Stormwater Source Control Practices Handbook

THE CITY OF
CALGARY
WATER RESOURCES

This guide is based on information contained in The City of Calgary, Water Resources *Source Control Practices Reference Manual (May 2007)* prepared by:

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I. OVERVIEW

1. Introduction

The City of Calgary is committed to becoming an environmentally sustainable community by providing the leadership to conserve, protect and improve the environment for the benefit of Calgarians and the regional community. This includes ensuring environmental considerations are part of all City of Calgary decisions respecting planning for growth, development and operations. The City is also dedicated to encouraging and demonstrating resource conservation and pollution prevention.

Environmental stewardship in the area of water management is a municipal responsibility that touches the lives of every citizen of our city and the surrounding communities. Calgary City Council has established the sustainable use of water resources and watershed protection as important priorities. The City is also subject to stringent provincial regulatory requirements aimed at preserving our water resources.

Our city's rapid population and urban growth since 1996 has raised concerns over our ability to sustain the health of our city's rivers and streams and the integrity of our watersheds. Residential development increases the city's total stormwater runoff, which can lead to channel erosion, higher pollutant loads, deterioration of receiving stream water quality, and can adversely impact aquatic ecosystems and wildlife habitat. Conventional land development practices can generate 10 to 100 times more stormwater runoff compared to predevelopment conditions. This generally occurs through elimination of natural ground cover, increase in the impervious areas, grading and soil compaction, and elimination of depression storage.

Alberta Environment and The City of Calgary have developed a Total Loading Management Plan aimed at limiting pollutant discharges and protecting the health of the Bow River. Since 2001, The City has been monitoring pollutant discharges in stormwater and calculating total loads entering the Bow River. The river is approaching assimilative capacity for some pollutants. Sediments are of particular concern as over 85 percent of sediment loads come from stormwater. These results highlight the importance of developing new stormwater management practices in new and existing communities to meet our regulatory requirements and protect the health of our streams, rivers and drinking water reservoirs.

This document is designed to serve as a toolbox of options for The City of Calgary and all local professionals involved in the management of stormwater runoff. Developed in the context of local economic, geologic and climatic conditions, the Source Control Practices (SCPs) in this document will help ensure that the rate of growth in our city does not outpace our ability to protect and enhance our valuable water resources from the potentially deleterious effects of stormwater runoff.

2. Evolution of stormwater management in Calgary

As of the end of 2006, The City of Calgary operated and maintained 116 wet ponds and wetlands, 83 dry ponds, 3,500 kilometres of storm sewer mains and over 400 outfalls. Up to one hundred kilometres of storm sewer mains and ten new stormwater wet ponds are constructed annually.

Since 1998, wet ponds or wetlands have been constructed in all new development areas to provide stormwater treatment. Although these treatment facilities usually provide adequate removal of large sediment particles to meet current provincial regulations, they do not remove finer particles and nutrients. In addition, they do not reduce the overall volume of stormwater nor do they promote the preservation of the natural hydrologic processes in the watershed. Older inner-city neighbourhoods and most residential developments constructed prior to 1998 have no stormwater treatment facilities and discharge untreated runoff to the Bow River.

The assessment of the Nose Creek, West Nose Creek and Pine Creek watersheds has established that the only options that would truly minimize changes to the morphology of the creek due to urban development include stormwater source control strategies that would reduce the overall volume of runoff discharges in addition to providing peak flow control. These findings identified the need for new approaches to deal with stormwater runoff from urban areas.

The limitations of conventional stormwater design and 'end-of-pipe' treatment facilities can be mitigated by introducing, adding or enhancing pollution prevention strategies in stormwater system design and controlling runoff close to or at its source. Source control of runoff reduces the volume and rate of runoff thus reducing the pollutant loads. Rainfall captured at the source can be returned to the original, natural hydrologic pathways through practices that promote infiltration, evaporation and reuse.

There are many types or classifications of SCPs that can be implemented to reduce pollution, flow rates and volumes of urban runoff. Using the concept of a "treatment train", four different levels of controls are typically defined, as shown in Table 1.

Table I-1 – Level of SCP Control

Level of SCP Control	Description
Pollution Prevention	Programs directed at good housekeeping practices, waste disposal programs, spill prevention and response programs, illicit discharge detection programs, and public education.
Site	Site-specific measures designed to minimize the generation of runoff and pollutants and to manage volumes and rates of runoff at or near its source, before it reaches a municipal conveyance system. These typically include better site design practices that reduce the impervious coverage and SCPs such as bioretention areas, green roofs, porous pavement options, and stormwater reuse practices.
Neighbourhood	Broader focus, primarily on public property that includes "green infrastructure" features such as grass swales, bioswales, buffer areas, and green streets or lanes.
Watershed	Primarily end-of-pipe controls constructed at a downstream point of stormwater system to manage runoff from large areas.

3. Important considerations regarding source control practices

This document does not encompass commonly accepted end-of-pipe practices such as wet ponds and constructed wetlands, erosion and sediment control, or proper housekeeping measures. Although it is recognized that the design and implementation of these measures can still be improved, they are covered in other documents issued by the City of Calgary, Water Resources.

Although this resource provides basic information on source control practices, design will vary depending on hydrologic and water quality targets, land use and whether the development is new or a retrofit.

This resource was developed using data and experience with stormwater management practices in Vancouver, British Columbia; Denver, Colorado; Minneapolis-St. Paul, Minnesota; Portland, Oregon; Maryland, Australia, Scandinavia and Germany. All published guidelines and standards were given careful consideration with respect to Alberta's unique climate and soil conditions. Throughout the document, where necessary and appropriate, comments are provided regarding local site-specific conditions.

4. Source Control Practices (SCPs)

This document provides an in-depth examination of the following seven (7) source control practices:

1. Better Planning Practices
2. Grass Swales or Bioswales
3. Absorbent Landscaping
4. Bioretention Areas
5. Porous Pavement
6. Stormwater Reuse
7. Green Roofs

The City of Calgary would consider any additional source control measures beyond the seven (7) presented here, if it is determined that they would be feasible under given circumstances.

5. Applicability of Source Control Practices

Table I-2 presents a summary overview of the potential applicability of source control measures within an urban context, distinguishing between ultra-urban development (i.e. inner-city/high-density), infill redevelopment, industrial, commercial and multi-family land uses, single-family residential subdivisions and parkland/open space.

Table I-2 Applicability Matrix

Source Control Types	Development Type					
	Ultra Urban	Infill Redevelopment	Industrial	Commercial and Multi Family	Residential	Parks and Open Space
Better Planning Practices	✓	✓	✓	✓	✓✓	✗
Stormwater Reuse	✓	✓	✓✓	✓✓	✓✓	✓✓
Grass Swales or Bioswales	✗	✓	✓✓	✓	✓✓	✓✓
Bioretention Areas	✓	✓✓	✓	✓✓	✓✓	✓✓
Green Roofs	✓✓	✗	✓✓	✓✓	✗	✗
Porous Pavement	✓	✓	✓	✓✓	✓✓	✓✓
Absorbent Landscaping	✓	✓	✓✓	✓✓	✓	✓✓

✓ Somewhat Applicable

✓✓ Highly Applicable

✗ Not Applicable

6. Potential performance of Source Control Practices

Table I-3 provides a summary matrix of the potential performance of the seven (7) source control practices.

Table I-3 Performance Matrix

		Suitability for Calgary Climate and Soils [1]	Environmental Performance			Maintenance	Community Acceptance	Cost [3]
			Pollutant Removal	Peak Flow Reduction [2]	Volume Reduction			
Types	**Better Planning Practices**	High	N/A	Medium	Medium	N/A	High	Low
	Grass Swales or Bioswales	High	High	Medium	Medium	Low	Medium	Low
	Absorbent Landscaping	High	High	Medium	High	Low	High	Low
	Bioretention Areas	High	High	Medium	Low	Medium	High	Medium
	Porous Pavement	Medium	Medium	Medium	Low	Medium	Medium	High
	Stormwater Reuse	High	N/A	Medium	High	Low	Medium	Low
	Green Roofs	High	N/A	Medium	High	Low	Medium	Medium

1 Subdrain system may be required.

2 The source control practices listed above are typically designed for smaller storms and the "peak flow reduction" should be considered in that context.

3 In many cases, costs can be offset by savings (e.g. reduced potable water use, smaller end-of-pipe facilities, etc.)

7. Assessment criteria

This document provides a detailed assessment of each of the seven (7) source control measures based on the following criteria:

1. Description
2. Application
3. Hydrologic benefits
4. Design:
   - Design approach

- Design examples
- Limitations
- Vegetation
- Space requirements

5. Construction
6. Performance and impact on surrounding community/environment:
   - Impact on adjacent infrastructure
   - Community and environmental factors
   - Performance with regard to pollutants of concern
   - Performance under cold climate conditions
7. Long-term issues:
   - Long-term sustainability
   - Life-cycle costs
   - Safety and liability
   - Failure scenarios

A detailed discussion of these criteria can be found in Appendix A.

II. Source Control Practices (SCPs)

1.0 Better Planning Practices (BPPs)

1.1 *Description*

BPPs are designed to accomplish three goals at development sites: (1) Reduce the amount of impervious cover, (2) Increase natural lands set aside for conservation, and (3) Use pervious areas for more effective stormwater treatment. To meet these goals, The City of Calgary encourages designers to scrutinize every aspect of a site plan – streets, parking spaces, setbacks, lot sizes, driveways and sidewalks – to determine if any of these can be reduced in scale. At the same time, creative grading and drainage techniques reduce stormwater runoff and encourage more infiltration and/or evaporation.

Stormwater BPPs are one aspect of sustainable development, which is widely described as land development that is more economically, environmentally and socially responsible. The intent of the approach is to build and/or rebuild communities that are in balance with the natural environment. Sustainable development aligns with The City of Calgary's triple-bottom-line approach to all municipal operations and decision-making.

A development philosophy based on sustainability focuses on:

Compact, complete communities

- Increased transportation options
- Reduced loads on water, waste and energy systems
- Protection and restoration of urban green space
- A lighter 'hydrologic footprint'
- Increased stream and wetland protection

In addition to incorporating street layout, housing type and architectural design considerations into a development, a BPP approach also integrates the following stormwater and environmental management elements:

- Hydrology – Water sensitivity is a guiding principle during initial site assessment and planning phases.
- Application of BPPs – Individual BPPs are distributed throughout the project site and influence the configuration of roads, lotting, and other infrastructure.
- Multi-functional approach – The development includes amenities that fulfill multiple functions e.g. aesthetic landscaping, visual breaks that increase a sense of privacy within a variety of housing densities, and a design element (of equal importance to architectural design and street plan layout) that promotes neighbourhood identity.

Traditionally, runoff from green or open space has been dealt with separately from runoff generated by roadways or other impervious surfaces. Since runoff from impervious surfaces is the primary cause of drainage-related concerns, such as stream degradation and flooding risks, limiting impervious coverage is an important means of reducing runoff flow rates and runoff volume. A reduction in effective impervious coverage on lots and roads can improve the efficiency of source controls by reducing the amount of runoff the controls are designed to manage.

1.2 *Application*

Table 1-1 presents a BPP checklist for new developments, redevelopment and retrofits.

Table 1-1 BPP Checklist

Minimize Stormwater Runoff		
	Use hydrology as the integrating framework	
		Reproduce pre-development hydrology
		Create a multi-functional landscape, which incorporates stormwater features into the landscape
		Use surface water elements as the focal civic spaces
	Site fingerprinting	
		Incorporate smaller lot sizes to minimize total impervious area
		Confine construction and development to least critical/sensitive areas
		Preserve open space/natural areas
		Reduce limits of clearing and grading
		Stage construction, i.e., limit area exposure of the site at any one time
		Minimize soil compaction
	Preserve and emulate natural drainage	
		Utilize existing flow paths
		Fit development to the terrain
		Restore the drainage and/or biological capacity of damaged or lost solids through mechanical improvements or soil amendments
	Impervious surfaces	
		Reduce
		Minimize
		Disconnect
Mitigate stormwater runoff		
	Think micromanagement	
		Control runoff at the source
		Minimize runoff by maximizing infiltration, evapotranspiration, and filtration
		Employ natural processes for water quality improvement
	Stormwater treatment train	
		Utilization of simplistic, non-structural methods
		Use redundant runoff treatment systems

- At a regional planning level stage, a series of maps should be produced identifying watercourses, wetlands, buffers, steep slopes and other hazard areas, significant wildlife habitat areas, and also permeable soils offering the best available infiltration potential. Maps can be combined as GIS or CAD layers to delineate the best areas for development. Building sites, road layout, and stormwater infrastructure should be configured within these development areas to minimize soil and vegetation disturbance and take advantage of a site's natural stormwater processing capabilities.

The implementation of BPPs is equally applicable to large-scale new subdivisions, brownfields, and small retrofit developments. Initial site management strategies include:

- A lighter ecological footprint – Establish limits of disturbance to the minimum area required for roads, utilities, building pads, landscape areas, and the smallest additional area needed to manoeuvre equipment.
- Conservation – Map and delineate natural resource protection areas with appropriate fencing and signage to provide protection from construction activities.
- Collaboration – Meet and walk the property with the owner, engineers, landscape architects, and others directing project design to identify problems and concerns that should be evaluated for developing the site plans.
- Water sensitive construction – Meet and walk the property with equipment operators prior to clearing and grading to clarify construction boundaries, limits of disturbance, and erosion and sediment control provisions.

The level of detail of the initial assessments is a function of the size of the site. For large sites, initial site management strategies will likely have to be repeated as part of the phasing of a development.

1.3 *Hydrologic benefits*

BPPs have multiple hydrologic benefits, notably the reduction in peak flow rates and runoff volumes. This has the added benefit of curbing the erosion of receiving streams and reducing the probability of flooding downstream.

Smaller runoff volumes also lead to smaller contaminant loadings to our receiving waters. BPPs help ensure that contaminants are directed to pervious surfaces where they can be adsorbed, broken down by microbes within the soil mass, or taken up by vegetation. Reduced runoff volumes also mean smaller volumes requiring treatment in response to a water quality event.

BPPs benefit wetlands because they help create a post-development hydrologic regime that more closely matches pre-development conditions than conventional drainage practices do. In the case of streams, BPPs reduce erosion potential of the channel and stream banks.

BPPs are most beneficial for average storm events. The benefits will be less pronounced for intense episodes of rainfall, as occurred in Calgary in June 2005, unless significant storage is provided or maintained within the watershed. Maintaining watershed storage is of particular importance for areas that are considered self-contained for pre-development conditions.

Re-use of stormwater reduces the loadings on our potable water supply.

1.4 *Design*

1.4.1. Design approach

Water sensitive urban development incorporates the following general principles:

- Open Space – Integrate public open space with conservation corridors, stormwater management systems and recreational facilities.
- Housing layout – Integrate residential blocks with the surrounding drainage function and public open space. Such housing layouts often include a more compact form of development, which reduces impervious surfaces.
- Road layout – Incorporate the natural features and topography of a site into the development i.e. locate roads beside public open spaces wherever possible, enhance

visual and recreational amenities, retain temporary storage, accommodate infiltration at or close to source and preserve water quality.

- Streetscape - Integrate road layout and vehicular and pedestrian requirements with stormwater management needs using design measures such as reduced frontages, zero lot-lines, local detention of stormwater in road reserves and managed landscaping.

1.4.2. Design Examples

1.4.2.1 Roadways and Parking Lots

Studies show that residential roads and parking lots typically contribute higher storm flow volumes and pollutant loads to urban stormwater than any other source area in residential developments.

To achieve more sustainable stormwater approaches to road and parking lot design, planners can:

- Reduce total impervious area (TIA) by reducing the overall road network coverage.
- Minimize or eliminate effective impervious area (EIA) and concentrated surface flows on impervious surfaces by reducing or eliminating hardened conveyance structures such as curb and gutters and storm sewer pipes.
- Infiltrate and slowly convey storm flows in roadside bioretention cells and swales, and through permeable paving and aggregate storage systems under the pavement.
- Design the road network to minimize site disturbance, avoid sensitive areas, and reduce fragmentation of landscape.
- Create connected street patterns and utilize open space areas to promote walking, biking and access to transit and services.
- Provide efficient fire and safety vehicle access.

1.4.2.2 Road layout

Designs for residential roads generally fall into three categories: grid, curvilinear and hybrids. Table 1-2 outlines the advantages and disadvantages of the grid and curvilinear road systems.

Table 1-2 Strengths and weaknesses of the grid and curvilinear approaches

Road Pattern	Impervious Coverage	Site Disturbance	Biking, Walking, Transit *	Safety	Auto Efficiency
Grid	27-36%	Less adaptive to site features and topography	Promotes by more direct access to services and transit	May decrease by increasing traffic throughout residential area	More efficient – disperses traffic through multiple access points
Curvilinear	15-29%	More adaptive to avoiding natural features, and reducing cut and fill	Generally discourages through longer, more confusing, and less connected system	May increase by reducing traffic in dead end streets	Less efficient – concentrates traffic through fewer access points and intersections

** Note: biking, walking and transit are included for liveability issues and to reduce auto trips and associated pollutant contribution to receiving waters.*

Source: PSAT, 2005.

Recently, planners have integrated these two prevalent models into a hybrid road system to incorporate the strengths of both. Hybrid road design provides:

- Minimal impervious road coverage per dwelling unit.
- Adequate turning radius for fire and safety vehicles.
- Through traffic flow with two points of access.
- A large bioretention area in the centre of the loop and a visual landscape break for homes facing the road.

Figure 1-1 Hybrid, or open space, road layout

Source: PSAT, 2005

The road configuration shown in Figure 1-1 is an alternative to the dead end street and provides multiple access points for emergency vehicles and residents. For similar impervious surface coverage, the loop road has the additional advantage of increasing available storm flow storage within the loop compared to the cul-de-sac design.

The following strategies can be used to create road layouts in medium to higher density residential developments that provide effective transportation networks and minimize impervious surface coverage:

- Cluster homes to reduce overall development envelope and road length. Examine alternative street layouts to determine the best option for increasing the number of homes per unit length.
- Create narrow lot frontages to reduce overall road length per home.
- For grid or modified grid layouts, lengthen street blocks to reduce the number of cross streets and overall road network per home, and provide mid-block pedestrian and bike paths to reduce distances to access transit and other services.
- Where cul-de-sacs are used, provide pedestrian paths to connect the end of the street with other pathways, transit or open space.
- Provide paths in open space areas to increase connection and access for pedestrians and bicyclists.

- Create pedestrian routes to neighbourhood destinations that are direct, safe and aesthetically pleasing.
- Reduce road widths for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency, maintenance, and service vehicle access.
- Reduce front yard setbacks to reduce driveway length.
- Minimize residential access road right-of-way to only accommodate needed infrastructure next to road.
- Where density, topography, soils and slope permit, vegetated swales should be used in the street right-of-way to convey and treat stormwater.
- Eliminate or minimize stream crossings.

1.4.2.3 Road width

Studies indicate that narrower roads enhance safety by reducing traffic speeds. Determining specific traffic, parking, and emergency vehicle access needs and designing for the narrowest width capable of meeting those requirements can significantly reduce total impervious area (TIA). To accommodate adequate street parking, parking bays can be installed at regular intervals.

1.4.2.4 Turnarounds

Dead end streets with excessive turnaround area (particularly cul-de-sacs) needlessly increase impervious area. A number of alternatives are available where topography, soils or other site-specific conditions suggest a turnaround-type road design.

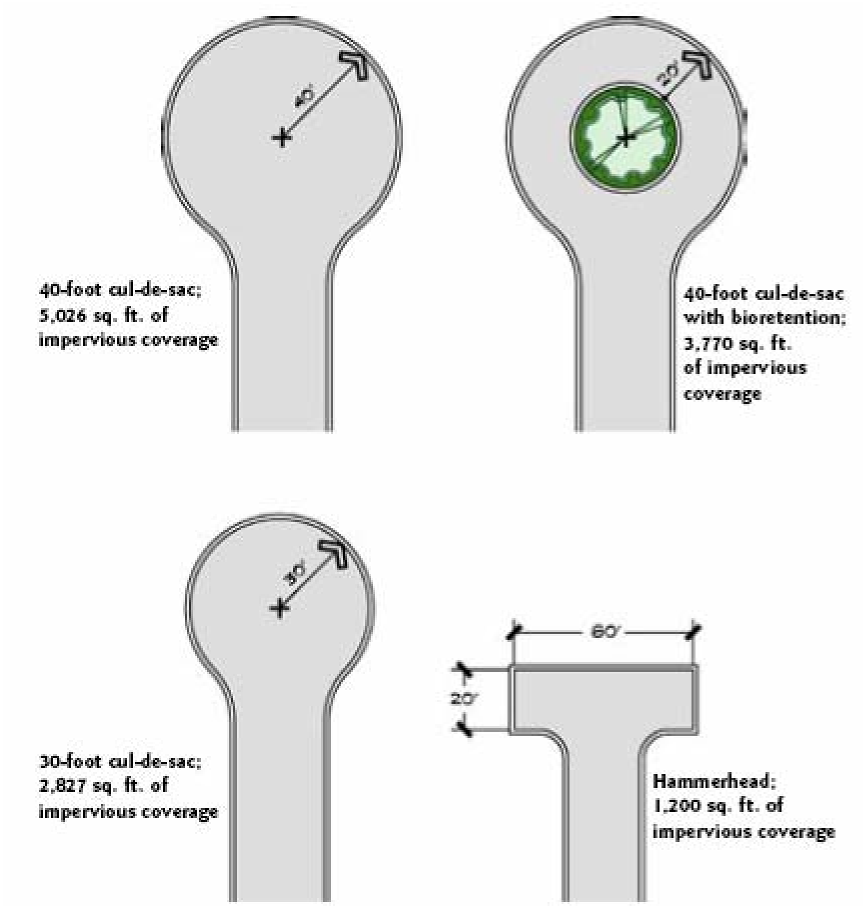
A 40-foot (12.19 m) radius with a landscaped centre allows access for service and safety vehicle needs when a minimum 20-foot (6.10 m) internal turning radius is maintained. Figure 1-2 shows an example of one of these cul-de-sacs in an established Calgary neighbourhood. In this particular example, the radius of the bulb is about six metres while the radius to the outer curb is about eleven metres. The design of this cul-de-sac accommodates street parking.

Figure 1-2 Example of cul-de-sac in Calgary with landscaped centre

Source: Bert van Duin, Westhoff Engineering Resources, Inc.

The turning area in a cul-de-sac can be enhanced by slightly enlarging the rear width of the radius to create a hammerhead-shaped turnaround. A 10-foot (3.05 m) reduction in radius can reduce impervious coverage by 44 percent and the hammerhead configuration generates approximately 76 percent less impervious surface than the 40-foot (12.19 m) cul-de-sac. Four turnaround options and associated impervious surface coverage are presented in Figure 1-3.

Figure 1-3 Turnaround areas and associated impervious coverage.



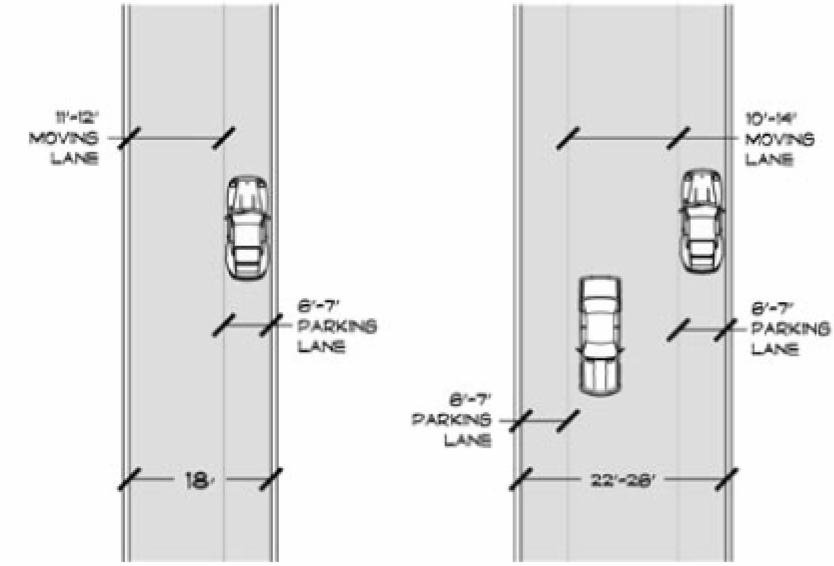
Source: PSAT, 2005.

Islands in cul-de-sacs should include bioretention with traplow capacity. A reversed concrete curb with or without curb cuts can be utilized to allow water into the facility.

1.4.2.5 Parking – Residential

Parking needs and traffic movement can be met on narrower roads where one or two on-street parking lane/s can serve as a traffic lane (queuing street). Figure 1-4 provides two examples of these queuing streets.

Figure 1-4 Examples of queuing type narrowed streets



Left: 18-ft (5.5 m) street with parking on one side.

Right: 22 (6.7 m) to 26-ft (7.9 m) street with parking on both sides.

Source: PSAT, 2005, adapted from NHAB.

In higher density residential neighbourhoods with narrow roads and where no on-street parking is allowed, pullout parking can be utilized. Pullouts (often designed in clusters of 2 to 4 stalls) should be strategically distributed throughout the area to minimize walking distances to residences. Depending on the street design, the parking areas may be more easily isolated and the impervious surface mitigated by slightly sloping the pavement to adjacent bioretention swales or bioretention cells.

Pullout parking areas, queuing lanes and dedicated on-street parking lanes can be designed, either entirely or in part, using permeable paving. Appropriate permeable paving systems can support the load requirements for residential use, reduce or eliminate storm flows from the surface, and may be more readily acceptable for use on lower-load parking areas by jurisdictions hesitant to use permeable systems in the travel way. Particular design and management strategies for subgrade preparation and sediment control should be implemented where pullout parking or queuing lanes receive storm flows from adjacent impervious areas.

1.4.2.6 Parking - Commercial

The large effective impervious coverage associated with parking areas accumulates high pollutant loads from atmospheric deposition and vehicle use. Auto pollutant contributions can be particularly heavy during stopping and starting a vehicle. As a result, commercial parking lots can produce significant levels of petroleum hydrocarbons and trace metals such as cadmium, copper, zinc and lead.

The following BPP strategies can reduce impervious coverage, storm flows, and pollutant loads from commercial parking areas:

- Establish minimum and maximum or median parking demand ratios and allow additional spaces above the maximum ratio only if parking studies indicate a need for added capacity.

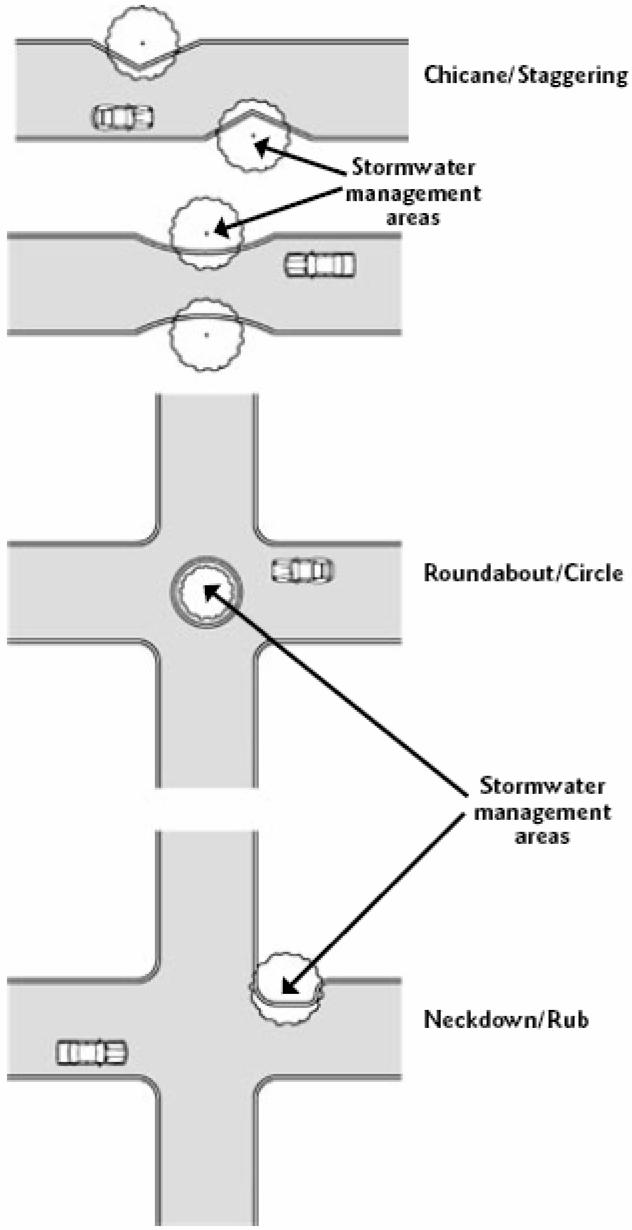
- Dedicate 20 to 30 percent of parking to compact spaces (typically 7.5 by 15 feet [2.3 x 4.6 m]).
- Use a diagonal parking stall configuration with a single line between stalls (reduces width of parking isle from 24 feet [7.3 m] to 18 feet [5.5 m] and overall lot coverage by 5 to 10 percent).
- Where density and land value warrant, or where necessary to reduce total imperviousness below a maximum allowed by land use plans, construct underground, under building or multi-story parking structures.
- Use permeable paving materials for the entire parking area or, at a minimum, for spillover parking that is used primarily for peak demand periods
- Integrate bioretention approaches into parking lot islands or planter strips distributed throughout the parking area to infiltrate, store, and/or slowly convey storm flows to additional facilities.
- Encourage cooperative parking agreements to coordinate use of adjacent or nearby parking areas that serve land uses with non-competing hours of operation—for example, a cooperative agreement between a church and an office or retail store.

1.4.2.7 Traffic calming strategies

Traffic calming strategies are used on residential roadways to reduce vehicle speeds and increase safety. These design features also offer an opportunity for stormwater infiltration and/or slowed down conveyance to additional stormwater management facilities downstream.

Figure 1-5 illustrates how traffic calming devices that take up relatively small amounts of space can provide water quality enhancement.

Figure 1-5 Combination Traffic Calming and Stormwater Management



(Note: Stormwater management areas are slightly lower than road surface.)

Source: PSAT, 2005

1.4.2.8 Alleys

Alleys or back lanes contribute large amounts of runoff to our drainage systems. In addition, large amounts of sediment are eroded and conveyed to streams from unpaved lanes.

- Ideally, alleys should be the minimum width required for usage by utility/service vehicles, constructed of permeable paving materials, and they should allow any surface flows to disperse and infiltrate to adjacent bioretention swales, shoulders or yards.

Figure 1-6 shows an example of an alley that uses a combination of concrete wheel strips, permeable pavers, reinforced plastic grid with grass, and under-drains to attenuate storm flows and create a more aesthetically pleasing layout.

Figure 1-6 Example of water sensitive alley

Source: PSAT, 2005. Photo by Curtis Hinman

1.4.2.9 Driveways

The following techniques can be used to reduce the impervious coverage associated with driveways:

- Create shared driveways.
- Minimize front yard setbacks to reduce driveway length.
- Reduce minimum driveway width to 3.0 m with a bulb-out at the garage.
- Use permeable paving materials and aggregate storage under wearing surface.
- Direct surface flow from driveways to compost-amended soils, bioretention areas or other dispersion and infiltration areas.

Figure 1-7 Example of driveway with paving strips in newer Calgary neighbourhood

Source: Liliana Bozic, City of Calgary Water Resources

1.4.2.10 Sidewalks

Impervious surface coverage generated by sidewalks can be reduced using the following strategies:

- Reduce sidewalk to a minimum width needed to provide wheelchair access.
- For low speed local access roads, eliminate sidewalks or provide a sidewalk on one side of the road.
- Design a bioretention swale or bioretention cell between the sidewalk and the street to provide a visual break and enhance safety.
- Install sidewalks at a two percent slope to direct storm flow to bioretention swales or bioretention cells—do not direct sidewalk water to the curb and gutter or other hardened roadside conveyance structures.
- Use permeable paving material to infiltrate or increase time of concentration of storm flows.

1.4.2.11 Lot layout

BPP approaches to lot layout employ clustering and other planning strategies to minimize site disturbance, maximize protection of native soil and vegetation, and permanently set aside the open tracts for multiple objectives including stormwater management. Four general objectives should guide the placement and orientation of lots for sustainable drainage projects:

- Minimize site disturbance.
- Strategically locate lots to facilitate dispersal of stormwater to open space areas.
- Orient lots and buildings to maximize opportunities for on-lot infiltration or open conveyance through bioretention swales or cells to downstream stormwater management facilities.
- Locate lots adjacent to, or with views of, open space to improve aesthetics and privacy.

Clustering is a type of development in which buildings are organized together into compact groupings that allow for portions of open space in the development site. Within a sustainable drainage context, the primary purpose of a cluster is to minimize the development envelope and reduce impervious coverage. Clusters also maximize native soil and forest protection and restoration.

The following objectives are appropriate for medium to high density clustering:

- Medium density (4 to 6 dwelling units per acre [10 to 15 units per ha]): Reduce the development envelope in order to retain a minimum of 50 percent open space.
- High density (more than 6 dwelling units per acre [15 units per ha]): Protect or restore native forest, grassland and soil areas to the greatest extent possible, using multifamily, cottage, condominium or mixed attached/ detached single family homes.
- To meet objectives for medium to high density clustering, planners can minimize individual lot size, amend disturbed soils to regain storage capacity of the soils, promote rainwater reuse within the house and garden, and set natural resource protection areas aside as permanent tracts of open space.

Figure 1-8 Conventional small lot development compared to LID cluster design

Source: PSAT, 2005.

1.4.2.12 Building design

The following building design strategies can be used to minimize storm flows and disturbance of natural areas:

- Implement roof-runoff capture and re-use.
- Disconnect roof runoff, thus eliminating roofs as effective impervious surface.

- Reduce building footprint. Designing taller structures can reduce building footprints and associated impervious surface by one-half or more in comparison to a single story configuration.
- Ensure compliance with Calgary's Drainage Bylaw, which stipulates that downspouts should be at least two (2) metres away from adjacent public roadways, sidewalks, lanes, etc.
- Limit clearing and grading to road, utility, building pad, landscape areas, and the minimum amount of extra land necessary to manoeuvre machinery.

1.5 *Construction*

In planning a development, it is important to consider the entire treatment train and how BPPs and source control practices interact and can complement each other.

In practice, reducing the amount of hard surface area by a given percentage does not necessarily address all impacts. For instance, in the case of redevelopment, a 20% target of total imperviousness reduction may sound impressive but if the starting point was 80% hard surface area, the resulting amount of imperviousness will still have significant impacts on our urban water resource. Additional measures may then be required.

Vegetation is a prominent feature of BPPs, including the preservation of existing vegetation and permeable soils wherever possible. Vegetation plays a significant role in the filtering of runoff and keeping the subsoils open and permeable. It also reduces erosion by shielding soils from the direct impact of precipitation and the erosive effects of flows. In winter, vegetation retains moisture in the soils by capturing snow.

The selection of vegetation should reflect those species that suit Calgary's soils and climate. Deeper-rooting vegetation enhances the filtering and percolation ability of the subsoils, but also reduces watering requirements, and is more resistant to drought conditions.

The intent of BPPs is to maximize the amount of land that is not affected by construction activities in order to maintain the integrity and permeability of the subsoils. Long-term sustainability and preservation of distributed source control practices greatly depend on erosion and sediment control during construction activities.

1.6 *Performance and impact on surrounding community/environment*

1.6.1. Impact on adjacent infrastructure

By their nature, BPPs minimize impacts on adjacent properties and adjacent infrastructure.

In fact, the intent of BPPs is to increase the liveability of our subdivisions and developments, without compromising Calgary's urban water resource. BPPs focus on designing, building and maintaining aesthetically pleasing communities that offer a high quality of life. At the same time, these communities are less prone to damage from flooding and inundation from extreme storm events.

1.6.2. Community and environmental factors

Public engagement is crucial during the development of these communities to ensure that they are responsive to the needs of future residents.

Cold climate conditions are not perceived to be problematic with regard to the implementation of BPPs. One of the key components is to ensure that any green or open space has visual and aesthetic interest and supports recreational activities throughout the year.

The long-term sustainability of neighbourhoods planned, laid out, and constructed using BPPs appears to be comparable to conventional neighbourhoods.

The implementation of BPPs brings down life-cycle costs. For instance, narrower roadways and denser, more compact communities reduce the need for paving and associated transportation infrastructure.

1.6.3. Failure scenarios

Wherever possible, stormwater management professionals (including City staff and contractors), should guard against the following potential failure scenarios of BPPs:

- The erosion of the BPP process e.g. filling in green/open space over time.
- The implementation of source control practices that are not appropriate for the local conditions.
- High densities without appropriate transportation networks.
- Lack of erosion and sediment control implementation and enforcement.
- Insufficient public consultation and public education.

2.0 Vegetated Swales

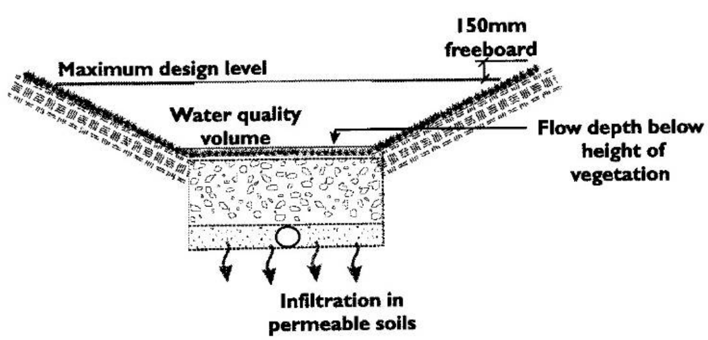
2.1 *Description*

Vegetated swales are open, densely vegetated drainage ways with low-pitched side-slopes that can be used as an alternative to the conventional curb and gutter and underground storm sewer system along roadways. This source control practice (SCP) is used to treat and attenuate the runoff volume from the water quality design event as well as to convey excess runoff from more severe events downstream. Vegetated swales incorporate the same design features as bioretention cells; however, they are designed as part of a conveyance system and have relatively gentle side slopes and flow depths that are generally less than 12 inches (300 mm).

There are two types of vegetated swales:

1) Dry swales – Dry swales allow the entire runoff volume generated by a water quality design event to be temporarily stored in a pool or series of pools created by permanent check-dams or ditch-blocks. Their relatively flat design facilitates a slow and shallow flow, thereby allowing sedimentation and filtration to occur while limiting erosion. The runoff volume held back in the pools either infiltrates into the subsoils or evaporates.
2) Bioswales – Bioswales combine aspects of dry grassed swales and infiltration trenches. The surface component of a bioswale is a shallow grassed channel, accepting flows from small areas of adjacent paved surfaces such as roads and parking. The bioswale is designed to hold the runoff volume from the water quality design event behind a weir, and then allow it to slowly infiltrate into the pores space of the underlying fine media layer. During and between runoff events, the media layer gradually dewaters into an underlying gravel or drain rock reservoir system. A subdrain pipe also maintains drainage of adjacent road base courses. The surface swale and weir structures provide conveyance for larger storm events to a surface outlet. Culverts are typically provided for roadway and driveway crossings.

Figure 2-1 Typical Bioswale



Source: CIRIA, 2004.

Bioswales provide flow attenuation as well as treatment of stormwater through settling, fine filtration, extended detention and some biological uptake.

Alternatives to gravel/drain rock, such as “milk crate” configurations, are commercially available. The subdrain system may be connected to a flow control consisting of an orifice, or equivalent, in a catchbasin or manhole. Depending on the overall grading of the site, at times a secondary overflow inlet is provided at adjacent catchbasins.

Vegetated swales represent a viable SCP for the Calgary region, as they are suitable for areas where subsoil permeability is generally poor.

2.2 *Application*

Vegetated swales can be positioned to collect overland flows from areas such as parking lots, buildings and office complexes, residential yards, roadways, parks and green space, golf courses and grassed buffer strips. In residential areas, they would typically be located in a drainage easement at the back or side of lots. They are less suitable for front yard arrangements in residential areas because of the need for numerous driveway culvert crossing and space requirements, unless the density is sufficiently low. Alternatively, a bioretention cell approach could be contemplated with cells located between the curb and sidewalk and excess flows routed back onto the roadway rather than having to continue through driveway culverts.

Similar to bioretention areas, vegetated swales are designed to serve relatively small catchment areas in order to accommodate water quality enhancement.

Bioswale vegetation can consist of grasses and rushes and with shrub and tree plantings along the edge of the swales.

Vegetated swales are comprised of the following eight (8) major components:

- Pre-treatment
- Flow entrance
- Ponding area
- Plant materials
- Organic layer or mulch
- Filter media
- Gravel or rock drain
- Subdrain and outlet
- Surface overflow

These eight components work together to improve water quality and quantity control by facilitating plant and root growth, organic decomposition, and the development of a macro and micro-organism community. This, in turn, helps develop a natural soil horizon and structure that will lengthen the facility’s life span and reduce the need for structural maintenance.

