4.9 Dry Swales

4.9.1 Overview

Description

A dry swale can be thought of as an enhanced grass swale that incorporates an engineered soil (*i.e.*, filter media or growing media) bed and optional perforated pipe underdrain or a bioretention cell configured as a linear open channel (Figure 4.9.1). They can also be referred to as infiltration swales or bio-swales. Dry swales are similar to enhanced grass swales in terms of the design of their surface geometry, slope, check dams and pretreatment devices. They are similar to bioretention cells in terms of the design of the filter media bed, gravel storage layer and optional underdrain components. In general, they are open channels designed to convey, treat and attenuate stormwater runoff. Vegetation or aggregate material on the surface of the swale slows the runoff water to allow sedimentation, filtration through the root zone and engineered soil bed, evapotranspiration, and infiltration into the underlying native soil. Dry swales may be planted with grasses or have more elaborate landscaping (Figure 4.9.1).

Figure 4.9.1 Dry swales can be vegetated with turf grass or more elaborate vegetation

Source: SVR Design (left); Seattle Public Utilities (right)

Common Concerns

If properly designed and maintained, dry swales can provide stormwater treatment while accenting the natural landscape and providing improved site aesthetics. Concerns associated with their use should be addressed through design and may include:

- *Risk of Groundwater Contamination*: Most pollutants in urban runoff are well retained by infiltration practices and soils and therefore, have a low to moderate potential for groundwater contamination (Pitt *et al.*, 1999). Chloride and sodium from de-icing salts applied to roads and parking areas during winter are not well attenuated in soil and can easily travel to shallow groundwater. Infiltration of de-icing salt constituents is also known to increase the mobility of certain heavy metals in soil (*e.g.*, lead, copper and cadmium), thereby raising the potential for elevated concentrations in underlying groundwater (Amrhein *et al.*, 1992; Bauske and Goetz, 1993). However, very few studies that have sampled groundwater below infiltration facilities or roadside ditches receiving de-icing salt laden runoff have found concentrations of heavy metals that exceed drinking water standards (*e.g.*, Howard and Beck, 1993; Granato *et al.*, 1995). To minimize risk of groundwater contamination the following management approaches are recommended (Pitt *et al.*, 1999; TRCA, 2009b):

  - stormwater infiltration practices should not receive runoff from high traffic areas where large amounts of de-icing salts are applied (*e.g.*, busy highways), nor from pollution hot spots (*e.g.*, source areas where land uses or activities have the potential to generate highly contaminated runoff such as vehicle fuelling, servicing or demolition areas, outdoor storage or handling areas for hazardous materials and some heavy industry sites);
  - prioritize infiltration of runoff from source areas that are comparatively less contaminated such as roofs, low traffic roads and parking areas; and,
  - apply sedimentation pretreatment practices (*e.g.*, vegetated filter strip, pea gravel diaphragm, sedimentation forebay) before infiltration of road or parking area runoff.

- *Risk of Soil Contamination:* Available evidence from monitoring studies indicates that small distributed stormwater infiltration practices do not contaminate underlying soils, even after more than 10 years of operation (TRCA, 2008).

- *On Private Property*: If dry swales are installed on private lots, property owners or managers will need to be educated on their routine maintenance needs, understand the long-term maintenance plan, and be subject to a legally binding maintenance agreement. An incentive program such as a storm sewer user fee based on the area of impervious cover on a property that is directly connected to a storm sewer (*i.e.*, does not first drain to a pervious area or LID practice) could be used to encourage property owners or managers to maintain existing practices. Alternatively, dry swales could be located in an expanded road right-of-way or “stormwater easement” so that municipal staff can access the facility in the event it fails to function properly.

- *Maintenance*: The major maintenance requirement associated with dry swales is mowing or trimming vegetation. Occasionally, sediment will need to be removed, although this can be minimized by ensuring that upstream areas are stabilized and incorporating pretreatment devices (*e.g.*, vegetated filter strips, sedimentation forebays, gravel diaphragms).

- *Erosion:* Erosion can be prevented by limiting the allowable longitudinal slope and incorporating check dams. Additionally, designers can provide permanent reinforcement matting for swales with high velocity and temporary matting during the vegetation establishment period.

