permeable paving is suitable in contexts with lighter use.

A bioretention cell with vertical walled sides that detains and infiltrates stormwater into the soil below.

A biofiltration cell has vertical sides, a closed bottom, and an underdrain. This cell treats runoff for quality before draining into a perforated pipe that directs flow back into the sewer. The soil and/or an orifice control device attenuate flow to reduce peak flows into the sewer.

A bioretention swale has graded side slopes, allowing greater variety of plantings and infiltrating into the soil below. It can also be designed with an underdrain pipe and lined system if infiltration is not desirable.

Figure 8-1: Green Street BMP examples (NACTO, 2017)

Boulevard

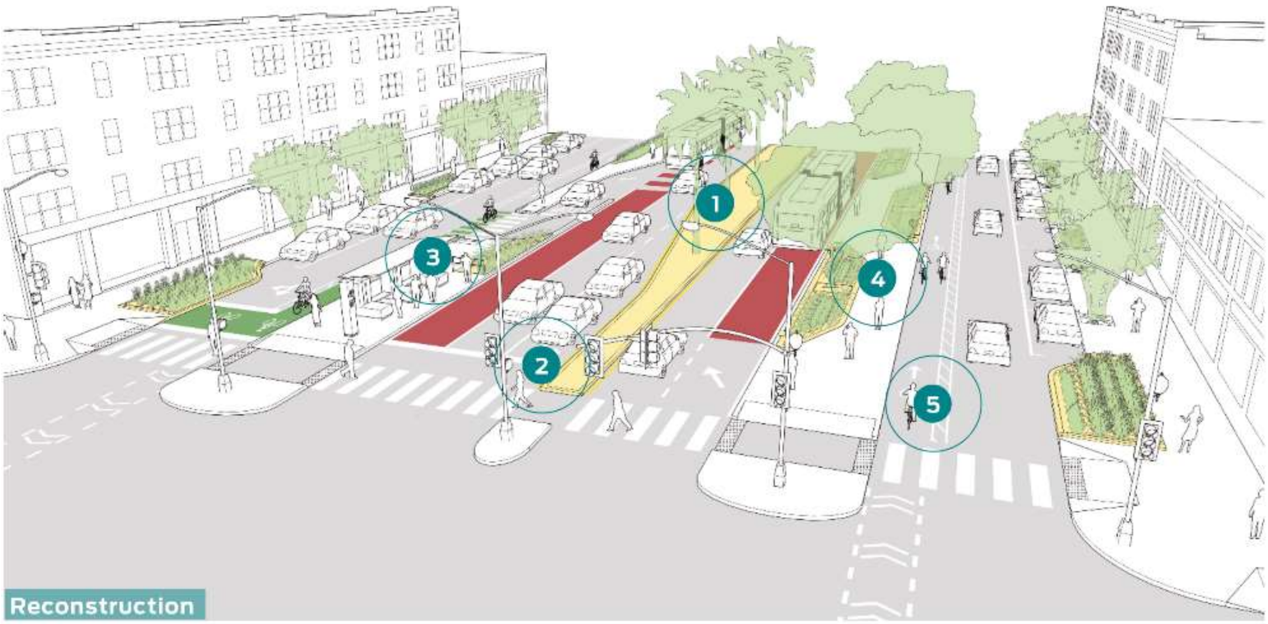


Figure 8-2: Boulevards. (NACTO, 2017)

Description

- Boulevards are often designed with wide streets and multiple lanes to maximize vehicle throughput but may be unsafe for pedestrians and cyclists.
- Boulevards with multiple wide roadbeds offer great opportunities for stormwater BMPs to reduce runoff. Road medians and curbsides can be utilized as space for BMPs.

Recommendations

1. Mature trees can manage stormwater while improving street aesthetics.
2. Consider the design of intersections to enable pedestrians to make safe, easy crossings, such as shortening and signalizing the left turn lane.
3. Bioretention BMPs are well suited for transit stops and stations
4. Bioretention swales with graded side slopes provide a buffer between pedestrian paths and the roadway
5. If applicable, permeable pavements may be used for bike routes or parking lanes

Potential BMPs

Median/Pedestrian Boulevard
- Bioretention Swale

Bikeway & Parking Lane
- Permeable Pavement

Sidewalk Planting Zone
- Tree Well or Trench
- Bioretention Planter
- Bioretention Swale

Curb Extensions (corner or midblock)
- Bioretention Planter
- Bioretention Swale

Sidewalk
- Permeable Pavement

Additional Considerations

- Street trees can be effective in the center median, providing shade and some infiltration. Bioretention may provide more runoff reduction, but it may be more expensive to implement and maintain. Consider weighing the costs and benefits of bioretention versus street trees in center medians.
- High vehicular and truck traffic may cause high sediment and debris loads. Bioretention BMPs may require larger pre-settling zones