Vegetated swales are more aesthetically pleasing than concrete or rock-lined conveyance systems, and are generally less expensive to construct than conventional curb and gutter and storm sewer systems.

Vegetated swales are suitable for most development situations, i.e., residential areas of low to moderate density, office complexes, rooftop runoff, parking and roadway runoff, park and green space, golf courses, etc. In parking lots they can be used to visually break up the impervious area.

With the provision of an adequate subdrain system, they can be used in most soils, including clay with infiltration rates as low as 0.6 mm/hr. With proper weir spacing, vegetated swales are practical for profiles of up to 10% slope. Runoff can enter either as sheet flow or via a curb and gutter collection and conveyance system.

2.3 *Hydrologic Benefits*

The benefits of vegetated swales include: (1) Reduced runoff, (2) Reduced local and downstream flooding, and (3) Water quality enhancement.

The magnitude of the runoff reductions depends on many factors including the amount of storage capacity available upstream of the weirs and/or culverts, the longitudinal slope of the swale, the width of the swale relative to the size of the catchment, the depth and composition of the filter media, the type of vegetation, and the permeability of the subsoils.

2.4 *Design*

2.4.1. Design approach

The following steps provide an outline of the design procedure for vegetated swales:

1. Make a preliminary assessment as to whether site conditions are appropriate for the use of a dry swale or bioswale.
2. Consider the following issues for initial suitability screening:
    - Site drainage area
    - Site topography and slopes
    - Soil infiltration capacity
    - Regional or local depth to groundwater and bedrock
    - Site location and minimum setbacks
3. Determine how the vegetated swale will fit into the overall stormwater management system.
4. Determine whether a vegetated swale is the only SCP required to address the treatment requirements.
5. Decide where the vegetated swale will most likely be located by:
    - Confirming design criteria and applicability, and,
    - Performing field verification of site suitability.
6. Carry out at least three (3) soil borings or test pits at the proposed location to determine soil types, infiltration capacity and depth of groundwater and bedrock (Note: Soil borings or test pits should be taken from 1.5 m below the bottom elevation of the proposed swale).
7. Record a soil profile, including the following information for each soil horizon or layer:
    - Thickness
    - Munsell soil colour notation
    - Soil mottle or redoximorphic feature colour, abundance, size and contrast
    - Soil textural class with rock fragment modifiers
    - Soil structure, grade size and shape
    - Soil consistence, root abundance and size
    - Soil boundary
    - Occurrence of saturated soil, impermeable layers/lenses, groundwater, bedrock or disturbed soil

8. Compute runoff control volume.
9. Determine size of vegetated swale including bottom width, side slopes, longitudinal slope, and depth (steps 5 through 8 are iterative).
10. Determine size of outlet structure and/or culverts.
11. Check volume, peak discharge rate, period of inundation and erosion potential.
12. Perform groundwater-mounding analysis.
13. Determine pre-treatment volume and design pre-treatment measures.
14. Prepare vegetation and landscaping plan.
15. Prepare construction specifications.
16. Prepare inspection, operation and maintenance plan.
17. Prepare maintenance agreement/covenant for facilities located on private property.

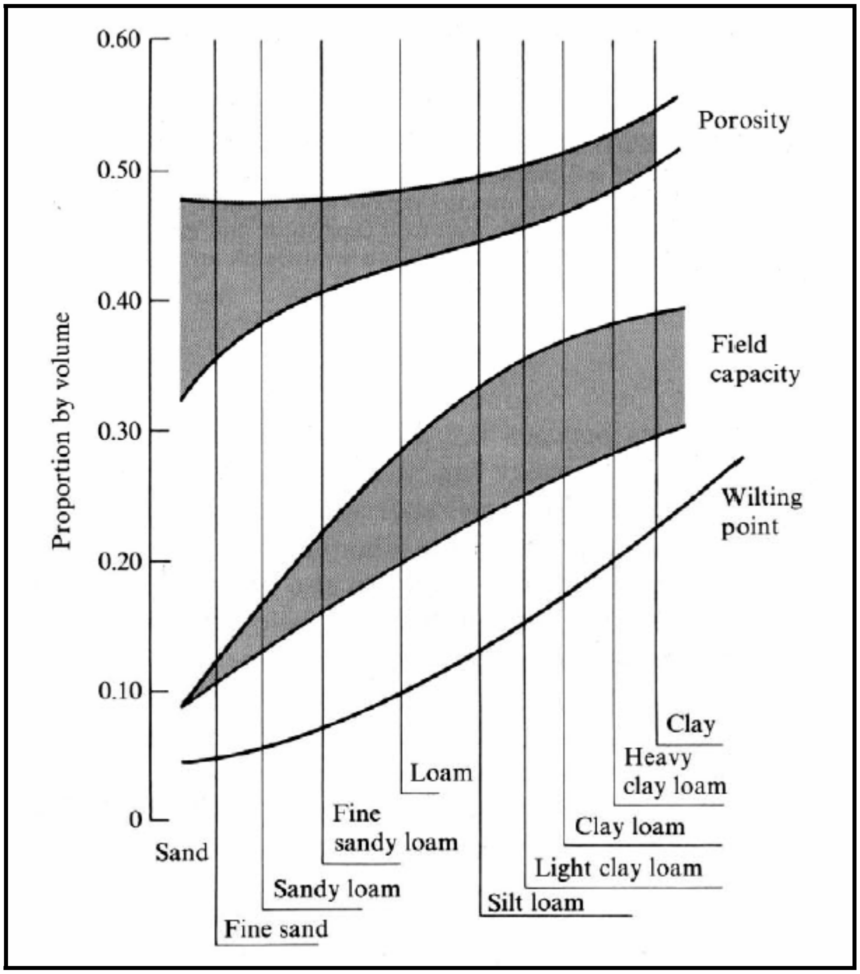
2.4.2. Design examples

The following factors should be considered in the design of a vegetated swale:

2.4.2.1 Flow criteria

To assess specific benefits of vegetated swales with respect to runoff volume reduction, a water balance analysis, incorporating both deep percolation and evapotranspiration, is needed. Since the filter media needs to be well drained to prevent waterlogging and standing water, vegetated swales should contain large amounts of sand with relatively minor moisture retention capability (See Figure 2-2).

Figure 2-2 Soil Moisture Retention Capability as function of Soil Texture



Source: Hayashi Lecture Notes, adapted from Dunne and Leopold (1978)

Swale geometry should ensure that 1:1 year peak velocities do not exceed 0.5 m/s and that 1:100 year peak velocities do not exceed 1.0 m/s. If non-erosive conditions cannot be ensured, the catchment area serviced by the swale should be reduced, or alternatively, a high-flow by-pass channel or overflow pipe underneath the swale should be installed.

2.4.2.2 Layout

As the size of the contributing catchment area increases downstream along a vegetated swale, the capacity of the swale may need to be augmented with an underground storm sewer system in order to convey the peak 1:100 year peak discharge rate without causing erosion or jeopardizing the desired water quality enhancement.

Vegetated swales in residential communities are most effective when incorporated into a street layout that consists of a network of short streets, i.e. 50 m to 100 m long, linked by collector roads with conventional underground storm sewer systems. The short local streets may not require any storm sewer system as the vegetated swales would have adequate capacity to convey the peak discharge rate while still providing adequate water quality treatment.

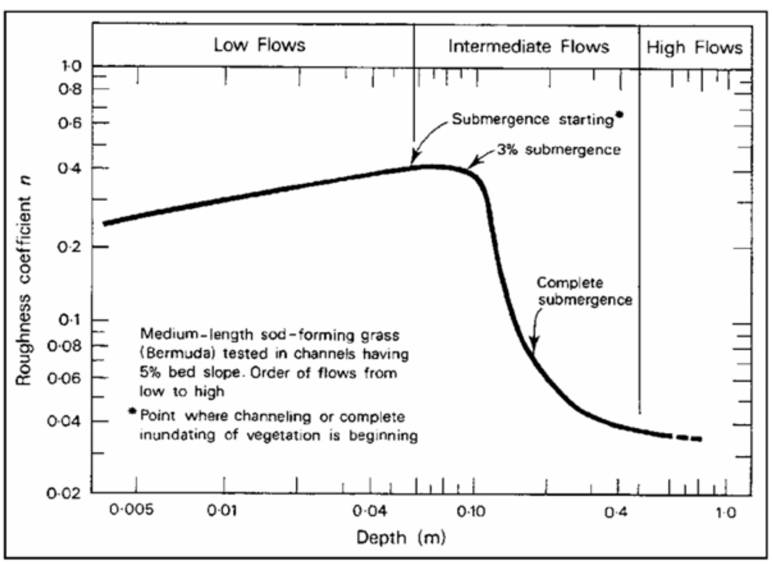
This same modular design concept of vegetated swales is also applicable to larger catchments by using pick-up locations that discharge into the storm sewer system at the end of each swale module. The optimal location for a pick-up point is where the design discharge reaches the discharge capacity of the swale. The location of the next downstream pick-up point will follow the same design principle such that the entire catchment area is served by a series of modular vegetated swales, with each module discharging stormwater via the pick-up points.

The methodology for the design of modular vegetated swales is to first determine the optimal dimensions of the swale for meeting water quality objectives within the available space. The discharge capacity of the swale can then be computed. The catchment area of each individual pick-up point along the swale should yield a peak design discharge (for the minor stormwater system) that corresponds to the discharge capacity of the swale.

Preferably, the runoff from the water quality design event should be stored upstream of weirs, culverts, grade control checks or drop checks and then slowly percolate into the underlying native soils. Configurations without the weirs or drop structures are possible; however, they do not provide the same level of water quality treatment. The vegetated swale, weirs and culverts provide conveyance for larger storm events to a discharge point or pick-up point into a storm sewer system.

Manning's equation can be used for the computation of the depth and velocity of flow for the design events of interest. The hydraulic roughness of vegetated swales, however, will vary with vegetation type and height, relative to flow depth, as well as slope. As shown in Figure 2-3, the value for Manning's roughness is between 0.15 and 0.3 for flow depths where the depth of flow is below the height of vegetation, dropping to 0.03 for extreme events when the vegetation is fully submerged.

Figure 2-3 Variation of Roughness as Function of Depth



Source: Wong et al, draft 2003

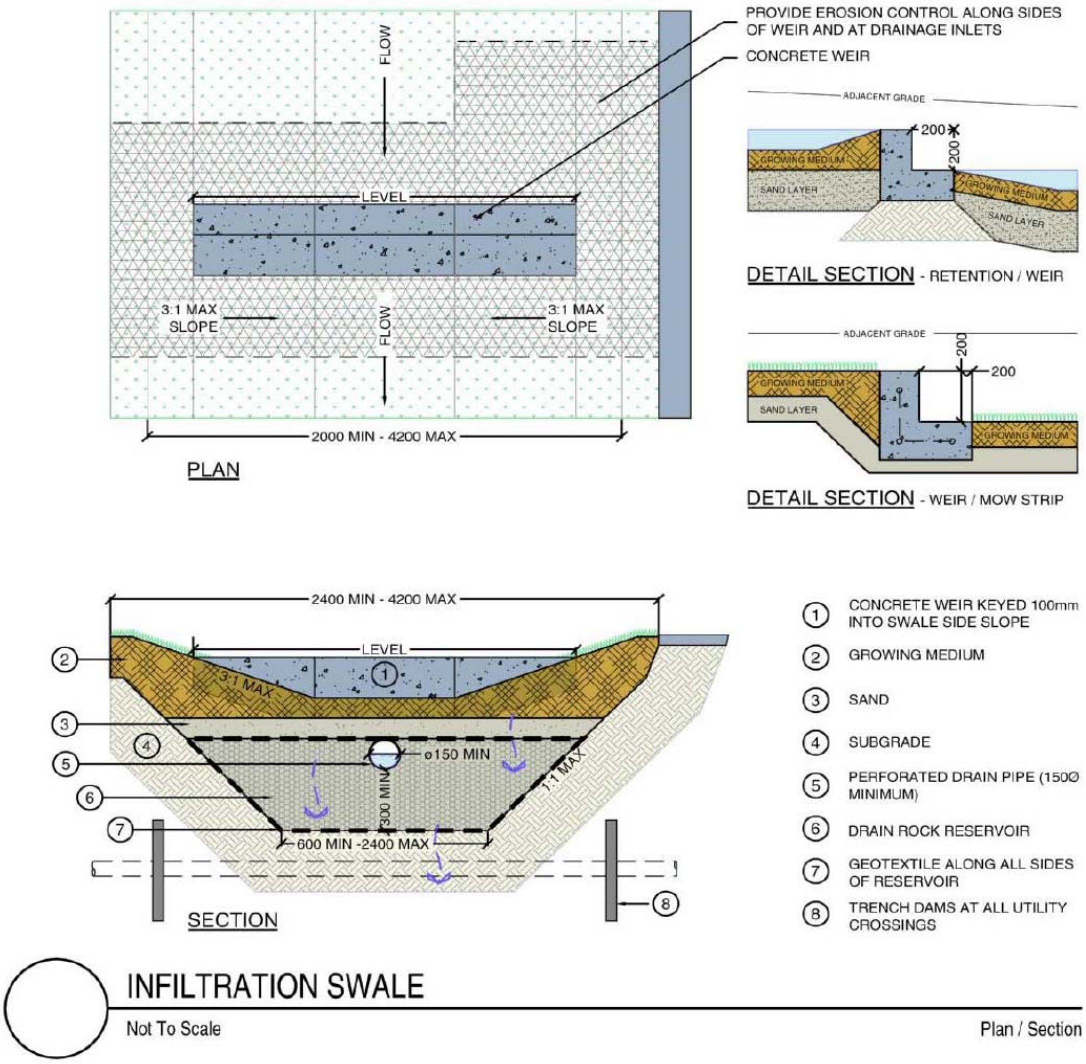
2.4.2.3 Grading

Vegetated swales are only practical at sites with general ground slopes of less than four (4.0) percent, unless the swales can be run parallel to the contours. Where the general terrain slope exceeds four (4.0) percent, a vegetated swale is often practical only on the upslope side of the adjacent street. Vegetated swales are not practical for sites steeper than six (6.0) percent unless the site can be terraced with bioswales running along the contours to pick-up points to a storm sewer system.

A soil depth (suitable soil) of at least 3 m should be available throughout a down-slope, developed hillside before infiltration practice should be contemplated. A qualified geotechnical engineer however will have to assess the potential impacts of infiltration on slope stability.

Figure 2-5 provides an example of an infiltration swale including sample weir and drop structures. The heights of the weirs or drop structures can be between 150 mm to 300 mm, with spacing no closer than 15 m. Energy dissipation should be provided below the drops. The weirs should have a level top to spread the flow and avoid channelization. In addition, they should be keyed in for at least 100 mm. Note that appropriate (vegetated) erosion control is to be provided along all sides of the weir.

Figure 2-5 Infiltration Swale Plan and Cross-Section – British Columbia



Source: GVRD, 2004

Note: The elevated subdrain system illustrated in Figure 5-4 is not feasible for the Calgary region because low permeability soils in a shallow system may cause icing problems during the winter months.

2.4.2.4 Side slopes

A vegetated swale should have a trapezoidal or parabolic cross-section with relatively flat side slopes. This maximizes the wetted perimeter, i.e., the length along the edge of the channel cross-section that is in contact with the runoff, and thus enhances treatment. Triangular cross-sections are not advisable, as they tend to concentrate flows, increasing the risk of scour and minimizing contact with vegetation.

The maximum side slope should be 3:1 (H:V) while a slope of 4:1 or even 5:1 (H:V) is preferable for maintenance purposes. A filter strip or other vegetated buffer should be located on both sides of the swale, particularly if nearby impervious surfaces drain into the swale.

2.4.2.5 Groundwater separation

Dry swales and bioswales should be separated from the groundwater table to ensure that groundwater does not intersect the bottom of the swale. Specifically, the seasonally high groundwater table should be at least 0.6 m to 0.9 m below the swale for water to infiltrate. In the case of dry swales without subdrains, this separation is calculated from the surface of the swale; for bioswales, it is calculated from the bottom of the excavation.

Detailed groundwater mounding analyses should be conducted by a qualified hydrogeologist as part of the design process.

Procedures for the quantification of in-situ infiltration rates for the native soils beneath dry swales or bioswales are discussed in Appendix E.

2.4.2.6 Depth of flow and ponding depth

The depth of flow during the water quality design event should not exceed 100 mm to ensure proper filtration. This depth should be computed using Manning's equation, with a roughness value between 0.15 and 0.30.

The combination of the depth and velocity of flow for the 1:100 year event should comply with Alberta Environment's guidelines. The minimum freeboard to adjacent paving shall be 100 mm.

A ponding area behind the weir, check-dam or drop structure provides for surface storage of stormwater runoff before it filters through the soil or filter media. The ponding area also allows for evaporation of ponded water as well as settling of sediment in the runoff.

The maximum depth of ponding is 300 mm for the water quality design event and 500 mm for the 1:100 year event, both of which correspond to the permissible maximum depth in traplows.

2.4.2.7 Drawdown/Emptying Time

As per Table A-2 of Appendix A, drawdown or emptying should occur within 12 hours for the Water Quality Design Event and within 3 days for the 24 hour, 1:100 year event. These timelines will facilitate:

- Wet-dry cycling between rainfall events.
- Unsuitable mosquito breeding habitat.
- Suitable habitat for vegetation.
- Aerobic conditions.
- Storage for back-to-back precipitation events.

2.4.2.8 Erosion and Sediment Control

Provision of appropriate erosion and sediment control in the tributary area is paramount.

2.4.2.9 Head Difference

An elevation difference of about 0.9 m to 1.5 m should be provided from the inflow to the outflow when a subdrain is used.

2.4.2.10 Flow entrance

The five (5) primary types of flow entrances to dry swales or bioswales are:

- *Dispersed, low velocity flow across a landscape area* – This is the preferred method of delivering flows to the swale.
- *Dispersed flow* – Runoff flows across pavement or gravel and past wheel stops for parking areas.
- *Curb cuts for roadside or parking lot areas* – Curb cuts should include rock or other erosion protection material in the channel entrance to dissipate energy. Flow entrance should drop 5 to 7.5 cm from curb line and provide an area for settling and periodic removal of sediment and coarse material before flow dissipates to the remainder of the cell.
- *Pipe flow entrance* – Piped entrances should include rock or other erosion protection material in the channel entrance to dissipate energy and/or disperse flow.
- *Catchbasin* - Catchbasins can be used to gradually release water to the swale through a grate for filtering coarse material.

In the case of concentrated flows to dry swales or bioswales, the entrance should be composed of erosion-resistant materials or equipped with appropriate, permanent erosion protection such as matting. Alternatively, sediment clean-out basins and weir flow spreaders can be provided at point-source inlets. The magnitude of the flow rate for design purposes is the 1:100 year.

Since dry swales and bioswales are susceptible to clogging, sediments should be captured and flow should be spread across the swale area. Pre-treatment will help to ensure the proper functioning of the swale and allow for longer periods between maintenance.

Runoff entering dry swales or bioswales through a grassy filter area should have a maximum sheet flow velocity of 0.9 m/s. The following grassed filter strip parameters are recommended:

Table 2-1 Length for Pre-treatment Swales for Bioretention Areas

Parameter	Impervious Parking Lots				Residential Lawns			
Maximum Inflow Approach Length	10.7 m		22.9 m		22.9 m		45.7 m	
Filter Strip Slope	≤ 2%	> 2%	≤ 2%	> 2%	≤ 2%	> 2%	≤ 2%	> 2%
Filter Strip Minimum Length	3.0 m	4.5 m	6.0 m	7.5 m	3.0 m	3.6 m	4.5 m	5.4 m

Source: Minnesota, 2005

2.4.2.11 Culverts

Culverts are required at street or driveway crossings. These culverts can fulfill two roles: (1) Creation of a pool for storage and subsequent infiltration of the runoff volume from the water quality design event, and, (2) Conveyance of the 1:100 year design peak discharge into downstream cells of the vegetated swale.

The longitudinal slope of the culvert should be at least 2 percent to minimize the chance of icing up and/or deposition of sediments in the culvert. Preferably, the culvert should be at least 450 mm in diameter to minimize the chance of icing up of the culvert during the winter months.

Appropriate erosion protection is required at the upstream and downstream ends of the culverts.

2.4.2.12 Filter media within bioswale

A two-layer treatment soil system is recommended for a bioswale. The top layer or upper rooting zone should be approximately 0.10 to 0.15 m deep and composed of 15-30% compost and 70-85% growing medium. The compost, which increases infiltration capacity, improves soil fertility and reduces compaction, should be mature with 50-60% organic matter and free from contaminants.

The growing medium should be free of plants, roots, sticks, building materials, wood chips and chemical pollutants. The pH should be between 5.0 and 6.0. The concentration of soluble salts should be less than 500 ppm, while the criteria for magnesium, phosphorus and potassium are 95, 275 and 234 kg/ha, respectively. The organic content should be 25-30% dry weight. The particle sizes and proportions of each size particle should be within the following ranges, with the proportion in percent of dry weight mineral fraction:

Particle Size	Proportion
Gravel (2 – 75 mm diameter)	0%
Sand (0.05 – 2 mm)	50 – 70%
Silt (0.002 – 0.05 mm)	10 – 30%
Clay (< 0.002 mm)	0 – 5%

The depth of the bottom layer or deep rooting/percolation zone, which extends from the top layer to the drain rock, should be 0.30 to 0.35 m, for a total preferred depth of 0.45 m.

The resulting initial infiltration rate of the treatment soil should be greater than 13 mm/hour (3.6×10^{-7} m/s) per ASTM Designation D2434 (Standard Test Method for Permeability of Granular Soils) at 80 percent compaction per ASTM Designation D1557 (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort). This initial infiltration rate corresponds to loam as per Table A-4 of Appendix A. A higher infiltration rate, however, is preferable, as that will decrease the size requirements of the bioswale.

2.4.2.13 Subdrain and drain rock for bioswales

A level, 300-mm thick gravel or drain rock layer with subdrain system should be located underneath the treatment soil system. Vertical placement of the subdrain will vary depending upon whether or not infiltration and de-nitrification are a design consideration.

The subdrain system should be composed of PVC, SDR 35, 150 mm diameter pipe, with filtersock and cleanouts/observation standpipe. The standpipe will:

- Indicate how quickly the bioswale dewaters following a storm
- Provide a maintenance cleanout port; and
- Connect to the subdrain system to facilitate cleanout of the subdrain.

The subdrain should be at a minimum 0.5% slope to ensure that the pipe is dry during inter-event periods and avoid root penetration of the pipe. The (slot) opening should be smaller than the smallest aggregate gradation for the drain rock blanket to prevent migration of material into the drain. This configuration should allow for pressurized water cleaning and root cutting if necessary. The capacity of the subdrain system should be greater than the hydraulic conductivity of the filter media.

Pipe joints and connections must be adequately sealed to avoid piping conditions, i.e., water seeping through pipe or structure joints. Pipe sections shall be coupled using suitable connection rings and flanges. Field connections to structures and pipes shall be sealed with polymer grout material that is capable of adhering to surfaces. Subdrain pipes shall be capped until completion of the site. Subdrains directly connected to a structure shall be non-perforated for a distance of at least 1.5 m from the structure interface to avoid possible piping problems. (Prince George's County, 2002).

In case a permeable liner is provided at the bottom of the drain rock, the subgrade underneath should be scarified to a minimum depth of 200 mm.

The gravel/drain rock reservoir should be level, composed of double-washed rock, and have the following particle size distribution:

Particle Size	Percentage Passing
37.5 mm	100%
28 mm	95 to 100%
13 mm	20 to 60%
5 mm	0 to 10%
2.36 mm	0 to 5%

2.4.2.14 Geotextiles

A geosynthetic liner should be provided on the bottom and sides of the basin for bioswale. If underlying soils are expansive, or if there is a concern about groundwater contamination, an impermeable liner should be installed, as specified by a certified geotechnical specialist. The liner should be protected from puncture by a geotextile fabric.

If soils are not expansive, a porous geotextile fabric can be used, again as determined by a geotechnical specialist. The same type of porous liner should be installed between the deep rooting/percolation zone and the drain rock zone. Alternatively, a 7.5 to 22.5 cm thick pea gravel diaphragm may be used as this provides greater porosity and is less likely to become blocked. This pea gravel should be washed, river-run, round diameter, 6 – 13 mm in size

2.4.3. Limitations

Vegetated swales are impractical in steep topography because of the extensive grading and number of weirs, check-dams or ditch blocks required. They are also susceptible to erosion when the flow rates and/or velocities are high during extreme storm events.

Vegetated swales require more right-of-way than what is typically needed for a storm sewer and cannot be used in areas with high groundwater levels. They also require more maintenance than curb and gutter systems. Roadside vegetated swales are not applicable to sites with many driveway culverts or extensive sidewalk systems.

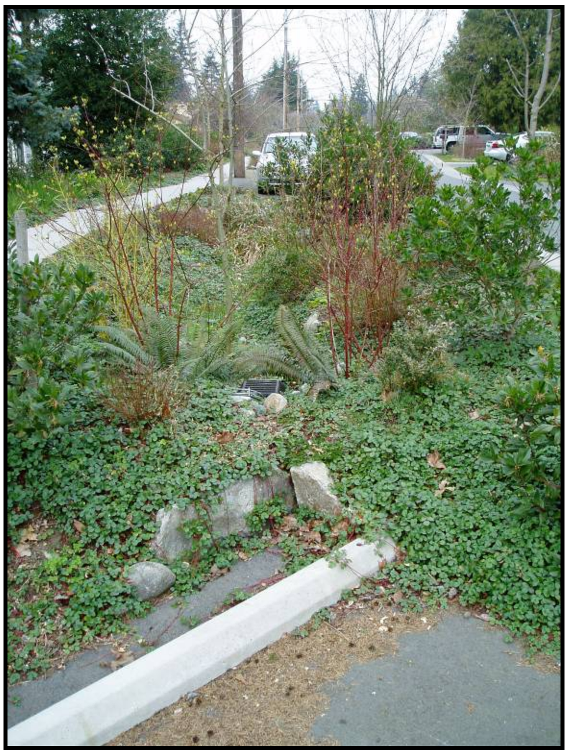
In general, 0.9 m to 1.5 m of elevation above an existing invert of the storm sewer system is needed to drive stormwater through bioswales.

Dry swales and/or bioswales should not be used for sites with continuous flow from groundwater, sump pumps or other sources.

2.4.4. Vegetation

Dense vegetation is a crucial component of vegetated swales (See Figure 2-4). Aboveground, vegetation helps attenuate and distribute flows and protects the surface of the vegetated swale from erosion. Below ground, vegetation helps trap suspended pollutants and sediments. Between storm events, plant growth plays an important role in macro-pore formation and maintenance. Vegetation height should exceed the water level that would result from the water quality design event.

Figure 2-4 Bioretention Area/Bioswale



Source: Bert van Duin, Westhoff Engineering Resources, Inc.

Deeper rooting vegetation that can access soil moisture at deeper levels in the media bed is preferred as it is less susceptible to drought conditions. Deep root systems will also keep the media layer open and allow for more uptake compared to shallow rooting vegetation. The selected vegetation should also be able to tolerate the progressive accumulation of contaminants on top and within the filter media.

Native grasses provide year-round cover and are best for enhancing biodiversity and wildlife habitat. Their extensive root systems enhance infiltration and drought-tolerance. They do, however, take longer to become well established, so a cover crop or other soil stabilization method are important.

Grass species should be selected for vigorousness and have a tendency to stay rigid and upright, even during flow times. If located along a roadway, they should also be salt-tolerant.

Sod provides immediate source control provided the seams are protected. This can be achieved by laying the strips perpendicular to the flow of water and hand-tamping them. Where high flow velocities are expected or slopes are at 3:1 (H:V), the sod should be secured with stakes (adapted from CIRIA, 2004). While it still only has limited commercial availability in Alberta, native sod is preferred over typical garden varieties of sod.

In addition to grasses, rushes and sedges with shrub and tree plantings along the edge of the vegetated swales can be used as well. By selecting sedges or other larger relatively sturdy plants, movement and traffic over the vegetated swale can be discouraged. Mulch is not recommended for vegetated swales as it is subject to erosion.

2.4.5. Space requirements

The dry swale or bioswale should cover about 10-20% of the upstream impervious area that it serves. The size of the swale is a function of the magnitude of the design event, the size and imperviousness ratio of the tributary catchment, the hydraulic conductivity of the subsoils or filter media, and the longitudinal slope of the swale. The performance of the swales should be confirmed by continuous flow modelling.

The space requirements of vegetated swales are a function of the magnitude of the water quality design event, the size and imperviousness ratio of the tributary catchment, and the hydraulic conductivity of the native soils or the filter media.

The width of dry swales or bioswales should be between 600 mm and 2400 mm. These dimensions ensure sufficient filtering for water quality treatment while minimizing the formation of small channels within the swale bottom. Wider widths are only appropriate if structural measures are used to ensure a uniform spread of the flow.

Providing impermeable barriers between the filter media/drain rock and adjacent soils and structures could alleviate concerns about clearance distances.

2.5 *Construction*

Effective construction techniques are critical to the success of vegetated swales as SCPs. Since they rely heavily on infiltration, dry swales and bioswales are particularly sensitive to any materials that may clog the subsoils or filter medium.

Clogging from dumped or eroded materials can occur during construction, and traffic may undermine vegetation and compact the filter media. As such, it is important to carefully manage construction activities and restrict any traffic over the swales. This can be accomplished through the application of appropriate erosion and sediment control measures in the tributary catchment, appropriate selection of vegetation, and/or through fencing. It may be necessary to provide a protective cover, such as a geofabric, over the bioretention area during the construction phase.

The following recommendations pertain to the construction of dry swales or bioswales:

1. The swale should be protected from sedimentation during construction, either by use of effective erosion and sediment control measures[1] upstream, or by delaying the construction of the swale until after all sediment-producing construction in the drainage

[1] For sites that incorporate vegetated swales for stormwater control, grading and sediment control practices are typically applied on a lot-by-lot basis to minimize the risk of soil transport.

area has been completed. Contaminated drain rock, filter media or compost must be removed and replaced.

2. Sediment control devices should be inspected at the end of each workday to verify additional sediment loading capacity.
3. Excavation should not be undertaken during wet conditions or when ground is saturated.
4. To minimize compaction of the underlying subsoils, no heavy equipment with narrow tracks, narrow tires, or large lugged, high pressure tires should be allowed on the bottom of the swales. Lightweight, low ground-contact pressure equipment should be used to excavate a swale, and the base should be ripped at completion to refracture the soil to a minimum of 0.30 m. The sidewalls of the swale should be roughened where sheared and sealed by heavy equipment.
5. Accurate grading is essential, as any departure from design slopes can undermine the effectiveness of treatment.
6. Geotextiles must not puncture, tear or become clogged during construction. If they are damaged they must be repaired or replaced. Filter media placed over the geotextiles should be placed by hand shovel rather than construction equipment.
7. Geotextiles should overlap by at least 0.50 m at seams to prevent short-circuiting or intrusion of fines, and be keyed in properly at the surface. Openings, e.g. for subdrain pipes, should be sealed.
8. Natural or fill soils should not be intermixed with gravel/drain rock. All contaminated stone aggregate must be removed and replaced.
9. Gravel/drain rock should be double-washed.
10. Gravel/drain rock should be installed in 300 mm lifts and compacted to eliminate voids between the geotextile and surrounding soils.
11. Filter media should not be delivered until the bioswale location has been excavated or graded to the design elevations and geotextile fabrics and subdrain systems are in place. Planting materials should not be delivered until the filter media has had time to settle and has been trimmed to the proper grade elevation.
12. Soil tests should be performed for every 382 m^3 (500 yd^3) of planting soil, with the exception of particle size distribution, pH and organic matter tests, which are required only once per bioswale.
13. Filter media should be placed in 200 mm (8 inches) to 300 mm (12 inches) lifts, and slightly compacted until the desired depth is reached. Compaction pressure should be minimal and can be applied to the filter media by tamping with a bucket from a dozer or backhoe. Depending on the filter media, up to 20% natural compaction may occur. The filter media can be overfilled above the proposed surface grade to accommodate natural settling to proper grade. To expedite settling, each lift can be sprayed with water until just saturated.
14. Measures such as providing a soil breach should be taken to eliminate the risk of adjacent non-native species invading the swale.
15. Mature plantings are recommended over seed because fluctuating water levels prior to germination can cause seeds to be transported.
16. After seeding, erosion control blankets need to be installed immediately to stabilize the channel before turf has become established.

17. All plant materials should be tagged for identification on delivery, have normal, well-developed branches and vigorous root systems, and be free from physical defects, plants diseases and insect pests.
18. Vegetation should be watered until established…. If possible, runoff not required for watering of vegetation should be diverted during the period of vegetation establishment.
19. If a minimum 50% vegetation coverage is not achieved after the first growing season, additional planting is required.

Construction specifications should include the following information:

1. Temporary Erosion Control
   - Install prior to site disturbance
   - Protect catchbasin and inlets
   - It is highly recommended that future vegetated swale locations not be used as temporary sedimentation basins. If used as temporary sedimentations basins, the bioswale should be over-excavated a minimum of 0.45 m below sedimentation basin grade.
2. Excavation, Backfill and Grading
   - Timing of grading of vegetated swales relative to total site development
   - Use of low-impact, earth moving equipment
   - Avoidance of over-excavation
   - Restoration in the event of sediment accumulation during construction of dry swales or bioswales
   - Drain rock backfill specifications
   - Drain rock filter specifications
   - Filter media specifications
   - Geotextile specifications
3. Native Plants, Planting and Transplanting
   - Site preparation of planting areas
   - Timing of (native) seeding, sodding and (native) planting
   - Weed control
   - Watering of plant material
4. Construction Sequence Scheduling
   - Temporary construction access
   - Location of erosion control measures to protect source control practices and downstream receiving waters
   - Removal and storage of excavated materials
   - Installation of underground utilities
   - Rough grading
   - Seeding and/or sodding disturbed areas
   - Road construction
   - Final grading
   - Site stabilization

- Installation of semi-permanent and permanent erosion control features
- Erosion control measure removal

5. Construction Observation

- Adherence to construction documents
- Verification of physical site conditions
- Erosion control measures installed appropriately.

Inspections during construction are needed to ensure that the vegetated swales are built in accordance with the approved design and standards and specifications. Detailed inspection checklists are used, which include sign-offs by qualified individuals at critical stages of the construction to ensure that the contractor's interpretation of the plan is correct. This checklist should include the following components:

1. Pre-Construction

- Pre-construction meeting
- Runoff diverted
- Vegetated swale area cleared
- Native soil tested for permeability
- Project benchmark near site
- Facility location staked out
- Temporary erosion and sediment protection properly installed

2. Excavation

a. Lateral slopes completely level
b. Native soils not compacted during excavation
c. Longitudinal slopes within design tolerances
d. Stockpile location not adjacent to excavation area and stabilized with vegetation and/or silt fence

3. Structural Components

a. Outlet installed per plans
b. Geotextile along bottom and sides installed per plans
c. Subdrain installed to grade
d. Drain rock gradation conforms to specifications
e. Drain rock installed per plans
f. Geotextile between drain rock and filter media installed per plans
g. Filter media composition and texture conforms to specifications
h. Inlets and pre-treatment devices installed per plans

4. Vegetation

a. Complies with vegetation specifications
b. Soil properly stabilized for permanent erosion control

5. Final Inspection

a. Dimensions per plan
b. Pre-treatment operational

c. Inlet/outlet operational
d. Filter bed permeability verified
e. Effective stand of vegetation stabilized
f. Construction generated sediment removed
g. Contributing watershed stabilized before flow is diverted to the practice

2.6 *Performance and impact on surrounding community/environment*

2.6.1. Impact on adjacent infrastructure

A geotechnical specialist should consider concerns about the effect of infiltrating water on buildings or properties adjacent to a vegetated swale. Potentially, infiltrating water could increase inflow and infiltration phenomena within the sanitary sewer system if preferential flow paths exist. Again, the advice of a qualified geotechnical specialist is emphasized.

The required clearance from buildings or property lines depends on the types of subsoils and presence of a subdrain system. Clearances of 1.0 m are recommended for unconfined sandy soils and 5.0 m for heavy clay soils. Clearance distances may be reduced if the device is “dry” in one, two or even three days after filling.

Bioswales should be located at least 30 m from wells, at least 3 m downslope of building foundations, and only in areas where foundations have weeping tiles. Zero clearance is an option only if an impermeable liner and a subdrain are provided.

An impermeable liner at least 12 mil thick should be provided on the bottom and sides of bioretention areas in areas with expansive or NRCS Type D soils, i.e. clay loam to clay soils with permeability less than 2.5 mm/hr or 6.9×10^{-7} m/s.

Utility or other crossings of dry swales or bioswales should be avoided. Where shallow or deep utility trenches must be constructed below the swales, clay plugs or other impervious materials should be installed in the trench to prevent infiltrating water from following the utility trench.

2.6.2. Community and environmental factors

Concerns about right-of-way requirements, standing water and potential icing up of driveway culverts, etc. reduce the acceptability of vegetated swales for front yards arrangements. As demonstrated in the West Rockborough development in northwest Calgary, side-yard or back-of-lot arrangements are more acceptable. Approval is generally highest in commercial, industrial or institutional areas where the swales can be readily incorporated in the overall landscape design.

Studies show that vegetated swales represent a practical and effective technique for controlling urban runoff. Check-dams, mild longitudinal slopes, permeable soils, dense grass cover, increased contact time, and small storm events contribute to successful pollutant removal.

A cascading bioswale approach has been very well received in other communities across North America because of the associated enhanced landscaping. In addition to aesthetic site features, they enhance privacy among residents; provide shade and windbreaks; and buffer structures from roads by absorbing noise.

As long as dry swales and bioswales are designed to draw down standing water within 72 hours, they will not provide breeding ground for mosquitoes and other vectors.

2.6.3. Performance with regard to pollutants of concern

Vegetated swales provide water quality enhancement by treating runoff from at least the water quality design event. Like bioretention areas, vegetated swales can be very effective in removing fine particles, trace metals, nutrients, bacteria and organics.

2.6.4. Performance under cold climate conditions

In cold climate regions such as Calgary, dry swales or bioswales can be used as occasional snow storage areas as long as they are planted with salt tolerant, and non-woody plant species.

The vegetative filtering of runoff diminishes once vegetation dies back in the fall. Some filtering will continue to occur if the vegetation density and depth are sufficient. The installation of a subdrain system will help keep the facility dry in the fall, thereby avoiding icing problems in winter.

Subdrains that are 200 mm in diameter make freezing less likely, and provide a greater capacity for draining standing water in the drain rock. The drain rock is also less susceptible to frost heaving than finer grained media. The incorporation of some storage capacity in the design of a bioswale will allow for routing and collecting of snowmelt runoff and encourage the start of filtration and infiltration in the spring.

In the case of bioswales in medians or along roadways, installing a buffer along the outside curb perimeter or a geotextile filter fabric along the perimeter of the bioretention area will help minimize the chance of runoff seeping under the pavement and causing frost heave during the winter months.

If bioretention is used to treat runoff from a parking lot or roadway that is frequently sanded during snow events, grass filters or grass channels at least 3 to 6 m long will convey flow to the bioretention areas and prevent clogging from sand in runoff. In this case, street sweeping is also an acceptable pre-treatment practice.

If bioswales are used to treat runoff from stormwater hot spots, additional SCPs should be incorporated to provide some treatment during the winter months when the bioswale may be frozen.

2.7 *Long-term issues*

2.7.1. Long-term sustainability

Vegetated swales require seasonal landscaping maintenance. Vegetated swales may initially require intense upkeep until vegetation is established. Designers should ensure that the swales are easily accessible for maintenance purposes. Plans should identify owners and delineate maintenance responsibilities.

These plans should include the following:

- Operating instructions for outlet component
- Vegetation maintenance schedule
- Inspection checklists
- Routine maintenance checklist

If responsibility for inspections and maintenance lies with a private entity such as a private landowner, community association or condominium association, a legally binding and enforceable maintenance agreement must be executed between the property owner and The City of Calgary.

An impermeable liner should be installed if there are concerns about groundwater contamination, specifically in case of runoff from stormwater hot spots.

2.7.2. Life-cycle costs

Although local life-cycle costing information is limited at this time, the following cost items should be included:

- Site Preparation
- Tree and plant protection
- Clearing and grubbing
- Topsoil salvage
- Site Formation
- Excavation and grading
- Hauling material offsite
- Structural components
- Subdrains
- Inlet structure(s)
- Outlet structure
- Site Restoration
- Filter strip
- Soil preparation
- Seeding and/or sodding
- Planting/transplanting
- Annual Operation and Maintenance, and Inspection
- Debris removal
- Sediment removal
- Weed control
- Inspection
- Mowing

Not included are typical cost items common to all construction projects such as mobilization, traffic control, erosion and sediment control, permitting, etc. Total cost varies, depending on soil conditions, density and types of plants, and specifically the need for control structures, curbing, storm drains, and subdrains. Overall, vegetated swales cost less compared to traditional structural stormwater conveyance systems.