- *Standing Water and Mosquitoes:* Properly designed dry swales will not pond water at the surface for longer than 24 hours following a storm event. However, poor design, installation, or maintenance can lead to nuisance conditions.

Physical Suitability and Constraints
Dry swales can be implemented on a variety of development sites where development density, topography and depth to water table permit their application. Some key constraints for dry swales include:

- *Wellhead Protection:* Facilities receiving road or parking lot runoff should not be located within two (2) year time-of-travel wellhead protection areas.

- *Available Space:* Dry swale footprints are approximately 5 to 15% of their contributing drainage area. When applied to residential areas, the swale segments between driveways should be at least 5 metres in length.

- *Site Topography:* Dry swales should be designed with longitudinal slopes generally ranging from 0.5 to 4%, and no greater than 6% (PDEP, 2006). On slopes steeper than 3%, check dams should be used.

- *Water Table:* Designers should ensure that the bottom of the swale is separated from the seasonally high water table or top of bedrock elevation by at least one (1) metre to prevent groundwater contamination.

- *Soils:* Dry swales can be located over any soil type, but hydrologic soil group A and B soils are best for achieving water balance benefits. Facilities should be located in portions of the site with the highest native soil infiltration rates. Where infiltration rates are less than 15 mm/hr (hydraulic conductivity less than $1x10^{-6}$ cm/s) an underdrain is required. Native soil infiltration rate at the proposed facility location and depth should be confirmed through measurement of hydraulic conductivity under field saturated conditions using the methods described in Appendix C.

- *Drainage Area and Runoff Volume to Site:* Dry swales typically treat drainage areas of less than two hectares. If dry swales are used to treat larger areas, the velocity through the swale becomes too great to treat runoff or prevent erosion. Typical ratios of impervious drainage area to dry swale area range from 5:1 to 15:1.

- *Pollution Hot Spot Runoff:* To protect groundwater from possible contamination, source areas where land uses or human activities have the potential to generate highly contaminated runoff (*e.g.*, vehicle fueling, servicing and demolition areas, outdoor storage and handling areas for hazardous materials and some heavy industry sites) should not be treated dry swales designed for full or partial infiltration. Facilities designed with an impermeable liner (filtration only facilities) can be used to treat runoff from pollution hot spots.

- *Setbacks from Buildings:* Dry swales should be setback four (4) metres from building foundations. When located within 3 metres of building foundations, an impermeable liner and perforated pipe underdrain system should be used.

- *Proximity to Underground Utilities:* Designers should consult local utility design guidance for the horizontal and vertical clearance between storm drains, ditches, and surface water bodies. It is feasible for on-site utilities to cross dry swales; however, this may require the use of special protection (*e.g.*, double-casing) for the subject utility line.

Typical Performance

The ability of various dry swale design variations to help meet stormwater management objectives is summarized in Table 4.9.1.

Table 4.9.1 Ability of dry swales to meet SWM objectives

BMP	Water Balance Benefit	Water Quality Improvement	Stream Channel Erosion Control Benefit
Dry swale with no underdrain or full infiltration	Yes	Yes – size for water quality storage requirement	Partial – based on available storage volume and infiltration rates
Dry swale with underdrain or partial infiltration	Partial – based on available storage volume beneath the underdrain and soil infiltration rate	Yes – size for water quality storage requirement	Partial – based on available storage volume beneath the underdrain and soil infiltration rate
Dry swale with underdrain and impermeable liner or no infiltration	Partial – some volume reduction through evapotranspiration	Yes – size for water quality storage requirement	Partial – some volume reduction through evapotranspiration

Water Balance

Limited data are available to define the typical runoff reduction rate for dry swales. Since they incorporate many of the same design elements, dry swales can be expected to perform similar to bioretention cells (Table 4.9.2).