Example Street Configuration

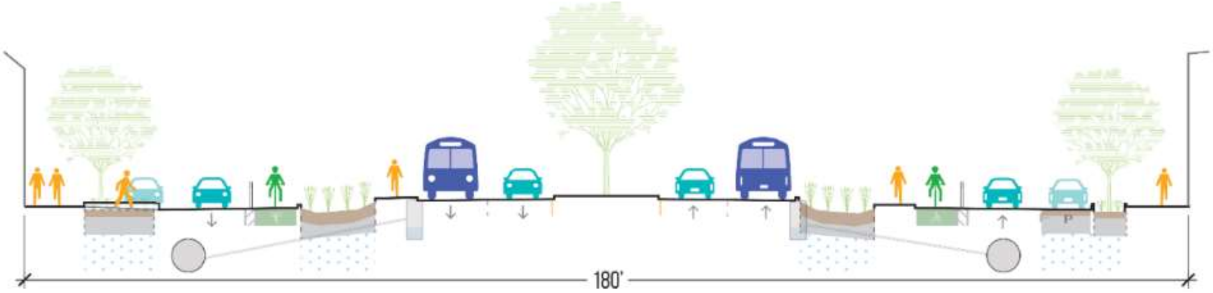
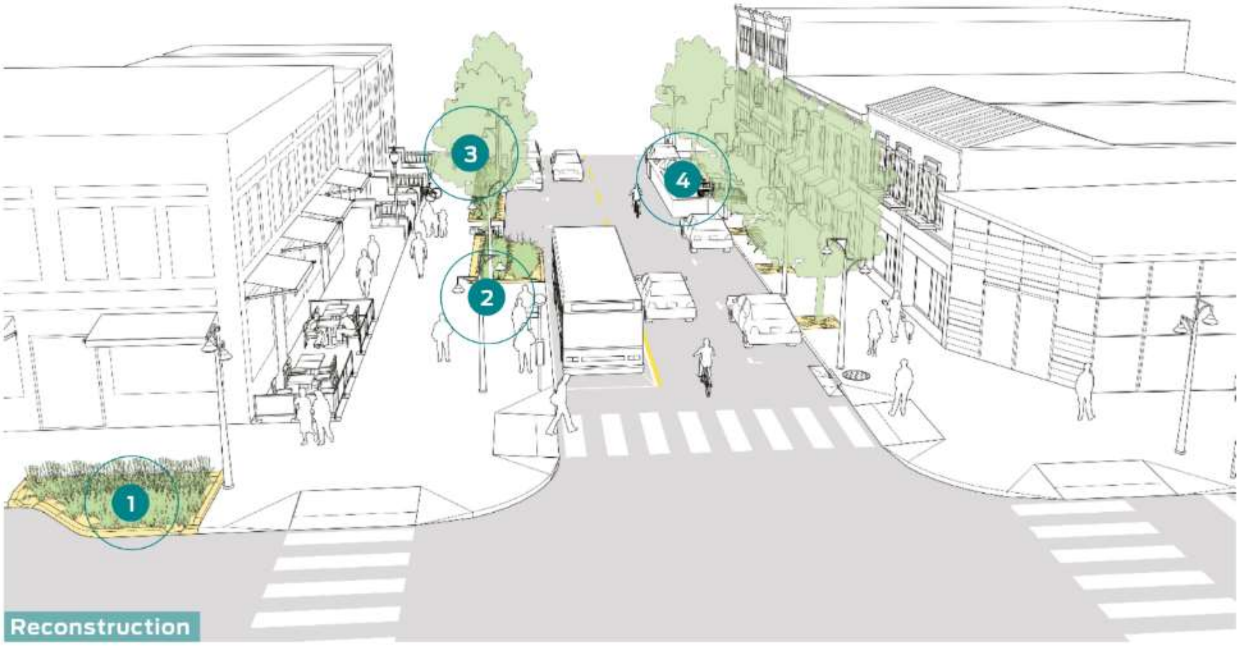


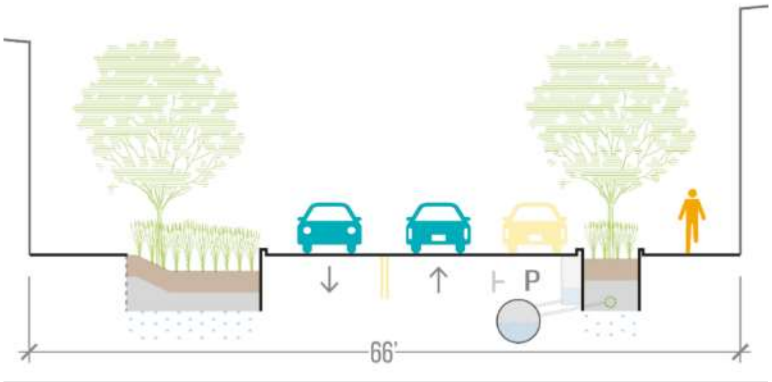
Figure 8-3: Example Boulevard Configuration (NACTO, 2017)

Figure 8-4: Bioretention area within roadway median (Montana Department of Environmental Quality, 2017)