2.7.3. Safety and liability

Properly designed and maintained swales pose a negligible safety risk. Design guidelines with respect to the depth of flow in vegetated swales are generally based on the water quality design event. Vegetated swales should be seen as only one component of a larger ‘treatment train’. Typically, flow velocities are kept low as part of the design in order to maintain the treatment capability and to minimize the chance of erosion during extreme events. As long as the maximum depth of ponding and the combination of the depth and velocity of flow meets City of Calgary and provincial guidelines, vegetated swales are no different than conventional drainage practices.

Shallow side slopes minimize the risk of a passer-by falling or vehicle overturning into a vegetated swale. The design configuration of a vegetated swale and selected plant types should provide adequate sight distances, clear spaces, and appropriate setbacks for roadway applications.

2.7.4. Failure scenarios

The main failure scenario of dry swales or bioswales is inadequate hydraulic conductivity (waterlogging) caused by a build-up of sediments in the native subsoils or filter media during the summer months. Excessive sedimentation can be caused by:

- Higher-than-estimated sediment loadings from the tributary catchment.
- Non-existent or inadequate pre-treatment.
- Inadequate erosion and sediment control during construction activities in the contributing catchment.
- Contamination of the native soils, filter media or drain rock by soil or sediments during construction.
- Compaction of the native soils or filter media during construction.
- Inappropriate composition of the filter media.
- Hydraulic overloading of the swale from an excessively large catchment area.

Other potential failure scenarios include:

- Frost damage to flow-retarding devices.
- Erosion within the swale bottom due to inadequate dispersion of flow through the swale.
- Dying-back of vegetation due to inappropriate selection of grasses, plants and shrubs.
- Dying-back of vegetation due to runoff from stormwater hotspots without proper pre-treatment.
- Excessive groundwater levels.
- Impacts on adjacent structures and properties from infiltrating water.

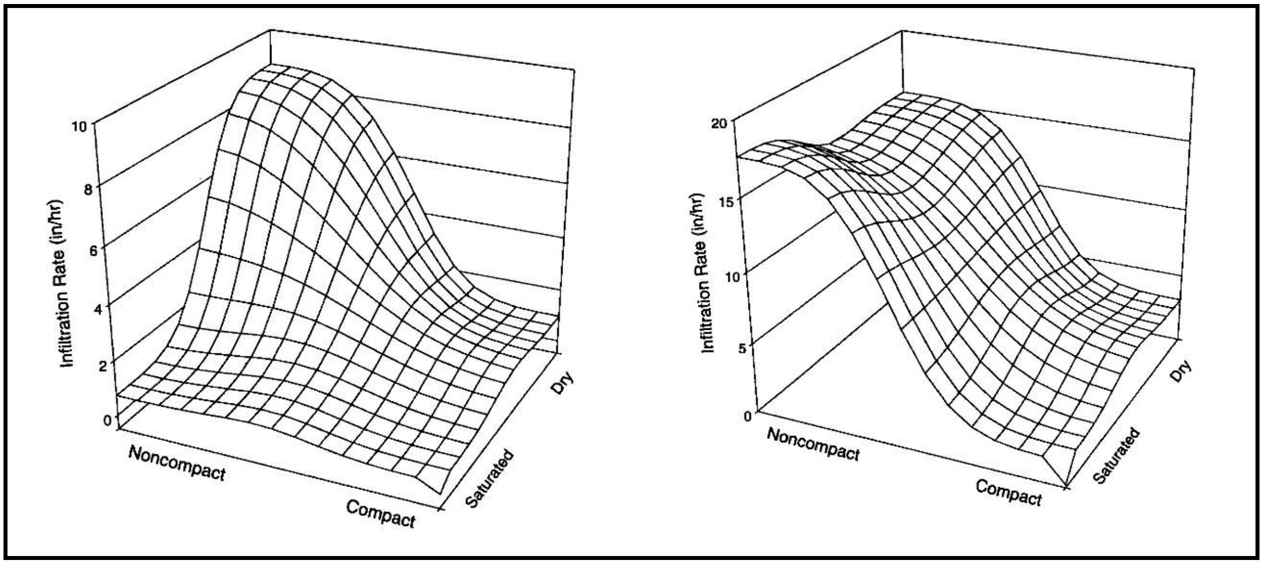
3.0 Absorbent Landscapes

3.1 *Description*

Preserving and/or restoring the moisture storage and infiltration capacities of soils can significantly reduce stormwater runoff. Prior to development, native soils act like a sponge, soaking up, storing and slowly releasing runoff. In undeveloped areas of the Calgary region, well over 90% of precipitation either percolates into the soils or evapotranspires. Landscape soils typically store from 7% (in sandy soil) to 18% (in loamy soil) of their volume as water before becoming saturated to field capacity and generating flow-through or runoff.

Construction activity removes the upper layers of soil from a site and compacts exposed sub-soils low in organic matter. Compacted, unamended soil in landscaped areas functions like an impervious surface, allowing considerable stormwater runoff. Figure 3-1 illustrates how infiltration rates are undermined by the compaction of subsoils.

Figure 3-1 Infiltration rates in clayey and sandy soils as function of compaction



1. Source: Pitt et al, 2002

The ability of soil to effectively store and slowly release water is dependent on soil texture, structure, depth, organic matter content, and biota. Plant roots, macro fauna, and microbes tunnel, excavate, penetrate and physically and chemically bond soil particles to form stable aggregates that enhance soil structure and porosity. Micro- and macro-pores improve water-holding capability and increase infiltration capacity and oxygen levels.

Organic matter is a critical component of a functioning soil system. Mixed into the soil, organic matter absorbs water, physically separates clay and silt particles, and reduces erosion. Vegetation enhances surface infiltration rates, prevents erosion, reduces the amount of rainfall directly impacting the ground surface and decreases runoff velocity.

3.2 *Application*

The hydrologic characteristics of any disturbed construction site soils for new or retrofit development projects can be enhanced by creating absorbent landscape and amending the soils with organic matter.

Organic matter derived from compost, stockpiled on-site soil, or imported topsoil can be beneficial in all areas subject to clearing and grading. Application rates and techniques for incorporating amendments will vary depending on the intended use of the site.

3.3 *Hydrologic benefits*

The purpose of preserving and/or creating absorbent landscapes is to reduce stormwater runoff by tapping into the water retention, infiltration and evapotranspiration capabilities of undisturbed or amended soils. Infiltration of stormwater through healthy soil is one of the most effective practices to improve water quality and remove urban pollutants. Proper design of the absorbent landscape facilitates and perpetuates natural cleansing processes and cycles in the soil/mulch/plant community.

In absorbent landscapes with amended soils, runoff is filtered through the soils as it percolates downwards.

- Pollutant removal in amended soils is accomplished through a number of processes e.g. sedimentation/filtration/adsorption (pollutants are retained in the soil); assimilation (nutrients and metals are taken up by vegetation); and, biodegradation (soil bacteria convert organic matter to carbon dioxide and water).
- Enhancing the filtration of runoff through subsurface soils also lowers water temperature. This helps reduce fish kills and degraded stream habitat caused by thermal pollution of streams from urban runoff.

3.4 *Design*

3.4.1. Design approach

The following design recommendations can help ensure the successful implementation of absorbent landscaping:

- Maximize the amount of absorbent landscape on a site, either by preserving existing landscape as much as possible or by using amended soils.
- Install temporary fencing around protected areas during construction.
- Disconnect impervious areas from the minor system, by having them drain to absorbent landscape with only an emergency escape route overflow to the minor system.
- Ensure that flow from hard surface areas is evenly distributed across the entire absorbent landscape.

The flow entering absorbent landscaping should be distributed sheet flow with a maximum sheet flow velocity of 0.9 m/s, traveling through a grassy filter area or grass swale prior to entering the absorbent landscape.

The flow rate for design purposes is typically the Water Quality Design Event; however, where larger flow rates from infrequent events cannot bypass the absorbent landscape, the design flow rate should be increased accordingly.

Absorbent landscape areas should be designed as gently sloping (i.e., ≤ 2%) or dished (concave) areas that temporarily store precipitation and/runoff and allow it to soak in with a maximum ponding time of 2 days, and with overflow only occurring during large storm events in excess of 20 to 30 mm precipitation.

Organic soil amendments, suitable for landscaping and stormwater management, should be a stable, mature compost derived from organic waste materials including yard debris, manures, bio-solids, wood wastes or other organic materials that meet the intent of the organic soil amendment specification.

Compost quality can be determined by qualitative tests. A simple way to judge compost quality is to smell and examine the finished product, which should have an earthy smell, be brown or black in color, and have mixed particle sizes. Soil samples must be tested for bulk density and percentage of organic matter. The compost is tested for bulk density, percentage of organic matter, moisture content, carbon-to-nitrogen ratio, and heavy metals. Compost and topsoil producers can often supply the required data for the amendment material.

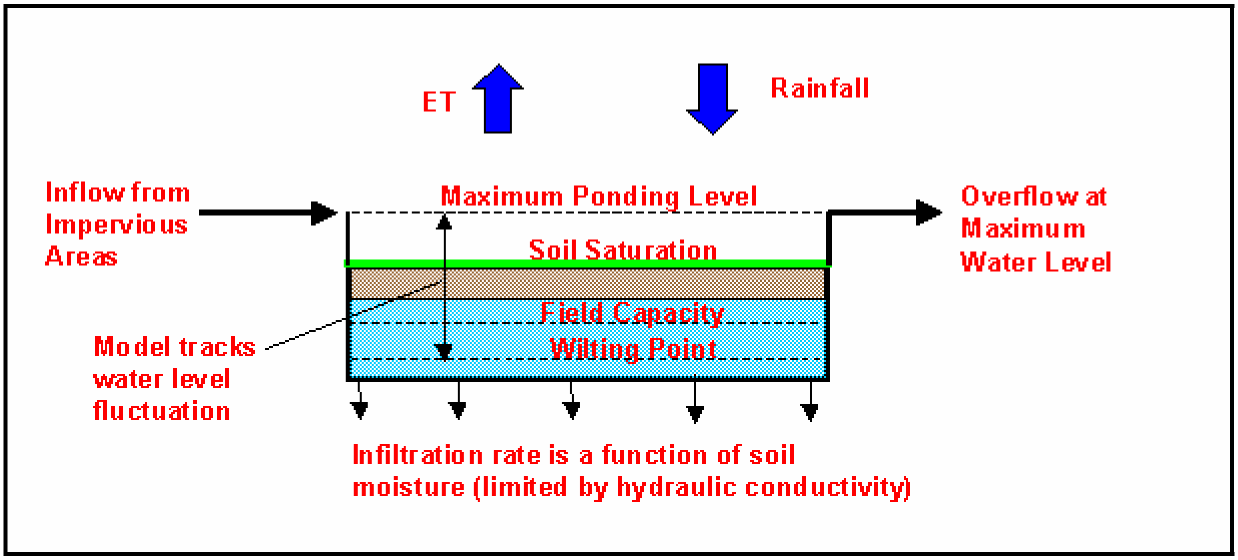
3.4.2. Design examples

The following considerations apply to design:

- The landscape subgrade or growing medium should not be over-compacted, as excessive compaction reduces infiltration rates. Subsoils that are excessively compact should be ripped or tilled, while compacted surface soils should be aerated.
- The subgrade surfaces should be scarified prior to placing amended soils, and be rototilled through layers of amended soils to create a transition in soil texture rather than discrete soil layers. Soils should not be installed in layers of different textures, as this can create barriers to infiltration.
- Vegetative cover (grass, groundcovers, shrubs, trees) or organic cover (mulch, straw, wood fiber) should be installed as early as possible in the construction process to avoid surface crusting from raindrop impact and to maintain surface permeability.
- Planting beds, outside of areas with concentrated flows, should be mulched with 50 to 75 mm (maximum) of organic material.
- Effective erosion control should be provided during construction, including erosion control on upstream sites that may flow into the absorbent landscape.
- To prevent possible groundwater contamination and practice failure, the seasonally high groundwater table should be at least 0.6 m to 0.9 m from the bottom of the amended soils if filtered water is to be infiltrated.

A water balance analysis can be used to assess the benefits of absorbent landscape and amended soils (see Figure 3-2).

Figure 3-2 Schematic for Water Balance Computation



Source: www.waterbalance.ca British Columbia Inter-Governmental Partnership

The selection of the soil properties, values for saturated hydraulic conductivity, maximum water content, field capacity and wilting point should be based on site-specific conditions and the characteristics of the amended soils.

Since runoff volume reduction is the prime objective of absorbent landscapes, irrigation of these sites should be kept to a minimum in order to maximize the storage capacity of the amended soils during subsequent storms. Absorbent landscapes should not be used for sites with a continuous flow from groundwater, sump pumps or other sources.

Absorbent landscapes are suitable for any site regardless of in-situ soil type as unsuitable soils can be amended.

3.4.3. Limitations

Sedimentation, excessive compaction, and lack of vegetative cover can impede efforts to preserve or regenerate absorbent landscape. Quality control is paramount with respect to installed soil properties, erosion and sediment control, and establishment of vegetation.

The amount of absorbent landscape on a site must be balanced with the amount of impervious area in order to meet typical performance targets. This can be accomplished by conducting a long-term water balance of the site. In addition, an emergency escape route or overflow should be provided. The successful implementation of absorbent landscapes is enhanced by better design principles, such as promoting building forms that minimize impervious building footprints, utilizing green roof systems, or by designing narrower roads and larger landscape islands in parking lots.

Stabilization of the absorbent landscape by vegetative methods cannot be implemented outside the growing season. Erosion control matting and a heavy mulch application are preferable to vegetative stabilization when construction continues into the fall.

3.4.4. Vegetation

Vegetation is a crucial component of absorbent landscaping. Vegetation has an important role both above and belowground.

Aboveground, appropriate vegetation acts to retard and distribute flows and protects the surface of the soils from erosion. Vegetation also helps trap suspended sediments.

Belowground, the vegetation in absorbent landscaping has a number of functions. During periods of filtration (or infiltration), water must pass through the root-zone of the plants. The root-zone of plants is a highly biologically active area. Plants roots support a wide range of microbiota and influence characteristics of the media for several millimeters around the root (i.e. the rhizosphere). As water passes through the rhizosphere, materials carried by the water can be either physically trapped by the high surface area of the media and rhizosphere or can be actively taken up by plant roots or other rhizosphere biota (bacteria and fungi). Bacteria and fungi associated with plant root systems can significantly increase the biological uptake of nutrients and water by plants.

During inter-event periods plant growth plays an important role in maintaining the structure and hydraulic conductivity of the media. Plant roots are constantly growing and dying. This growth and death cycle results in macro-pore formation and maintenance, which is a major factor in soil structure maintenance and fertility as well as soil hydraulic conductivity. Plant shoot emergence through the surface of soils similarly maintains soil surface structure and hydraulic conductivity. The action of wind also creates movement on the aboveground parts of plants, which also helps to maintain surface porosity.

Plant selection should be based on the amount of sunshine, soil moisture fluctuations and soil type on the site. Native plant species require less maintenance than non-native species. They are also better for water quality because they do not require the fertilizer that introduced species require. Since they develop very deep root systems, native grasses and wildflowers provide very good long-term erosion control. Mature plantings are recommended over seed because seeds can be transported if water enters the absorbent landscape prior to germination. Seed is also difficult to establish through mulch.

Temporary seeding should be applied on exposed soil where additional work (grading, etc.) is not scheduled for more than 45 days. Temporary seeding of annual grasses may be carried out for up to 12 months to temporarily stabilize exposed areas. Permanent seeding should be applied if the areas will be idle for more than a year. Idle areas should be seeded as soon as possible after grading (within 7 days).

All plant materials should have normal, well-developed branches and vigorous root systems, and be free from physical defects, plants diseases and insect pests. All plants should be tagged for identification when delivered. Establishing non-native planting sometimes requires a fertilizer application to initiate growth. Apply these nutrients according to soil test recommendations.

Mulch should be applied around trees and shrubs immediately after planting.

Vegetation should be watered until established. If a minimum coverage of 50% is not achieved after the first growing season, a reinforcement planting is required.

Lawns should be planted with high-quality, low maintenance grass species. In shady areas, substitute shade-loving native plants for turf grass. Mown lawn areas should be reduced or entirely eliminated in areas that are not used for active recreation. Planting appropriate herbaceous perennials or shrubs will help reduce runoff volume, filter sediment and provide wildlife habitat.

If the site is well drained and acceptable for traditional lawn installation, then a compost-amended soil lawn will drain equally well while providing superior storm flow storage, pollutant processing, and growth medium. A drainage route or subsurface collection system may be necessary for composted or non-composted turf applications in poorly draining soils.

Design configuration and selected plant types should provide adequate sight distances, clear spaces, and appropriate setbacks for roadway applications.

3.4.5. Space requirements

Space requirements of absorbent landscape are a function of the magnitude of the source control target, the size and imperviousness ratio of the tributary catchment, the depth and composition of the amended soils, and the hydraulic conductivity of the subsoils. Where absorbent landscapes do not receive runoff from adjacent hard surface areas, space requirements are identical to what would normally be set aside for landscaping. In that case, the main functions of the absorbent landscape are reduced runoff volume and reduced watering requirements compared to conventional landscaping.

Where absorbent landscapes are used to accommodate runoff from impervious surfaces, the absorbent landscape area should be at least twice the size of the tributary hard surface area. This value should be confirmed with actual water balance computations.

Smaller, distributed areas are better than single large-scale facilities. For larger areas, it becomes increasingly difficult to disperse the runoff evenly over the absorbent landscape without eroding or overloading the amended soils.

Utility or other crossings of absorbent landscapes should be avoided. Where shallow or deep utility trenches must be constructed below the amended soils, clay plugs or other impervious materials should be installed in the trench to keep infiltrating water from following the utility trench.

3.5 *Construction*

The following recommendations relate to achieving quality results in the construction of absorbent landscapes:

1. Isolate absorbent landscape from the risk of sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the construction of the absorbent landscape until after all sediment-producing construction in the drainage area has been completed. Any soils contaminated with sediment must be removed and replaced.

2. Stockpile on-site topsoil from cleared and graded areas and replace prior to planting. Cover stockpiled soil with a weed barrier or other breathable material that sheds moisture yet allows air transmission prior to grading. Test the stockpiled material and amend with organic matter or topsoil if required to achieve organic content to 200 mm depth.

3. Grading should not be undertaken during wet or saturated conditions.

4. Grade absorbent landscape area using lightweight, low ground-contact pressure equipment to minimize compaction of the underlying subsoils. No heavy equipment with narrow tracks, narrow tires, or large lugged, high-pressure tires should be allowed within the absorbent landscape area. After grading, the base should be ripped at completion to refracture the soil to a minimum of 0.30 m.

5. Compacted soils should be deep tilled or "ripped" to a depth of at least 450 mm. Then, a minimum depth of 150 mm of organic compost should be applied and tilled into the top 300 mm of the soil.
6. Do not scarify soil within drip-line of existing trees to be retained. Within 1.0 m of tree drip-line, amendment should be incorporated no deeper than 75 to 100 mm to minimize damage to roots.
7. New amended soils should not be delivered until the absorbent landscape area has been graded to the design elevations. Planting materials should not be delivered until the amended soils have had time to settle and have been trimmed to the proper grade elevation.

Soil can be amended using one of the following methods:

1. Amend existing disturbed topsoil or subsoil.

Scarify or till soil to a depth of 200 mm (8 inches) (or to a depth needed to achieve a total depth of 300 mm [12 inches] of uncompacted soil after the calculated amount of amendment is added). The entire surface should be disturbed by scarification and amendment applied on soil surface.

Landscaped Areas (15 percent organic content): Place and till 75 mm [3 inches] (or custom-calculated amount) of composted material into 125 mm [5 inches] of soil (a total depth of about 238 mm [9.5 inches], for a settled depth of 200 mm [8 inches]). Rake beds smooth, remove rocks larger than 50 mm (2 inches) diameter and mulch areas with 50 mm [2 inches] of organic mulch.

Turf Areas (8 percent organic content): Place and till 44 mm (1.75 inches) (or custom calculated amount) of composted material into 159 mm [6.25 inches] of soil (a total amended depth of about 238 mm [9.5 inches], for a settled depth of 200 mm [8 inches]. Water or roll to compact soil to 80 percent of maximum. Rake to level, and remove surface woody debris and rocks larger than 25 mm [1-inch] diameter.

2. Replace stockpiled topsoil.

If replaced topsoil plus compost or other organic material would amount to less than 300 mm [12 inches], scarify or till subgrade to a depth needed to achieve 300 mm [12 inches] of loosened soil after topsoil and amendment are placed. The entire surface should be disturbed by scarification and amendment applied on soil surface.

Landscaped Areas (15 percent organic content): Place and till 75 mm [3 inches] of composted material into 125 mm [5 inches] of replaced soil (a total depth of about 238 mm [9.5 inches], for a settled depth of 200 mm [8 inches]). Rake beds to smooth, remove rocks larger than 50 mm [2 inches] diameter, and mulch areas with 50 mm [2 inches] of organic mulch or stockpiled duff.

Turf Areas (8 percent organic content): Place and till 44 mm [1.75 inches] of composted material into 159 mm [6.25 inches] of replaced soil (a total amended depth of about 238 mm [9.5 inches], for a settled depth of 200 mm [8 inches]). Water or roll compact soil to 80 percent of maximum. Rake to level, and remove surface woody debris and rocks larger than 25 mm [1-inch] diameter.

3. Import topsoil with required organic-matter-content standards.

Scarify or till subgrade in two directions to a 150 mm (6-inch) depth. The entire surface should be disturbed by scarification and amendment applied on soil surface.

- *Landscaped Areas (15 percent organic content):* Use imported topsoil mix containing 15 percent organic matter (typically around 60 percent compost). The soil portion must be sand or sandy loam as defined by the USDA soil classification system. Place 75 mm [3 inches] of imported topsoil mix on surface and till into 50 mm [2 inches] of soil. Place 75 mm [3 inches] of topsoil mix on the surface. Rake smooth, remove surface rocks over 50 mm [2 inches] in diameter, and mulch planting beds with 50 mm [2 inches] of organic mulch.
- *Turf Areas (8 percent organic content):* Use imported topsoil mix containing 8 percent organic matter (typically around 38 percent compost). Soil portion must be sand or sandy loam as defined by the USDA soil classification system. Place 75 mm [3 inches] of topsoil mix on surface. Water or roll to compact soil to 80 percent maximum. Rake to level and remove surface rocks larger than 25 mm [1-inch] diameter. The soil portion of the topsoil must be sand or sandy loam as defined by the USDA soil classification system. The soil and compost mix should have less than 25 percent pass through a #200 sieve and 100 percent should pass through a ¾-inch screen.

Proper construction methods and sequencing play a significant role in reducing problems with operation and maintenance. The most important action for preventing operation and maintenance difficulties is to ensure that the contributing drainage area has been fully stabilized prior to bringing the practice on line.

Inspections during construction will ensure that the absorbent landscape is built in accordance with the approved design, standards and specifications. The inspection checklists should include:

2. Pre-Construction
   - Pre-construction meeting
   - Runoff diverted
   - Facility area cleared
   - Native soil tested for permeability
   - Project benchmark near site
   - Facility location staked out
   - Temporary erosion and sediment protection properly installed
3. Grading
   - Lateral slopes completely level
   - Native soils not compacted during excavation
   - Longitudinal slopes within design tolerances
   - Stockpile location not adjacent to excavation area and stabilized with vegetation and/or silt fence
4. Structural Components
   - Overflow installed per plans
   - Amended soil composition and texture conforms to specifications
   - Inlets and pre-treatment devices installed per plans
5. Vegetation

- Complies with vegetation specifications
- Mulch complies with specifications in composition and placement
- Soil properly stabilized for permanent erosion control

6. Final Inspection

- Dimensions per plan
- Pre-treatment operational
- Inlet/outlet operational
- Amended soil permeability verified
- Effective stand of vegetation stabilized
- Construction-generated sediment removed
- Contributing watershed stabilized before flow is diverted to the practice

3.6 *Performance and impact on surrounding community/environment*

3.6.1. Community and environmental factors

Community acceptance of absorbent landscapes is generally very high because of their aesthetic value.

In order to prevent absorbent landscape from becoming a breeding ground for mosquitoes and other vectors, a water balance of the site should be conducted. The absorbent capacities of the amended soils must not be overwhelmed by disproportionately high inflows from impermeable surfaces. A surface and subsurface overflow should ensure that standing water dissipates within 72 hours.

3.6.2. Performance with regard to pollutants of concern

In the case of filtering runoff from stormwater hot spots and concerns about potential groundwater contaminations, appropriate pollution prevention and good housekeeping measures as well as pre-treatment of runoff should be implemented.

3.6.3. Performance under cold climate conditions

In cold climates, absorbent landscapes can be used as temporary snow storage areas. When used for this purpose, or to treat parking lot runoff, the absorbent landscapes should be planted with salt tolerant plant species. One problem with infiltration or filtration areas in cold weather is the ice that forms both on top of the facility and within the soil interstices. Since absorbent landscapes do not have subdrain systems, the actual soil moisture regime of absorbent landscapes at the onset of winter is weather dependent.

If absorbent landscapes are used to treat runoff from a parking lot or roadway that is frequently sanded during snow events, there is a high potential for clogging from sand in runoff. Grass filters or grass channels at least 3 to 6 m long should be installed to convey flow to the amended soils in these situations. Street sweeping would be an acceptable pretreatment practice.

3.7 *Long-term Issues*

3.7.1. Long-term sustainability

Absorbent landscapes require seasonal landscaping maintenance. In many cases, absorbent landscapes require intense maintenance initially until plants are established, but less maintenance in the long term. Proper maintenance will not only increase the expected life span of the facility, but will also improve aesthetics and property values.

Designers should ensure that the absorbent landscape area is easily accessible for inspection, maintenance and landscaping upkeep using appropriate equipment and vehicles. The use of pesticides and fertilizers should be minimized or, if possible, eliminated. An integrated pest management program, which works by balancing natural mechanisms on a given site, should be implemented.

The designer should prepare a site-specific Inspection, Operation and Maintenance Plan. This plan should include operating instructions for the overflow component, a vegetation maintenance schedule, and inspection and routine maintenance checklists.

This plan should also identify owners and indicate those responsible for maintenance. When the responsibility for inspections and maintenance lies with a private entity such as private landowner, community association or condominium association, a legally binding and enforceable maintenance agreement must be executed between the property owner and The City of Calgary.

3.7.2. Life-cycle costs

Compared to traditional structural stormwater conveyance and treatment systems, absorbent landscaping is a cost-efficient practice. Construction costs for absorbent landscapes are slightly higher than for the required landscaping for new developments. The difference is a function of the soil conditions and need for amendments, density and types of plants, and specifically the need for inflow and overflow controls. In the case of retrofit situations, costs could be higher because of added demolition costs and removal and replacement of soil.

The cost of plants varies substantially and can account for a significant portion of the expenditures. While the cost estimates may be slightly higher than those of typical landscaping treatment, those landscaping expenses that would be required regardless of the absorbent landscape installation should be subtracted when determining the net cost.

3.7.3. Failure scenarios

The main failure scenario of absorbent landscape is waterlogging of the soils during the summer months. Runoff can collect in the absorbent landscape during the winter months and early spring; however, this ponding should dissipate when the ground thaws. Detrimental effects would be limited if an appropriate emergency escape route is provided.

Waterlogging of the amended soils is a direct consequence of inadequate hydraulic capacities of the soils, which could result from:

- Sediment loadings to the absorbent landscape from the tributary catchment being much greater than what was assumed as part of the original analysis and design.
- Missing or inadequate pre-treatment.

- Inadequate erosion and sediment control during the construction activities in the contributing catchment.
- Compaction of the amended soils during construction.
- Inappropriate composition of the amended soils so that they do not have the hydraulic capacity specified in the design.
- Hydraulic overloading of the absorbent landscape by routing water from too large an area to the amended soils.
- Overestimation of the hydraulic conductivity of the subsoils if the subsoils are designed to drain the absorbent landscape between runoff events.

Other potential failure scenarios include:

- Erosion within the soil bed due to inadequate dispersion of the flow over the absorbent landscape.
- Dying back of vegetation that cannot withstand fluctuations in soil moisture or accumulation of contaminants.
- Dying back of vegetation due to runoff of water from stormwater hotspots being routed into absorbent landscape without proper pre-treatment.
- Excessively high groundwater levels.
- Impacts on adjacent structures and properties from infiltrating water.

4.0 Bioretention Areas

4.1 *Description*

A bioretention area, also known as an (infiltration) rain garden or porous landscape detention, is a source control practice (SCP) that consists of depressed, landscaped areas underlain by a fine media layer and, depending on the permeability of the subsoils, a granular or equivalent subbase with a subdrain pipe. Bioretention areas facilitate attenuation of runoff flow as well as treatment of stormwater through settling, fine filtration, extended detention and some biological uptake. This SCP is generally incorporated into the landscaping of a site.

A shallow ponding layer exists above the bioretention area for temporary storage of excess runoff from roofs or paved areas. During a storm event, runoff accumulates in the vegetated zone and gradually infiltrates into the underlying fine media layer, filling up the pore space in the media. On subsoils with low infiltration rates, as are prevalent in the Calgary region, bioretention areas often have a gravel/drain rock reservoir and perforated subdrain system to collect excess water. Between runoff events, the media layer gradually dewaters into the native subsoils, or if a subdrain is provided, into a nearby channel, swale or storm sewer.

Alternatives to gravel/drain rock such as “milk crate” configurations have become commercially available. Contingent on the desired hydrologic functionality of this SCP, the subdrain system may be connected to a flow control consisting of an orifice, or equivalent, in a catchbasin or manhole. Depending on the overall grading of the site, a secondary overflow inlet is sometimes provided at adjacent catchbasins. The strategic, uniform distribution of bioretention facilities across a development site results in smaller, more manageable sub-watersheds, which help control runoff close to the source. Runoff can enter either as sheet flow or via a curb and gutter collection and conveyance system.

Bioretention areas have nine (9) major components:

1. Pre-treatment
2. Flow entrance
3. Ponding area
4. Plant materials
5. Organic layer or mulch
6. Filter media
7. Gravel or rock drain
8. Subdrain and outlet
9. Surface overflow

These components serve complimentary functions to improve water quality and quantity control through biologic and physical processes. In conjunction with plant and root growth, organic decomposition, and the development of a macro and micro-organism community, bioretention areas help develop a natural soil horizon and structure.

4.2 *Application*

Bioretention areas can be located in virtually any open space of a development site. They are ideally suited for small installations such as:

- Parking lot islands (see Figure 4-1)
- Street medians
- Traffic circles
- Cul-de-sacs
- Roadside swale features (e.g., between the curb and sidewalk)
- Tree box filters (see Figure 4-2)
- Shared facilities located in common areas for individual lots
- Common landscaped areas in apartment complexes or other multifamily housing designs
- Commercial setbacks, and
- Site entrance or buffer features

Figure 4-1 Bioretention landscaped island with curb cuts

Source: PSAT, 2005. Photo by Larry Coffman

Figure 4-2 Tree Box Filter

Source: PSAT, 2005.

Though generally associated with relatively small catchment areas, bioretention areas can also provide infiltration for larger sites if adequate storage capacity and ponding depth are included.

Bioretention areas are suitable for most development situations, i.e., residential areas, office complexes, rooftop runoff, parking and roadway runoff, park and green space, golf courses, etc. They are well suited to many highly impervious areas, and can be used both in new and stormwater retrofit situations, by modifying existing landscape areas, or if a parking lot is being resurfaced.

With the provision of an adequate subdrain system, bioretention areas can be used in most soils, including clay with infiltration rates as low as 0.6 mm/hr. They also represent an effective means of removing fine particles, trace metals, nutrients, bacteria and organics.

4.3 *Hydrologic Benefits*

While deep percolation and the evapotranspiration of moisture by vegetation reduce the volume of runoff from a catchment, the storage capacity of bioretention areas reduces local flooding as well as peak flow rates to downstream systems. This, in turn, reduces downstream flooding, protects stream bank integrity, and provides groundwater recharge and base flow in nearby streams.

The magnitude of these reductions depends on many factors including the amount of storage capacity available above the filter bed, the size of the bioretention area relative to the size of the catchment, the depth and composition of the filter media, the type of vegetation, and the permeability of the subsoils.

Since bioretention areas are only one component of a larger, overall treatment train, other regional storage facilities will likely need to be used in conjunction with bioretention areas to meet peak discharge and water quantity criteria for larger sites.

Bioretention areas are named for their ability to retain nutrients and other pollutants. Bioretention is dependent on the natural cleansing processes that occur in the filter media/mulch/plant community. Depending on the availability of a subdrain system, it may then be collected in a perforated pipe and discharged to the receiving water bodies via conventional stormwater pipes. In most of the Calgary area, the hydraulic conductivity of the filter media is significantly higher than the surrounding soils. This means that the flowpath of infiltrated stormwater is well defined and exfiltration from the bioretention trench to the surrounding soils is minimized.

Bioretention systems require an even flow distribution to allow water to infiltrate the filter media evenly. Treatment can be enhanced by allowing the runoff to pond over the filter media. This increases the amount of time that runoff can infiltrate and also increases the volume of runoff that is treated. Plants are essential in maintaining the porosity of the soil filter media.

4.4 *Design*

4.4.1. Design approach

The following steps provide an outline of the design procedure for bioretention practices:

1. Make a preliminary assessment as to whether site conditions are appropriate for the use of a bioretention area, and identify the function of the practice in the overall treatment system:
   - Consider the following basic issues for initial suitability screening:
     - Site drainage area
     - Site topography and slopes
     - Soil infiltration capacity
     - Regional or local depth to groundwater and bedrock
     - Site location and minimum setbacks
   - Determine how the bioretention practice will fit into the overall stormwater management system
   - Determine whether the bioretention area is the only source control practice to be employed, or if there are other source control practices addressing some of the treatment requirements
   - Decide where on the site the bioretention practice is most likely to be located
   - Confirm design criteria and applicability

2. Perform field verification of site suitability
   - If the initial evaluation indicates that a bioretention practice would be a good source control practice for the site, it is recommended that a qualified geotechnical professional dig at least three (3) soil borings or test pits at the location of the proposed bioretention practice to verify soil types and infiltration capacity characteristics, and to determine the depth to groundwater and bedrock
   - The soil borings or test pits should be 1.5 m below the bottom elevation of the proposed bioretention area
   - A soil profile description should be recorded, which should include the following information for each soil horizon or layer:
     - Thickness
     - Munsell soil colour notation
     - Soil mottle or redoximorphic feature colour, abundance, size and contrast
     - Soil textural class with rock fragment modifiers
     - Soil structure, grade size and shape
     - Soil consistence, root abundance and size

- Soil boundary
- Occurrence of saturated soil, impermeable layers/lenses, groundwater, bedrock or disturbed soil.

3. Compute runoff control volume
4. Determine size of bioretention area (steps 5 through 8 are iterative)
5. Determine size of outlet structure and/or flow diversion structure
6. Check volume, peak discharge rate and period of inundation
7. Perform groundwater mounding analysis
8. Determine pre-treatment volume and design pre-treatment measures
9. Prepare vegetation and landscaping plan
10. Prepare construction specifications
11. Prepare inspection, operation and maintenance plan
12. Prepare maintenance agreement/covenant for facilities located on private property

4.4.2. Design examples

4.4.2.1 Groundwater separation

Bioretention areas should be separated from the groundwater table to ensure that the groundwater does not intersect with the bottom of the bioretention area. This will prevent possible groundwater contamination and practice failure. Specifically, the seasonally high groundwater table should be at least 0.6 m to 0.9 m from the bottom of the bioretention area if filtered water is to be infiltrated.

The distance between the bottom of bioretention area and the groundwater table can be reduced to 0.30 m if the contributing area of the bioretention cell has:

- Less than 450 m^2 of pollution-generating impervious surface.
- Less than 900 m^2 of impervious surface.
- Less than 3,000 m^2 of lawn.

Procedures for the quantification of in-situ infiltration rates for the native soils beneath bioretention areas are discussed in Appendix E.

4.4.2.2 Run-off flow

The five (5) primary types of flow entrances for bioretention areas are:

- *Dispersed, low velocity flow across a landscape area:* This is the preferred method of delivering flows to the bioretention area.
- *Dispersed flow*: Runoff flows across pavement or gravel and past wheel stops for parking areas.
- *Curb cuts for roadside or parking lot areas:* Curb cuts should include rock or other erosion protection material in the channel entrance to dissipate energy. Flow entrance should drop 5 to 7.5 cm from curb line and provide an area for settling and periodic removal of sediment and coarse material before flow dissipates to the remainder of the cell.
- *Pipe flow entrance:* Piped entrances should include rock or other erosion protection material in the channel entrance to dissipate energy and/or flow dispersion.

- *Catchbasin:* Catchbasins can be used to “slowly” release water to the bioretention area through a grate for filtering coarse material.

In the case of concentrated flows at the inlet to bioretention area, the entrance should be composed of non-erodable materials or equipped with appropriate, permanent erosion protection such as matting. The magnitude of the flow rate for design purposes is typically the Water Quality Design Event, however, in case larger flow rates from infrequent events cannot bypass the bioretention area, the design flow rate should be increased accordingly.

Since bioretention areas are susceptible to clogging from sediments, measure should be taken to capture as much of the (gross) sediments as possible and spread the flow across the bioretention area. Pre-treatment will help ensure the proper functioning of the bioretention area and allow for longer periods between maintenance.

Preferably, the flow entering bioretention areas should be distributed sheet flow, traveling through a grassy filter area or grass swale prior to entering the bioretention area.

The following guidelines are recommended for a grassed, pre-treatment swale:

- Parabolic or trapezoidal cross-section with bottom width between 0.6 m and 2.4 m
- Swale slopes no steeper than 3:1 (H:V)
- Flow velocity smaller than or equal to 0.3 m/s for the peak flow rate associated with the Water Quality Design Event
- Flow depth smaller than or equal to 0.10 m for the peak flow rate associated with the Water Quality Design Event
- Length for swale greater than 6 m.

Table 4-1 provides recommended sizing for a grassed filter strip.

Table 4-1 Length for Pre-treatment Swales for Bioretention Areas

Parameter	Impervious Parking Lots				Residential Lawns			
Maximum Inflow Approach Length	10.7 m		22.9 m		22.9 m		45.7 m	
Filter Strip Slope	≤ 2%	> 2%	≤ 2%	> 2%	≤ 2%	> 2%	≤ 2%	> 2%
Filter Strip Minimum Length	3.0 m	4.5 m	6.0 m	7.5 m	3.0 m	3.6 m	4.5 m	5.4 m

Source: Minnesota, 2005

A 300 mm stone drop or small stilling basin can be provided at the inlet of bioretention areas where flow enters through curb cuts or other concentrated flow inlets.

Contaminated runoff, e.g. from roads, parking areas and driveways, should be separated from runoff from roof areas to reduce sediment loadings to a bioretention area.

An overflow or emergency escape route, composed of non-erodable materials, should be provided to maintain the integrity of the bioretention area during extreme events, or events in excess of the design storm that was used to plan the bioretention area.

The overflow design is more critical in commercial or industrial settings where large quantities of runoff can be generated by the paved surfaces. Flow-through bioretention facility designs are not recommended.

Bioretention areas should not be used for sites with continuous flow from groundwater, sump pumps or other sources.

4.4.2.3 Grading

The bioretention area should have a flat or dished bottom with maximum 1% slope. Bioretention areas on steeper sites of up to 10% grade must be properly terraced.

Infiltration devices should be excluded from steep-slope sites in the absence of thorough exploration of site and down-slope geology. A soil depth (suitable soil) of at least 3 m should be available throughout a down-slope, developed hillside before infiltration practice should be contemplated.

4.4.2.4 Mulch layer

Many references recommend the provision of a 50 – 75 mm layer of organic mulch composed of well-aged (i.e. at least 12 months) compost, bark mulch or similar weed-free material. The mulch is important for erosion control, and for maintaining infiltration capacity by preventing the crusting of the soil surface. The mulch also retains moisture in the plant zone, minimizes weed establishment and filters pollutants, specifically retaining metals. It provides an environment conducive to the growth of micro-organisms, which degrade petroleum-based products and other organic material.

The mulch should be kept 50 mm away from trunks and stems of vegetation to prevent rotting of bark. Mulch depths greater than 75 mm interfere with the cycling of carbon dioxide and oxygen between the soil and atmosphere.

Where organic mulch is used for metal removal, the mulch should be replaced in spring. Old mulch should be removed and disposed of.

The mulch should meet City of Calgary, Parks landscaping specifications.

Mulch is recommended in conjunction with groundcover until the latter is established. In time, the plants can fulfill the role of the mulch layer (see Figure 4-6).

Figure 4-6 Bioretention Area/Bioswale

Source: Bert van Duin, Westhoff Engineering Resources, Inc.