Water Quality - Pollutant Removal Capacity

While few field studies of the pollutant removal capacity of dry swales are available from cold climate regions like Ontario, it can be assumed that they would perform similar to bioretention facilities (see Section 4.5.1). Bioretention provides effective removal for many pollutants as a result of sedimentation, filtering, plant uptake, soil adsorption, and microbial processes. It is important to note that there is a relationship between the water balance and water quality functions. If a dry swale infiltrates and evaporates 100% of the flow from a site, then there is essentially no pollution leaving the site in surface runoff. Furthermore, treatment of infiltrated runoff will continue to occur as it moves through the native soils.

Table 4.9.2 Volumetric runoff reduction1 achieved by dry swales

LID Practice	Location	Runoff Reduction[1]	Reference
Dry Swale without underdrain	Washington	98%	Horner *et al.* (2003)
	United Kingdom	94%	Jefferies (2004)
Dry Swale with underdrain	Maryland	46 to 54%	Stagge (2006)
Bioretention without underdrain	Connecticut	99%	Dietz and Clausen (2006)
	Pennsylvania	80%	Ermilio (2005)
	Pennsylvania	70%	Emerson and Traver (2004)
Bioretention with underdrain	Ontario	58%	TRCA (2008b)
	North Carolina	40 to 60%	Smith and Hunt (2007)
	North Carolina	33 to 50%	Hunt and Lord (2006)
	Maryland and North Carolina	20 to 50%	Li *et al.* (2009)
Runoff Reduction Estimate[2]		**85% without underdrain; 45% with underdrain**	

Notes:
1. Runoff reduction estimates are based on differences in runoff volume between the practice and a conventional impervious surface over the period of monitoring.
2. This estimate is provided only for the purpose of initial screening of LID practices suitable for achieving stormwater management objectives and targets. Performance of individual facilities will vary depending on site specific contexts and facility design parameters and should be estimated as part of the design process and submitted with other documentation for review by the approval authority.

Performance results from both laboratory and field studies indicate that bioretention systems have the potential to be one of the most effective BMPs for pollutant removal (TRCA, 2009b). Excellent pollutant removal rates have been observed through field studies for total suspended solids (Roseen *et al.*, 2009), polycyclic aromatic hydrocarbons (TRCA, 2008b; Diblasi *et al.*, 2009), and metals (Davis *et al.*, 2003; Hunt *et al.*, 2006; Roseen *et al.*, 2006; Davis, 2007; TRCA, 2008b). Good removal rates for metals have even been observed in bioretention facilities receiving snow melt that contains de-icing salt constituents (Muthanna *et al.*, 2007).

Field investigations of nutrient removal by bioretention facilities have produced more variable results (TRCA, 2009b). Some facilities have been observed to increase total phosphorus in infiltrated water (Dietz and Clausen, 2005; Hunt *et al.*, 2006; TRCA, 2008b). These findings have been attributed to leaching from the filter media soil mixture which contained high phosphorus content. To avoid phosphorus export, the phosphorus content (*i.e.*, Phosphorus Index) of the filter media soil mixture should be examined and kept between 10 to 30 ppm (Hunt and Lord, 2006). While moderate reductions in total nitrogen and ammonia nitrogen have been observed in laboratory studies (Davis *et al.*, 2001) and field studies (Dietz and Clausen, 2005), nitrate nitrogen has consistently observed to be low.

Little data exists on the ability of bioretention to reduce bacteria concentrations, but preliminary results report good removal rates for fecal coliform bacteria (Rusciano and Obropta, 2005; Hunt *et al.*, 2008; TRCA, 2008b).

Several factors that can greatly increase or decrease the pollutant removal capacity of dry swales are provided in Table 4.9.4.

Table 4.9.3 Factors that influence the pollutant removal capacity of dry swales

Factors that Reduce Removal Rates	Factors that Enhance Removal Rates
Longitudinal slope > 3%	Longitudinal slope between 0.5 to 3%
Measured soil infiltration rate is less than 15 mm/hr	Measured soil infiltration rate is 15 mm/hr or greater
Filter media P-Index values $\geq$ 30 ppm[1]	Filter media P-Index values < 30 ppm[1]
Flow velocity within swale > 0.5 m/s during a 4 hour, 25 mm Chicago storm event	Flow velocity within swale is 0.5 m/s or less during a 4 hour, 25 mm Chicago storm event
No pretreatment	Pretreatment with vegetated filter strips, gravel diaphragms and/or sedimentation forebays
Swale side slopes steeper than 3:1 (H:V)	Swale side slopes 3:1 (H:V) or less

Notes:
1. P-index values refers to phosphorus soil test index values in parts per million (ppm). See www.omafra.gov.on.ca for information on soil testing and a list of accredited soil laboratories.