Neighborhood Main Street



Example Street Configuration



Potential BMPs

Bikeway or Parking Lane
- 〉 Permeable Pavement ●

Sidewalk Planting Zone
- 〉 Tree Well or Trench ●
- 〉 Bioretention Planter ●
- 〉 Bioretention Swale ●

Curb Extensions (corner or midblock)
- 〉 Bioretention Planter ●
- 〉 Bioretention Swale ●

Figure 8-5: Neighborhood Main Street. (NACTO, 2017)

Description

- Neighborhood main streets are typified by a relatively high volume of pedestrians and cyclists, and frequent parking turnover and freight access.
- Neighborhood main streets provide social, economic, and community activity for cities. Green infrastructure can make neighborhood streets more inviting by providing shade, absorbing heat, and improving the aesthetics of the street.

Recommendations

1. Consider adding curb extensions with bioretention BMPs at intersections and midblock locations, which can improve pedestrian mobility and safety, shorten crossing distances, and calm vehicle traffic by narrowing the road.
2. Bioretention BMPs are well suited for transit stops and stations and may be a way to reallocate space if sidewalk space is limited.
3. Bioretention planters, stormwater tree wells, and tree trenches can be an effective reallocation of space in neighborhood main streets.
4. Parklets can provide an opportunity for bioretention and infiltration while also being vibrant community spaces

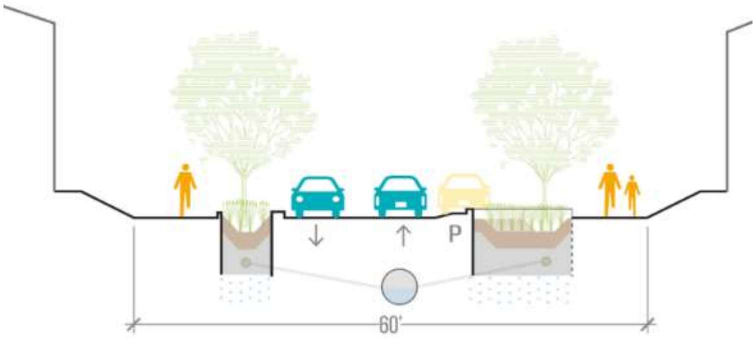
Additional Considerations

- BMPs should be designed with frequent curb access in mind, as local business activity generates high demand for delivery and freight activity.
- Coordination with business owners is key for BMP success in neighborhood main streets. Consider forming maintenance agreements with local businesses for debris removal and weeding
- If basement or building flooding is a concern for property owners, bioretention BMPs can be lined to prevent groundwater migration.

Figure 8-6: (A) T-intersection curb extension in Portland, Oregon. (B) Transit Stop in Portland, Oregon. (C) Midblock crossing in Portland, Oregon. (D) SE Division Street, Portland, Oregon (NACTO, 2017)

Residential Street

Example Street Configuration



Potential BMPs

Bikeway or Parking Lane

〉 Permeable Pavement ●

Sidewalk Planting Zone

〉 Tree Well or Trench ●

〉 Bioretention Planter ●

〉 Bioretention Swale ●

Curb Extensions (corner or midblock)

〉 Bioretention Planter ●

Sidewalk

〉 Permeable Pavement ●

Figure 8-7: Residential Street. (NACTO, 2017)

Description

- Residential streets typically have low traffic and pedestrian volumes.
- If roadways are overly wide and underutilized, space can be reallocated with green infrastructure to manage stormwater, calm streets, and provide aesthetic benefits to the neighborhood.

Recommendations

1. Planting strips can offer a large surface area for infiltration. Graded bioretention cells can be placed adjacent to sidewalks. If space is limited, tree wells and trenches may be considered.
2. Curb extension planters at the end of blocks can help manage motor vehicle volume, increase pedestrian visibility, and shorten crossing distance.
3. Midblock curb extensions may also be used to slow traffic if desired