4.4.2.5 Side Sloping

The side slopes of the bioretention area should be greater than 2:1 (H:V). A side slope of 4:1 (H:V) is preferred for maintenance purposes.

4.4.2.6 Depth of Ponding

The ponding area above the filter media provides for surface storage of stormwater runoff before it passes through the filter media. The ponding area also allows for evaporation of ponded water as well as settling of sediments.

Recommendations in literature for the maximum ponded level vary from 150 mm to 300 mm.

Ponding targets of 200 mm depth for the 15 mm water quality design event and 500 mm depth for the 1:100 year design event can be used. The maximum depth of ponding for the 1:100 year event corresponds to the permissible maximum depth in traplows.

4.4.2.7 Drawdown/emptying time

Duration of 12 hours is recommended for the Water Quality Design Event and up to 72 hours for the 24 hour, 1:100 year event. These values may be changes over time depending on the outcome of local pilot studies.

These durations are well below the value of 96 hours suggested in literature for maintaining aerobic conditions for water quality treatment (Minnesota, 2001).

4.4.2.8 Filter media

A two-layer treatment soil system is recommended for the bioretention area. The top layer or upper rooting zone should be composed of 15-30% compost and 70-85% growing medium. The compost addition increases infiltration capacity, improves soil fertility and reduces compaction. This top layer should have a depth of 0.20 to 0.30 m.

The compost should be mature with 50-60% organic matter, free from contaminants.

The growing medium should be free of plants, roots, sticks, building materials, wood chips and chemical pollutants. The pH should be between 5.0 and 6.0. The concentration of soluble salts should be less than 500 ppm, while the criteria for magnesium, phosphorus and potassium are 95, 275 and 234 kg/ha, respectively.

The organic content should be 25-30% dry weight. The particle sizes and proportions of each particle should be within the following ranges, with the proportion in percent of dry weight mineral fraction:

Particle Size	Proportion
Gravel (2 – 75 mm diameter)	0%
Sand (0.05 – 2 mm)	50 – 70%
Silt (0.002 – 0.05 mm)	10 – 30%
Clay (< 0.002 mm)	0 – 5%

The minimum depth of the bottom layer or deep rooting/percolation zone, which extends from the top layer to the drain rock, should be 0.25 m, while a depth of 0.90 m is desirable.

Combined, the filter media should be 0.10 m deeper than the bottom of the largest root ball and preferably 1.20 m. This depth will provide adequate depth for the plants' root systems to become established, prevent plant damage due to severe wind, and provide adequate moisture capacity. In addition, a soil depth of 1 m thick gives the maximum pollutant removal efficiency.

Where larger trees are not part of the design, a 0.75 m soil depth is sufficient as little additional pollutant removal is accomplished beyond that depth.

The initial infiltration rate of the treatment soil should be greater than 13 mm/hour. This initial infiltration rate corresponds to loam as per Table A-4 of Appendix A. A higher infiltration rate, however, will decrease the size requirements of the bioretention area. During construction, it should be confirmed that the actual infiltration rate of the treatment soils used match the design assumptions.

4.4.2.9 Subdrain and drain rock layer

A 300 mm thick gravel or drain rock layer with subdrain system should be installed under the treatment soil system. The subdrain should be provided for all facilities installed in residential areas and in areas where the in-situ soils have an infiltration capacity of less than 25 mm/hour. Vertical placement of the subdrain will vary depending upon whether or not infiltration and de-nitrification are a design consideration.

The subdrain system should be composed of PVC, SDR 35, 150 mm diameter pipe, with filter sock and cleanouts/observation standpipe. The standpipe will serve the following three primary functions:

- Indicate how quickly the bioretention area dewaters after a storm.
- Provide a maintenance cleanout port.

- Connect to the subdrain system to facilitate cleanout of the subdrain.

The subdrain should be at a minimum 0.5% slope to ensure that the pipe is dry during inter-event periods to avoid root penetration of the pipe. The (slot) opening should be smaller than the smallest aggregate gradation for the drain rock blanket to prevent migration of material into the drain. This configuration should allow for pressurized water cleaning and root cutting if necessary. The capacity of the subdrain system should be greater than the hydraulic conductivity of the filter media.

Pipe joints and connections must be adequately sealed to avoid piping conditions, i.e. water seeping through pipe or structure joints. Pipe sections should be coupled using suitable connection rings and flanges. Field connections to structures and pipes should be sealed with polymer grout material that adheres to surfaces. Subdrain pipes should be capped until construction is complete. Subdrains directly connected to a structure should be non-perforated for a distance of at least 1.5 m from the structure interface to avoid possible piping problems.

When a permeable liner is provided at the bottom of the drain rock, the subgrade underneath should be scarified to a minimum depth of 200 mm. The gravel/drain rock reservoir should be level, composed of double-washed rock, and have the following particle size distribution:

Particle Size	Percentage Passing
37.5 mm	100%
28 mm	95 to 100%
13 mm	20 to 60%
5 mm	0 to 10%
2.36 mm	0 to 5%

Installation of the gravel/drain rock reservoir and subdrain may not be necessary where tests at the level of the base of the proposed bioretention area show an infiltration rate that exceeds the ultimate hydraulic conductivity of the filter media. This scenario is rare in the Calgary area.

4.4.2.10 Utility crossings

Utility or other crossings of bioretention areas should be avoided. Where shallow or deep utility trenches must be constructed below the bioretention area, clay plugs or other impervious materials should be installed in the trench to avoid infiltrating water from following the utility trench.

4.4.2.11 Geotextiles

A geosynthetic liner should be provided on the bottom and sides of the bioretention basin. If underlying soils are expansive, or if there is a concern about groundwater contamination, an impermeable liner should be installed, as specified by a certified geotechnical specialist. The liner should be protected from puncture by a geotextile fabric.

If soils are not expansive, a porous geotextile fabric can be used, again as determined by a geotechnical specialist. The same type of porous liner should be installed between the deep rooting/percolation zone and the drain rock zone. Alternatively, a 7.5 to 22.5 cm thick pea gravel diaphragm may be used as this provides greater porosity and is less likely to become blocked. This pea gravel should be washed, river-run, round diameter, 6 – 13 mm in size.

4.4.3. Limitations

The hydraulic conductivity of the filter media must not exceed those specified in the design criteria or the media's contaminant removal capability may decrease.

Bioretention systems are particularly sensitive to clogging of the filter medium. If there are moderate to high levels of silts and clays in the runoff, pre-treatment is required. Runoff from industrial/commercial hotspots requires pre-treatment or source control practices upstream of bioretention areas.

It is important to restrict any traffic over the bioretention area and carefully manage construction activities to avoid damaging the vegetation and compacting and clogging the filter medium. This can be done through the application of appropriate erosion and sediment control measures in the tributary catchment, appropriate selection of vegetation, and/or through isolation methods such as fencing. It may be necessary to provide a protective cover such as a geofabric over the bioretention area during construction.

Inverts of the existing storm drain system can be a limiting factor. In general, a 1.2 m to 1.8 m elevation above the invert of the storm sewer system is required to drive stormwater through bioretention areas.

4.4.4. Vegetation

Vegetation is an important component of bioretention systems. Plants remove water through evapotranspiration and remove pollutants and nutrients through uptake. Plant roots enhance the infiltration capacity of the soil, providing conduits for percolation. Plant shoot emergence through the surface of soils helps maintains soil surface structure and hydraulic conductivity. Surface porosity is also maintained as vegetation moves in the wind.

Planting design should respect the varying soil moisture conditions that are expected in the bioretention area. Plants selected for use in bioretention areas need to be able to tolerate periods of inundation because a portion of the soil profile could be saturated for several days, as well as extended dry periods between runoff events.

Deeper rooting vegetation is recommended as it can access soil moisture at deeper levels in the media bed and is, therefore, less susceptible to drought conditions. Deep root systems will also keep the media layer open and allow for more uptake than shallow roots. In addition to being able to tolerate varying soil moisture levels, the selected vegetation should also be able to tolerate progressive accumulations of contaminants on top and within the filter media.

Recommended vegetation includes irrigated bluegrass for erosion control and multiple use, or natural grasses, rushes and sedges with shrub and tree plantings. By selecting sedges or other larger relatively sturdy plants, movement and traffic over the bioretention area can be discouraged. Plants with a spreading, rhizomatous or suckering habit are preferred. Those with a tendency to grow in clumps can cause undesirable channelling, erosion and preferential flowpaths. Selected plants should be low-maintenance.

Plants that are native to the Calgary area are preferred as they are inherently suitable to the climate conditions. Non-native plants may also be used if their habitat requirements are similar to the expected conditions. Selected plants must be non-invasive and must not be included on Alberta's restricted plants lists.

The City of Calgary recommends planting three (3) species each of both trees and shrubs at a rate of 2500 trees and shrubs per hectare (1000 per acre). This diversity protects against insect attack and disease. The shrub-to-tree ratio should be 2:1 to 3:1. On average, the trees should be spaced 3.6 m (12 ft) apart and the shrubs should be spaced 2.4 m (8 ft) apart. To ensure adequate vegetation cover in a short time, the initial density of the planting arrangement should be thick.

Trees should not be planted directly over subdrains; the best location for trees is along the perimeter of the bioretention area.

Perennials should be planted along the edge of the retention area, where colour and seasonal interest are desirable. Herbaceous ground cover (at least three or four species) should be provided to protect the mulch layer from erosion. Overall, the planting should have a random and natural layout. Woody species should not be placed near the inlet(s) and outlet(s) as they can cause blockage from falling debris and leaves.

Parking lot island bioretention areas are particularly susceptible to extended dry conditions. A layered planting scheme will help discourage weeds and help create a suitable microclimate.

4.4.5. Space requirements

The bioretention area dimensions will generally be a function of a size and type of contributing catchment. In most cases, a minimum bottom width of 600 mm is recommended, while a width of 3000 mm is desirable. The length to width ratio should be 2:1.

The size of the bioretention area should equal approximately 10-20% of the upstream impervious area that it serves. The size of the bioretention area is a function of the magnitude of the design event, the size and imperviousness ratio of the tributary catchment, and the hydraulic conductivity of the filter media. The performance of bioretention areas should be confirmed by continuous flow modelling. Smaller, distributed bioretention areas are better than single large-scale facilities.

To avoid erosion and overloading of the filter bed, multiple, smaller bioretention areas are preferred in larger catchments.

On residential and commercial lots, bioretention facilities should be located near the source of the runoff generated from impervious surfaces. However, they should be located away from public pathways to avoid compaction.

The required clearance distance from buildings or property lines depends on the type of subsoils and presence of a subdrain system. Clearances ranging from 1.0 m for unconfined sandy soils to 5.0 m for heavy clay soils are recommended. The potential for swelling and therefore clearance distances can be reduced if the device dries up within one, two or even three days after filling.

Bioretention areas should be located at least 30 m from wells, at least 3 m down-slope of building foundations, and only in areas where foundations have weeping tiles.

Zero clearance is possible in the case of flow-through planter boxes (see Figure 4-4 and Figure 4-5). In these cases, however, an impermeable liner as well as a subdrain should be provided, with overflow directed away from the building.

An impermeable liner is recommended for the bottom and sides of bioretention areas with expansive soils.

Figure 4-4 Zero clearance bioretention area in shape of planter

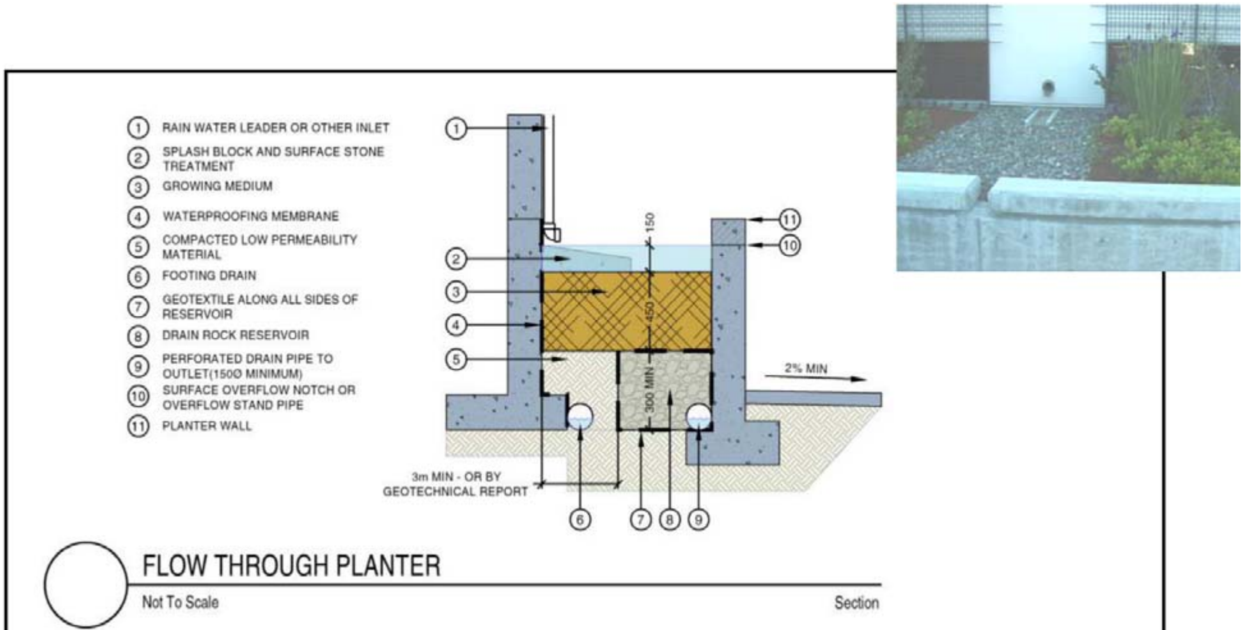
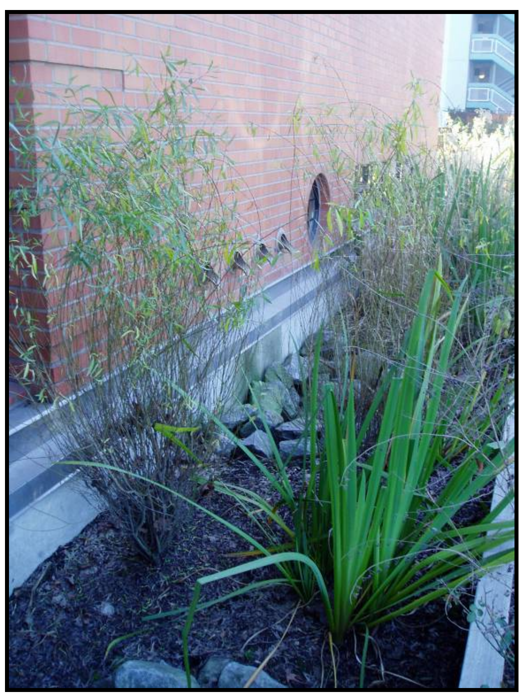


Figure 8: Flow-thru planter – a formal-shaped raingarden that provides water quality treatment and limited flow attenuation - adapted to a near-building location at Buckland Terrace in Portland, Oregon. *Credit: Lanarc Consultants*

Source: GVRD, 2004.

Figure 4-5 Bioretention planter in Portland, Oregon



Source: Bert van Duin, Westhoff Engineering Resources, Inc.

Rather than focus on the minimum sizing criteria, designers are encouraged to develop the bioretention area to fit the available space and setback restrictions, selecting plants that work well with the facility's location and hydrologic regime.

4.5 *Construction*

The following recommendations pertain to the construction of bioretention areas:

1. The bioretention area should be isolated from sedimentation during construction, either by use of effective [2]erosion and sediment control measures upstream, or by delaying the construction of the bioretention area until after all sediment-producing construction in the drainage area is complete. Any drain rock, filter media or compost contaminated by sediment must be removed and replaced.
2. Sediment control devices should be inspected at the end of each workday. All sediment traps should have room for additional sediment loading capacity.
3. Excavation should not be allowed during wet or saturated conditions.
4. The bioretention area should be excavated using a backhoe excavator. The equipment must avoid running over the bioretention area to minimize compaction of the underlying subsoils. No heavy equipment with narrow tracks, narrow tires, or large lugged, high-pressure tires should be allowed on the bottom of the bioretention facility. If machinery must operate in the bioretention cell for excavation, light weight, low ground-contact pressure equipment should be used, while the base should be ripped at completion to refracture the soil to a minimum of 0.30 m. The sidewalls of the trench shall be roughened where sheared and sealed by heavy equipment.
5. Care should be taken to ensure that geotextiles are not clogged, punctured or torn during construction. If they are damaged they must be repaired or replaced. Filter media placed over the geotextiles should be placed by hand shovel rather than construction equipment.
6. Geotextiles should overlap by at least 0.50 m at seams to prevent short-circuiting or intrusion of fines, and be keyed in properly at the surface. Openings for e.g. subdrain pipes should be sealed.
7. Prevent natural or fill soils from intermixing with the gravel/drain rock. All contaminated stone aggregate must be removed and replaced.
8. Gravel/drain rock should be double-washed.
9. Gravel/drain rock shall be installed in 300 mm lifts and compacted to eliminate voids between the geotextile and surrounding soils.
10. Filter media should not be delivered until the bioretention facility location has been excavated or graded to the design elevations and geotextile fabrics and subdrain systems are in place. Planting materials should not be delivered until after the filter media has had time to settle and trimmed to the proper grade elevation.

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2 For conventional site design, erosion and sediment control often typically consists of a sediment control pond at the lowest point of the property under development. This sediment basin would then be used for stormwater management control after construction is complete. Sites that incorporate bioretention for stormwater control require closer attention to detail because drainage areas are reduced and massive grading to one low point is discouraged. As a result, grading and sediment control practices are typically applied on a lot-by-lot basis to minimize the opportunity for soil transport.

11. Soil tests should be performed for every 382 m^3 (500 yd^3) of planting soil, with the exception of particle size distribution, pH and organic matter tests, which are required only once per bioretention area.
12. Filter media should be placed in 200 mm (8 inches) to 300 mm (12 inches) lifts, and slightly compacted until the desired depth is reached. Minimal compaction effort can be applied to the filter media by tamping with a bulldozer or backhoe bucket. Over time, settlement and compaction of the soil mixture will occur naturally. Depending on the composition of the filter media, up to 20% natural compaction may occur. The filter media can be overfilled above the proposed surface grade to accommodate natural settling to proper grade. To speed settling, each lift can be sprayed with water until just saturated.
13. Adjacent non-native invasive species should be identified and measures such as providing a soil breach should be taken to eliminate the threat of these species invading the bioretention area.
14. Mature plantings are recommended over seed because fluctuating water levels following seeding (prior to germination) can cause seeds to be transported. Seed is also difficult to establish through mulch.
15. All plant materials should have normal, well-developed branches and vigorous root systems, and be free from physical defects, plants diseases and insect pests. Large tree roots must be trimmed flush with the sidewalls in order to prevent puncturing or tearing during subsequent installation procedures. The minimum recommended calliper size for trees planted within a bioretention area is 1 inch.
16. All plants should be tagged for identification when delivered.
17. Mulch should be provided immediately after trees and shrubs are planted.
18. Vegetation should be watered until established.
19. If a minimum coverage of 50% is not achieved after the first growing season, a reinforcement planting is required.

Construction specifications should include the following information:

1. Temporary Erosion Control
   - Install prior to site disturbance
   - Protect catchbasin and inlets
2. Excavation, Backfill and Grading
   - Coordinate timing of grading of bioretention facilities with total site development
   - Use low-impact, earth-moving equipment
   - Do not over-excavate
   - Restore any areas affected by sediment accumulation during construction
   - Follow drain rock backfill, drain rock filter, filter media and geotextile specifications
3. Planting and Transplanting
   - Ensure proper site preparation of planting areas
   - Ensure proper timing of (native) seeding and (native) planting
   - Control weed growth
   - Water plant material
4. Construction Sequence Scheduling

- Ensure appropriate timing of:
- Temporary construction access
- Location of erosion control measures to protect source control practices and downstream receiving waters
- Removal and storage of excavated materials
- Installation of underground utilities
- Rough grading
- Seeding and mulching of disturbed areas
- Road construction
- Final grading
- Site stabilization
- Installation of semi-permanent and permanent erosion control features
- Erosion control measure removal

5. Construction Observation

- Ensure adherence to construction documents
- Verify of physical site conditions
- Ensure appropriate installation of erosion control measures
- Ensure that the contributing drainage area has been fully stabilized prior to bringing the practice on line

4.5.1.1 Inspection

Inspections during construction are needed to ensure that the bioretention area is built in accordance with the approved design and standards and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of the construction to ensure that the contractor's interpretation of the plan is acceptable to the professional designer. This checklist, adapted from Minnesota (2005), should include the following components:

1. Pre-Construction

- Pre-construction meeting
- Runoff diverted
- Facility area cleared
- Native soil tested for permeability
- Project benchmark near site
- Facility location staked out
- Temporary erosion and sediment protection properly installed
- Excavation
- Lateral slopes completely level
- Native soils not compacted during excavation
- Longitudinal slopes within design tolerances
- Stockpile location not adjacent to excavation area and stabilized with vegetation and/or silt fence

2. Structural Components

- Outlet installed per plans
- Geotextile along bottom and sides installed per plans
- Subdrain installed to grade
- Drain rock gradation conforms to specifications
- Drain rock installed per plans
- Geotextile between drain rock and filter media installed per plans
- Filter media composition and texture conforms to specifications
- Inlets and pre-treatment devices installed per plans

3. Vegetation

- Complies with vegetation specifications
- Mulch complies with specifications in composition and placement
- Soil properly stabilized for permanent erosion control

4. Final Inspection

- Dimensions per plan
- Pre-treatment operational
- Inlet/outlet operational
- Filter bed permeability verified
- Effective stand of vegetation stabilized
- Construction generated sediment removed
- Contributing watershed stabilized before flow is diverted to the practice

4.6 *Performance and impact on surrounding community/environment*

4.6.1. Impact on adjacent infrastructure

Impacts of bioretention area on adjacent infrastructure are believed to be limited as long as the effects of infiltrating water, if any, are accounted for. When bioretention areas have an appropriate clearance distance from adjacent buildings or other infrastructure or are lined with impermeable liners, impacts are minimal.

4.6.2. Community and environmental factors

Bioretention areas are generally well accepted in the community because of the associated enhanced landscaping. In addition to aesthetic site features, they enhance residents' privacy, provide shade and windbreaks, and absorb road noise.

Bioretention areas do not provide breeding ground for mosquitoes and other vectors as long as the emptying time is less than 72 hours (mosquitoes need at least 4 days of standing water to develop as larva). In fact, these areas can be designed to attract preferred creatures such as butterflies.

4.6.3. Performance with regard to pollutants of concern

Bioretention areas store water above the filtration media i.e., soil, sand, etc. The filtration media itself facilitates the removal of pollutants from stormwater through processes such as sedimentation, evaporation, filtration, assimilation, etc. Adequate contact time between the surface of the filter media and the contaminants must be provided in the design of the system for the removal processes, specifically adsorption, to occur.

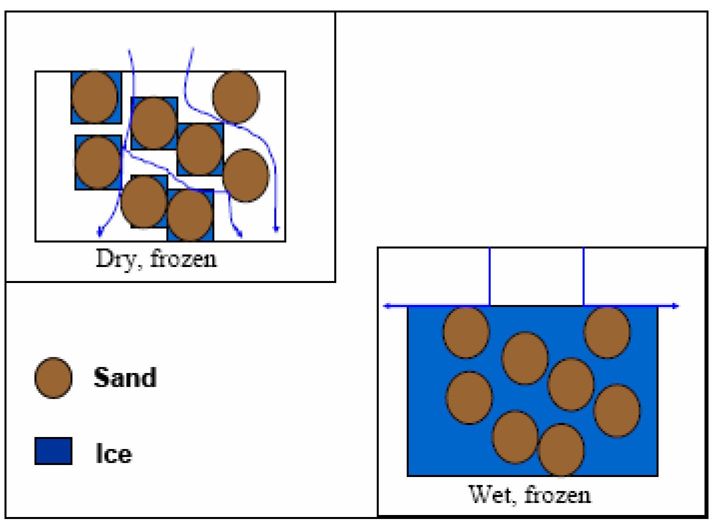
Bioretention has been shown to be effective in the treatment of phosphorus. Studies from laboratory and field experiments indicate that phosphorus is reduced by 60-80% as it is adsorbed on compounds containing iron, aluminum and calcium. For nitrogen, the removal rates are generally lower as nitrates are highly soluble and can easily infiltrate and contaminate groundwater. However, the bioretention design may be customized to specifically treat expected runoff pollutants such as nitrates by increasing depth, adding anaerobic zones, changing the mulch layer, or adding filter media amendments.

4.6.4. Performance under cold climate conditions

In cold climates, bioretention areas can be used for temporary snow storage. When used for this purpose, or to treat parking lot runoff, the bioretention area should be planted with salt tolerant, non-woody plant species.

Bioretention is only marginally effective for treating snowmelt runoff because of the dormancy of the vegetation during the cold season; treatment may still occur as long as a flow path is available and the filter media are not frozen solid. The problem with infiltration or filtration in cold weather is that ice forms both on top of the facility and within the soil interstices (see Figure 4-7).

Figure 4-7 Ice Formation in Infiltration Systems



Source: Minnesota, 2005.

To avoid these problems, the facility should be constructed so that it can dry out before it freezes in late fall. The provision of a subdrain system is one of the key methods identified. The incorporation of some storage capacity in the design of a bioretention area will provide an opportunity to route and collect snowmelt runoff in early spring and begin the filtration and infiltration processes.

Installing a subdrain with a diameter of 200 mm makes freezing less likely, and provides a greater capacity to drain standing water in the drain rock. For its part, drain rock is also less susceptible to frost heaving than finer grained media.

Bioretention areas in medians or traffic islands may require a buffer along the outside curb perimeter to minimize the chance of drainage seeping under the pavement section, and creating frost heave during the winter months. Alternatively, the installation of a geotextile filter fabric "curtain wall" along the perimeter of the bioretention area will achieve the same result.

When bioretention areas are used to treat runoff from stormwater hot spots, additional practices should be incorporated as a treatment train for limited treatment during the winter months when the bioretention area is subject to freezing.

4.7 *Long-term issues*

4.7.1. Long-term sustainability

Bioretention areas require seasonal landscaping maintenance. In many cases, bioretention areas require intense maintenance initially until plants are established, but less maintenance in the long term.

Designers should ensure that the bioretention area is easily accessible for inspection, maintenance and landscaping upkeep using appropriate equipment and vehicles.

Prior to putting the bioretention practice into operation, a site-specific Inspection, Operation and Maintenance Plan should be prepared by the designer. This plan should include the following:

- Operating instructions for outlet component
- Vegetation maintenance schedule
- Inspection checklists
- Routine maintenance checklist

This plan should also identify owners and indicate those responsible for maintenance. If responsibility for inspections and maintenance lies with a private entity such as private landowner, community association or condominium association, a legally binding and enforceable maintenance agreement must be established between the property owner and The City of Calgary.

4.7.2. Life cycle costs

Construction costs for bioretention areas are slightly higher than those for conventional landscaping for new developments. Cost variations are a function of the soil conditions, density and types of plants, and specifically the need for control structures, curbing, storm drains, and subdrains. In retrofit situations, costs are higher still because of the need for demolition and removal and replacement of soil. However, the cost savings compared to the use of traditional structural stormwater conveyance systems makes bioretention areas financially feasible.

The following items should be included in a cost assessment of a bioretention area:

- Site Preparation
- Tree and plant protection
- Clearing and grubbing
- Topsoil salvage

- Site Formation
- Excavation and grading
- Hauling material offsite
- Structural components
- Subdrains
- Inlet structure(s)
- Outlet structure
- Site Restoration
- Filter strip
- Soil preparation
- Seeding and/or sodding
- Planting/transplanting
- Annual Operation and Maintenance, and Inspection
- Debris removal
- Sediment removal
- Weed control
- Inspection
- Mowing

Not included are typical cost items common to all construction projects such as mobilization, traffic control, erosion and sediment control, permitting, etc.

4.7.3. Safety and liability

To ensure safety, the design configuration and selected plant types in the bioretention area must provide adequate sight distances, clear spaces, and appropriate setbacks for roadway applications.

The main potential liability is the effect of infiltrating water on adjacent buildings or properties. Path flows must be designed to avoid a scenario where infiltrating water could increase inflow and infiltration phenomena within the sanitary sewer system.

4.7.4. Failure scenarios

Waterlogging of the bioretention area and filter media is a direct consequence of inadequate hydraulic conductivity of the filter media or subsoils if deep percolation is a factor. Inadequate hydraulic conductivity can result from excessive build-up of sediments. This can be caused by:

- Sediment loadings to the bioretention area from the tributary catchment being much greater than assumed as part of the original analysis and design.
- Excessive sediment loadings to the bed due to missing or inadequate pre-treatment.
- Inadequate erosion and sediment control during construction activities in the contributing catchment.
- Contamination of the filter media and drain rock by soil or sediments during construction.
- Other causes for inadequate hydraulic conductivity include:
- Compaction of the filter media during construction.

- Inappropriate composition of the filter media so that it does not have the specified design hydraulic conductivity
- Hydraulic overloading of the bioretention area from routing too large an area to the bioretention area.
- Overestimation of the hydraulic conductivity of the subsoils if the subsoils are counted on to empty the bioretention area in between runoff events.

Other potential failure scenarios include:

- Frost damage to flow-retarding devices.
- Erosion within the filter bed due to inadequate dispersion of the flow over the filter bed.
- Dying back of vegetation due to selection of vegetation that cannot withstand fluctuations in soil moisture or accumulation of contaminants.
- Dying back of vegetation due to runoff from stormwater hotspots being routed into bioretention areas without proper pre-treatment.
- Excessive groundwater levels.
- Impacts on adjacent structures and properties from infiltrating water.

5.0 Permeable Pavement

5.1 *Description*

Permeable (pervious, porous) pavement consists of:

- A permeable surface, which allows precipitation and runoff from adjacent areas to percolate into the ground beneath;
- An underlying open-graded reservoir base where rainfall is stored;
- An underlying subgrade through which water is exfiltrated, and/or;
- A subdrain that removes infiltrated stormwater.

Permeable pavement is typically intended for use in low-speed and low-volume traffic areas to accommodate pedestrian or vehicular traffic while facilitating infiltration of precipitation falling directly on the porous or pervious surface or flowing from adjacent areas.

5.1.1. Surface component

The surface component of permeable pavement can consist of: 1) porous asphalt or porous concrete; 2) permeable unit pavers; or, 3) turf/gravel paving.

5.1.1.1 Porous asphalt and concrete

Compared to conventional, dense asphalt, porous asphalt contains a low amount of filler, i.e. grain size < 0.075 mm diameter (see Figure 5-1). Stormwater infiltrates through the asphalt, which has 15-25 percent pore space. Polymers are added to the asphalt binder to prevent migration, and polymer-reinforcing fibres further enhance the bond. In addition, sufficiently large particles are used so that the remaining openings are large enough to allow infiltration, even if some migration occurs.

The same mixing and application equipment used for conventional asphalt can be used for porous asphalt. For porous asphalt, the amount of binder required is about 6% by weight, which is higher than what is required for conventional asphalt mixes.

Figure 5-1 Porous Asphalt at Currie Barracks, Calgary Source Control Practice Pilot Projects

Source: Brad Dardis, Westhoff Engineering Resources, Inc.

Porous concrete has a coarser appearance than its conventional counterpart (see Figure 5-2). It is created by mixing water and cement-like materials into a paste that forms a thick coating around the aggregate particles. This mixture contains little or no sand and forms a system of highly permeable, interconnected voids that drain quickly. A void ratio of 15 to 25 percent is achieved in the hardened concrete, which allows for average flow rates of over 12,000 mm/hr.

While the equipment used for porous and standard concrete is the same, larger pea gravel and a lower water-to-cement ratio are used in porous concrete to achieve a pebbled, open surface that is roller compacted.

Figure 5-2 Porous Concrete in Denver, Colorado

Source: Bert van Duin, Westhoff Engineering Resources, Inc.

5.1.1.2 Permeable unit pavers

Permeable unit pavers, also called cobblestone block pavers, consist of impervious concrete paving units, typically laid on a gravel subgrade (see Figure 5-3). Open voids are created by bevelling the corners of each block and/or widening the space between the blocks. Unit pavers decrease the effective imperviousness of a site. They also capture and treat runoff volume from the Water Quality Design Event and provide water detention.

Figure 5-3 Permeable Unit Pavers at Parking Lot in Olympia, Washington

Source: Bert van Duin, Westhoff Engineering Resources, Inc.

The openings in the surface are filled with unstabilized permeable material to allow water to pass through the surface pavement down to the layers below. The pavement is comprised of the paver surface, a (sand) bedding layer, a base course and a subbase course (if needed), and the existing subgrade. The bedding layer, placed immediately below the surface layer, is usually about 25 mm in thickness. The composition of bedding and base layers must be carefully selected to accommodate infiltrated water and traffic loads while providing adequate water treatment. Permeable unit pavers provide the added benefit of low-cost maintenance.

5.1.1.3 Turf/gravel paving

Turf paving options include modular paving blocks or grids, cast-in-place concrete grids and soil enhancement technologies. Gravel paving is another related option. All of these methods increase a site's load-bearing capacity, and allow for foot and vehicle traffic and healthy grass growth (see Figure 5-4).

Figure 5-4 Turf Pavers planted with grass

Source: http://www.mutualmaterials.com[3]

Modular turf paving blocks consist of concrete or plastic interlocking units that provide structural stability and resist compaction while a series of gaps planted with turf grass allow for infiltration. Some blocks may also be filled with gravel and left unplanted. A sand setting bed and gravel subbase is often added to encourage infiltration and prevent settling.

Cast-in-place concrete grids incorporate gaps that are filled with topsoil and grass for a free-draining pavement with the structural capacity to handle most heavy vehicle loads. When reinforced with wire mesh, this option provides a strong surface and avoids the differential settlement sometimes experienced with modules. However, the installation is more labour-intensive than that of the pre-cast modular pavers.

[3] Acknowledgement of products and companies in this handbook does not constitute endorsement.

Plastic grid systems, often made from recycled materials, allow water to gradually percolate into the soil below. Some are designed to be filled with gravel on top of an engineered aggregate material, while others are filled with a sand/soil mixture on top of an aggregate/topsoil mix that allows grass to be planted on the surface, resulting in a natural turf surface with an engineered load-bearing root zone (see Figure 5-5) The grids support heavy vehicles and are often used for overflow parking lots, golf courses, recreational fields and other areas where the aesthetic appeal of uninterrupted grass is important.

Figure 5-5 Plastic Grid System filled with Grass (a) and Gravel (b)


(a)


(b)

Source: http://www.drainproducts.nl and http://www.atlantiscorp.com.au/Home

Gravel paving systems are typically considered to be most appropriate for industrial sites and uses as they have a relatively simple cross-section and are not difficult or expensive to rebuild when performance begins to degrade over time.

An alternative to modular concrete blocks for the permeable turf paving system is soil enhancement, i.e. the use of an engineered growing medium mixed with mesh elements on site or obtained as solid slabs of turf with built-in mesh elements.

5.1.2. Subbase

As the major load-carrying element, the subbase:

- Distributes stormwater to the level where it can be tolerated by the subgrade without failure.
- Laterally drains water that is infiltrated through the pavement surface.
- Serves as a capillary barrier, which prevents water from moving upwards into the pavement base.
- Secures the pavement's structural integrity.
- Prevents ice lenses from forming in the pavement.

The subbase can consist either of open-graded gravel or drain rock, whose gradation is a trade-off between the structural integrity (i.e., stiffness) of the subbase and the stormwater management objectives (i.e., permeability and storage capacity). An alternative to the open-graded gravel or drain rock is the provision of structural drainage tanks (in the shape of 'milk crates'), which are reinforced in order to withstand traffic loadings (see Figure 5-6). The more conventional gravel or drain rock subbase and the structural drainage tanks are typically overlain by a geotextile and a sand bedding course layer which have a dual function of structural support for the surface layer and filtering of fine particulates.

Figure 5-6 Subbase Alternative in Heritage Mews, Australia

Source: http://www.atlantiscorp.com.au/Home

The subbase may be followed by a layer of improved or stabilized subgrade if the structural properties of the soil are insufficient.

The attenuation of stormwater volume and flow rate by this SCP depends on the amount of storage capacity available above the pavement surface, the size of the permeable pavement area relative to the size of the catchment, the capacity of the reservoir, the depth and composition of the subbase, the hydraulic conductivity of the subsoils, the presence of flow controls, the magnitude of the storm event, and the accumulation of sediments in the pavement layers.

5.2 *Application*

Permeable pavement systems are ideal for small sites where surface detention and stormwater treatment are hampered by space constraints, or where runoff volume reduction is an important design parameter. These systems can be used in new developments, retrofits and redevelopment areas.

Permeable pavement is suited to low-speed and low-volume traffic areas such as:

- Driveways
- Parking lots
- Residential street parking lanes

- Roadway shoulders
- Storage yards
- Bike and pedestrian paths
- Walkways
- Recreational vehicle pads
- Service roads or fire lanes
- Low vehicle movement airport zones such as parking aprons and maintenance roads
- Crossover/emergency stopping/parking lanes on divided highways

In addition to being used to manage direct precipitation, permeable pavements can provide a drainage path for water discharged from adjacent areas, such as roofs or impermeable parking areas. They are also suitable for rainwater re-use projects.

5.3 *Hydrologic benefits*

Permeable pavement systems reduce both peak flow and volume of stormwater runoff from a catchment. The degree to which runoff is reduced depends on: the hydraulic conductivity of the subsoils; the composition of the subbase; the elevation of a subdrain system; the presence of flow controls; and the ratio of permeable pavement area to catchment area. A water balance analysis that incorporates both deep percolation and evapotranspiration is necessary to determine precise runoff volume reduction benefits.

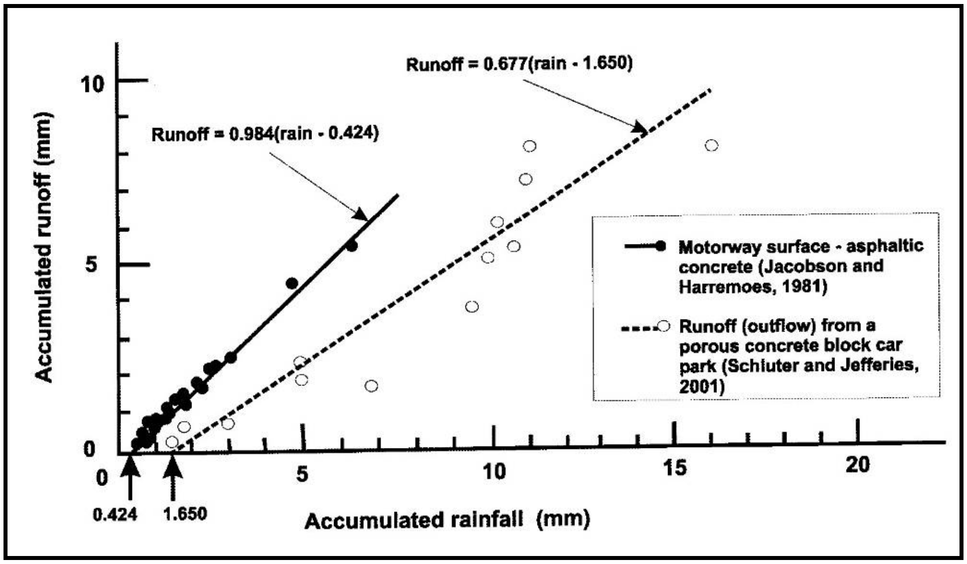
Properly constructed pervious surfaces allow rainwater to infiltrate across their entire surface. Pervious surfaces are most advantageous when laid at grades less than 2%, so that rainfall infiltrates where it hits the surface.

Figure 5-7 Permeable Unit Pavers in Denver, Colorado

Source: UD&FCD, courtesy of Wenk Associates

Figure 5-8 shows how permeable pavement structures compare with conventional pavement in reducing runoff.

Figure 5-8 Comparison of Volumetric Runoff from Conventional and Permeable Surfaces



Source: Pratt et al, 2002

5.4 *Design*

5.4.1. Design approach

The following steps provide an outline of the design procedure for permeable pavement systems:

1. Make a preliminary assessment as to whether site conditions are appropriate for the use of a permeable pavement system, and identify the function of the practice in the overall treatment system.
2. Consider basic issues for initial suitability screening:
   - Site drainage area
   - Site topography and slopes
   - Soil infiltration capacity
   - Regional or local depth to groundwater and bedrock
   - Site location and minimum setbacks
   - Intended use
   - Traffic patterns
3. Determine how the permeable pavement practice will fit into the overall stormwater management system.
4. Determine whether the permeable pavement area is the only source control practice to be employed, or if there are other source control practices addressing some of the treatment requirements.
5. Decide where on the site the permeable pavement practice will be located.
6. Confirm design criteria and applicability.
7. Perform field verification of site suitability.
8. Specifically for turf paving systems without the provision of impermeable liners at the bottom of the subbase, if the initial evaluation indicates that permeable pavement would be a good source control practice for the site, it is recommended that at least three (3) soil borings or test pits be carried out at the location of the proposed installation to verify soil types and infiltration capacity characteristics, and to determine the depth to groundwater and bedrock. The soil borings or test pits should be 1.5 m below the bottom elevation of the proposed permeable pavement area.
9. Create a soil profile description, which should include the occurrence of saturated soil, impermeable layer/lenses, groundwater, bedrock or disturbed soil.
10. Compute runoff control volume.
11. Determine size of permeable pavement area relative to catchment area.
12. Determine size of outlet structure.
13. Check volume, peak discharge rate and period of inundation.
14. Estimate lifespan.