Stream Channel Erosion Control
While most dry swales are not designed to provide channel erosion control storage volume, the high degree of runoff reduction reported in performance monitoring studies suggests that they have the potential to protect downstream channels from erosion. If space is available, they may be designed for extended detention.

4.9.2 Design Template

Applications
The linear nature of dry swales makes them well-suited to treat road runoff as they can be incorporated into road rights-of-way (see Figure 4.9.2). They are also a suitable practice for managing runoff from parking lots, roofs and pervious surfaces, such as yards, parks and landscaped areas. Dry swales can be used for storing and treating snow from the contributing drainage area.

Dry swales require a considerable amount of space, often making them impractical in densely developed urban areas. Where development density, topography and depth to water table permit, dry swales can be used to provide stormwater conveyance in place of conventional curb and gutter and storm drain systems.

Dry swales vary in appearance based on the type of vegetation. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees (Figure 4.9.2).

Figure 4.9.2 Dry swales are well suited to road rights-of-way and parking lots

Source: City of Portland (left); Lake County Illinois (centre); Portland Public Schools (right)

Design Guidance

Geometry and Site Layout

Design guidance regarding the geometry and layout of dry swales is provided below:

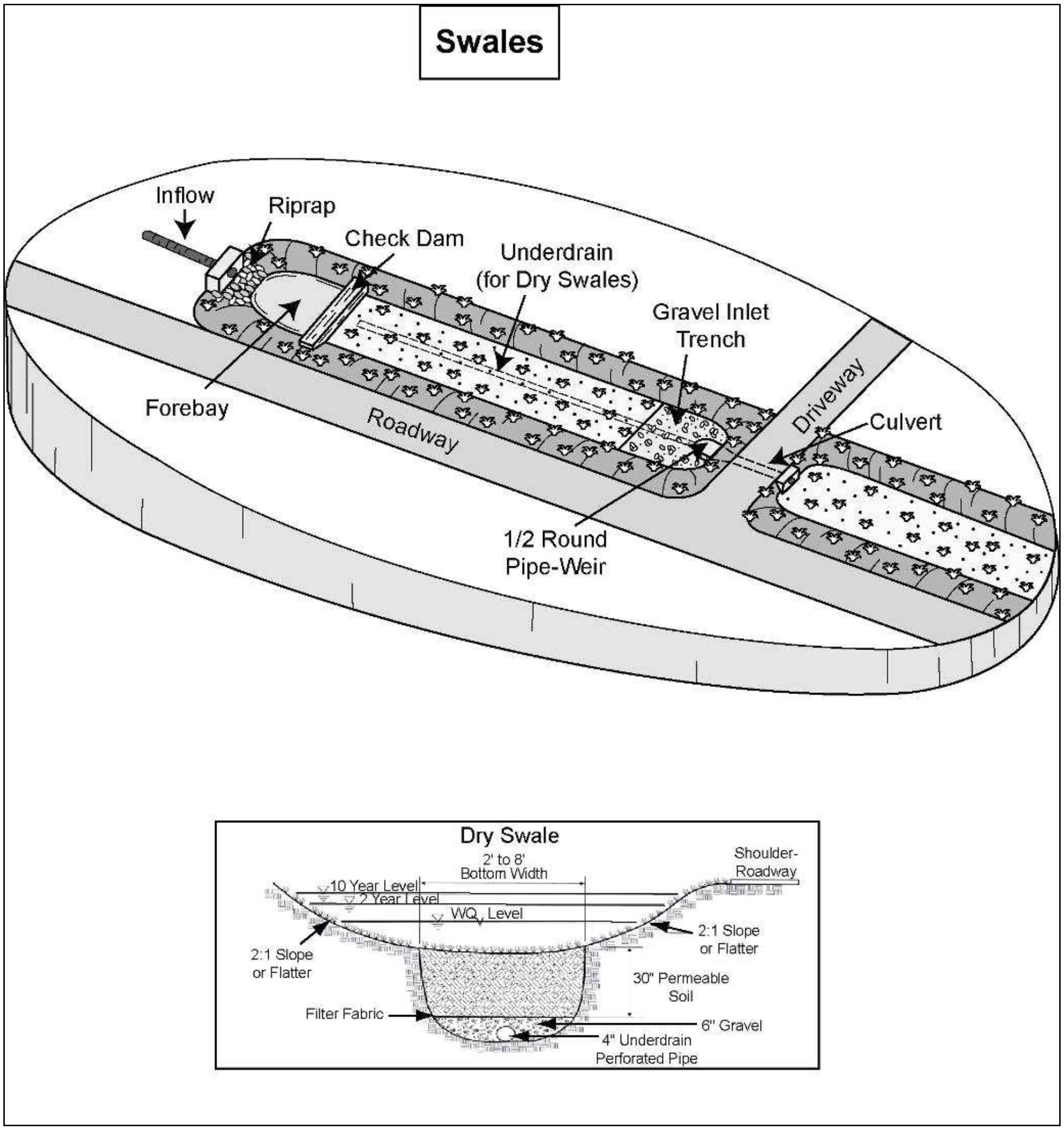
- *Shape:* A parabolic shape is preferable for aesthetic, maintenance and hydraulic reasons. However, design may be simplified with a trapezoidal cross section as long as the engineered soil (filter media) bed boundaries lay in the flat bottom areas. Swale length between culverts should be 5 metres or greater.
- *Bottom Width:* For the trapezoidal cross section, the bottom width should be between 0.75 and 3 metres. When greater widths are desired, bioretention cell designs (Section 4.5) should be used.