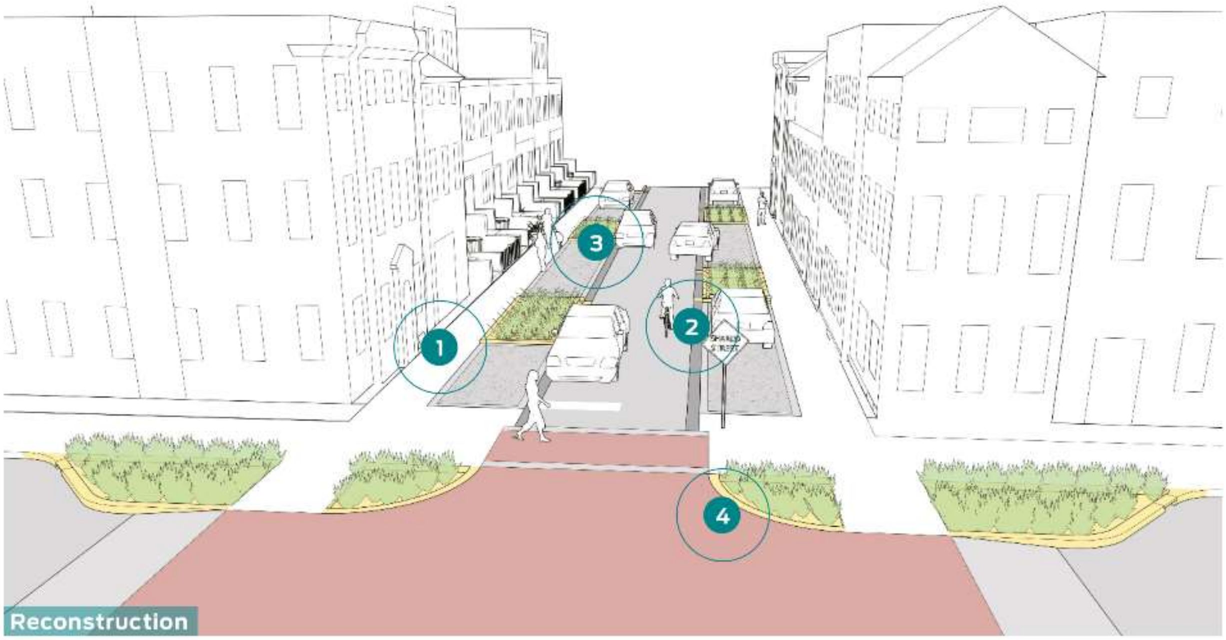
4. Usage of permeable pavement on the full roadbed or in parking zones may also help capture runoff.

Additional Considerations

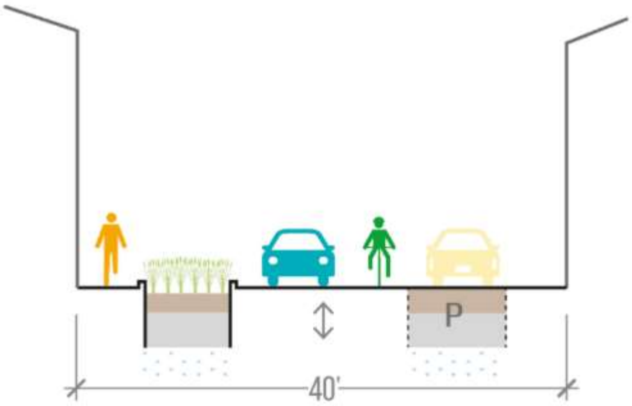
- Space may be limited for bioretention BMPs by frequent driveways and mature trees.
- Low vehicular traffic means relatively lower sediment and debris loads, making for ideal sites for bioretention and permeable pavement BMPs.

Figure 8-8: (A) Rain garden in St. Paul, Minnesota (B) Curb Extension in Portland, Oregon (City of Portland, 2012) (C). Bioretention in 34th & Cloverdale in Seattle, WA. (D) Bioretention Swale in a residential street. (NACTO, 2017).

Residential Shared Street



Example Street Configuration



Potential BMPs

Shared Roadway
- 〉 Permeable Pavement ●

Planting Zone
- 〉 Tree Well or Trench ●
- 〉 Bioretention Planter ●
- 〉 Bioretention Swale ●

Parking Lane
- 〉 Permeable Pavement ●

Figure 8-9: Residential Shared Street. (NACTO, 2017)

Description

- Residential shared streets are typified by low pedestrian and vehicle volume and non-existent or substandard sidewalks and green infrastructure. Lack of stormwater drainage in these streets can cause flooding to be a common occurrence.
- Residential shared streets can be redesigned with pedestrians and cyclists in mind to make it a more accessible shared space.

Recommendations

1. Textured or permeable pavements can be used to help delineate that the street is shared with pedestrians. Material selection should be compatible with winter maintenance and snow plowing.
2. Trench drains can also be utilized to collect and direct runoff into bioretention planters, while also helping to delineate the street.
3. The street grade should be at least 1% to drain runoff but cannot exceed 2% to remain accessible to pedestrians.
4. Pinch-points, speed humps, raised crosswalks, or speed tables may be utilized to slow or restrict or slow traffic flow if desired.

Additional Considerations

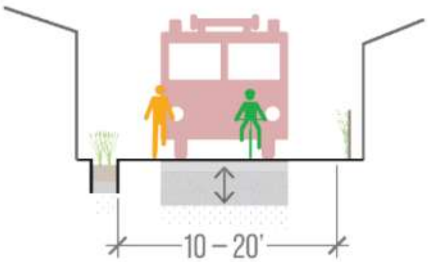
- Residential shared streets, despite sometimes lacking sidewalks, function as de-facto shared spaces.
- Low fencing or slotted curbs may be placed around bioretention BMPs to prevent pedestrians and vehicles from trampling them.
- Bioretention BMPs with vertical walls should be designed with shallow depth and tight geometries to reduce tripping or injury.