15. Perform groundwater mounding analysis for turf paving systems.

16. Determine pre-treatment volume and design pre-treatment measures, if any.

17. Prepare vegetation and landscaping plan for turf paving systems.

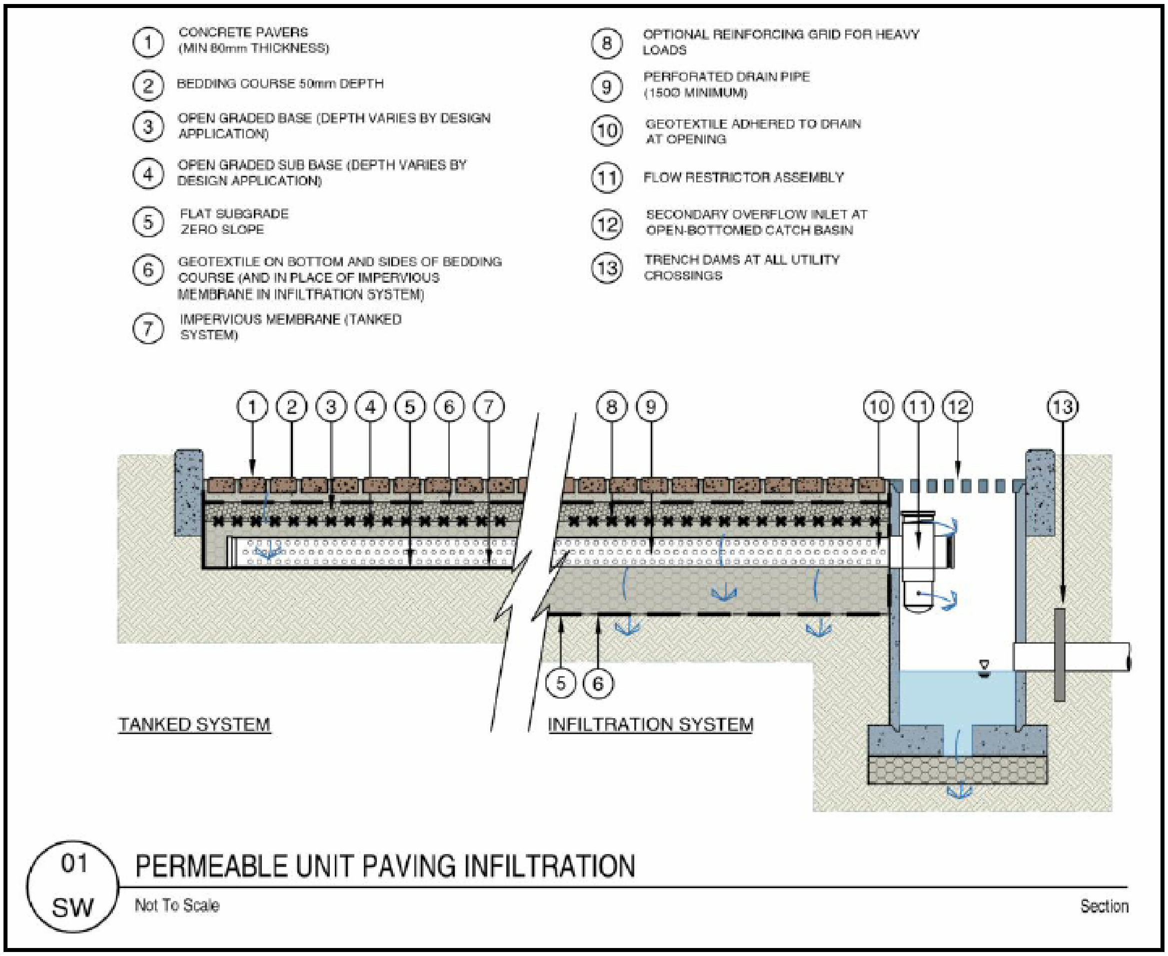
18. Prepare construction specifications.

19. Prepare inspection, operation and maintenance plan.

20. Prepare maintenance agreement/covenant for facilities located on private property.

Figure 5-9 illustrates a sample permeable pavement structure.

Figure 5-9 Sample Permeable Pavement Structure



Source: GVRD, 2004

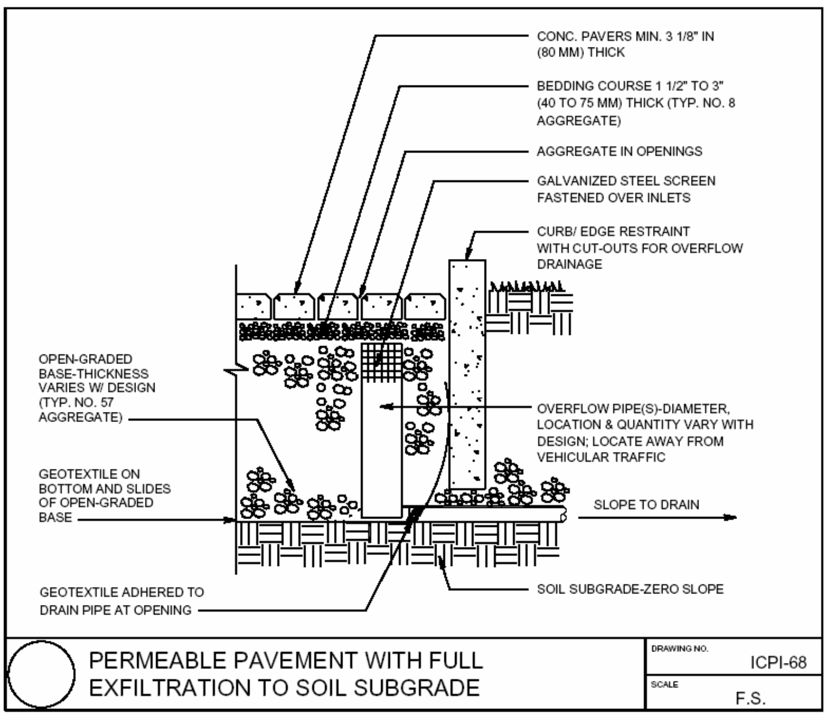
The successful application of any permeable paving system depends on adherence to accurate design specifications, experienced contractors and sediment and erosion control. Although similar to conventional pavement design, the design methods for permeable pavement structures should allow for the different properties of the component materials and the presence of water in the pavement structure.

Permeable pavement systems fall into one of the following three categories:

1. Full Exfiltration - Inflow infiltrates into the underlying subsoils. An overflow pipe at the top of the reservoir provides secondary drainage in the event that the base become clogged or loses capacity over time (see Figure 5-10).
2. Partial Exfiltration - Some water infiltrates into the underlying soil while the remainder is drained by the subdrain system (see Figure 5-11).
3. No Exfiltration, or Tanked Systems - The reservoir is lined with an impermeable membrane, and water is removed at a controlled rate through a subdrain system. Tanked systems are essentially underground detention systems, and are used in cases where, a) the underlying soil has low permeability and low strength, b) there is high water table, or c) there are water quality limitations (see Figure 5-12).

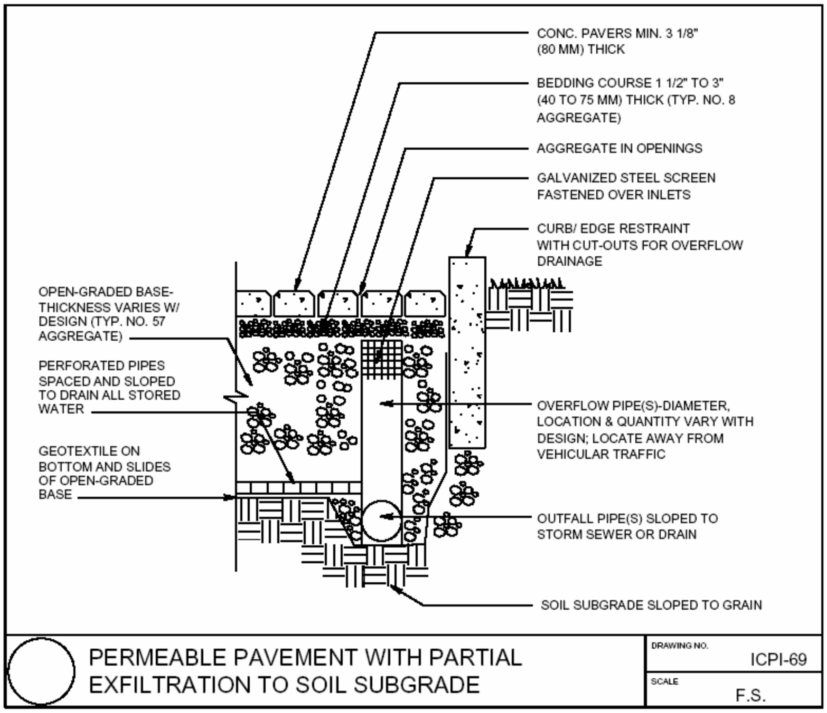
Most of the systems in the Calgary region will be Type 2 or 3 because of the low permeability of subsoils in this area. Type 1 will only be feasible along the Bow River and Elbow River valleys or for turf paving applications, as long as there is no risk of groundwater contamination.

Figure 5-10 Permeable Pavement with Full Exfiltration to Soil Subgrade



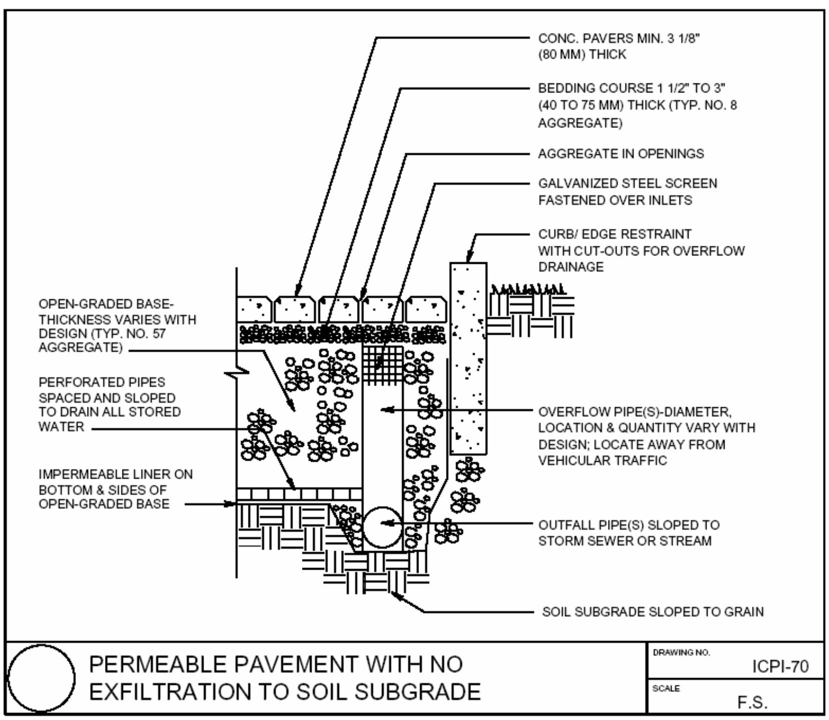
Source: Interlocking Concrete Pavement Institute, n.d.

Figure 5-11 Permeable Pavement with Partial Exfiltration to Soil Subgrade



Source: Interlocking Concrete Pavement Institute, n.d.

Figure 5-12 Permeable Pavement with Partial Exfiltration to Soil Subgrade



Source: Interlocking Concrete Pavement Institute, n.d.

5.4.1.1 Materials

The following factors must be considered in the design and specifications of materials:

- The stiffness of the materials must be assessed as pervious pavements use materials with high permeability and void space.
- Water in the pavement structure can soften and weaken materials.
- Existing design methods assume full friction between layers; any geotextiles or geomembranes must be carefully specified to minimize loss of friction between layers.
- Porous asphalt loses adhesion (binder stripping) and becomes brittle as air passes through the voids. Its durability is therefore lower than conventional materials.
- Single-size grading of materials means that care must be taken to ensure that loss of finer particles between unbound layers does not occur.

5.4.1.2 Soils

Where the permeable pavement structure empties through the base of the structure to groundwater, the hydraulic conductivity of the underlying subsoils is a factor in how much water is retained. However, this hydraulic conductivity is less important than the pervious surface infiltration rate. The internal storage capacity within the pavement structure should be designed to be adequate for the intended stormwater management purpose. The detention of runoff within the pavement structure will have to be considered when reviewing the suitability of construction materials.

For designs that rely on full exfiltration from the reservoir into underlying soils, the infiltration rate of the underlying soil should be greater than or equal to 12.5 mm/hr. For this reason, exfiltration type permeable pavement systems are not suitable for sites with soils with clay content greater than 30%. A 12-mil-thick, or heavier, impermeable liner must be installed on the bottom and sides of permeable pavement systems in locations with expansive soils. Care must be taken that the subbase will remain stable while saturated.

Silt loam and sandy clay loams provide marginal infiltration rates, and should only be considered for partial exfiltration systems. Soils with a combined silt/clay content of over 40% by weight are susceptible to frost heave, and may not be suited for these applications. These systems should never be constructed over fill soils, which often form an unstable upgrade, and are prone to slope failure. If fill is required, it should consist of additional aggregate and not compacted soil. The need to extend the subbase to below the frost line should be assessed by a qualified geotechnical professional.

The most critical factor in determining the applicability of full or partial exfiltration systems is the infiltration capacity of the underlying soil. Core samples or trenches at least 0.6 m to 1.2 m below the anticipated level of the bottom of the subbase should be examined for any impermeable soil strata that might impede infiltration, such as localized clay lenses, hardpans, or fragipans. Subsurface drainage may be required if the soil does not exhibit adequate infiltration capacity. Subsoils containing more than 3% of particles smaller than 0.02 mm in diameter are generally susceptible to frost heave. Such soils do not allow infiltration from the facility and should be avoided.

5.4.1.3 Groundwater separation

To prevent possible groundwater contamination and practice failure, permeable pavement systems should not intersect with the groundwater table. Specifically, the seasonally high groundwater table or bedrock elevation should be at least 0.6 m from the bottom of the permeable pavement structure if filtered water is to be infiltrated. A minimum of 0.9 m (preferably 1.2 m) of separation is needed between the bottom of the subbase and the bedrock level. This data can be inferred from local soil data maps, but needs to be confirmed by actual soil test bores.

Procedures for the quantification of in-situ infiltration rates for the native soils beneath permeable pavement systems are discussed in Appendix E.

5.4.1.4 Erosion and sediment control

Appropriate erosion and sediment control in the tributary area is paramount.

In addition, pre-treatment using filter strips or vegetated swales for removal of coarse sediments is recommended to increase the lifespan of permeable pavement systems.

Clogging often occurs when runoff-carrying soil from adjacent landscaped areas enters a permeable pavement system. Therefore, landscaped areas should never slope towards the permeable pavement and should be constructed at least 50 mm below the level of the pavement edge or the top of the curb, whichever is applicable.

5.4.1.5 Entrance

Permeable pavement installations should have a back-up method for water to enter the aggregate subbase (see Figure 5-19). These back-up inlets will ensure the functionality of the infiltration and storage systems even if the permeable pavement is compromised.

Figure 5-19 Porous Parking Lot with Stone Edge Drain

Source: PSAT, 2005.

5.4.1.6 Overland or emergency escape route

An overflow or emergency escape route, composed of non-erodable materials, should be provided to maintain the integrity of the permeable pavement system during extreme events, or events in excess of the design storm.

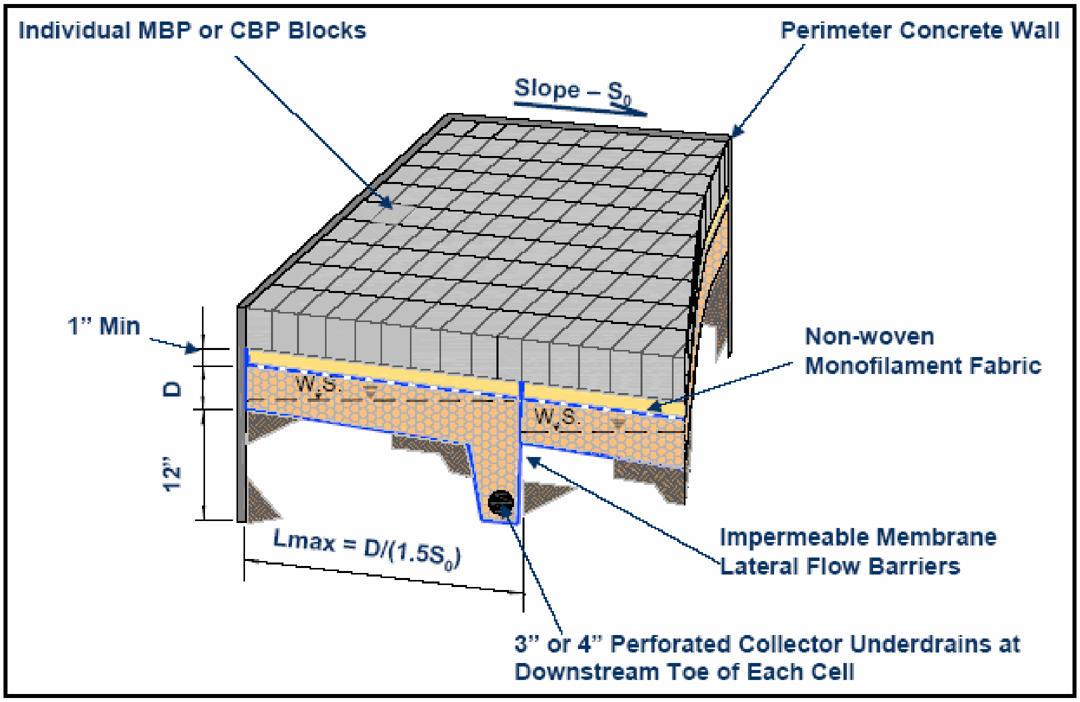
5.4.1.7 Grading

Permeable pavement areas should have a flat surface with a maximum two (2) percent slope.

The available internal storage volume of the subbase should be carefully assessed, particularly where the surface grade is sloping (see Figure 5-20). Where the subgrade slopes and only a wedge storage volume is available, water levels must not be allowed to rise to the point of flooding in the downstream end of the wedge.

Typically, the subbase gradient does not need to be more than 0.1 percent for the water to drain towards the subdrain system. Impermeable partitions as per Figure 5-20 and Figure 5-21 should be used as part of the permeable pavement design for steeper gradients of up to 2 percent. Underground weirs made up of undisturbed native material or constructed ditch blocks can be used to create the necessary pooling in the subbase.

Figure 5-20 Grading of Permeable Pavement Structure



Source: Ben Urbonas, UD&FCD, 2005

5.4.1.8 Drawdown/emptying time

As per Table A-2 of Appendix A, a drawdown or emptying time duration of 12 hours is recommended for the Water Quality Design Event and 3 days for the 1:100 year event.[4]

In the case of full exfiltration systems, it may be necessary to limit the depth of the subbase to ensure complete draining of the subbase in 72 hours if the underlying soils have low exfiltration rates. The resulting subbase depth limitations for permeable pavement systems are shown in Table 5-1.

Table 5-1 Subbase Depth Limitations for Permeable Pavement

Soil Type	Minimum Infiltration Rate	SCS Soil Group*	Maximum Depth of Storage** (in m) for Emptying Time of

[4] Drawdown duration refers to the amount of time required for the entire pavement structure, including the subbase, to drain.

	mm/hour		48 hours	72 hours
Sand	210.0	A	15.10	25.20
Loamy Sand	61.2	A	4.42	7.37
Sandy Loam	25.9	B	3.10	4.65
Loam	13.2	B	1.585	2.36
Silt Loam	6.86	C	0.81	1.25

*Sandy Clay Loams, Clay Loams, Silty Clay Loams, Sandy Clay, Silty Clay, and Clay soils are not included as these soil types are not feasible for full exfiltration systems.

**Maximum Depth of subbase that can drain completely within 48 or 72 hours after a storm, given the soil infiltration rate.

Source: US EPA, 2004

A continuous simulation model should be used to verify the performance of the permeable pavement system. Both the initial and the ultimate hydraulic conductivity (k_h) of the permeable pavement structure should be used in assessing the performance of the system. The ultimate value is 20% of the new product value to ensure acceptable lifespan performance.

5.4.1.9 Bedding course layer

The bedding course layer for permeable unit pavers should be 50 mm thick. This layer as well as the joint-filling material should be open-graded crushed 5 mm aggregate, or ASTM No. 8 sand. A surface finish of 3 mm clean crush aggregate (or ASTM No 89) should be applied and brushed in.

5.4.1.10 Subbase and subdrain

The maximum depth of the subbase is a function of the desired storage capacity, the desired discharge rate and allowable drawdown time, the porosity of the aggregate, and the hydraulic conductivity of the subsoils. The derivation of the depth of the subbase should also take into account the elevation of the seasonally high water table and bedrock and the frost line.

The depth of the pavement surface layer and underlying subbase is also dependent on the strength of the subsoils (defined by California Bearing Ratio [CBR]), the projected traffic intensities (defined by the average daily equivalent axle load [AEL]), and the susceptibility of the soils to frost heave.

If the pavement is being designed for heavy loads and/or horizontal forces, e.g. from heavy vehicles braking or turning, optional reinforcing grids can be included in the pavement subbase.

The subbase should be composed of clean, crushed stone, graded from 10 mm to 63 mm, with void space ratio >35%. The following gradation is typically recommended:

Particle Size	Percentage Passing
63 mm	100%
37.5 mm	85 – 100%
20 mm	0 – 25%
10 mm	0 – 5%

All aggregate used in the subbase below permeable pavement surfaces should also comply with the following requirements:

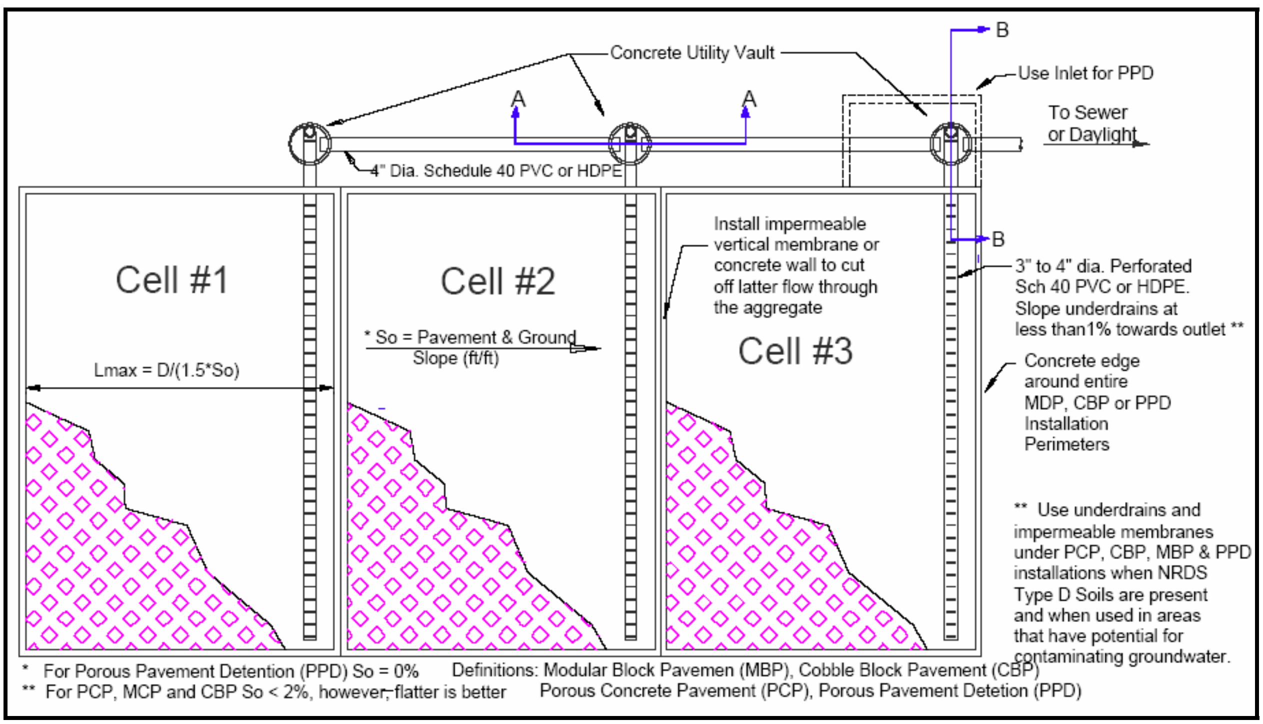
- **Los Angeles abrasion test** (determines the resistance of rocks to abrasion and drying/wetting)**:** Should have wear values of < 25 percent.
- **10 percent fines test** (indicates an aggregate's resistance to crushing)**:** Test should be carried out on saturated samples. Should have 10 percent fines value of greater than 100 kN when tested in accordance with BS 812:Part 111:1990, *Testing aggregates. Methods for determination of 10% fines value*.
- **Flakiness index (Measures flatness of aggregate particles):** Maximum value should be 25 percent, when tested in accordance with BS 812:Section 105.1:1989 *Flakiness index*.
- **Plate bearing tests on placed material** (Used to determine CBR value, in accordance with BS 1377:Part 9:1990)**:** Minimum CBR of open-graded aggregates should be 30 percent.

The subdrain system, if any, should be composed of PVC, SDR 35, 150-mm diameter pipe, with filtersock and cleanouts/observation standpipe. The standpipe serves three primary functions:

- Indicates how quickly the pavement structure dewaters following a storm
- Provides a maintenance cleanout port
- Connects to the subdrain system to facilitate cleanout of the subdrain

Figure 5-21 provides an example of the possible spacing of the subdrain system.

Figure 5-21 Subdrain System Layout for Permeable Pavement



Source: UD&FCD, 2005

The practical depth of cover over the subdrain pipe may be the determining factor in the depth of the subbase. The vertical placement of the subdrain may vary depending on whether or not infiltration is a pertinent design consideration.

The (slot) opening should be smaller than the smallest aggregate gradation for the subbase materials to prevent migration of material into the drain. This configuration should allow for pressurized water cleaning if necessary. The capacity of the subdrain system is a function of the permissible discharge rate from the pavement structure and should allow the structure to drain within the desired emptying time.

Pipe joints and connections must be adequately sealed to avoid leakage. Pipe sections should be coupled using suitable connection rings and flanges. Field connections to structures and pipes should be sealed with polymer grout material that is capable of adhering to surfaces. Subdrain pipes must be capped until completion of the site. Subdrains directly connected to a structure should be non-perforated for a distance of at least 1.5 m from the structure interface to avoid possible piping problems.

In principle, the subdrain may be deleted where infiltration tests at the level of the base of the proposed pavement structure show an infiltration rate that exceeds the ultimate hydraulic conductivity of the subbase. It is expected that the number of applications in the Calgary area where this would be the case is very limited.

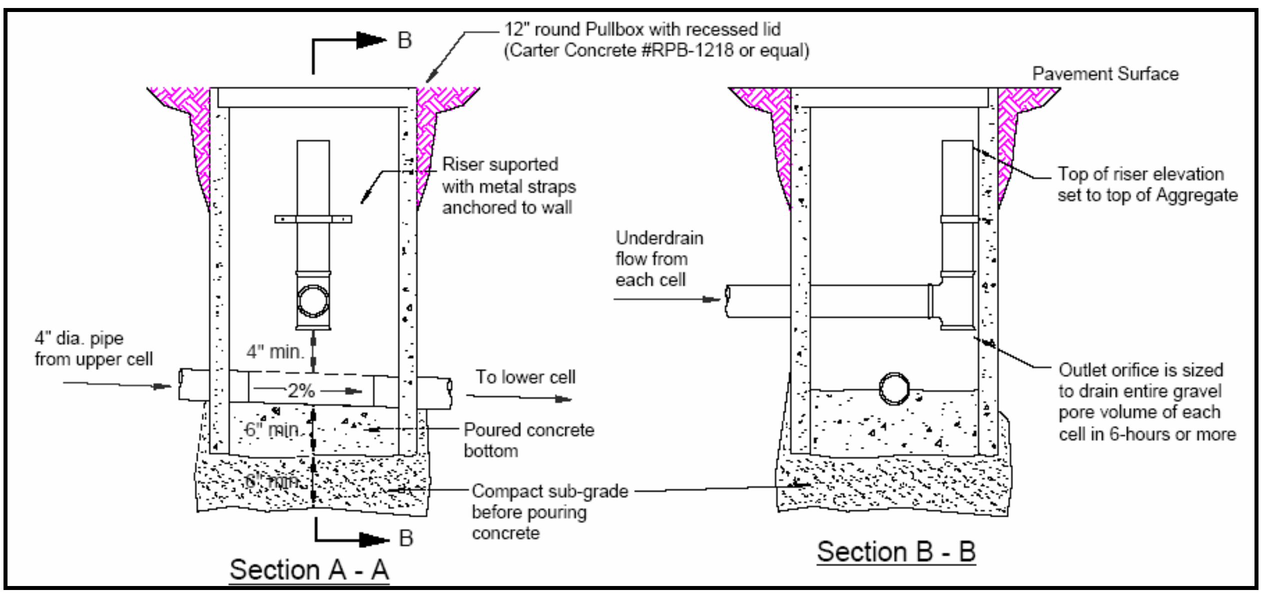
An elevation difference of between 1.2 m and 1.8 m should be provided from the inflow to the outflow when a subdrain is used.

5.4.1.11 Flow restrictions

When the design calls for partial or no exfiltration into the subsoils, a subdrain collection system with flow control is required. The dimensions of the flow control are to be based on the permissible discharge rate to the downstream drainage system, while taking into account the desired emptying time of the pavement structure.

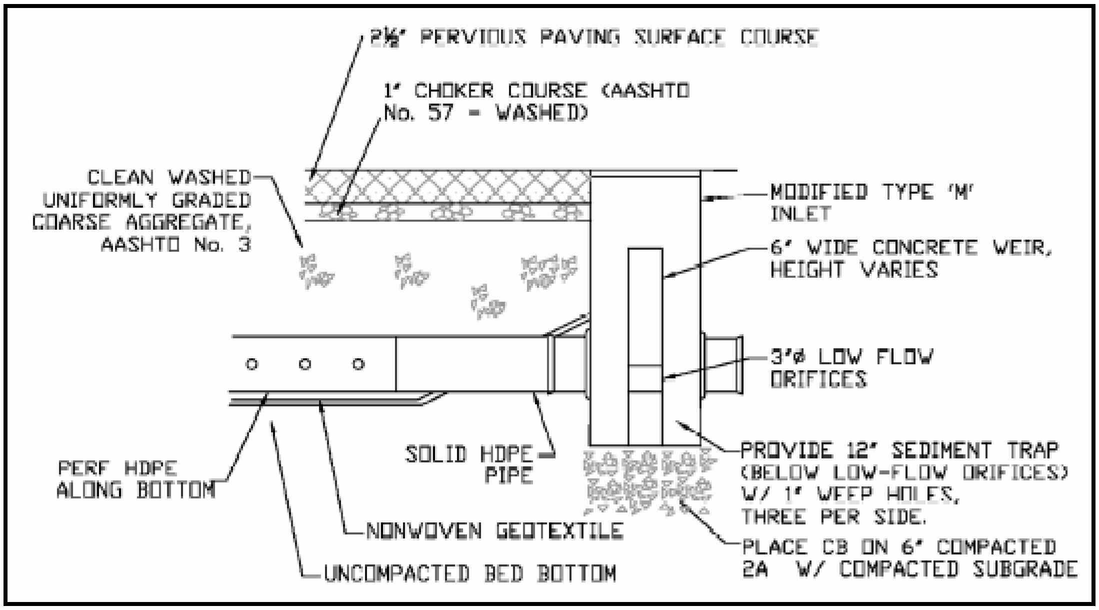
Figure 5-22 shows a sample control structure. This structure corresponds to the subdrain system layout illustrated in Figure 5-21. For comparison purposes, Figure 5-23 illustrates another sample control structure.

Figure 5-22 Example of Control Structure – UD&FCD



Source: UD&FCD, 2005

Figure 5-23 Example of Control Structure – Pennsylvania DEP



Source; Pennsylvania DEP, 2005

5.4.1.12 Geotextiles

A geosynthetic liner should be provided on the bottom and sides of the pavement structure to prevent soil ingress and aggregate penetration of the subgrade. This geotextile is also important for pollution retention, as it encourages the accumulation of silts and sediment, which assist in the further retention of pollutants.

To reduce the effects of water on the strength and stiffness properties of the subgrade below permeable pavement structures, a geotextile separator layer should always be provided over moisture-sensitive, fine-grained subgrades. This will enhance the performance of the pavement structures by:

1. Preventing pumping of finer soils into the open graded aggregate of the subbase.
2. Enhancing resistance to deformation of the subgrade under load, by providing a tensile resistance.

A 200 mm sand layer can be used on the bottom of the subbase as an alternative to the geotextile.

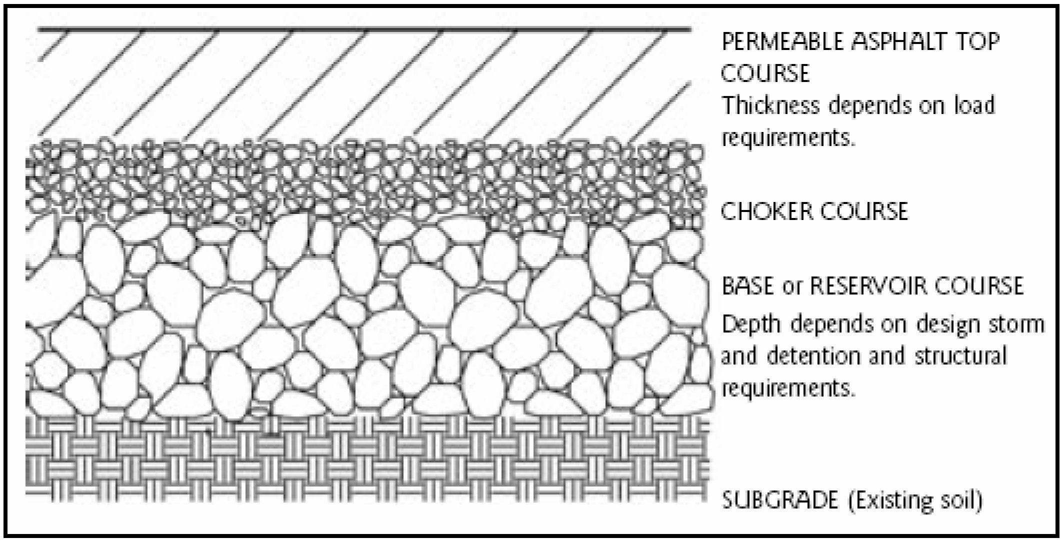
The geotextiles should be properly keyed in at the top of the excavation.

5.4.2. Design examples

5.4.2.1 Porous asphalt and concrete

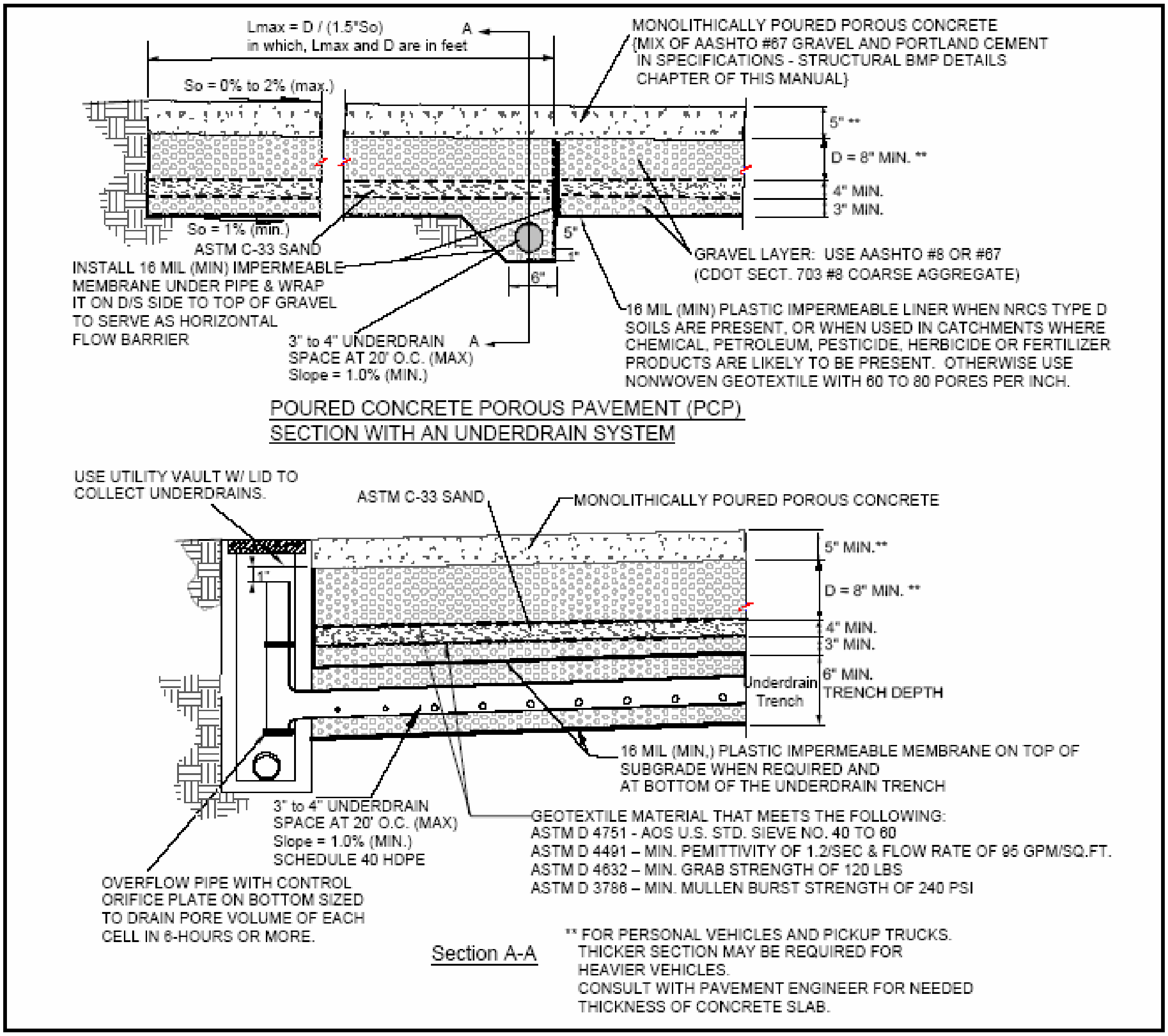
The following cross-sections of porous asphalt and concrete structures relate to the design specifications below.

Figure 5-13 Porous Asphalt Cross-Section



Source: PSAT, 2005

Figure 5-14 Porous Concrete Pavement Structure Example



Source: UD&FCD, 2005

The following table presents design specifications for porous asphalt and porous concrete:

Porous asphalt	Porous concrete
1. Depth	
The depth of porous asphalt/concrete must be adequate to support the traffic and vehicle types the permeable pavement structure will have to carry.	

Porous asphalt	Porous concrete
2. Composition	
The porous asphalt mix and subbase composition should strictly adhere to the porous asphalt mix and aggregate specifications provided in Appendix A of this handbook. A small percentage of fine aggregate is necessary to stabilize the larger porous aggregate fraction. The finer fraction also increases the viscosity of the asphalt cement and controls asphalt drainage characteristics. Total void space should be approximately 16 percent (conventional asphalt is 2 to 3 percent).	The porous concrete mix and installation mix of ASSHTO #67 aggregate and Portland cement should strictly adhere to the porous concrete mix specifications provided in Appendix A of this handbook.
3. Subbase	
The subbase shall be 12 to 63 mm (0.5 to 2.5 inch) uniformly graded, crushed (angular), thoroughly washed AASHTO No. 3 aggregate. The thickness of the subbase should satisfy the structural bearing needs of the pavement and the desired stormwater storage capacity within the pavement structure.	The subbase should consist of AASHTO No. 8 or #67 (CDOT Section 703) coarse aggregate as called for in Figure 5-19. Assume 30 percent is open pore space. Unless an impermeable membrane liner is required as per Figure 5-19, at least 150 mm (6-inches) of the subgrade underlying the subbase must be sandy and gravelled material with no more than 10% clay fraction. The thickness of the subbase should satisfy the structural bearing needs of the pavement and the desired stormwater storage capacity within the pavement structure.
4. Choker course	
The choker course should be 25 to 50 mm in depth and consist of 38 mm (1.5-inch) to U.S. sieve size number 8, uniformly graded, crushed and washed stone (AASHTO #57) for final grading of subbase reservoir. The upper course is needed to reduce rutting from construction vehicles delivering and installing asphalt and to more evenly distribute loads to the subbase material.	N/A
5. Sand Filter	
Whenever the porous asphalt/concrete pavement structure is being installed over expansive soils and subdrains are required, a sand filter (ASTM C33 gradation) must be installed to remove most of the fine particulate pollutants from the water column before the water reaches the subdrains.	