- *Side Slopes:* The side slopes of the channel should be no steeper than 3:1 for maintenance considerations (mowing). Flatter slopes are encouraged where adequate space is available to aid in providing pretreatment for sheet flows entering the swale.

- *Longitudinal Slope*: The slope of the swale should be as gradual as possible to permit the temporary ponding of the water quality storage requirement. Dry swales should be designed with longitudinal slopes generally ranging from 0.5 to 4%. On slopes steeper than 3%, check dams should be used. Check dam spacing should be based on the slope and desired ponding volume. They should be spaced far enough apart to allow access for maintenance equipment (*e.g.*, mowers).

Typical Details

Figure 4.9.3 Schematic of a dry swale



Also see Figure 4.10 from the OMOE *Stormwater Management Planning and Design Manual* (OMOE, 2003).

Pretreatment

Pretreatment devices capture and remove coarse sediment particles before they reach the engineered soil (*i.e.*, filter media) bed to prevent premature clogging and prolong effective function of dry swales. A two-cell design that incorporates a sedimentation forebay is recommended as it provides the most-effective pretreatment. Several pretreatment measures are feasible, depending on the method of conveyance and the drainage area:

- *Sedimentation forebay (two-cell design):* Forebay ponding volume should account for 25% of the water quality storage requirement and be designed with a 2:1 length to width ratio. This pre-treatment device is the most effective and has the easiest sediment-removal mechanism.

- *Grass filter strip (sheet flow):* These grass strips should ideally be a minimum of three metres in width. However, space constraints at some sites prohibit this width. If smaller strips are used, more frequent maintenance of the filter bed can be anticipated.

- *Gravel diaphragm (sheet flow):* A gravel diaphragm at the end of pavement should run perpendicular to the flow path to promote settling. The pea gravel diaphragm (a small trench running along the top of the dry swale) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow into the dry swale. If the contributing drainage area is steep, then larger stone should be used in the diaphragm._ A 50 to 150 mm drop from a hard-edged surface into a gravel or stone diaphragm can be used to dissipate energy and promote settling.

- *Rip rap and/or dense vegetation (channel flow):* These energy dissipation techniques are acceptable as pre-treatment on small swales with a drainage area of less than 100 square metres.