- Street furniture, such as benches, planters, streetlights, sculptures, trees, bicycle parking, and bollards can be used to delineate pedestrian spaces. If basement or building flooding is a concern for property owners, bioretention BMPs can be lined to prevent groundwater migration

Figure 8-10: Residential shared street examples. ("Residential Shared Street," NACTO, 2015)

Green Alley

Example Street Configuration



Potential BMPs

Roadbed

- 〉 Permeable Pavement ●

Property Line/Adjacent Properties

- 〉 Bioretention Planter ●
- 〉 Permeable Pavement ●

Figure 8-11: Green Alley. (NACTO, 2017)

Description

- Alleyways typically have infrequent maintenance, potholes, and puddling, making them unattractive and inaccessible.
- Alleys can be redesigned with green infrastructure to transform them from unattractive spaces to more positive ones while improving accessibility for service vehicles, delivery vehicles, pedestrians, and cyclists.

Recommendations

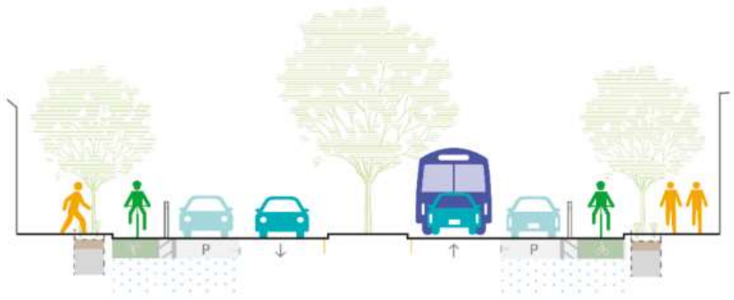
1. Permeable pavements with high reflectivity can be used to reallocate space while also managing stormwater and reducing heat island effects. Permeable pavements should be located away from waste and recycling containers to prevent debris from being deposited in the pavement.
2. Bioretention BMPs can manage stormwater while making alleyways more aesthetically pleasing.

Additional Considerations

- Surface or subsurface space may be limited in some areas due to utilities.

Intersection

Example Street Configuration



Potential BMPs

Plaza / Curb Extension
- 〉 Bioretention Planter ●
- 〉 Bioretention Swale ●
- 〉 Tree Trench ●

Planting Zone
- 〉 Bioretention Planter ●
- 〉 Bioretention Swale ●
- 〉 Tree Well or Trench ●

Bike / Parking Lane
- 〉 Permeable Pavement ●

Figure 8-12: Intersection. (NACTO, 2017)

Recommendations

1. Curb extensions can shorten crossing distances and curb radii to accommodate pedestrians while also providing a site for bioretention BMPs.
2. Tree wells and tree trenches can provide shade and increase walking comfort while using little space.
3. Consider adding pedestrian safety islands where possible to improve pedestrian safety and provide a location for bioretention BMPs.

Additional Considerations

- Minimize unused space. Large intersections are often over-designed and difficult for both vehicles and pedestrians. Assess if all travel lanes are necessary and the impact of removing a lane of traffic.

- Avoid placing drainage grates and catch basins at corners or places where pedestrians may trip when stepping on or off the curb.

Figure 8-13: Intersection examples. (A) (NACTO, 2017). (B) ("Major Intersections", NACTO, 2015).

8.2. Applications for Parking Lots

With some planning and creativity, one can find numerous opportunities to implement BMPs in limited spaces. Figure 8- 14 shows an example of five potential BMP in a small region around a parking lot using bioretention cells, an infiltration planter, and a rain garden, demonstrating how easy it is to visualize existing parking lots with green infrastructure. That said, BMP designers should still conduct physical feasibility analyses to confirm if these sites are applicable based on the location of underground utilities, soil type, etc..

City ordinance dictates how much of a private property can be covered with permanent structure which includes asphalt and concrete parking lots. River rock is allowed, but a certain amount of green is required. Green spaces require some sort of trees, shrubs, grasses or other plantings.

Figure 8-14: Examples of potential BMP applications in parking lots

Bioretention [right bottom] ("Stormwater Quality"). Bioretention [right middle] ("LID Urban Design Tools – Bioretention"). Bioretention [top right] (Sustainable Stormwater Using Bioretention: Engineering Better Water Quality, 2019). Rain Garden ("Rain Gardens and Stormwater Ponds."). Infiltration Planter (Madroño Landscape Design Studio, 2010).

8.3. Bioretention Design Example

This section provides a design example for a bioretention cell for a parking lot. The parking lot will have an assumed slope towards the corner of the parking lot. For this design, the required parameters are total runoff depth (see 5.2.1 Design Storm) and hydraulic conductivity (see Figure 5-4 & Table 5-5). Table 8-1 shown below lists the assumptions and design values for the bioretention cell.

The required storage depth was found using Eq 8-1 below which was modified from Eq 8-3. Table 5-8 was added below for reference. Eq 8-4 was modified to find the ponding storage depth. The total storage depth was assumed to be the same required storage depth found in Eq 8-1. To find the ponding depth Eq 8-2 was modified from Eq 8-4.