Porous asphalt	Porous concrete
6. Sand filter cover	
A non-woven monofilament geotextile fabric should be placed over the sand filter layer. Place by rolling fabric parallel to the contours starting at the most downstream part of the pavement structure, providing a minimum of 450 mm (18-inches) of overlap between adjacent sheets. Use a geotextile material that meets the following requirements: • ASTM D 4751 - AOS U.S. Std. Sieve No. 40 to 60 • ASTM D 4632 – Minimum grab strength of 120 lbs • ASTM D 3786 – Minimum Mullen Burst Strength of 240 psi.	
7. Impermeable membrane	
When installing over expansive soils or if the tributary catchment supports activities that can contaminate runoff, install an uninterrupted and puncture free impermeable membrane and provide a subdrain system under the subbase.	
8. Containment cells	
On sloped surfaces, create containment cells by installing lateral-flow cut-off barriers using 16-mil, or thicker, PE or PVC membrane to prevent flow of water downstream and then surfacing at the toe of the permeable pavement installation.	
9. Subdrains	
Subdrains are required when the permeable pavement system is located on low permeability soils such as clayey silt, sandy clays, clays, etc. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 6.0 m (20-foot) spacing. Use a control structure sized to drain the pore volume of each cell within the desired emptying time.	
10. Flow	
Every effort should be made to ensure even flow distribution over the entire permeable surface.	

Bituminous asphalt cement should contain 5.5 to 6.0 percent (by weight) of dry aggregate. This ensures adequate asphalt cement film thickness around the aggregate to reduce photo-oxidation degradation and increase cohesion between aggregate. The upper limit is to prevent the mixture from draining during transport.

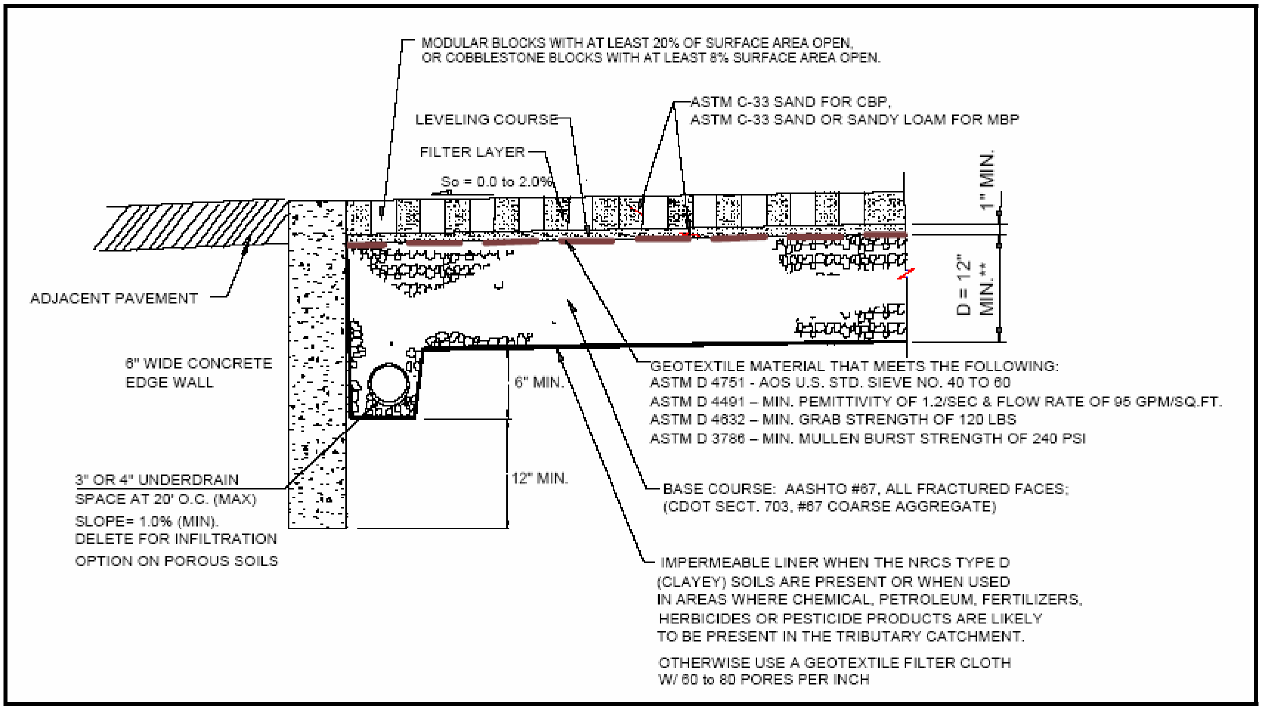
An elastomeric polymer can be added to the bituminous asphalt to reduce drain-down. Hydrated lime can be added at a rate of 1.0 percent by weight of the total dry aggregate to mixes with granite stone to prevent separation of the asphalt from the aggregate and improve tensile strength.

Bituminous asphalt cement should provide 85 to 100 percent penetration.

5.4.2.2 Permeable unit pavers

The following sample cross-section relates to the design guidelines below:

Figure 5-15 Sample Cross-Section of Permeable Unit Pavers



Source: UD&FCD, 2005

The following table presents design recommendations for permeable unit pavers:

Permeable Unit Pavers
1. General specifications
The pavers should be permeable interlocking concrete pavers meeting CSA A231.2, designed and tested by the manufacturer for use as part of a permeable unit paving system with an initial infiltration rate greater than 280 mm/hr, and an ultimate infiltration rate over the 20-year ‘lifespan’ greater than 28 mm/hr.
2. Void space
The void space should be at least 8% of the total surface area. Paver block openings should be filled with ASTM C-33 graded sand (i.e., fine concrete aggregate) and should be placed on a 25 mm thick levelling course of the sand. [5] Alternatively, a 50 mm bedding course and joint filling material composed of open-graded crush 5 mm aggregate, without sand (ASTM No. 8) may be used. A surface finish of 3 mm clean crush aggregate (or ASTM No 89) should be applied to the finished surface and brushed in.

5 ASTM C-33 sand, which is typically used for traditional interlocking concrete pavement bedding layer construction, is not recommended, as it tends to reduce infiltration rates.

Permeable Unit Pavers

3. Subbase

The subbase should be composed of AASHTO No. 67 (CDOT Section 703) coarse aggregate with all fractured surfaces. Assume 30 percent is open pore space. Unless an impermeable membrane liner is required, at least 150 mm (6-inches) of the subgrade underlying the subbase should be sandy and gravelled material with no more than 10% clay fraction. The depth of the subbase should satisfy the structural bearing needs of the pavement and the desired stormwater storage capacity within the pavement structure.

4. Sand filter cover

- A non-woven monofilament geotextile fabric should be installed over the sand filter layer. Place by rolling fabric parallel to the contours starting at the most downstream part of the pavement structure, providing a minimum of 450 mm (18-inches) of overlap between adjacent sheets.

5. Edge restraint

Provide an edge restraint to contain the pavers. One option is to provide a concrete perimeter wall to confine the edges of the block area. The wall should be at least 150 mm wide and 150 mm deeper than all the porous media and modular block depth combined. Plastic edgers that use spikes are not recommended.

6. Impermeable membrane

When installing over expansive soils or if the tributary catchment will support activities that store, manufacture or handle fertilizers, chemical or petroleum products, install an uninterrupted and puncture free 16-mil PE or PVC impermeable membrane and provide a subdrain system under the subbase. Otherwise, to permit infiltration, install a non-woven geotextile membrane that has pore openings equivalent to ASTM D 4751 AOS U.S. Std. Sieve No. 60 to 80.

7. Containment cells

On sloped surfaces, create containment cells by installing lateral-flow cut-off barriers using 16 mil, or thicker, PE or PVC membrane liner or concrete walls parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the permeable pavement installation. The spacing of these impermeable barriers should follow Equation 5-1:

$$L_{MAX} = \frac{D}{1.5 * S_o}$$ **Equation 5-1**

Where L_{MAX} = maximum distance between vertical barriers, normal to the flow (m)
D = depth of the gravel subbase (m)
S_0 = slope of the subbase (m/m)

8. Subdrains

Subdrains are required when the permeable pavement system is located on low permeability soils such as clayey silt, sandy clays, clays, etc. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 6.0 m (20-foot) spacing. Use a control structure sized to drain the pore volume of each cell within the desired emptying time.

9. Flow

Upon installation, every effort should be made to ensure even flow distribution over the entire permeable surface.

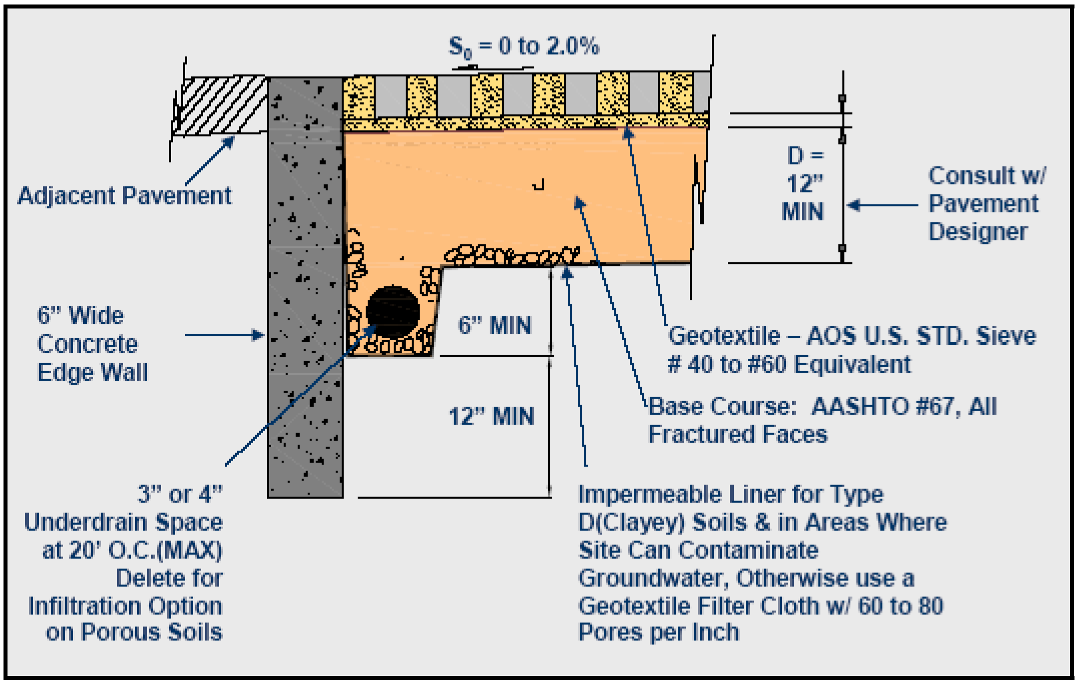
5.4.2.3 Turf Paving Systems

The following design recommendations apply to turf paving systems, which include: a) modular paving blocks or grids and cast-in-place concrete grids; b) soil enhancement technologies; and, c) gravel paving system.

a) Modular paving blocks or cast-in-place concrete grids

At least 20% of the surface area of modular paving blocks or cast-in-place concrete grids should be open space. Figure 5-2 shows a sample cross-section of a modular block installation and its subgrade.

Figure 5-16 Sample Cross-Section of Modular Paving Blocks

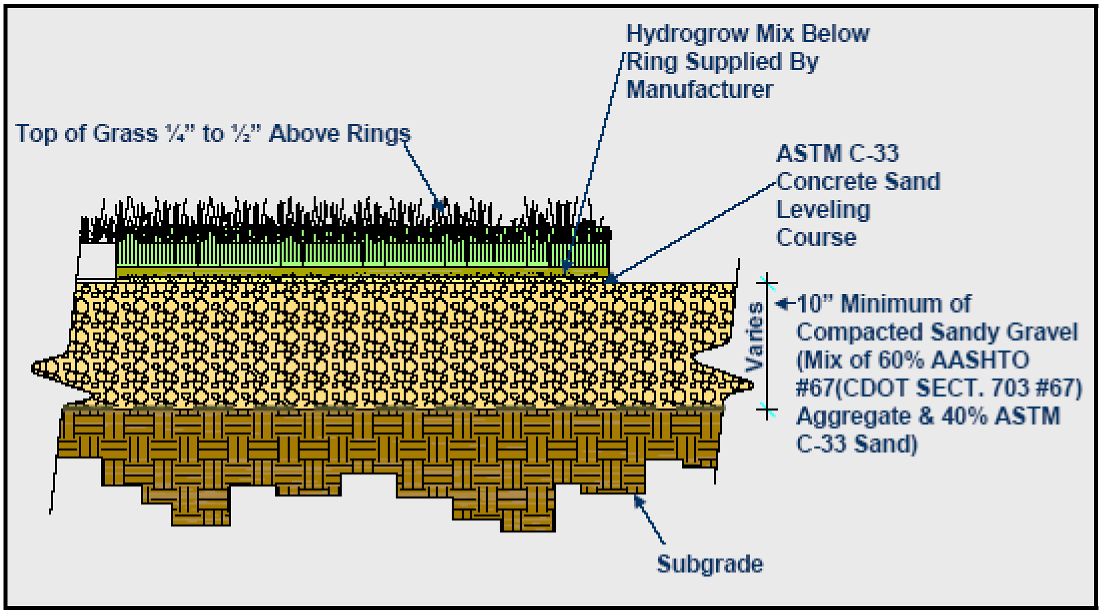


Source: UD&FCD, 2005

b) *Soil enhancements*

An alternative to modular concrete blocks for the permeable turf paving system is the use of an engineered growing medium mixed with mesh elements on site or obtained as solid slabs of turf with mesh elements already present in the growing medium.

Figure 5-17 Example Cross-Section of Grass Pave Section



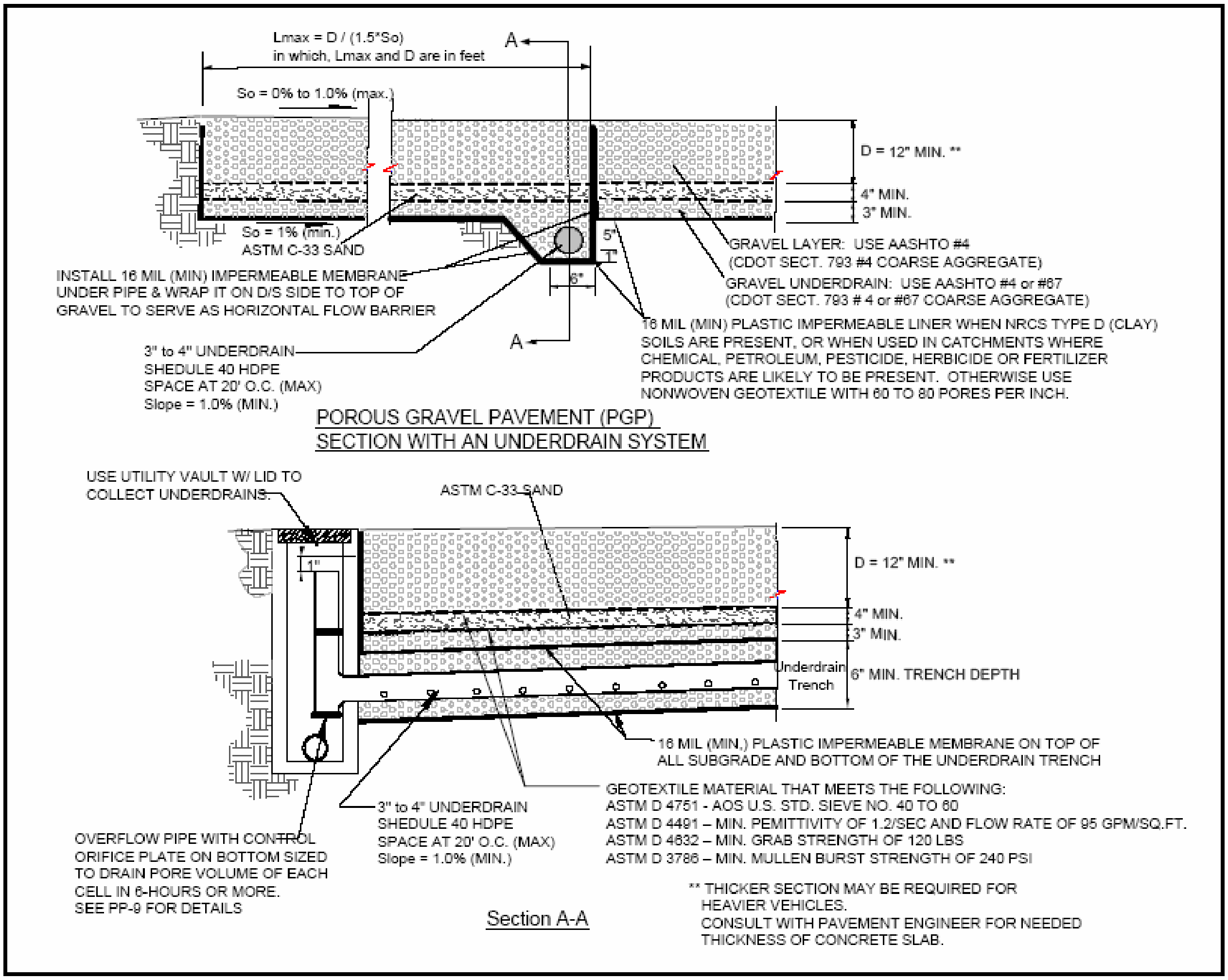
Source: UD&FCD, 2005

The root zone medium will typically be 150 to 200 mm deep. The composition and depth of the subbase depends on vehicle loading and subgrade strength. The depth varies from 100 to 500 mm, with the latter for a weak subgrade and use by heavy trucks.

When the hydraulic conductivity of the existing subsoils is poor, slit drains may be necessary. They consist of perforated or porous pipes, or approved equivalent, in gravel-filled trenches draining to a storm sewer system. The spacing of the drains, typically 0.9 to 1.5 m, will depend on location and intended use (Minnesota, 2001).

c) Gravel paving system

Figure 5-18 Porous Gravel Pavement Structure Example



Source: UD&FCD, 2005

The following table outlines the design procedure and criteria for turf paving systems:

Modular paving blocks/cast-in-place concrete grids	Gravel paving system	Soil enhancements
1. General specifications		
For the purpose of sizing downstream drainage systems, one can assume that the permeable pavement areas are only 50% impervious and 50% pervious when using blocks with 20% open surface area and 35% impervious and 65% pervious when using blocks with 40%	N/A	N/A

<table>
<tr><th>Modular paving blocks/cast-in-place concrete grids</th><th>Gravel paving system</th><th>Soil enhancements</th></tr>
<tr><td>or more of open area.</td><td></td><td></td></tr>
<tr><td colspan="3">2. Void space</td></tr>
<tr><td>Select modular blocks with void space amounting to at least 20% of the total surface area. The paver block openings should be filled with ASTM C-33 graded sand, i.e. fine concrete aggregate, and should be placed on a 25-mm-thick levelling course of the sand.</td><td>N/A</td><td>N/A</td></tr>
<tr><td colspan="3">3. Subbase</td></tr>
<tr><td>The subbase should be composed of AASHTO No. 67 (CDOT Section 703) coarse aggregate with all fractured surfaces.</td><td>The subbase shall be AASHTO No. 4 (CDOT Section 703) coarse aggregate. Under the sand filter layer, as per (4) below, AASHTO No. 67 aggregate may be substituted for No. 4.</td><td>• The subbase shall be AASHTO No. 4 (CDOT Section 703) coarse aggregate.</td></tr>
<tr><td colspan="2">Assume 30 percent is open pore space. Unless an impermeable membrane liner is required. Below, at least 150 mm (6-inches) of the subgrade underlying the subbase should be sandy and gravely material with no more than ten (10) percent clay fraction. The thickness of the subbase should satisfy the structural bearing needs of the pavement and the desired stormwater storage capacity within the pavement structure.</td><td>N/A</td></tr>
<tr><td colspan="3">4. Sand filter</td></tr>
<tr><td></td><td>When the porous gravel pavement structure is being installed over expansive soils and subdrains are required, a sand filter (ASTM C33 gradation) layer should be installed to remove most of the fine particulate pollutants from the water column before the water reaches the subdrains.</td><td></td></tr>
<tr><td colspan="3">5. Subbase/sand filter cover</td></tr>
<tr><td colspan="3">Place a non-woven monofilament geotextile fabric over the subbase or sand filter layer. Place by rolling fabric parallel to the contours starting at the most downstream part of the pavement structure, providing a minimum of 450 mm (18-inches) of overlap between adjacent sheets. Use a geotextile material that meets the following requirements:
• ASTM D 4751 - AOS U.S. Std. Sieve No. 40 to 60
• ASTM D 4632 – Minimum grab strength of 120 lbs
ASTM D 3786 – Minimum Mullen Burst Strength of 240 psi.
Bring the geotextile to the top of the perimeter walls and glue to the walls with roofing tar.</td></tr>
</table>

Modular paving blocks/cast-in-place concrete grids	Gravel paving system	Soil enhancements
6. Edge restraint		
Provide an edge restraint to contain the pavers or provide a concrete perimeter wall to confine the edges of the block area. The wall should be at least 150 mm wide and 150 mm deeper than all the porous media and modular block depth combined. Plastic edgers that use spikes are not recommended.	N/A	N/A
7. Impermeable membrane		
When installing over expansive soils or if the tributary catchment will support activities that store, manufacture or handle fertilizers, chemical or petroleum products, install an uninterrupted and puncture free 16-mil PE or PVC impermeable membrane and provide a subdrain system under the subbase.	When installing over expansive soils or if the tributary catchment may have activities that store, manufacture or handle fertilizers, chemical or petroleum products, install an uninterrupted and puncture free 16-mil PE or PVC impermeable membrane and provide a subdrain system under the subbase. Bring the impermeable membrane to the top of the perimeter walls and glue to the walls with roofing tar. Seal all joints of impermeable membrane to render leak-proof.	If the tributary catchment has activities that have a potential for groundwater contamination, install an uninterrupted and puncture free 16-mil PE or PVC impermeable membrane and provide a subdrain system under the subbase. Roll the geotextile fabric parallel to the contours starting at the most downstream part of the porous pavement structure. Provide a minimum of 450 mm (18-inches) of overlap between adjacent sheets. Bring the geotextile and impermeable membrane to the top of the perimeter walls and glue to the walls with roofing tar. Seal all joints of impermeable membrane to render leak-proof.

<table>
<tr><th>Modular paving blocks/cast-in-place concrete grids</th><th>Gravel paving system</th><th>Soil enhancements</th></tr>
<tr><td colspan="3">8. Containment cells</td></tr>
<tr><td colspan="2">On sloped surfaces, create containment cells by installing lateral-flow cut-off barriers using 16 mil, or thicker, PE or PVC membrane liner or concrete walls parallel to the contours (i.e., normal to the flow) to prevent flow of water downstream and then surfacing at the toe of the permeable pavement installation. The spacing of these impermeable barriers should follow Equation 5-4:

$$L_{MAX} = \frac{D}{1.5 * S_o}$$ Equation 5-4

Where L_{MAX} = maximum distance between vertical barriers, normal to the flow (m)
D = depth of the gravel subbase (m)
S_0 = slope of the subbase (m/m)</td><td>N/A</td></tr>
<tr><td colspan="3">9. Subdrains</td></tr>
<tr><td colspan="2">Subdrains are required when the permeable pavement system is located on low permeability soils such as clayey silt, sandy clays, clays, etc. Locate each perforated pipe just upstream of the lateral-flow cut-off barrier. Do not exceed 6.0 m (20-foot) spacing. Use a control structure sized to drain the pore volume of each cell within the desired emptying time.</td><td>N/A</td></tr>
<tr><td colspan="3">10. Vegetation</td></tr>
<tr><td>If vegetation is desirable, plant with “park grade” turf grasses which are more drought tolerant than “elite grade” grasses.</td><td>N/A</td><td>N/A</td></tr>
</table>

5.4.3. Limitations

Compared to impermeable pavements, permeable pavements require more careful management of design and construction. The infiltration rate of permeable surfaces is very high when first installed but tends to drop off rapidly as the pavement clogs with sediments. The presence of a geotextile that is subject to clogging may reduce the surface infiltration rate even further. To avoid surface plugging, it is critical to protect permeable pavement systems from sedimentation both during and after construction. In addition, it is important to identify pollutant sources, particularly in industrial/commercial hotspots, that require pre-treatment or upstream source controls. Regular maintenance can unclog pervious pavement.

The texture of permeable surfaces is not ideal for areas that require accessibility for disabled persons or the elderly. Permeable interlocking concrete pavers with wide joints and turf paving systems should not be used for disabled parking stalls or pedestrian ramps. Permeable pavement should not be used for curb ramps as the rougher surface may obscure the scoring or truncated domes that indicate to the blind that they are approaching a traffic area.

Permeable pavement cannot be used in areas with high traffic volume and vehicle loads and where snow plowing is required.

Clay soils limit the infiltration capability of turf pavers. Since turf paving encourages infiltration, it should not be applied in stormwater hotspots because pollutants can contaminate underlying soil and groundwater. The risk of contamination is higher in places with high soluble contaminant discharge, such as parking lots, road intersections, service stations and areas with associated high infiltration rates.

Porous concrete should not be used for installations with aboveground detention because the integrity of the concrete structure can be undermined when standing water freezes on it. A sufficiently thick aggregate subbase is required under the porous concrete slab to store the runoff and allow it to infiltrate slowly into the ground or drain out using a subdrain system.

5.4.4. Vegetation (for turf paving systems)

As part of turf paving systems, vegetation provides dense cover and dense root structure to resist erosion, and attenuates flows and increases residence time and filtering of pollutants. Planting design should respect the varying soil moisture conditions that are expected in turf paving systems. Overall, there is a preference for deeper rooting vegetation that can access soil moisture at deeper levels in the soils and is thus less susceptible to drought conditions. In addition to being able to tolerate the varying soil moisture levels, the selected vegetation must also be able to tolerate progressive accumulations of contaminants on top and within the soils.

Native grasses provide year-round cover and are best for enhancing biodiversity and wildlife habitat. Their extensive root systems enhance infiltration and drought-tolerance. If the area is to be mowed regularly, park-grade Kentucky bluegrass or fescue should be used.

Vegetation that is native to the Calgary area is preferred as it is inherently suitable to the climate conditions. For turf paving systems that need to resemble lawns, plant high-quality, low-maintenance grass species. If the site is well drained, a compost-amended soil lawn will drain equally well while providing superior storm flow storage, pollutant processing, and growth medium. An important consideration of turf paving systems is the filling ratio of the soil between the reinforcement matrixes. The filling ratio is a trade-off between the structural stability of the pavement system and the necessary protection of the root system to traffic. Figure 5-24 illustrates an installation that was largely overfilled with soil; significant amounts of the root systems have died off because of damage from vehicle wheels. In addition, the over-compacted soil now has limited infiltration capability.

Figure 5-24 Improperly Installed Turf Paving Stone System

Source: Bert van Duin, Westhoff Engineering Resources, Inc.

Typically, vegetation within turf pavement systems must be established by seeding. Seed should be applied uniformly with a cyclone seeder, drill or cultipacker seeder, or hydroseeder. When feasible, seed that has been broadcast should be covered by raking or dragging and then lightly tamped into place using a roller or cultipacker. If hydroseeding is used, the seed and mulch must be applied in separate applications. Refer to City of Calgary Parks Standards for seed mix types and specific planting information.

5.4.5. Space requirements

The area of permeable pavement should total at least 25% of the upstream impervious area it serves. Beyond this minimum requirement, the size is contingent on the magnitude of the design event, the depth and composition of the pavement structure, the hydraulic conductivity of the subsoils, and the presence of flow controls. Even distribution of precipitation and runoff from adjacent areas over the permeable pavement sections must be considered.

5.5 *Construction*

Control of construction sediments is critical. Rigorous installation and maintenance of erosion and sediment control measures are required to prevent sediment deposition on the pavement surface or within the stone bed. Construction traffic must be prevented from tracking mud and soil into the pervious surface. Proper supervision and inspection must be carried out on all projects.

Construction practices for permeable pavement structures are different than for conventional, non-porous pavement. Considerations include:

- Proper gradation and installation of the gravel and sand materials at various levels of the permeable pavement structure.
- Proper use and installation of geotextile and impermeable liner membranes.
- Edge restraints for modular block types of permeable pavement.
- Proper transport and pouring of porous asphalt and concrete mixes.
- Uniform gradation of gravels and soils for reinforced turf type pavements.

The following steps outline additional considerations for the installation of permeable pavement:

1. The excavated bed for permeable pavement installations may be used as temporary sediment basins or traps provided they are excavated to within 150 to 300 mm of the designated bed bottom elevation. Once the site is stabilized and sediment storage is no longer required, the sediment shall be removed and the bed excavated to its final grade.
2. Where the native soils in the existing subgrade are suitable for infiltration, the subgrade under the bed areas shall not be compacted or subject to excessive construction equipment traffic prior to geotextile and aggregate placement. When the subbase is deliberately compacted to provide greater pavement stability or is inadvertently compacted by construction equipment, infiltration capacity is significantly reduced. Compaction can be prevented by using light track equipment instead of heavy construction equipment, delivering gravels and concrete via conveyors and stopping all work when the subbase is wet or thawing.
3. When compaction of the subbase is needed for structural support of the pavement that will carry or park vehicular traffic, a subdrain system may be needed to compensate for the loss

of infiltration capacity. A subdrain is required if the subbase soils have significant fractions of silt or clay and are not granular in nature.

Compaction of the sub-grade is also recommended for sites where the pavement will be placed on top of fill. Unless the fill is composed of predominantly granular materials, subdrains are needed for all permeable pavement types.

4. Earthen berms (if used) between infiltration beds shall be left in place during excavation. These berms do not require compaction if proven stable during construction.
5. Sediment laden runoff should be diverted away from the constructed bed or permeable surface.
6. Natural or fill soils should be prevented from intermixing with the reservoir base, subbase, or bedding courses and filter cloths. Cover the surfaces with heavy flexible impermeable membrane whenever construction activities threaten to deposit sediment onto the permeable pavement area.
7. Where erosion of the subgrade has caused accumulation of fine materials and/or surface ponding, all contaminated stone aggregate and cloth must be removed and replaced. All sediments shall be removed with light equipment and the underlying soils scarified to a minimum depth of 150 mm (6 inches) with a York rake (or equivalent) and light tractor. All fine grading shall be done by hand.
8. Geotextile and bed aggregate shall be placed immediately after approval of subgrade preparation. The geotextile is to be placed in accordance with the manufacturer's standards and recommendations. The geotextiles should be made from high quality fabrics that resist puncturing by angular rock and during installation.
9. On sloped installations, containment cells can be created by installing lateral-flow cut-off barriers using 16 mil, or thicker, PE or PVC membrane liner (see Figure 5-27) or concrete walls parallel to the contours (i.e., normal to the flow); this prevents water from flowing downstream and surfacing at the toe of the permeable pavement installation.
10. Clean (washed) uniformly graded aggregate is placed in the bed in maximum 150 mm (6 in) lifts. Each lift shall be compacted by using a 10-ton, or heavier, vibrating steel drum roller. Make at least four passes with the roller, with the initial passes made while vibrating the roller and the final one to two passes without vibration.
11. After all the lifts are compacted, the specified geotextile fabric shall be laid down on top of the compacted aggregate and the sand, or soil, materials spread on top. The sand, or soil, material shall be compacted using at least four passes of the 10-ton steel drum static roller. Then lay down the specified geotextile fabric on top of the sand as called for in the plans.
12. If the design calls for an upper layer of the subbase, install it using the same layer depths and compaction requirements described under (9) above. Follow-up the installation of the uppermost layer of the subbase by installing the specified geotextile fabric on top of it. The levelling course or permeable pavement, as required by the plans, is then applied over the uppermost geotextile fabric.
13. When a sand-levelling course is called for in the plans, compact it using the drum roller before laying the paver units on top of it. If the tops of the subbase, sand filter layer or the levelling course layers are disturbed and not uniform, they must be re-levelled and re-compacted. The top of each layer below the levelling course shall be uniform and will not deviate more than +12 mm (1/2-inch) when a 3.0 m (10 foot) straight edge is laid on it surface. The top of the levelling course shall not deviate more than +10 mm (3/8-inch) in 3.0 m (10 feet).

14. Following placement of subbase aggregate and again after placement of the surface layer, the filter fabric should be folded over placements to protect installation from sediment inputs. Excess filter fabric should not be trimmed until site is fully stabilized.

5.5.1. Porous Asphalt

The following construction recommendations relate specifically to porous asphalt installations:

1. Adapting aggregate specifications can influence bituminous asphalt cement properties and permeability of the asphalt-wearing course. Before final installation, test panels are recommended to determine asphalt cement grade and content compatibility with the aggregate.
2. Prior to installation, the porous pavement mix shall not be stored in excess of 90 minutes. Transporting of the mix to the site shall be in vehicles with smooth, clean dump beds that have been sprayed with a non-petroleum release agent. The mix shall be covered during transport to control cooling.
3. Install the subbase aggregate in maximum 200 mm lifts and compact lightly after each lift.
4. Once the subbase aggregate is installed to the desired grade, a 25 to 50 mm (1 to 2 in) layer of choker base course (AASHTO #57) aggregate shall be installed uniformly over the surface in order to provide an even surface for paving.
5. The porous bituminous asphalt is installed just like standard bituminous asphalt. Porous pavement shall be laid in one lift directly over the storage bed and stone base course to a 63 mm (2.5 in) thickness. It shall not be installed on wet surfaces or when the ambient temperature is 15.5 degrees Celsius (60 degrees Fahrenheit) or lower. Compaction of the surface course shall take place when the surface is cool enough to resist a 10-ton roller. One or two passes is all that is required for proper compaction. More rolling could cause a reduction in the surface course porosity.
6. After final rolling, no vehicular traffic of any kind shall be permitted on the surface until cooling and hardening has taken place, and in no case within the first 48 hours.
7. The full permeability of the pavement surface shall be tested by application of clean water at the rate of at least 0.3 L/s (5 gpm) over the surface, using a hose or other distribution devise. All applied water shall infiltrate directly without puddle formation or surface runoff.
8. Surface sediments shall be removed by a vacuum sweeper and shall not be power-washed into the bed.

5.5.2. Porous concrete

The following steps outline additional installation considerations for porous concrete:

1. The porous concrete mix should be poured directly onto the compacted subbase.

2. It is critical to keep the residence time of the mix in the delivery truck to less than one hour after the water has been added to the mix. It is also important that no additional water be added after it is first introduced into the mix. Extended delivery times and added water weaken the cementitious bond between the aggregate stones and result in premature pavement unravelling, potholing and other failures.

3. Asphalt-laying equipment can be used to lay down the pavement, flowed with a light roller compaction to settle the aggregate into place. Do not use vibrators to work the concrete, as these will cause the cement to separate from the aggregate and flow to the bottom of the pavement.

4. It is also critical that concrete trucks do not drive over the subbase and the compacted base course in areas where porous concrete is to be installed. Use concrete pumpers (if they are compatible in moving the porous concrete mix), conveyor belts, or small tracked front-end loaders to deposit concrete.

5. Closely follow the placement, compaction and finishing instruction in the sample specifications provided in Appendix A of this handbook.

5.5.3. Permeable Unit Pavers

The following steps outline additional installation considerations for permeable unit pavers:

1. Isolate the permeable paving site from sedimentation during construction, either by use of effective erosion and sediment control measures upstream, or by delaying the excavation of 300 mm of material over the final subgrade of the pavement until all sediment-producing construction in the drainage area has been completed.
2. The subgrade should be compacted to 95% Standard Proctor (per ASTM D1557) for pedestrian/cycling areas, and 95% Modified Proctor (per ASTM D698) for vehicular areas. Remove and replace soft areas.
3. Prevent natural or fill soils from mixing with the reservoir base, subbase, or bedding courses and filter cloths. All contaminated stone aggregate and cloth must be removed and replaced.
4. Reservoir drain rock subbase and base courses shall be installed in 100 to 150 mm lifts and compacted with at least 4 passes with a minimum 10-ton steel drum roller. Initial passes can be with vibration and the final two passes should be static. Testing for appropriate density per ASTM D698 or D1557 will likely not provide accurate results. Adequate density and stability exist when no visible movement is observed in the open-graded subbase after compaction.
5. When all base courses are compacted the surface should be topped with filter cloth and a layer of bedding aggregate, and the surface graded carefully to final slopes, as the bedding aggregate will compact down much less than sand.
6. Unit pavers shall be placed tightly butt-jointed according to manufacturers' specifications. Before compacting the pavers into place, cut and place paver units to tightly fill spaces between adjacent pavers and the retaining wall at the edges.
7. Compact the installed paver blocks initially using a 75 to 90 Hz plate compactor that exerts a minimum of 5,000 lbs/ft^2 when using 100 mm (4-inch) thick pavers and a minimum of 6,800 lbs/ft^2 when using pavers thicker than 100 mm (4-inches). After initial compaction, fill the paver openings and joints to the top with ASTM C-33 sand and compact again. If the sand infill drops more than 3 mm (1/8 inch) below the top of the paver block, add more sand and re-compact. Remove excess sand by broom-sweeping the surfaces.
8. Paver installation can be done by hand or using mechanical equipment specially designed for this type of work. If the latter is used, follow the requirements and procedures provided in the ICPT (1998) publication *Technical Specification 11 – Mechanized Installation of Interlocking Concrete Pavements*.

5.5.4. Turf Paving Systems

The following recommendations pertain to turf paving systems, including modular paving blocks or grids, cast-in-place concrete grids as well as soil enhancement technologies.

5.5.4.1 Modular paving blocks or cast-in-place concrete grids

All eight (8) recommendations under “Permeable unit pavers” apply to modular paving blocks and cast-in-place concrete grids, plus the following:

1. Cells may be planted in one of three ways:
    1. Fill with a porous backfill mix (some products require sharp sand), scrape or back-rake the entire surface to expose the pattern. Broadcast seed, or provide stolons, or hydro-seed and then top dress and fertilize as required.
    2. Fill and scrape or back-rake as above, then lay 16 mm (5/8-inch) sod on the assembled pavers. Water the sod, then use a hand water roller or power-driven roller to compress the sod and root system completely into the cells.
    3. Do not fill the cells with any type of soil mixture. Lay 25 mm (1-inch) sod on the assembled pavers. Water the sod and compress as under (b) above.
2. Some manufacturers may supply or recommend a polymer-growing medium to be used with their paving product.

5.5.4.2 Soil enhancements

The following installation considerations apply to an engineered growing medium mixed with mesh elements on site or solid slabs of turf with mesh elements already in the growing medium, both of which are alternatives to modular concrete blocks:

- Sand or a proprietary growing medium is blended with a specific proportion of mesh elements using a mechanical shovel. A 20 kg sample of mixed material will contain 54.4 - 66.7 g of mesh elements (or approximately 44 lb mesh for 5 cubic yards of sand mix). For precise proportions, refer to the manufacturer’s specifications.
- For some proprietary systems, materials can be sourced locally with the patent-holder acting as project manager for the installation, which is then undertaken using specially designed equipment.
- Grass cover is best established using pre-germinated seed, washed turf or conventional seed.
- Non-essential traffic should be kept off the area until the grass is well established.

5.6 *Performance and Impact on Surrounding Community/Environment*

5.6.1. Impact on adjacent infrastructure

The required clearance distance from buildings or property lines, roadways and parking lots with conventional pavement structures depends on the type of subsoils and the presence of a subdrain system. Recommended clearances range from 1.0 m for unconfined sandy soils to 5.0 m for heavy clay soils. The potential for swelling and the associated need for greater clearance distances can be reduced if the device is “dry” in at most three days after filling. A seepage analysis should be conducted to determine drawdown time.

Permeable pavement systems should be located at least 30 m from wells, and at least 3 m down-slope of building foundations, and only in areas where foundations have weeping tiles.

All permeable pavement systems should be set back from the subgrade of adjacent roads by at least 6 m when the frost depth exceeds 1 metre. This is to reduce the potential for frost lenses and heaving of soils under the adjacent roadway.

Zero clearance is possible when an impermeable liner and a subdrain are provided, with an overflow away from the critical areas.