Conveyance and Overflow

Dry swales should be designed for a maximum velocity of 0.5 m/s or less for a 4 hour 25 mm Chicago storm event. The swale should also convey the locally required design storm (usually the 10 year storm) at non-erosive velocities with freeboard provided above the required design storm water level.

Monitoring Wells

A capped vertical standpipe consisting of an anchored 100 to 150 millimetre diameter perforated pipe with a lockable cap installed to the bottom of the facility at the furthest downgradient end is recommended for monitoring the length of time required to fully drain the facility between storms.

Gravel Storage Layer

- *Depth:* Should be a minimum of 300 mm deep and sized to provide the required storage volume. Granular material should be 50 mm diameter clear stone.

- *Pea gravel choking layer:* A 100 mm deep layer of pea gravel (3 to 10 mm diameter clear stone) should be placed on top of the coarse gravel storage layer as a choking layer separating it from the overlying filter media bed.

Filter Media

- *Composition*: The recommended bioretention filter media soil mixture is:

Component	Percent by Weight
Sand (2.0 to 0.050 mm dia.)	85 to 88 %
Fines (< 0.050 mm dia.)	8 to 12 %
Organic matter	3 to 5 %

  To ensure a consistent and homogeneous bed, filter media should come pre-mixed from an approved vendor. The filter media soil mixture should have the following properties:

  - The recommended Phosphorus soil test (P- index) value is between 10 to 30 ppm (Hunt and Lord, 2006). Visit the Ontario Ministry of Agriculture, Food, and Rural Affairs website (www.omafra.gov.on.ca) for information on soil testing and a list of accredited soil laboratories.
  - Soils with cationic exchange capacity (CEC) exceeding 10 milliequivalents per 100 grams (meq/100 g) are preferred for pollutant removal (Hunt and Lord, 2006).
  - The mixture should be free of stones, stumps, roots, or other similar objects larger than 50 mm.
  - For optimal plant growth, the recommended pH is between 5.5 to 7.5. Lime can be used to raise the pH, or iron sulphate plus sulphur can be used to lower the pH. The lime and iron sulphate need to be uniformly mixed into the soil (Low Impact Development Center, 2003a).
  - The media should have an infiltration rate of greater than 25 mm/hr.

  One adaptation is to design the media as a sand filter with organic content only at the top. Leaf compost tilled into the top layers will provide organic content for the plants. If grass is the only vegetation, the ratio of compost may be reduced (Hirschman, 2008; Smith and Hunt, 2007).

- *Depth:* The recommended filter bed depth is between 1.0 and 1.25 metres. However, in constrained applications, pollutant removal benefits may be achieved in filter beds as shallow as 500 millimetres. (Davis *et al*., 2009; and Hunt *et al.,* 2006). If trees are included in the bioretention design, then the filter bed depth must be at least 1.0 metre and have soil volume to accommodate the root structure of mature trees. A minimum of 12 cubic metres of shared root space is recommended for healthy canopy trees. Use perennials, shrubs or grasses instead of trees when landscaping shallower filter beds.

- *Mulch:* A 75 millimetre layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, and pre-treats runoff before it reaches the filter bed. Shredded hardwood bark mulch makes a very good surface cover, as it retains a significant amount of nitrogen and typically will not float away. The mulch layer also plays a key role in the removal of heavy metals, sediment, and nutrients (Davis *et al*., 2001; Davis *et al*., 2003; Davis *et al*., 2006; Dietz and Clausen, 2006; Hunt, 2003; and Hsieh and Davis, 2005). Alternately, temporary or permanent erosion control matting can be used in lieu of the mulch layer. The matting should be coconut fiber or another durable material, and should be installed prior to the landscaping. Matting is recommended where flow velocities would likely wash the mulch away.