Table 8-1: Bioretention Cell Design Values

Calculated	
Total Runoff Depth (in)	0.781
Hydraulic Conductivity (ft/day)	2.835
Assumed	
BMP Percent Area	5%
Soil Media Storage Depth (in)	18
Underdrain Gravel (in)	6

$$D_{s,r}\ (in) = \frac{Total\ Rainfall\ [ft]}{Percent\ BMP\ Area} \qquad \text{(Eq 8-1)}$$

$$D_{s,r}\ (in) = \frac{0.781}{0.05} = 16.62\ in$$

Table 5-8: Bioretention Cell Layer Thickness and Porosity for full-infiltration sections (Montana Department of Environmental Quality, 2017)

	Thickness		
	max (in)	min (in)	Porosity (μ)
Surface Ponding Storage	12	0	1
Soil Media Storage	∞	18	0.25
Underdrain Gravel	∞	6	0.4

$$\text{Ponding Depth (in)} = \text{D}_{\text{s,r}} - (\text{Soil Media Depth} * \mu) - (\text{Underdrain Gravel Depth} * \mu) \qquad \text{(Eq 8-2)}$$

$$\text{Ponding Depth (in)} = 16.62\text{ in} - (18\text{ in} * 0.25) - (6\text{ in} * 0.4) = 9.72$$

Lastly, the drainage time is calculated using Eq 5-5 with the hydraulic conductivity that was previously found. The calculated drainage time was less than the required 48 hours, no additional drainage systems are required.

$$\mathrm{T_d\ (day)} = \frac{\text{Ponded Layer Thickness [ft]} \times 2}{\text{Saturated Hydraulic Conductivity} \left[\frac{\text{ft}}{\text{day}}\right]} \qquad \text{(Eq 8-2)}$$

$$\mathrm{T_d\ (day)} = \frac{9.72\ \text{in}/12}{2.835\ \frac{\text{ft}}{\text{day}}} = .286\ \text{days}$$

9. Conclusion

With recent development in Sturgis, SD, much of the land surface has become impervious, making the city susceptible to flooding. The environmental impacts of runoff include stream degradation, water pollution, and property damage, leading cities to consider more environmentally conscious solutions to stormwater management. With this in mind, green infrastructure can be an effective solution while providing Sturgis numerous environmental, economic, and community benefits. Discussed was an overview of the factors to consider in BMP selection, design, and maintenance, emphasizing Sturgis' cold semi-arid climate. In sum, with the effects of increased urbanization in mind, proper stormwater management is of vital importance. If implemented correctly, green infrastructure can manage stormwater in an effective, sustainable, and cost-effective manner.

For more specific guidance for selection, design, and maintenance of BMPs, consider consulting the Minnesota Stormwater Manual, Urban Storm Drainage Criteria Manual (USDCM), and Denver Ultra-Urban Green Infrastructure Guidelines, among other resources.

See Sturgis Stormwater Design Requirements for more detailed design parameters.

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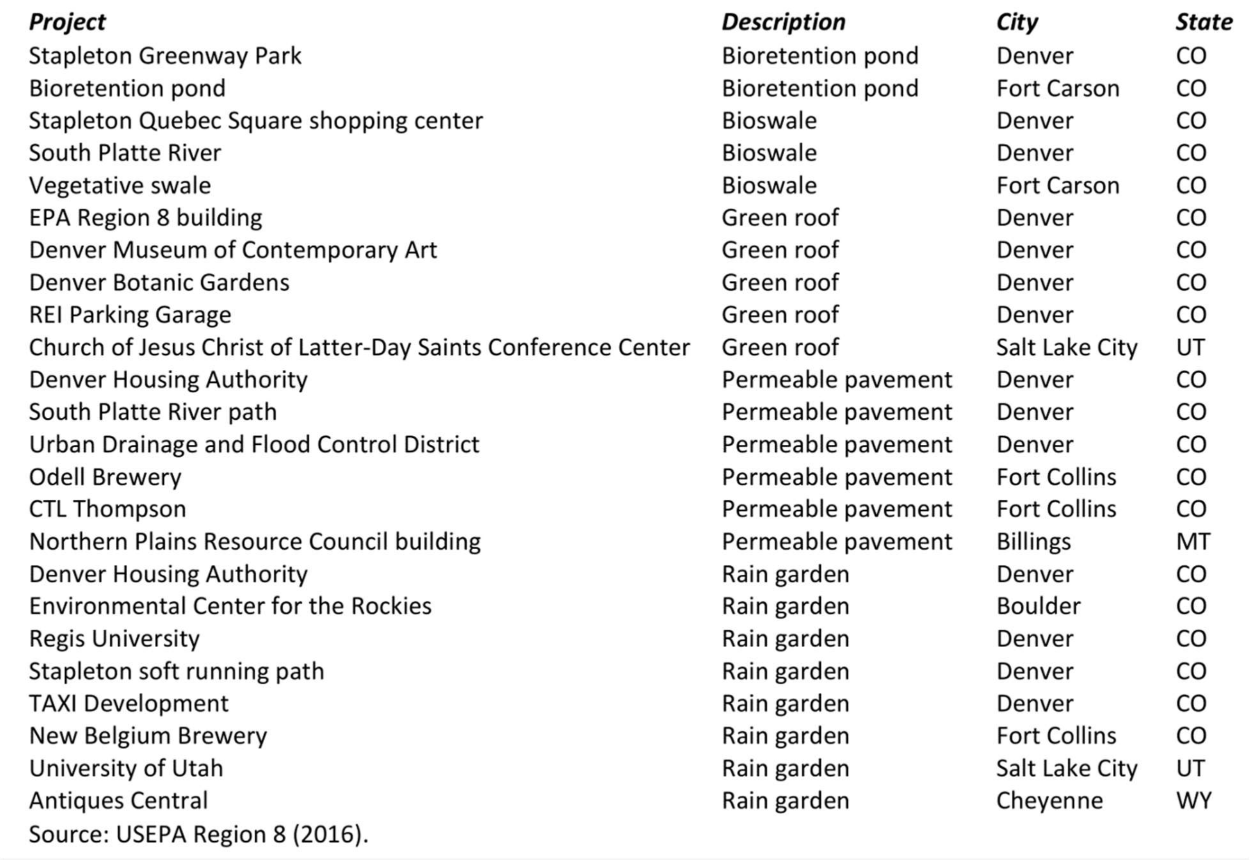
Appendix A: Additional Figures and Tables