Utility or other crossings of permeable pavement systems should be avoided. Where shallow or deep utility trenches must be constructed below the permeable pavement area, clay plugs or other impervious materials should be installed in the trench to avoid infiltrating water from following the utility trench.

5.6.2. Community and environmental factors

With regard to the acceptance of permeable pavement in the community, the main perceived disadvantage is the lack of accessibility for the disabled and the elderly, specifically with respect to permeable unit pavers and turf paving systems. Fewer concerns are expected in the case of permeable asphalt or concrete surfaces.

In terms of aesthetics, permeable asphalt and concrete are very similar to their non-permeable counterparts. Permeable unit pavers can add considerable aesthetic appeal as they come in various shapes and colours (see Figure 5-25). Turf paving systems can be even more aesthetically appealing as they break up the visual monotony associated with asphalt or concrete pavement.

Figure 5-25 Aesthetic Benefits of Permeable Unit Pavers

Source: Bert van Duin, Westhoff Engineering Resources, Inc.

Permeable asphalt and concrete pavement are reported to produce less traffic noise than impermeable pavement types. The fact that permeable unit pavers produce more noise than conventional impermeable pavements is generally not an issue as they are recommended for low-speed areas.

Contamination of soil and groundwater sources is likely to be increased in places with high soluble contaminant discharge, such as areas with risk of industrial/hazardous material contamination, parking lots, road intersections, service stations, recycling facilities and vehicle storage, service and cleaning facilities, land uses that drain runoff contaminated with pesticides or fertilizers, and areas with associated high infiltration rates.

5.6.3. Performance with regard to pollutants of concern

Permeable pavement facilitates removal of particulate pollutants such as metals, oil, and grease. This is accomplished through sedimentation, runoff filtration and entrapment through the sand and gravels of the subbase, assimilation, nitrification, denitrification, biodegradation, decomposition, volatization, adsorption and ion exchange, all of which occur as stormwater travels through the underlying soils before it reaches groundwater.

Removal rates for dissolved constituents are low to moderate, depending on the filtering media used and the specific constituent. The temperature of runoff from permeable pavement systems tends to be lower than that commonly associated with impervious cover.

Positive factors that influence pollutant removal include:

- High exfiltration volumes;

- High surface area;
- Routine vacuum sweeping;
- Maximum drainage time of two days;
- Highly permeable soils;
- Clean-washed aggregate;
- Organic matter in subsoils; and
- Pre-treatment of off-site runoff.

Studies show that the concentration of suspended solids in runoff from a pervious surface varies from near zero to 50 mg/L, which is considerably less than in discharges from impermeable surfaces (i.e., typically 30 – 300 mg/L but up to 1000 mg/L). Pollutants are either reduced because there is less runoff or they are retained within the pervious construction.

The contaminants are trapped within the permeable pavement at various locations according to the type of pavement. In cases where a geotextile is installed, much of the pollution is retained on the geotextile.

Besides the trapping of some pollutants, some types of permeable pavement structures can hasten degradation by micro-organisms of trapped oils and other hydrocarbons. Permeable pavements can act as hydrocarbon traps with 98.7% efficiency and can also act as powerful in-situ aerobic bioreactors. When installed in the upper layers of the permeable pavement structure, the geotextile was found to retain 60 – 90 percent of typical discharges of oil in the structure as a whole.

5.6.4. Performance under cold climate conditions

Experience with permeable pavement systems in other jurisdiction indicates that they function well in freeze-thaw cycles and are generally more resistant to freezing than conventional impermeable pavements.

There is no evidence that any of the pervious pavements systems presented in this handbook adversely affect the depth of frost penetration into the ground. The open-voided nature of the materials, which have high air content, may be beneficial and reduce the depth of frost penetration. Risk of frost damage can be minimized by extending the base of the permeable pavement system to a minimum of half the frost depth.

In one study, porous asphalt samples were tested over 265 freeze-thaw cycles and no physical dimensional changes were observed. However, ice mushrooms have been observed when freezing water expands through the voids in the upper surface. The subbase material should not become fully saturated. This can be prevented by increasing the design storage volume by 30 percent or incorporating a subdrain system into the design. Increasing the diameter of the subdrain makes freezing less likely, and provides a greater capacity to drain standing water in the subbase.

The possibility of large, rapid volumes of meltwater during melt events should be factored into the design of permeable pavement systems in cold climates. In this case, the following guidelines should be considered:

1. Chlorides and sand can be concentrated in meltwater. Removal of chlorides is nearly impossible for any source control practice, so it is recommended to use isolation methods. It is recommended to stockpile snow with chlorides and/or sand away from

permeable pavement sites. Possible locations include parking lot islands or bioretention areas.

2. If salts are used for de-icing a permeable pavement area, then the groundwater should be monitored to ensure chloride levels do not exceed government regulations. This can be done through the sampling of water in observation wells that are located in the pavement base and soil.
3. When the frost depth exceeds one (1) metre, permeable pavement systems should be set back from the subgrade of adjacent roads by at least six (6) metres to reduce the potential of frost lenses and heaving of soils under the adjacent roadway.
4. If winter sanding is extreme, maintenance should include annual inspection in the spring and vacuum removal of the surface sediment. This will ensure continued infiltration performance of the pavement.
5. A one (1) to two (2) percent slope can be incorporated as a safety factor for overflow in the event the system is unable to infiltrate all runoff under winter conditions.

5.7 *Long-term issues*

5.7.1. Long-term sustainability

Properly constructed and maintained permeable pavement systems installed in areas with climatic conditions similar to the Calgary region generally have a service life of 20 to 25 years, which is comparable to or longer than conventional asphalt.

The infiltration capacity of permeable surfaces steadily decline over time to the point where reconstruction or reinstatement is necessary.

Research indicates that a lifespan of 40 years can be expected for an installation such as a parking lot with an impervious-to-permeable paving ratio I/P = 1.0. Lifespan estimates vary depending on impervious-to-permeable paving ratios. For example, if I/P is increased to 7.0, which increases the loading on the filter system six-fold, the lifespan is reduced to 12 years.

5.7.2. Life cycle costs

The following items should be included in an assessment of the cost of installing a permeable paving system:

- Site Preparation
- Tree and plant protection
- Clearing and grubbing
- Topsoil salvage
- Site Formation
- Excavation and grading
- Hauling material offsite
- Structural components
- Subdrains
- Outlet structure

- Site Restoration
- Seeding (in case of turf paving systems)
- Debris removal
- Sediment removal
- Weed control
- Inspection

Not included are typical cost items common to all construction projects such as mobilization, traffic control, erosion and sediment control, permitting, etc.

In other jurisdictions, on a unit area basis, permeable asphalt with additives has cost 10 to 20 percent more than conventional asphalt. Permeable concrete, as a material, is generally more expensive than asphalt and requires more labour and experience for installation due to specific material constraints. Permeable unit pavers vary in cost depending on type and manufacturer. The added cost of a permeable pavement system lies mainly in the underlying subbase, which is generally deeper than a conventional subbase and wrapped in geotextile.

However, the additional costs associated with permeable pavement are often offset by the significant reduction in the required number of inlets and pipes. Since permeable pavement areas are often incorporated into the natural topography of a site, there is generally less earthwork and/or deep excavations involved. Furthermore, permeable pavement areas with subsurface infiltration beds often eliminate the need (and associated costs, space requirements, etc.) for detention basins. When all of these factors are considered, permeable pavement with infiltration has proven to be less expensive than the conventional approach.

Materials and mixing costs for permeable asphalt are similar to conventional asphalt. However, since local contractors are not as familiar with permeable asphalt installation, additional costs for handling and installation should be anticipated.

5.7.3. Safety and liability

Potential contamination of soils and/or groundwater may constitute a liability if runoff from stormwater hotspots is directed onto permeable pavement types, especially when the soils are highly permeable. When used on commercial or industrial sites where spillage of chemicals and petroleum products is possible, an impermeable liner with a subdrain is required to prevent groundwater and soil contamination.

Permeable pavement systems should not provide a breeding ground for mosquitoes, as they generally do not hold standing water. There is a risk of structural support problems from traffic loadings on permeable pavement that does not drain properly, especially in the case of systems without a subdrain.

5.7.4. Failure scenarios

The main failure scenario of permeable pavement systems appears to be waterlogging of the pavement structure, which is a direct consequence of inadequate permeability of the structure (and/or subsoils if deep percolation is counted on in the case of turf paving systems). Inadequate permeability can be caused by:

- Inappropriate composition of the subbase so that it does not have the specified design permeability

- Hydraulic overloading of the permeable pavement by routing too large an area to the permeable pavement
- Overestimation of the hydraulic conductivity of the subsoils if the subsoils are counted on to empty the turf paving system between runoff events
- Excessive build-up of sediments within the pores of the structure
- Other potential failure scenarios include frost damage to flow retarding devices, pavement displacement due to frost heave, and surface icing due to retention of moisture within the surface layer of the pavement. Turf paving systems can fail if vegetation dies due to inappropriate selection for soil and climatic conditions, or if runoff from stormwater hotspots is routed into turf paving systems areas without proper pre-treatment.

6.0 Rainwater Harvesting and Reuse

6.1 *Description*

The capture and reuse of rainwater is a viable source control practice (SCP) that can reduce the volume of stormwater run-off and help diminish the demand on our potable water supply as part of integrated water management planning.

Frankfurt International Airport in Germany has been operating a water recapture program since 2000 (see Figure 6-1). All rainwater from the roof, as well as grey water from the sinks, is collected and re-used for toilet flushing in the building.

Figure 6-1 Rainwater Harvesting at Frankfurt International Airport, Germany

Source: Klaus W. König

Rainwater harvesting and stormwater re-use effectively reduce the volume of runoff discharged to receiving water bodies. Reductions in the volume of runoff result in reduced pollutant loadings, reduced erosion, and an improvement in the overall hydrologic balance of the watershed.

Rainwater harvesting is typically defined as the collection of runoff from a roof area or other impermeable surface before it discharges onto the ground or drains into a storm sewer system. The water collected can be re-used for irrigation and, if treated, potable water purposes.

Any building - residential, commercial or industrial - can be used for rainwater harvesting purposes, as long as appropriate provisions for the collection, storage, treatment and distribution of the harvested rainwater can be made. This chapter focuses on rainwater harvesting systems where untreated rainwater from roof systems is collected in a variety of ways, and then stored in a cistern or storage tank for use on an as-needed basis.

6.2 *Application*

Given the risk of contamination, untreated rainwater cannot be used for any potable purposes. Current uses within Calgary are limited to irrigation and toilet flushing.

6.3 *Hydrologic benefits*

The hydrologic benefits of stormwater re-use include the attenuation of stormwater run-off and the associated reduction of flooding, potential for erosion and contaminant loadings.

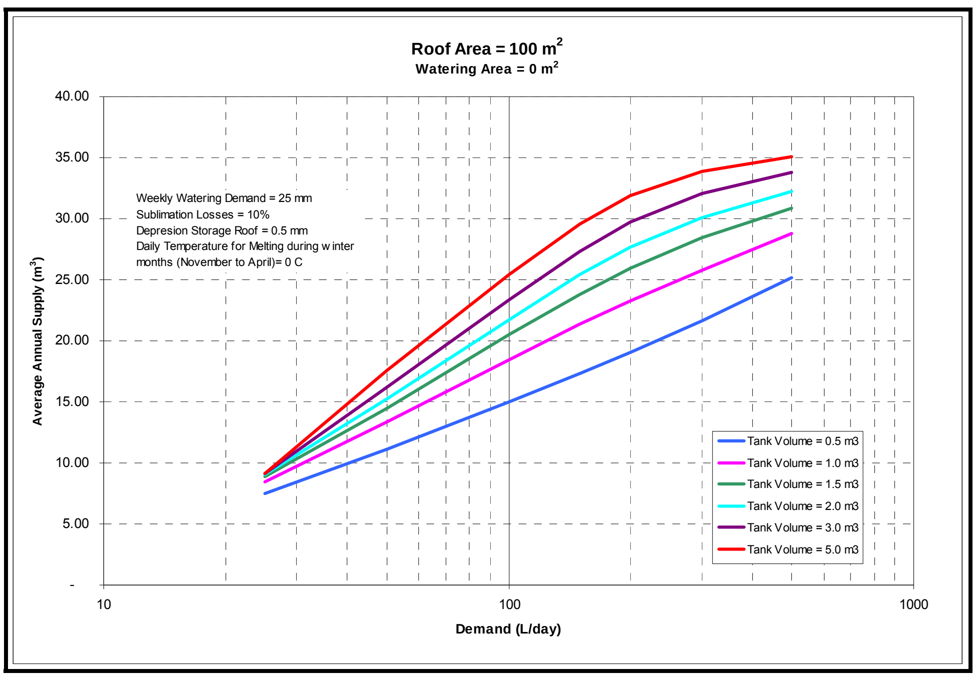
The magnitude of these reductions depends on many factors including the size of the catchment area, the capacity of the storage tank, the precipitation pattern, and the water consumption patterns of the users of the rainwater harvesting system.

Rainwater harvesting systems are typically most effective in reducing overall runoff volume, as they are sized for average precipitation patterns, not for extreme events. However, they do reduce the severity and frequency of nuisance inundation, e.g. in parking lots. By reducing runoff volumes, rainwater capture and re-use scenarios decrease erosion of receiving streams and the associated morphologic changes.

The harvested water acts as an alternate supply source for non-potable uses. This reduces the risk of insufficient conventional supply and can postpone water distribution system upgrades.

The potential for potable water savings can be calculated for Calgary's precipitation by means of water balance computations. Figure 6-2 illustrates the yield for a typical residential dwelling in Calgary with a 100 m^2 roof area, a constant demand related to indoor non-potable uses, and no additional demand for irrigation purposes.

Figure 6-2 Rainwater harvesting yield in Calgary for residential dwelling – Constant demand without irrigation demand

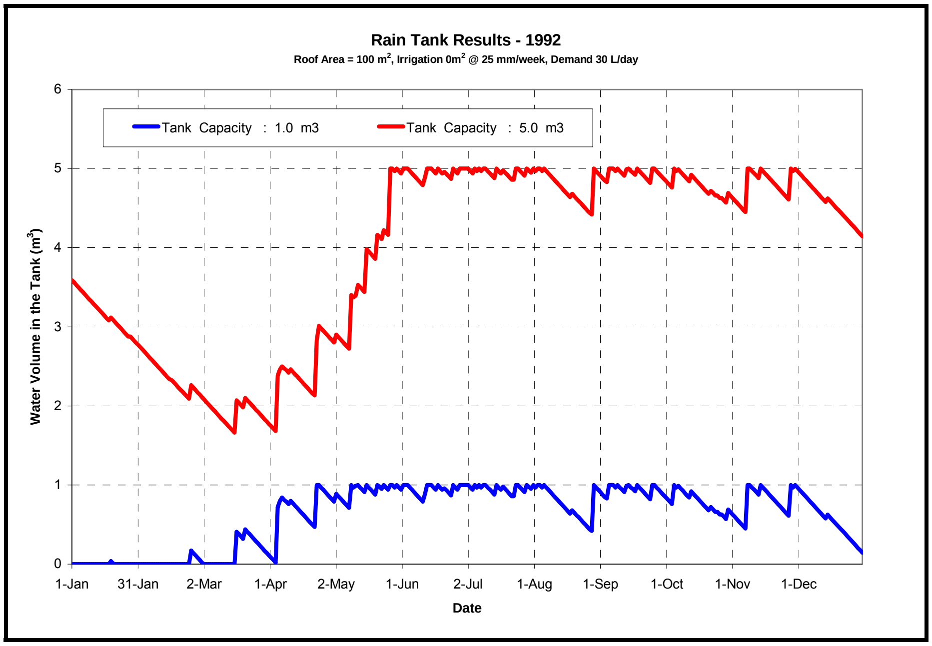


Source: Bert van Duin, Westhoff Engineering Resources, Inc.

The maximum average yield for a 100 m^2 is in the order of 35 m^3 or 350 mm on a unit area basis for the combination of a large tank and high demand. This maximum yield is equal to the runoff volume of the roof area; it is smaller than the average annual precipitation of 400 mm because of wetting losses of the roof surface and sublimation of snow during the winter months.

The potential reduction in stormwater runoff is directly related to the building's demand for water i.e. when demand is low, the water volume in the storage tank is not reduced quickly enough to allow water from subsequent storm events to be collected and reused.

Figure 6-3 Low demand scenario – No irrigation use



Source: Bert van Duin, Westhoff Engineering Resources, Inc.

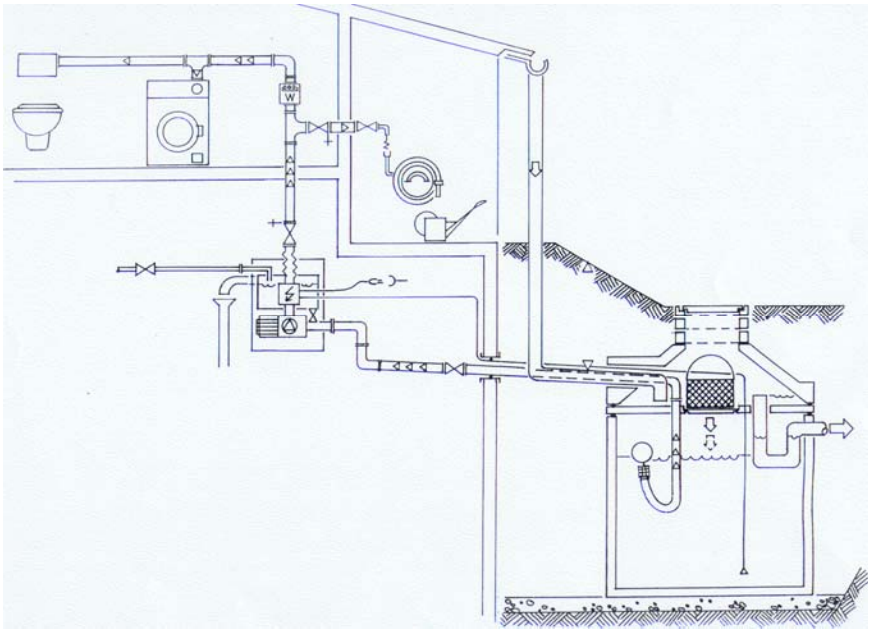
A continuous simulation, which would take into account tank capacity and demand patterns, is required to quantify volume reduction benefits.

6.4 *Design*

6.4.1. Design approach

Rainwater harvesting systems begins at the point where precipitation hits a surface and terminates where the harvested water exits at household plumbing fixtures or as irrigation water (see Figure 6-5).

Figure 6-5 Components of a Rainwater Harvesting System



Source: Klaus W. König, 2005

The components of a rainwater harvesting system include:

1. Roof or other impermeable surface

The surface onto which the rain falls represents the catchment area. In residential areas, the roofs of buildings are the primary catchment areas.

2. Cistern or storage tank

A cistern or storage tank retains the captured water and is the central component of a rainwater harvesting system.

3. Roof washer

A roof washer pre-treats rainwater by collecting and treating the water from a roof before it enters the storage tank.

4. Gutter/downspout system

Gutters and downspouts are used to convey the rainwater from the roof surface to the roof washer and storage tank.

5. Pumping and piping/distribution system

A pump is often required to distribute the harvested rainwater from the storage tank to the designated fixtures. The piping system conveys the harvested rainwater and distributes it to the various fixtures.

6. Water treatment system

Water treatment systems include a variety of treatment processes to settle, filter, and disinfect the collected rainwater.

6.4.2. Design examples

6.4.2.1 Roof catchment area

The catchment surface is limited to the area of roof that is guttered. The rainwater and/or snowmelt yield varies with the size and texture of the catchment area. Smoother, cleaner, and more impervious roofing materials contribute to optimal water quantity and quality. Regardless of the roofing material, many designers assume up to a 25% loss on annual precipitation. These losses are due to roofing material texture (which slows down the flow), evaporation/sublimation, and inefficiencies in the collection process.

Any tree branches that overhang the roof should be trimmed as they provide perches for birds and produce leaves and other debris.

6.4.2.2 Roof washers

The purpose of pre-treatment using a roof washer is to remove dirt, leaf litter, particulate matter, etc., and/or divert the first several minutes of rain to waste, before water collection commences.

The simplest of these systems consists of a standpipe and a gutter downspout located ahead of the downspout from the gutter to the storage tank. Most of these types of roof washers extend from the gutter to the ground. The gutter downspout and top of the pipe are fitted and sealed so water will not flow out of the top. Once the pipe has filled, the rest of the water flows to the downspout connected to the tank. These systems should be designed so that at least 40 L (10 gallons) of water are diverted for every 90 m^2 (1000 square) feet of collection area.

The more advanced self-cleaning systems can either be installed in the downspout or just prior to the storage tank. The filter is easily exchangeable and consists of a stainless steel mesh with 0.2 or 0.4 mm openings. The filter unit can also attach to different pipe sizes.

No separate overflow line into landscaping or into a sewer is necessary. Where the filters allow for diversion of the initial flow from the roof, the water loss should be less than 10% of the runoff volume. Filters should have a free-flow capacity of 300 L/s/ha and the inside diameter of the filter feed must be uniform throughout.

6.4.2.3 Gutters and downspouts

The most common materials for gutters and downspouts are aluminum or galvanized steel. A seamless aluminum 15 cm gutter with a 10 cm downspout can serve about 90 m^2 of roof area and is recommended for most storage tank installations. Downspouts are typically designed to handle 32 mm of rainfall during a 10-minute period.

In order to keep leaves and other debris from entering the system, the gutters should have a continuous leaf screen, made of 6 mm mesh in a metal frame, and a screen or wire basket at the head of the downspout.

6.4.2.4 Cisterns/storage tanks

Cisterns or storage tanks can be placed both above and below ground. While aboveground installations avoid the costs associated with possible excavation and more complex maintenance, storage tanks installed below ground benefit from the cooler year-round ground temperatures.

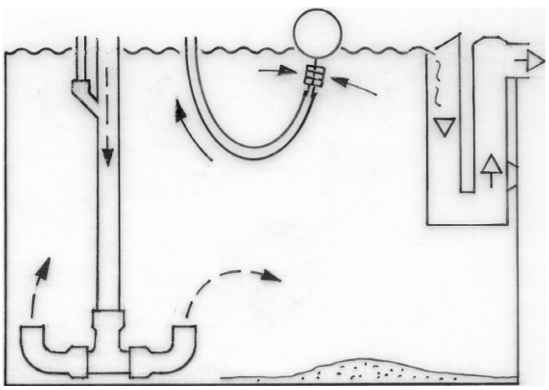
To maximize efficiency, storage tanks should be located as close as possible to both the supply and demand points. And, to facilitate the use of gravity or lower stress on a pump, the tank should be placed at the highest workable elevation.

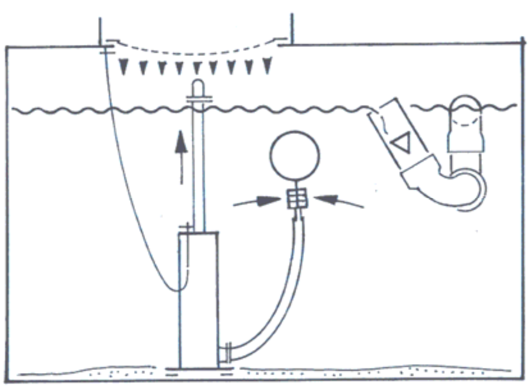
Regardless of the type of material selected, the storage tank should have a durable, watertight exterior and a clean, smooth interior, sealed with a non-toxic joint sealant. A tight-fitting cover is essential.

The quality of the water in the storage tank and, ultimately, of the water delivered to the user, can be improved by installing:

- A calm inlet that allows for quiescent flows that do not stir up deposited sediments;
- A floating suction connection to the pump that does not disturb deposited sediments;
- An emergency overflow siphon equipped with screen to prevent entry of rodents; and,
- A sewer back flow prevention valve.

Figure 6-6 Examples of inlet and pump configurations





Source: Klaus W. König, 2005.

Exterior tanks should be installed below the frost line so that the water does not freeze during sustained periods of cold. Alternatively, the system may be disconnected and emptied before the onset of winter. For interior installations, the ambient temperature must be kept above freezing.

Adequate measures must be taken so that air inside the storage tank can escape with the onset of fresh inflow without emptying the siphon spillway. Systems made up of several interconnected containers must have openings for pressure equalization between the tanks, since any trapped air will prevent the tanks from filling properly. In standard installations, the downspouts from the roof are connected straight onto the rain reservoir; this provides adequate venting for single tanks.

Tank storage volume can be calculated by using the general form of the water balance approach as follows:

$$\frac{dV}{dt} = V_{precipitation} - V_{sublimation/evaporation} - V_{demand} - V_{spill} \qquad \textbf{Equation 6-1}$$

Where:

Where:	dV/dt	=	change in volume in the tank over time period dt
	$V_{precipitation}$		total volume of precipitation over the roof area over time period dt
	$V_{sublimation/evaporation}$	=	sublimation, evaporation and other losses over time period dt
	V_{demand}	=	total volume of water consumed by the user(s) over time period dt
	V_{spill}	=	total volume of water spilled from the rainwater harvesting system over time period dt when storage capacity of the tank is fully utilized.

In practice, some rainwater is always lost to first flush, evaporation, splash-out or overshoot from the gutters in hard rains, and possibly leaks. In order to maximize stormwater management benefits, spillover volume should be minimized.

6.4.2.5 Pumping and distribution system

Pumps are required for virtually all rainwater harvesting systems for conveying water from the storage tank to the plumbing fixtures. The pumps are to be designed based on the desired flow rates and length of the piping. The design and construction of the pumps and piping are to comply with City of Calgary plumbing regulations and the Alberta Plumbing Code.

6.4.2.6 Water treatment

Dirt, rust, scale, silt and other suspended particles, bird and rodent feces, airborne bacteria and cysts may enter the storage tank even when design features such as roof washers, screens and tight-fitting lids are properly installed. To ensure water quality, filtration and disinfection are the minimum recommended treatments if the water is to be used indoors. If the rainwater is to be used outside for landscape irrigation, where human consumption of the untreated water is less likely, the presence of contaminants may not be of major concern and treatment requirements can be less stringent or omitted.

Rainwater treatment techniques can include screening, settling, filtering, and in some cases chemical or UV disinfection.

Filtration can be as simple as the use of cartridge filters or those used for swimming pools and hot tubs. A cartridge sediment filter, which traps and removes particles of five microns or larger, is the most common filter used for rainwater harvesting. Sediment filters used in series, referred to as multi-cartridge or in-line filters, sieve the particles from increasing to decreasing size. These sediment filters are often used as a pre-filter for other treatment techniques such as ultraviolet light or reverse osmosis filters which can become clogged from large particles. In all cases, proper filter operation and maintenance in accordance with the accompanying instruction handbook must be followed to ensure safety.

A disinfectant such as chlorine or iodine can be added to rainwater in the storage tank. Ultraviolet light or ozone can also be used for disinfection.

6.4.3. Limitations

If the demand is too low, the storage tank will not empty and insufficient storage capacity will be available to effectively reduce runoff volumes.

The total amount of water that can be harvested is a function of the roof area and precipitation patterns. The benefits with respect to reductions in water consumption are a function of the supply and demand amounts and patterns.

6.4.4. Vegetation

N/A

6.4.5. Space requirements

The only space requirement associated with rainwater harvesting systems pertains to the footprint of the storage tank. If installed outside but underground, the surface can be paved over or landscaped as long as the tank is accessible for inspection and cleaning.

6.5 *Construction*

All components of the system should be procured from one company as this allows for complete information on the design and clear responsibility for the product quality with guarantees. Packaged units/plug-in systems should consist of a tank unit including filter, sedimentation items and fittings for plug-in connections of pipes and an overflow with backflow prevention.

All controls, overflows and cleanouts should be readily accessible while alerts for system problems should be easily visible and audible. Potable water backup should only be provided through a free outlet to ensure that the individual rainwater system cannot impact the public water distribution system. A 20 mm air gap should be provided between the potable water supply inlet and the storage tank water level.

No cross-connections are allowed and rainwater distribution pipes and rainwater serving valves should be clearly labelled.

6.6 *Performance and Impact on surrounding community/environment*

6.6.1. Impact on adjacent infrastructure

Rainwater harvesting systems should have no impact on adjacent infrastructure as long as the overflow systems are properly directed away from the building.

6.6.2. Community and environmental factors

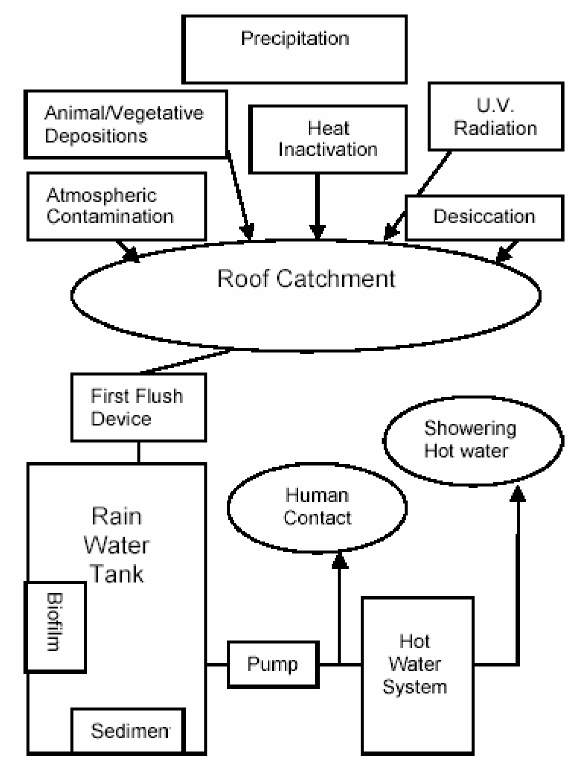
In addition to reducing the demands on the potable water system, especially during the peak summer season, rainwater harvesting systems raise public awareness of the need for source protection and water conservation.

Reductions in runoff volumes decrease the accelerated erosion associated with urbanization and decrease contaminant loadings as well. The smaller runoff volumes will also allow other SCPs to operate at higher treatment efficiency.

6.6.3. Performance with regard to pollutants of concern

Stormwater harvesting systems provide several processes for enhancing the quality of water captured from a rooftop for re-use (see Figure 6-4).

Figure 6-4 Treatment train of a household rainwater harvesting system



Source: Spinks et al, 2003

- While the rooftop and gutter system provide an entry point for contaminants, the microbiological load is reduced through exposure to high UV levels, intense heat, and desiccation.
- Biofilms (layers of bacteria that develop rapidly on surfaces in low nutrient conditions) in rainwater storage tanks have been shown to increase the adsorption of heavy metals, nitrogen and phosphorus.
- Many contaminants, particularly heavy metals that are attached to particulate matter, appear to be removed from the water column by the passive process of sedimentation.
- When water from the storage tank passes through a pump and/or hot water system, the structure and integrity of bacterial cells are disrupted. Studies show that hot water systems maintained at above 60°C will achieve rapid pathogen reductions within a few minutes.

6.6.4. Performance under cold climate conditions

The biggest challenge with respect to the performance of rainwater harvesting systems is poor maintenance and the potential for frost damage during winter. Storage tanks located outside must be disconnected and emptied prior to the onset of winter. Seasonal disconnection of rainwater harvesting systems does not necessarily reduce the overall efficiency of the system because only 25 percent of the total annual precipitation occurs from October to April.

6.7 *Long-term Issues*

6.7.1. Long-term sustainability

Although little information is available about the long-term sustainability of rainwater harvesting systems, in principle it should be comparable to typical plumbing systems. However, practitioners are strongly recommended to keep the various failure scenarios discussed under Section 6.7.5 in mind.

Maintenance includes regular cleaning of roof washers and tanks, maintaining pumps, and filtering water.

A site specific Inspection, Operation and Maintenance Plan should be prepared by the designer prior to putting the rainwater harvesting system into operation. This plan should include the operating instructions, inspection checklists, and routine maintenance checklist. Qualified personnel should be used for the operation and maintenance of the system such as cleaning of the storage tank, treatment equipment, etc. Additionally, the system may require Alberta Environment approval if it is intended to serve a communal system or public facility (Calgary Health Region, 2005).

6.7.2. Life-cycle costs

The following items should be included in a cost estimate of a rainwater harvesting system:

- Pre-treatment systems such as roof washers and/or filters
- Storage tank
- Pumping system
- Overflow system
- Treatment system
- A rainwater harvesting system designed as an integrated component of a new construction project is generally more cost-effective than retrofitting a system onto an existing building.

Based on an average re-use demand of 100 L/day, an average total residential demand of 20 m^3/month, and a tank size of 1.5 m^3 (i.e., 400 US gallons), the average annual amount supplied by the rainwater harvesting system is about 20.5 to 26.5 m^3. This amounts to about 8.5 to 11% of the total residential use or 56 to 73% of the re-use demand for annual savings of \$30 to \$40, based on a combined water/sanitary sewer charge of \$1.50/m^3. It is estimated that approximately 58 to 75% of the annual precipitation falling on the roof would be diverted from runoff.

Table 6-1 presents a breakdown of the costs and potential savings of the rainwater harvesting system that was constructed for a condominium complex in The Bridges development in Calgary.

Table 6-1 Cost Breakdown of Rainwater Harvesting System at The Bridges, Calgary

Component (beyond City requirements)	Approximate Cost ($)
Wall in storage tank separating rainwater and stormwater storage	14,000
Waterproofing premium (more durable)	5,000
Water treatment and pump	24,000
Specific recycled water plumbing and irrigation	15,000
Total	**58,000**
Cost savings/year (@ water rate of $0.9448/m^3 and Sewer charge of 64.56% of water rate)	**2,269**

Source: Peachman and Sawers, 2005

The cost of rainwater harvesting systems are expected to come down considerably when packaged systems, which include a tank, pump, treatment system and electronics, become commercially available in North America.

The implementation of rainwater harvesting system in watersheds that require runoff volume reduction such as the Nose Creek and Pine Creek basins will decrease the need for and costs and land requirements associated with other stormwater source control practices.

6.7.3. Safety and liability

To ensure the regulatory compliance of rainwater reuse, the system must satisfy the City of Calgary and provincial pluming codes, as well as Calgary Health Region requirements. At this time, harvested rainwater cannot be used for potable purposes. Colour-coded (i.e., purple pipe) plumbing should be installed to easily identify the non-potable supply. Piping should be labelled as containing non-potable water and building occupants should be informed of rainwater reuse. Back-flow prevention devices should be installed at any potential cross connections. Proper signage should also be installed on outdoor fixtures such as hose bibs and irrigation connections reading: “Not safe for human consumption”.

6.7.4. Failure scenarios

The principal failure scenario of rainwater harvesting systems is inadequate demand and/or demand patterns that are significantly different from the initial design assumptions. This disturbs the water balance and prevents the tank from being emptied.

A second failure scenario involves damage to the contents of the building due to failure or collapse of any component of the rainwater harvesting collection, storage and distribution system. This risk is comparable to that of conventional plumbing systems.

7.0 Green Roofs

7.1 *Description*

Green roofs are veneers of living vegetation installed on top of buildings – from small garages to large industrial structures. Green roofs, also called eco-roofs, vegetated roofs, and rooftop gardens, help manage stormwater through a variety of hydrologic processes that otherwise take place at ground level. Plants on green roofs capture rainwater on their foliage and absorb it in their root zone, encouraging evapotranspiration and reducing the volume of stormwater entering receiving water bodies. Water that does leave the roof is slowed and kept cooler, which benefits downstream water bodies. Green roofs are especially effective in controlling intense, short-duration storms and have been shown to reduce cumulative annual runoff by over 50 percent in temperate climates, depending on the composition and thickness of the growing media.

A green roof system has been in place at the Head-Smashed-In Buffalo Jump Interpretative Centre at Fort MacLeod for over two decades (see Figure 7-1).

Figure 7-1 Green Roof at Head-Smashed-In Buffalo Jump at Fort MacLeod

Source: Trevor Sziva, Soprema Inc.

In 2005, a pilot green roof was constructed at the Alastair Ross Technology Centre for Calgary Technologies Inc. (CTI). (Figure 7-2)

Figure 7-2 Green Roof Pilot Project at Alastair Ross Technology Centre in Calgary

Source: Trevor Sziva, Soprema Inc.

Green roof systems are also planned for the Pine Creek Wastewater Treatment Plant Facility and the new Water Centre at the City of Calgary Manchester Yard.

Key practical considerations for implementing green roofs include structural and load-bearing capacity of the buildings in question, plant selection, waterproofing and drainage or water storage systems.

Green rooftops can be built in a variety of ways, but the simplest, called an extensive green roof, involves a relatively light system of drainage and filtering components and a thin layer of soil mix (5 to 10 cm), which is installed and planted with drought-tolerant, self-sustaining herbaceous vegetation. (See Figure 7-3) These systems are often designed to perform stormwater, insulation and climate amelioration functions, and usually have no public access.

Figure 7-3 Extensive Green Roof System at Schiphol (Amsterdam) International Airport

Source: GVRD, 2004, courtesy of Lanarc Consultants

More complex green roofs, called intensive systems, employ deeper soils to accommodate shrub and tree root systems and structures to support human use (see Figure 7-4). Although intensive green roofs have greater stormwater benefits, they are heavier, more expensive and require higher structural load capacity.

Figure 7-4 Intensive Green Roof System at Fairmont Hotel Herb Garden

Source: GVRD, 2004, courtesy of Goya Ngan

The differences between intensive and extensive roof systems are summarized in Table 7-1.

Table 7-1 Comparison of Extensive and Intensive Green Roof Systems

Extensive Green Roof	Intensive Green Roof
Features: Thin growing medium Little or no irrigation Stressful conditions for plants Low plant diversity	**Features:** Deep soil Irrigation system More favourable conditions for plants High plant diversity Often accessible
Advantages: Lightweight; roof generally does not require reinforcement Suitable for large areas Suitable for roofs with 0 - 30º slope Low maintenance and long life Often no need for irrigation and specialized drainage systems Less technical expertise needed Often suitable for retrofit projects Can leave vegetation to grow spontaneously Relatively inexpensive Looks more natural Easier for planning authority to demand as a condition of planning approvals	**Advantages:** Greater diversity of plants and habitats Good insulation properties Can simulate a wildlife garden on the ground Can be made very attractive visually Often accessible, with more diverse utilization of the roof, i.e., for recreation, growing food, as open space More energy efficiency and stormwater retention capability Longer membrane life
Disadvantages: Less energy efficient and fewer stormwater retention benefits More limited choice of plants Usually no access for recreation or other uses Unattractive to some, especially in winter	**Disadvantages:** Greater weight loading on roof Need for irrigation and drainage systems requiring energy, water, materials Higher capital and maintenance costs More complex systems and expertise

Source: adapted from CMHC, 1998.

7.2 *Application*

Green roof systems are suitable for rooftops on commercial, institutional and industrial buildings with flat or sloped roofs.

The benefits of green roofs are summarized in Figure 7-5:

Figure 7-5 Chain of Benefits

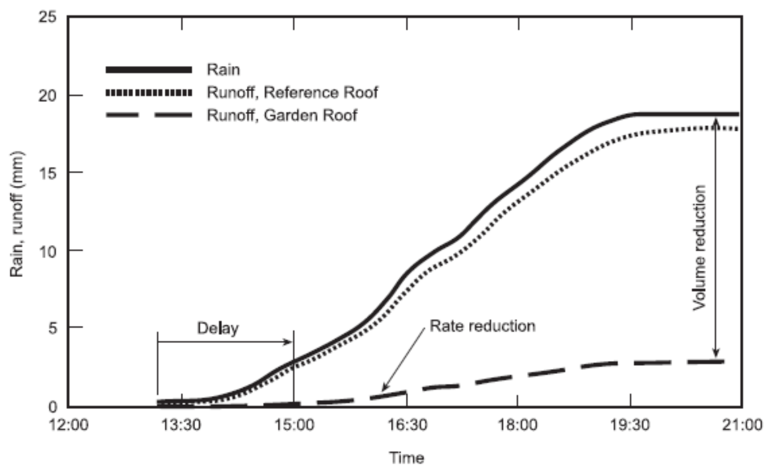
Source: Waterloo, 2005.

7.3 *Hydrologic benefits*

A green roof can help manage both the quantity and quality of stormwater in urban areas. The plants and growing media absorb and filter rainwater instead of loading the drainage system with large quantities of potentially contaminated runoff. A typical extensive green roof comprised of approximately 75 mm of growing media can reduce annual runoff volume by more than 50 percent.

Vegetation plays a major role in preserving or alternatively restoring the moisture storage and infiltration capacities of soils. Plant materials work to condition the soil – providing a regular supply of organic matter and opening up macropores in the soil through the process of root growth. Surface vegetation is also very effective at preventing erosion by protecting the soil from erosion by raindrops, runoff, water currents and wind. Plants decrease the amount of rainfall directly impacting the ground surface by intercepting and holding a portion of the water on the leaves and stems as well as decreasing runoff velocities.

Figure 7-6 Cumulative Rain and Runoff during a Typical Rain Event



Source: Liu and Baskaran, 2005.