Underdrain

- Only needed where native soil infiltration rate is less than 15 mm/hr (hydraulic conductivity of less than $1x10^{-6}$ cm/s).
- Should consist of a perforated pipe embedded in the coarse gravel storage layer at least 100 mm above the bottom of the gravel storage layer.
- HDPE or equivalent material perforated pipes with smooth interior walls should be used. Pipes should be over-sized to accommodate freezing conditions. A minimum 200 mm diameter underdrain is recommended for this reason (MPCA, 2005). Underdrains should be capped on the upstream end(s).
- A strip of geotextile filter fabric placed between the filter media and pea gravel choking layer over the perforated pipe is optional to help prevent fine soil particles from entering the underdrain. Table 4.5.7 provides further detail regarding geotextile specifications.
- A vertical standpipe connected to the underdrain can be used as a cleanout and monitoring well.

Landscaping

Designers should choose grasses, herbaceous plants, or trees that can withstand both wet and dry periods as well as relatively high velocity flows within the swale. Where possible a combination of native trees, shrubs and perennial herbs should be used in addition to grasses. For applications along roads and parking lots, where snow may be plowed or stored, non-woody and salt tolerant species should be chosen. A list of native plant species suitable for dry swale applications and direction on picking the right plants is provided in Appendix B.

Other Details

Check dams or weirs may be used to obtain the necessary water quality storage volume. The check dams should be spaced based on the longitudinal slope and ponding requirements, while considering the maximum ponding depth. Check dams should be composed of wood or stone. Alternatively, driveway culverts can be used for this purpose.

In urban settings, trash accumulation and pedestrian traffic call for special consideration. Consider the following adaptations:

- To protect vegetation and prevent soil compaction, fencing (low, wrought iron fences), low walls, bollards and chains, curbs, and constructed walkways can be incorporated.
- Trash racks can be installed between pretreatment devices and the swale or across curb cuts.

Other Design Resources
Several other manuals that provide useful design guidance for dry swales are:

Center for Watershed Protection (CWP). 2007b. Urban Stormwater Retrofit Practices: Manual 3 in the Urban Subwatershed Restoration Manual Series. Ellicott City, MD.

Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. Center for Watershed Protection. Ellicott City, MD.

Ontario Ministry of the Environment (OMOE). 2003. Stormwater Management Planning and Design Manual. Ontario, Canada.

BMP Sizing
The surface channel component of dry swales should be designed for a maximum flow velocity of 0.5 m/sec. during the 25 mm, 4 hour Chicago storm event over the drainage area.

The sizing methodology for the filter media bed component of dry swales is the same as that for bioretention practices. The depth of a dry swale filter media bed designed for full infiltration (i.e., no underdrain) is dependent on the native soil infiltration rate, porosity (void space ratio) of the filter bed and gravel storage layer media (i.e, aggregate material used in the stone reservoir) and the targeted time period to achieve complete drainage between storm events. Assuming a void space ratio of 0.4 for both the filter bed and gravel storage layer media, the maximum allowable depth of the filter bed can be calculated using the following equation:

$$d_{b\,max} = i * (t_s - d_p / i) / V_r$$

Where:

$d_{b\,max}$ = Maximum filter media bed depth (mm)
i = Infiltration rate for native soils (mm/hr)
V_r = Void space ratio for filter bed and gravel layer (assume 0.4)
t_s = Time to drain (design for 48 hour time to drain is recommended)
d_p = Maximum surface ponding depth (mm)

For designs that include an underdrain, the filter media bed should be 1 to 1.25 metres in depth. The following equation can be used to determine the maximum depth of the stone reservoir below the invert of the underdrain pipe:

$d_{r\,max} = i * t_s / V_r$

Where:

$d_{r\,max}$ = Maximum depth of stone reservoir below the underdrain pipe

The value for native soil infiltration rate (i) used in the above equations should be the design infiltration rate that incorporates a safety correction factor based on the ratio of the mean value at the proposed bottom elevation of the practice to the mean value in the least permeable soil horizon within 1.5 metres of the proposed bottom elevation (see Appendix C, Table C2). For designs with no underdrain that are located on less permeable soils, a minimum filter bed depth of 0.5 metres is recommended to ensure water quality benefits will be achieved. For designs with filter bed depths less than 1 metre, a maximum surface ponding depth of 85 to 100 mm is recommended.