Table 0-1: EPA Region 8 green infrastructure projects in the semi-arid west (Lee and Schumer, 2016)



Project	***Description***	***City***	***State***
Stapleton Greenway Park	Bioretention pond	Denver	CO
Bioretention pond	Bioretention pond	Fort Carson	CO
Stapleton Quebec Square shopping center	Bioswale	Denver	CO
South Platte River	Bioswale	Denver	CO
Vegetative swale	Bioswale	Fort Carson	CO
EPA Region 8 building	Green roof	Denver	CO
Denver Museum of Contemporary Art	Green roof	Denver	CO
Denver Botanic Gardens	Green roof	Denver	CO
REI Parking Garage	Green roof	Denver	CO
Church of Jesus Christ of Latter-Day Saints Conference Center	Green roof	Salt Lake City	UT
Denver Housing Authority	Permeable pavement	Denver	CO
South Platte River path	Permeable pavement	Denver	CO
Urban Drainage and Flood Control District	Permeable pavement	Denver	CO
Odell Brewery	Permeable pavement	Fort Collins	CO
CTL Thompson	Permeable pavement	Fort Collins	CO
Northern Plains Resource Council building	Permeable pavement	Billings	MT
Denver Housing Authority	Rain garden	Denver	CO
Environmental Center for the Rockies	Rain garden	Boulder	CO
Regis University	Rain garden	Denver	CO
Stapleton soft running path	Rain garden	Denver	CO
TAXI Development	Rain garden	Denver	CO
New Belgium Brewery	Rain garden	Fort Collins	CO
University of Utah	Rain garden	Salt Lake City	UT
Antiques Central	Rain garden	Cheyenne	WY

Source: USEPA Region 8 (2016).

Table 0-2: Studies exploring contributions of green spaces and nature to human health. Adapted from (Tzoulas, 2007)

Author	Type of study	Human health aspect
Kellert and Wilson (1993)	Interdisciplinary studies synthesis	Innate need to be in contact with biodiversity for psychological well-being and personal fulfilment
Takano et al. (2002), Tanaka et al. (1996)	Epidemiological	Urban green space users have greater longevity
de Vries et al. (2003)	Epidemiological	Urban green space users had better self-reported health
Payne et al. (1998)	Questionnaire and diary survey	Urban park users reported better general perceived health, more physical activity, and relaxation
Ulrich (1984), Ulrich et al. (1991)	Experimental	Natural views provide relaxation, increased positive self-reported emotions, and recovery from stress
Kim and Kaplan (2004)	Survey	Natural features and open spaces in a residential area enhance sense of community

Table 0-3: Increase in property values from trees. Adapted from (Wolf, 2007)