In general, summer retention rates vary between 70-100% and winter retention between 40-50%, depending on factors such as substrate and vegetation depths, temperature, sun and wind. Runoff that does occur is also stretched out over several hours, thereby reducing peak flow rates. Most of the stormwater is stored by substrate and then taken up by plants, through which it is returned to the atmosphere through evapotranspiration. In addition, extra rainwater not absorbed by the plants can be stored in cisterns or storage tanks and used later to irrigate the roof garden.

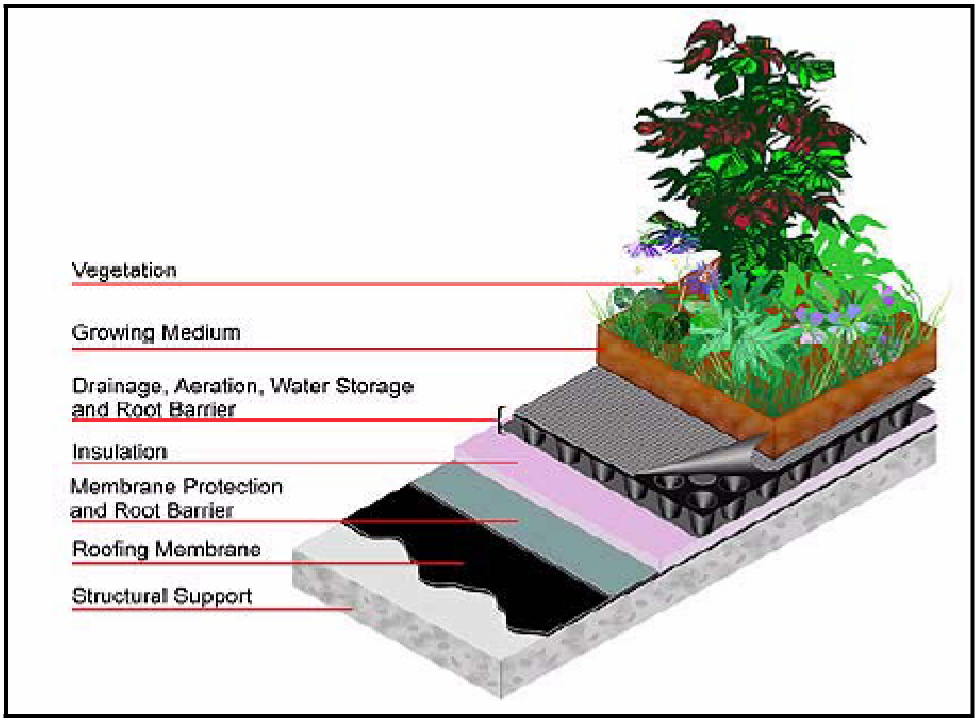
It is recommended that water balance computations be conducted to estimate the actual benefits of green roof systems. Specific emphasis, however, should be placed on ensuring that the actual field or design conditions including irrigation practices match the assumed conditions.

7.4 *Design*

7.4.1. Design approach

The basic features of a green roof design are illustrated in Figure 7-7.

Figure 7-7 Layers of a Green Roof System



Source: CCPP, 2003, courtesy of American Wick Drain Company

Structural support

The bottom layer is composed of the structural support of the building (e.g., concrete).

Waterproof Membrane

The next layer is a waterproof membrane, which prevents water from leaking into the building.

Membrane Protection and Root barrier

A membrane protection layer on top of the waterproof membrane prevents roots from penetrating the membrane and protects the membrane from UV radiation damage.

Insulation

Next, a thermal insulation layer is placed on the roof to prevent water stored in the green roof system from extracting heat in the winter and cool air in the summer.

Drainage Layer, Aeration, Water Storage and Root Barrier

A drainage layer and root barrier are then added on top of the insulation layer. It is important to have a drainage layer that will store some water, but also allow excess water to drain away. Insufficient drainage can cause leaks in the membrane, due to continuous contact with water or wet soil, and cause plants to drown or rot.

Growing Medium

The growing medium is usually comprised of a lightweight mixture of materials such as gravel, sand or humus. The composition and depth of the growing medium is critical to long-term plant survival, stormwater retention, thermal mass transfer, and habitat for birds, mammals and invertebrates.

Plants

Vegetation forms the final layer. The plantings provide aesthetic benefits, insulation, biodiversity protection, fire retardant potential, shade, and transpiration. In addition, they filter pollutants, sequester carbon dioxide and produce oxygen. They also perform a stormwater management function.

The design of a green roof should be undertaken at the same time as the design of the building or retrofit project, so that the structural load of the green roof can be balanced with the structural design of the building. All disciplines, i.e. structural, mechanical and electrical engineers, architects, landscape architects and roofing design professionals, should be involved in the green roof design process.

The following steps are essential to the successful implementation of green roof systems:

1. Establish stormwater management runoff volume and rate control targets.
2. For an existing building, conduct a structural assessment to obtain roof load capacity estimate
3. Select a green roof type based on the available load capacity:
4. Prepare roof plan and details including extent of green roof coverage, drainage patterns, appropriate plant species and irrigation requirements
5. Conduct a water balance analysis to establish whether stormwater targets are met.

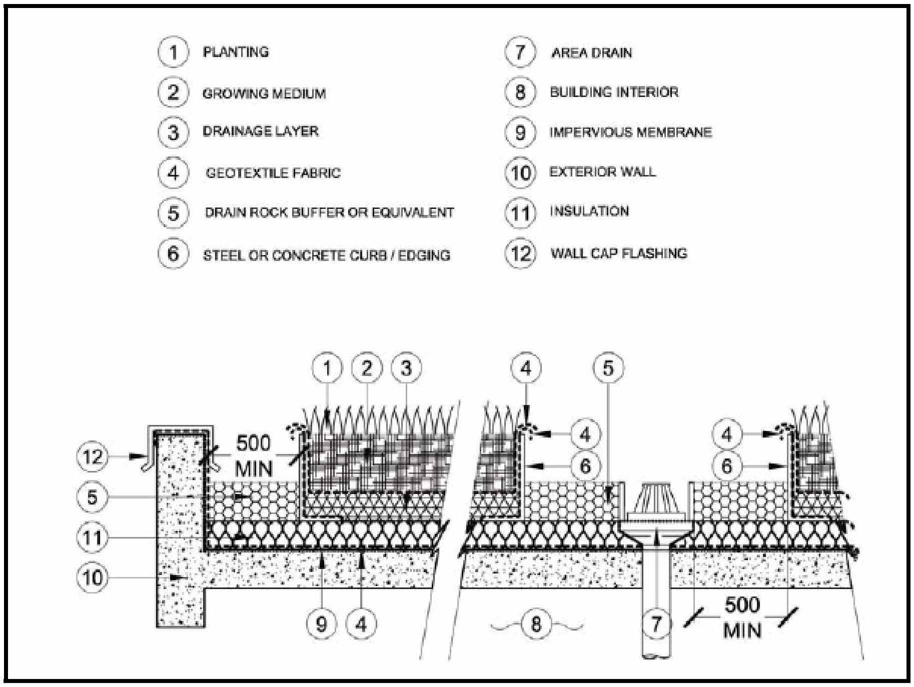
7.4.2. Design examples

There are two possible designs for extensive green roof systems:

1. Multiple layer construction, consisting of either a three-layer system with a separate drainage course, filter layer and growing medium or a two layer system where the growing medium is sized to not require a filter between it and the underlying drainage layer. (See Figure 7-8)

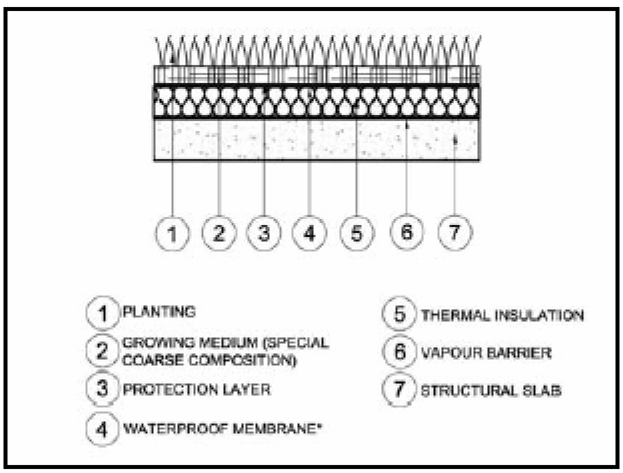
2. Single layer construction consisting of a growing medium, which includes the filter and drainage functions. (See Figure 7-9)

Figure 7-8 Extensive Green Roof with Three-Layer Construction on Inverted Roof



Source: GVRD, 2004

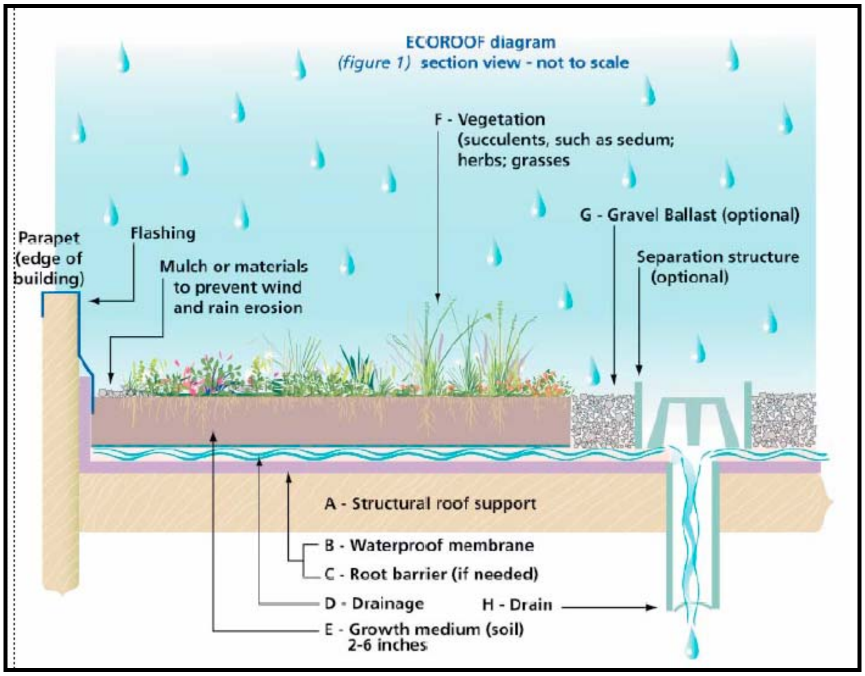
Figure 7-9 Extensive Green Roof with Single-Layer Construction on Inverted Roof



Source: GVRD, 2004

For comparison purposes, Figure 7-10 illustrates an intensive green roof system.

Figure 7-10 Intensive Green Roof on Inverted Roof



Source: City of Portland, 2004

7.4.2.1 Standards

The following active standards are available from the ASTM (Green Roof Design 101):

- E2396-05 *Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green-Roof Systems*
- E2397-05 *Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems*
- E2398-05 *Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems*
- E2399-05 *Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems*
- *Standard Guidelines for Selection, Installation, and Maintenance of Plants for Green Roofs* (see reference WK4235)

Standards currently under development include:

- *Standard Guide for Use of Expanded Shale, Clay and Slate (ESCS) as a Mineral Component in Growing Media for Green Roof* (see item reference WK7319)
- *Practice for Assessment of Green Roofs* (see item reference WK575)

Green roofs, as extensions of the roofing system, should also comply with the Alberta Building Code.

7.4.2.2 Access and safety measures

The following access and safety considerations should be included in a green roof design:

1. Provide construction and maintenance access.
2. If the green roof allows for public access, provide safe lighting and full perimeter protection around the roof.
3. Provide a hose bib for watering during establishment if no automatic irrigation system is planned.
4. Provide plant-free zones to facilitate access for inspection and maintenance and to prevent plants from spreading moisture onto exposed structural components.
5. Locate firebreaks of non-combustible material, such as gravel or concrete pavers.

7.4.2.3 Structural design issues

A vegetated rooftop design must take into account both the dead load, –i.e. the total weight of roof materials (including soil and plants) along with snow, and live load, which, includes people who will be performing maintenance activities on the roof.

The design of green roofs can circumvent some structural limitations by placing soil and plants over load-bearing members.

In calculating structural loads, always design for the saturated weight of each material. Calculations must include plant weight at maturity.

Flat roofs and, depending on the design, some sloped roofs require a drainage layer to move water away from the root zone and the waterproof membrane. Slopes between 5 and 20 degrees are most suitable, and can provide natural drainage by gravity. Roofs with slopes greater than 20 degrees require a lath grid to hold the soil substrate and drainage aggregate in place.

Follow local standards with respect to wind resistance of rooftop elements. Since uplift pressures tend to be higher at roof corners and perimeters, these areas may be designed as “vegetation-free zones.”

7.4.2.4 Waterproofing and insulation

Waterproof membrane comes in a variety of materials, including modified asphalts (bitumens), synthetic rubber (EPDM), hypolan (CPSE), and reinforced PVC. Thermoplastic membranes, such as PVC (polyvinyl chloride) or TPO (thermal polyolefin) are typically installed over a vapour barrier and insulating layer. Elastomeric membranes like the synthetic rubber EPDM (ethylene-propylene rubber materials) have high tensile strength and are well suited to large roof surfaces with fewer roof penetrations. Modified bitumen sheets are usually applied in two layers and are commonly available.

Factors in choosing a waterproofing system include: resistance to root penetration; resistance to acids released by some plant roots; roof conditions; budget; and, ease of repair. They have a lifespan of 30-50 years.

The membrane can be applied as a liquid monolithic layer or in sheets, which are seamed or lapped. Liquid-applied membranes are generally applied in two liquid layers with reinforcement in between.

Monolithic membrane, a rubberized asphalt product applied as a hot liquid, is generally thought to provide superior waterproofing and easier maintenance.

Asphalt-based roofing material should be covered with high-density polyethylene membrane to prevent roots and other organisms from utilizing the organic asphalt as an energy source.

A protective layer should be installed to protect the waterproof membrane/root barrier from physical damage caused by construction activities, sharp drainage materials and subsequent stresses placed on the roof.

Although green roof membranes will last longer than others, leaks can still occur at flashings or through faulty workmanship. An electronic leak detection system can pinpoint the exact location of water leaks, thus allowing easy repair.

7.4.2.5 Drainage

As with a conventional roof, a green roof must safely drain runoff from the roof to an approved stormwater destination. A drainage system must be installed across a green roof to ensure that excess rainwater is drawn away from vegetation, to prevent any drowning or rotting of plants. The drainage layer needs to be protected from clogging by fine particles in the growing medium with a non-woven geotextile filter. The filter layer needs to be lightweight, inert, and water-resistant. Roofs with less than 2% slope require special drainage construction to prevent higher rates of runoff.

The drainage layer may be a thin layer of gravel or drain rock, but is often a lightweight composite such as lava, expanded clay pellets, expanded slate or crushed brick. Lightweight and long-lasting rigid prefabricated drainage mats that allow rapid lateral drainage may be used. The drainage layer may also store water and make it available to the vegetation during dry periods. The top of the drainage layer should always be separated from the growing medium by a non-woven filter fabric. The permeability of the drainage layer must not be affected by freezing.

To compensate for dry periods, the design can include an automated or a drip irrigation system. Alternatively, plants can be watered manually.

7.4.2.6 Growing medium

Soils for green roofs are lighter weight than typical soil mixes; they generally consist of 75-90 percent mineral and 10-25 percent organic material. They must be carefully formulated to meet oxygen, nutrient, moisture and pH needs of plants. Growing medium is a manufactured soil mix; native or potting soils should not be used for green roofs.

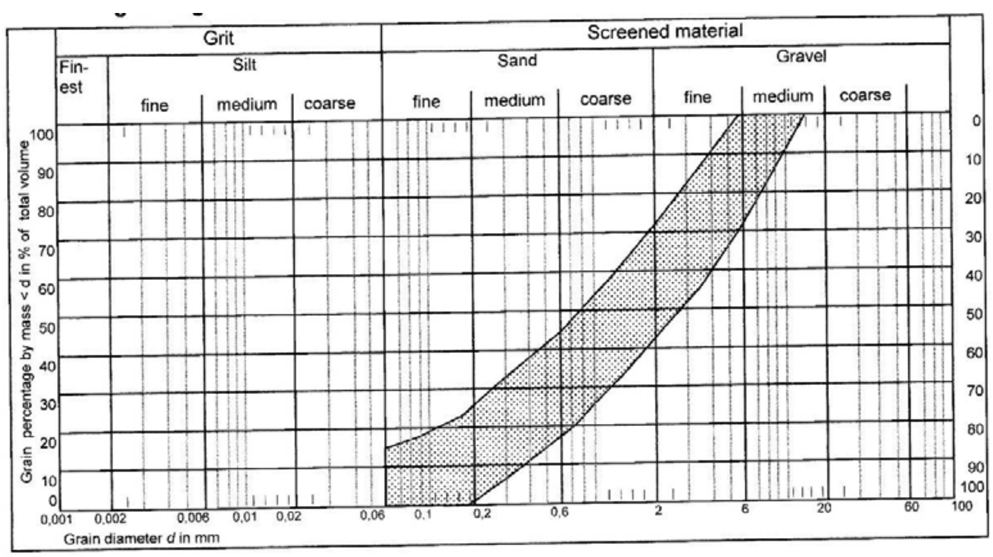
The composition of the growing medium is determined by weight loads, climate, drainage needs and plant requirements. The growing medium should have a high void ratio, sufficiently porosity to provide internal aeration, ability to prevent, shrinkage and compaction, and resistance to rot and heat.

Table 7-2 Key Values for Extensive/Intensive Green Roof with Multiple Layer Construction

• Criteria	• Extensive Roof	• Intensive Roof
Combined clay and silt content (d < 0.063 mm)	Should not exceed 15% by mass	Should not exceed 20% by mass

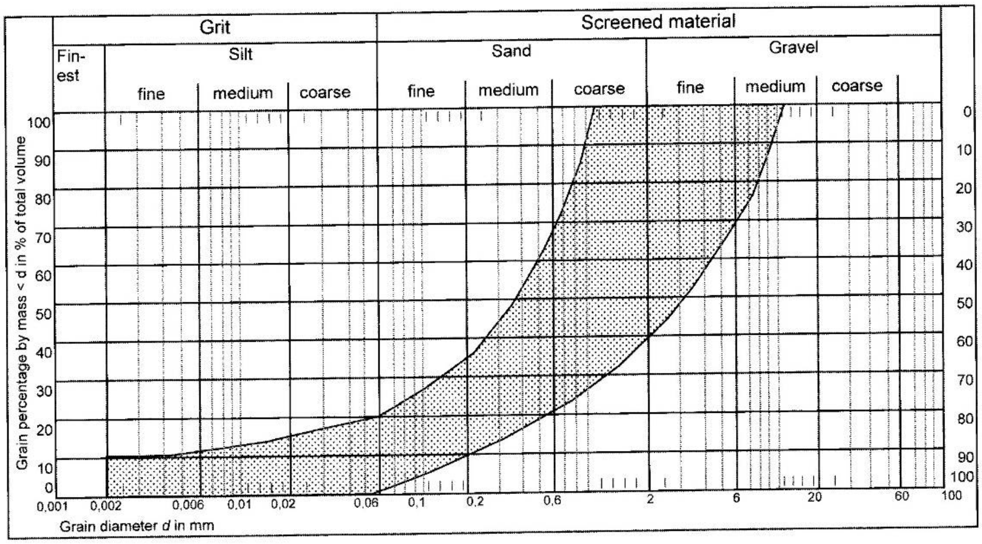
Grain size distribution:	(See Figure 7-11)	(See Figure 7-12)
Content of organic substance	8% mass (with apparent density = 0.8 g/cm³ in dry condition), 6% mass (with apparent density < 0.8 g/cm³ in dry condition)	12% mass (with apparent density = 0.8 g/cm³ in dry condition), 6% mass (with apparent density < 0.8 g/cm³ in dry condition)
Permeability	≥ 0.6 mm/min	≥ 0.3 mm/min
Maximum water capacity	≥ 35% volume; the maximum water capacity should not exceed 65% by volume in order to avoid waterlogging	≥ 45% volume. The maximum water capacity should not exceed 65% by volume in order to avoid waterlogging
pH value	6.5 - 8.0	5.5 - 8.0
Nutrient content	N ≤ 80 mg/L, P_2O_5 ≤ 200 mg/L; K_2O ≤ 700 mg/L and Mg ≤ 160 mg/L	N ≤ 80 mg/L, P_2O_5 ≤ 200 mg/L; K_2O ≤ 700 mg/L and Mg ≤ 160 mg/L
Salt content (water extract)	= 3.5 g/L	= 2.5 g/L

Figure 7-11 Granulometric distribution range for vegetation substrates at multiple-course extensive green roof installations



Source: FLL, 2002.

Figure 7-12 Granulometric distribution range for vegetation substrates at intensive green roof installations

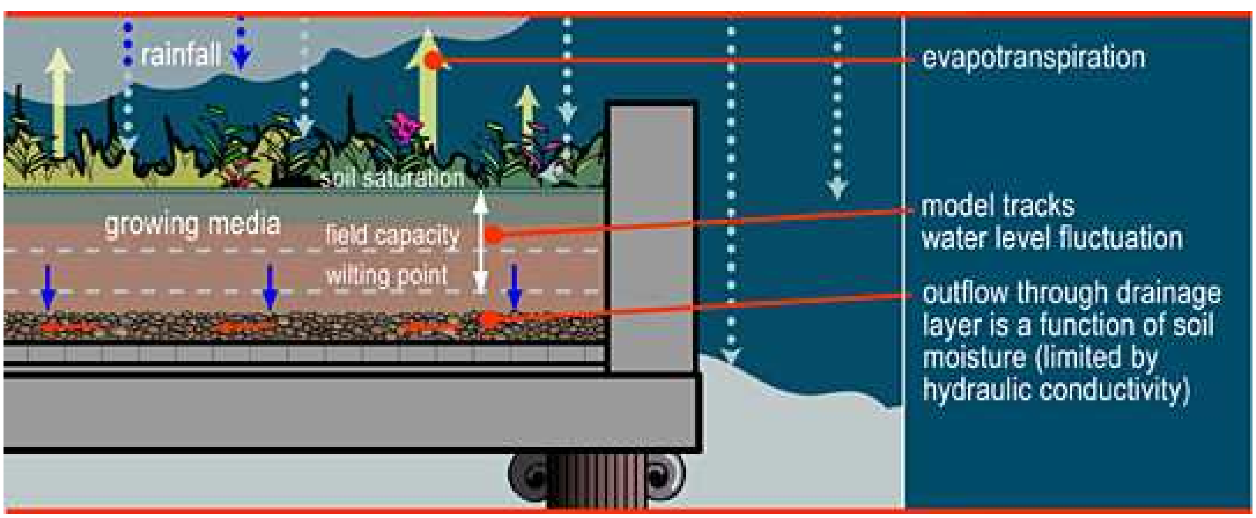


Source: FLL, 2002.

7.4.2.7 Water balance analysis

The benefits of green roof systems should be assessed using a water balance analysis. Figure 7-13 presents a schematic of the water balance approach.

Figure 7-13 Schematic for Water Balance Computation



Source: www.waterbalance.ca British Columbia Inter Governmental Partnership

The water balance analysis computes the change in soil moisture over time due to precipitation, inflow, overflow, evapotranspiration and drainage layer fluxes, representing the storage within the growing medium as a reservoir, as per Equation 7-1.

$$\frac{\Delta S}{\Delta t} = P + In + Ir - AET - Dr - Ov$$ **Equation 7-1**

where $\frac{\Delta S}{\Delta t}$	=	change in soil moisture (mm)
P	=	precipitation (mm)
In	=	inflow volume (mm)
Ir	=	irrigation volume (mm)
AET	=	actual evapotranspiration (mm)
Dr	=	drainage layer flux (mm)
Ov	=	overflow volume (mm)

In Equation 7-1, the inflow, irrigation and overflow volumes have all been expressed on a unit area basis. The vertical dimension of the reservoir is defined by the depth of the growing medium d_{max}.

The wilting point is the minimum amount of soil moisture above which plants are able to extract water for evapotranspiration. As such, the minimum effective water level in the reservoir equals the wilting point water content WC_{wp} times the depth of the growing medium d_{max}.

The field capacity is the minimum amount of soil moisture after which pore water starts draining by gravity; thus it cannot be held in the pore space by capillary forces and begins to flow through the porous medium. Infiltration into the underlying drainage layer occurs above this threshold and no infiltration occurs below it. The associated effective water level in the reservoir at field capacity equals the field capacity water content WC_{fc} times the depth of the growing medium d_{max}.

In case of precipitation or inflows from adjacent paved roof section, the soil moisture can increase above the field capacity. The maximum water content in the growing medium corresponds to full saturation, and is a function of the porosity of the growing medium. The associated water level in the reservoir equals porosity n times the depth of the growing medium d_{max}.

The values for the wilting point, field capacity and porosity will be a function of the composition of the growing medium.

After the growing medium is fully saturated, or when the sum of precipitation and inflows from adjacent areas exceed the hydraulic conductivity of the surface soils, water would pond on the surface up to the depth of ponding $d_{ponding}$ at which time overflow would commence. The maximum amount of water in the reservoir therefore corresponds to n x $d_{max} + d_{ponding}$.

After a rain or irrigation event, when the growing medium is at or near field capacity, plants transpire at a rate that is close to the potential evapotranspiration (PET), which is the maximum amount of evapotranspiration if an infinite supply of soil moisture is available. The potential evapotranspiration is a function of the type of vegetation and soil type. The actual evapotranspiration, however, decreases as the available water in the growing medium decreases with time. (See Figure 7-14) Typically, the actual evapotranspiration is expressed as a function of the potential evapotranspiration as per Equation 7-2.

$$AET = PET \ x \ f\left\{\frac{AW}{AWC}\right\}$$ **Equation 7-2**

where AET = actual evapotranspiration (mm)

PET = potential evapotranspiration (mm)

AW = available water content (mm) = (water content – WC_{wp}) x d_{max}

AWC = available water capacity (mm) = (WC_{fc} – WC_{wp}) x d_{max}

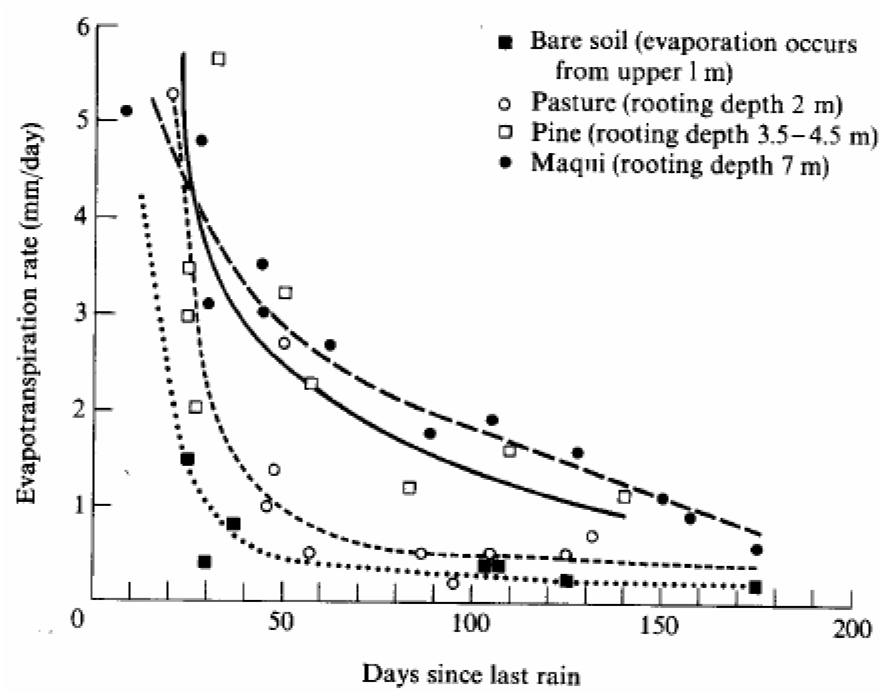
The function depends on many factors, the most important of which are the soil and vegetation types. In irrigation engineering, the factor AET/PET is also called the crop coefficient.

As discussed above, water starts to infiltrate into the underlying drainage layer when the soil moisture exceeds field capacity. The actual infiltration rate is a function of the volume of water in the growing medium matrix that exceeds the field capacity threshold. The Water Balance Model suggests a first-order exponential declining function for this relationship. However, the infiltration rate can never exceed the upper limit defined by either the drainage layer or the surface hydraulic conductivity, whichever is less.

The selection of the growing medium properties, values for saturated hydraulic conductivity, maximum water content, field capacity, wilting point, should be based on site-specific conditions and the composition of the growing medium.

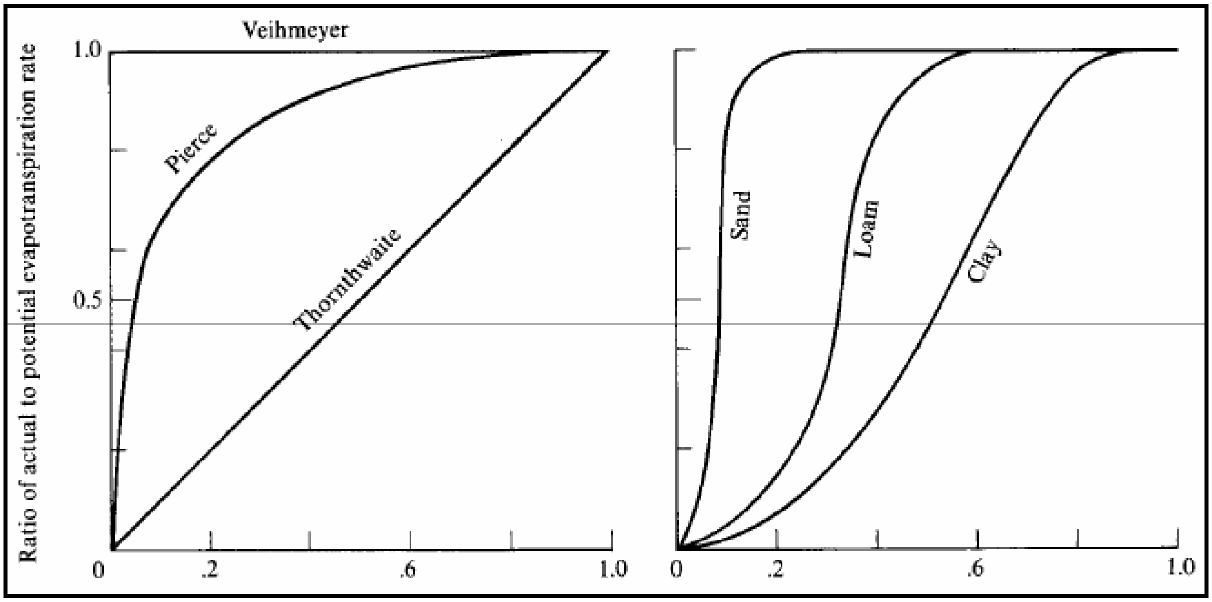
Irrigation of green roof systems should be minimized in order to maximize the storage capacity of the growing medium for storm events.

Figure 7-14 Decrease in Evapotranspiration following last rain



Source: Hayashi Lecture Notes, adapted from Dunne and Leopold (1978)

Figure 7-15 Ratio of Actual to Potential Evapotranspiration



Source: Hayashi Lecture Notes, adapted from Dunne and Leopold (1978)

7.4.3. Limitations

As there are only five companies that supply products and services specifically related to green roof installations in North America, specialized green roof products are currently difficult to obtain. There are also no Canadian technical standards for green roofs, which means that there are no standards in building codes, while the warranties that are offered by the suppliers are reported to vary widely.

Green roofs must be designed with an awareness of the loading of the roof on the underlying structure. However, use of lightweight growing media has created solutions where saturated growing media can be installed without structural upgrading beyond the standard requirements, especially in concrete buildings or new construction. Given Calgary's harsh climate, irrigation may be required to preserve vegetation and minimize the chance of erosion of the growing medium when it has dried out.

Green roof technology requires constant maintenance for the first two years. Technical difficulties cannot be completely overcome, but if the green roof is installed properly, maintained correctly and monitored well, problems can be avoided (CCPP, 2003).

It is anticipated that the stormwater management benefits for high-rise buildings are limited because of the wind effects around these buildings and the fact that the majority of the precipitation is directed at the walls of the building and not the roof. As such, stormwater benefits appear to be more pronounced for typical one to three-storey buildings that are used in commercial and industrial applications.

7.4.4. Vegetation

The criteria for choosing suitable vegetation for rooftop landscapes include the amount of sunlight the roof receives, shade conditions, precipitation amounts and patterns, temperature variation, wind, air pollution and building height.

Extensive roofs typically comprise a variety of mosses, sedums, sempervivums, alliums, irises, other bulbs and herbs, grasses and wildflowers. All have shallow root systems, grow no higher than a foot tall and tolerate shallow soils. Deeply shaded areas are not suitable for extensive roof planting species.

Intensive roofs can support more weight with larger plants. The list of plants suitable for an intensive roof is virtually limitless. Vegetation should be adapted or native to the installation area. For specific applications, a plant resource guide for Alberta should be referenced.

In the first two years after the installation of a green roof, shading devices, irrigation and fertilization may be required while the plants adapt to the extreme conditions. Heartier plants such as grasses and sedums require less maintenance. More elaborate designs can accommodate infrastructure such as irrigation, increased insulation and venting from interior heat sources to offset microclimate stressors.

Green roof vegetation should:

- Require little or no irrigation after establishment (drought-tolerant)
- Feature fibrous root systems
- Follow a growth pattern that allows the plant to thoroughly cover the soil; at least 90% of the overall surface should be covered
- Require no fertilizers, pesticides, or herbicides (self-sustaining)
- Withstand heat, cold, and high winds
- Need little or no mowing or trimming (low maintenance)
- Be perennial or self-sowing, low spore-producing and fire-resistant

7.5 *Construction*

The long-term success of green roof systems is a function of both the design and the construction techniques employed. Poor construction practices will cause the best-designed facility to fail prematurely, usually from leakage or dieback of vegetation. To counter this problem, proper training of crews and adequate and proper inspection are paramount. Installers should have experience with green roof systems. It may be preferable to have one company handle the entire project from roofing to planting to avoid scheduling conflicts and damage claims. If this is not possible, the responsibilities of the roofing contractor and the green roof (landscaping) contractor should be clearly delineated.

The following recommendations are made with respect to the construction of green roof systems:

1. Correct and meticulous application of the waterproof membrane is essential to the viability of the rooftop. Special care must be taken to waterproof areas around flashings, walls and roof perimeter.
2. After the installation, the waterproof membrane should be tested by flooding and thoroughly inspected.
3. The installation of an electronic leak detection system between or underneath the waterproof membrane should be considered.
4. Temporary ballasting of individual components and erosion control may be necessary to avoid wind uplift during installation.

5. Four methods (or combinations of them) can be used to install the vegetation:
   a. Vegetation mats: Vegetation mats are sod-like, pre-germinated mats that achieve immediate full plant coverage. They provide immediate erosion control, do not need mulch, and minimize weed intrusion. They also need minimal maintenance during the establishment period and little ongoing watering and weeding.
   b. Plugs/potted plants: Individual plugs or potted plants may provide more design flexibility than mats. However, they take longer to achieve full coverage, are more prone to erosion, need more watering during establishment, require mulching and more weeding.
   c. Sprigs: Sprigs are hand-broadcast. They require more weeding, erosion control, and watering than mats. Cuttings spread over the substrate are slower to establish and will likely have a high mortality rate; however, this is a good method for increasing plant coverage on a roof that is in the process of establishing a plant community.
   d. Seeding: Seeds can be either hand-broadcast or hydroseeded. Like sprigs, they require more weeding, erosion control, and watering than mats.
6. Lightweight growing medium can be subject to wind erosion when dry; it should therefore be damp when applied and covered until the plants are established. If planting is delayed through a dry weather season, provide a biodegradable mesh wind erosion control blanket over the growing medium.
7. Compaction is estimated at 20%.

Figure 7-16 shows a series of pictures highlighting the construction process of the green roof system at the Alastair Ross Centre in Calgary. Options for the placement of the growing medium are shown in Figure 7-17.

Figure 7-16 Construction of Green Roof System at Alastair Ross Centre

(a) Installation of drainage board

(c) Green roof perimeter underneath

(d) Walkway elevated to allow drainage

(e) Installation of root barrier

(f) Installation of Root Barrier

(g) Spreading growing medium

Figure 7-17 Placement Options for Growing Media

Source: Trevor Sziva, Soprema Inc.

7.6 *Performance and impact on surrounding community/environment*

7.6.1. Community and environmental factors

Green roof systems provide a number of community benefits, including adding esthetic value, creating green space for employees and/or community members, improving air quality, and reducing the "urban heat island" effect.

The "greening" of roof surfaces has long been used as a technique for insulating buildings. By trapping an air layer within the plant mass, the building surface is cooled in summer and warmed in winter. Roof vegetation cools the building in the summer and reduces the heat loss in the winter.

Environment Canada found that a typical one-story building with a grass roof and 10 cm (3.9 inches) of growing medium would result in a 25% reduction in summer cooling costs.

With respect to reducing heat loss in the winter, studies show that with 30 cm of growing medium, roof temperatures do not drop below 0ºC even when outside temperatures are -20ºC.

Green roofs can provide sound insulation, with the growing medium blocking lower frequencies of sound, and the plants blocking the higher frequencies. Tests show that 12 cm (5 inches) of growing medium alone can reduce sound by 15 to 40 db.

Green roofs have been proven to protect the roofing membrane against UV radiation, extreme temperature fluctuations and physical damage from recreation or maintenance.

7.6.2. Performance with regard to pollutants of concern

Green surfaces not only retain much of the precipitation that falls on them, they also moderate the temperature of the water and act as natural filters for any water that runs off. Heavy metals and nutrients carried by the rain are retained in the substrate instead of being discharged. Studies show that as much as 95% of cadmium, copper and lead, and 16% of zinc are taken out of rainwater by green roof systems. Lower temperature runoff reduces the “thermal pollution” of receiving streams and promotes healthier aquatic environment.

7.6.3. Performance under cold climate conditions

The presence of a green roof is beneficial for the long-term performance of roof membranes because of the reduced temperature fluctuations and protection from damaging UV radiation.

Vegetation is one aspect of green roofs that is vulnerable to the extreme temperature swings and harsh winds of winter in the Calgary region. Experience in Quebec shows that the depth of the growing medium can have a significant impact on the mortality rate of some species. Long-term issues

7.7 *Long-term issues*

7.7.1. Long-term sustainability

A green roof system has been in place at the Head-Smashed-In Buffalo Jump Interpretative Centre at Fort MacLeod for over two decades, while Alexander Calhoun Library at 14th Street and 33rd Avenue SW is reported to have had a green roof system for over 35 years.

Existing data suggests that green roofs can extend the life expectancy of conventional roofing by a factor of 2 or 3. The increase in life expectancy can be attributed to the green roof’s ability to protect roof surfaces from UV radiation and harsh weather elements that impose material stresses. Typical temperature ranges extend from -40°C to well over +40°C to +60°C, with expansion/contraction of up to 10% of the original size depending on the type of material.

7.7.2. Life-cycle costs

In general, it costs 50 percent more to install a green roof than a conventional roof, however, long-term savings in roof replacements and energy costs should be considered as part of the cost estimate.

The following factors impact the cost of a green roof system:

- Type of roof (intensive or extensive)
- Requirement for structural upgrades of the building

- Size and height of the roof
- Type of materials, vegetation and medium used to build the roof
- Cost of labour
- Ease of roof access
- Maintenance requirements

The implementation of green roof systems in watersheds that require runoff volume reduction such as the Nose Creek and Pine Creek basins will decrease the need, costs and land requirements for other SCPs.

7.7.3. Safety and liability

The main safety and liability issue involving green roofs is the potential for overloading the roof structure, which could lead to catastrophic failure of the roof.

Integration of "fire breaks" at regular intervals across the roof is recommended to reduce the fire hazard associated with dry roof vegetation. , Other options would be the use of "fire retardant plants", such as sedums, which have a high water content, or a sprinkler irrigation system connected to the fire alarm.

The potential for leak damage appears to be similar to traditional roof systems unless plantings include aggressive root systems without appropriate root protection barriers. The probability of damage due to leakage may be significantly reduced with the installation of an appropriate leak detection system. The risk of damage is also minimized by the fact that the growing media protects waterproof membranes from temperature extremes, solar radiation, and user impact.

7.7.4. Failure scenarios

Potential failure scenarios of green roof systems include:

- Insufficient depth or composition of the growing medium so that the runoff volume objectives are not satisfied.
- Eventual abandonment of the green roof system.
- Failure of the waterproof membrane, resulting in water damage to the roof and/or building contents.
- Die-off of vegetation because of inadequate maintenance or unsuitability to the harsh rooftop conditions.
- Inappropriate growing medium, which can result in inadequate drainage, weed problems, or plant loss.