Usage	Price Increase	Condition	Author
Yard and Street Trees	2%	Mature yard trees (greater than 9-inch dbh)	(Dombrow and Sirmans, 2000)
	3-5%	Trees in front yard landscaping	(Anderson and Cordell, 1988)
	6-9%	Good tree cover in a neighborhood	(Morales et al., 1976)
	10-15%	Mature trees in high-income neighborhoods	(Theriault et al., 2002)
Tree Retention in Development	18%	Building lots with substantial mature tree cover	(Morales et al., 1983)
	22%	Tree-covered undeveloped acreage	(Payne and Strom, 1975)
	19-35%	Lots bordering suburban wooded preserves	(Thorsnes, 2002)
	37%	Open land that is two-thirds wooded	(Payne, 1973)
Parks and Open Space	10%	Inner-city home located within 1/4 mile of a park	(Watcher and Gillen, 2006)
	10%	House two to three blocks from a heavily used, active recreation park	(Crompton, 2001)
	17%	Home near cleaned-up vacant lot	(Watcher and Gillen, 2006)
	20%	Home adjacent to or fronting a passive park area	(Crompton, 2001)
	32%	Residential development adjacent to greenbelts	(Corell et al., 1978)
Retail and Commercial	7%	Rental rates for commercial offices having quality landscape	(Laverne and Geidman, 2003)
	9-12%	Reported increase in consumer spending in forested business districts	(Wolf, 2005)
	23%	Homes within 1/4 mile of "excellent" commercial corridor	(Watcher and Gillen, 2006)

Table 0-4: Stormwater Treatment Suitability Matrix. Adapted from (City of Lincoln, NE, 2020)

BMP Family	BMP List	RUNOFF HYDROLOGY		WATER QUALITY BENEFIT			
		Rate Control	Volume Reduction	TSS	P & N	Metals	Fecal Coliform
Retention	Wet Pond	High	Low	Primary	Secondary	Secondary	Secondary
	Extended Storage Pond	High	Low	Primary	Secondary	Secondary	Secondary
	Wet Vaults	Medium	Low	Primary	Secondary	Secondary	Minor
Detention	Dry Pond	High	Low	Secondary	Minor	Minor	Minor
	Oversized Pipes	High	Low	Secondary	Minor	Minor	Minor
	Oil Grid/Separator	Low	Low	Secondary	Minor	Minor	Minor
	Dry Swale	Medium	Low	Primary	Secondary	Primary	Minor
Infiltration	On-Lot Infiltration	Medium	High	Primary	Primary	Primary	Secondary
	Infiltration Basin	Medium	High	Primary	Primary	Primary	Secondary
	Infiltration Trench	Medium	High	Primary	Primary	Primary	Secondary
Wetland	Stormwater Wetland	High	Medium	Primary	Secondary	Secondary	Primary
	Wet Swale	Low	Low	Primary	Secondary	Secondary	Minor
Filtration	Surface Sand Filters	Low	Low	Primary	Secondary	Primary	Secondary
	Underground Filters	Low	Low	Primary	Secondary	Primary	Secondary
	Bioretention	Medium	Medium	Primary	Primary	Primary	Secondary
	Filter Strips	Medium	Medium	Secondary	Minor	Minor	Minor

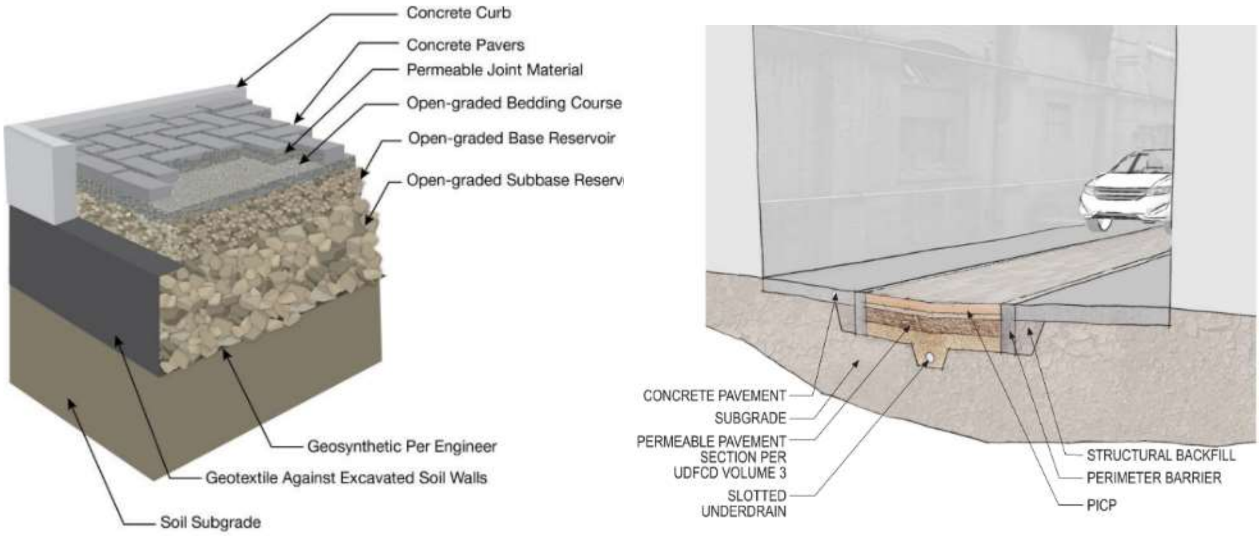


Figure 0-1: Permeable pavements details (City and County of Denver, 2016).