Once the depth of the filter media bed is determined the water quality volume, computed using the methods in the relevant CVC and TRCA stormwater management criteria documents (CVC, 2010; TRCA, 2010), can be used to determine the footprint needed using the following equation:

$A_f = WQV / (d_b * V_r)$

Where:

A_f = Footprint surface area (m^2)
WQV = Water quality volume (m^3)
d_b = Filter media bed depth (m)
V_r = Void space ratio for filter bed and gravel layer (assume 0.4)

The ratio of impervious drainage area to footprint surface area of the practice should be between 5:1 and 15:1 to limit the rate of accumulation of fine sediments and thereby prevent clogging.

Design Specifications

Recommended design specifications for dry swales are provided in Table 4.9.4.

Table 4.9.4 Design specifications for dry swales

Component	Specification	Quantity
Filter Media Composition	Filter Soil Mixtures to contain: ▪ 85 to 88% sand ▪ 8 to 12% soil fines ▪ 3 to 5% organic matter in form of leaf compost Other Criteria: ▪ Phosphorus soil test (P-Index) value 10 to 30 ppm ▪ Cationic exchange capacity (CEC) greater than 10 meq/100 g ▪ pH between 5.5 to 7.5	Recommended depth is between 1.0 and 1.25 metres. Alternative depths may be appropriate in constrained applications. Volumetric computation based on surface area and depth used in design computations.

Component	Specification	Quantity
Geotextile	Material specifications should conform to Ontario Provincial Standard Specification (OPSS) 1860 for Class II geotextile fabrics. Should be woven monofilament or non-woven needle punched fabrics. Woven slit film and non-woven heat bonded fabrics should not be used as they are prone to clogging. Primary considerations are: - Suitable apparent opening size (AOS) for non-woven fabrics, or percent open area (POA) for woven fabrics, to maintain water flow even with sediment and microbial film build-up; - Texture (*i.e.*, grain size distribution) of the overlying native soil, filter media soil or aggregate material; and - Permeability of the native soil. The following geotextile fabric selection criteria are suggested (adapted from AASHTO, 2002; Smith, 2006; and U.S. Dept. of Defense, 2004): Apparent Opening Size (AOS; max. average roll value) or Percent Open Area (POA) For fine grained soils with more than 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) For fine grained soils with 50 to 85% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.3 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarser grained soils with 5 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 4% (woven fabrics) For coarse grained soils with less than 5% of particles smaller than 0.075 mm (passing a No. 200 sieve): AOS ≤ 0.6 mm (non-woven fabrics) POA ≥ 10% (woven fabrics) Hydraulic Conductivity (k, in cm/sec) k (fabric) > k (soil) Permittivity (in sec^{-1}) Where,	Between the filter media bed and gravel storage layer (stone reservoir).

Component	Specification	Quantity
	Permittivity = k (fabric)/thickness (fabric): For fine grained soils with more than 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.1 sec^{-1} For coarser grained soils with 15 to 50% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.2 sec^{-1}. For coarse grained soil with less than 15% of particles smaller than 0.075 mm (passing a No. 200 sieve), Permittivity should be 0.5 sec^{-1}.	
Gravel	Washed 50 mm diameter clear stone should be used to surround the underdrain and for the gravel storage layer Washed 3 to 10 mm diameter clear stone should be used for pea gravel choking layer.	Volume based on dimensions, assuming a void space ratio of 0.4.
Underdrain	Perforated HDPE or equivalent, minimum 100 mm diameter, 200 mm recommended.	▪ Perforated pipe for length of swale where required. ▪ Non-perforated pipe as needed to connect with storm drain system. ▪ One or more caps. ▪ T's for underdrain configuration.
Check Dams	▪ Check dams should be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric conforming to local design standards. ▪ Wood used for check dams should consist of pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.	Computation of check dam material needed based on surface area and depth used in design computations.
Mulch or Matting	▪ Mulch should be shredded hardwood bark at least 75 mm deep. ▪ Where flow velocities dictate, use erosion and sediment control matting – coconut fiber or equivalent.	▪ A 75 mm layer on the surface of the filter bed. ▪ Matting – based on surface area of filter bed.

Construction Considerations

Sequencing

Ideally, dry swale sites should remain outside the limit of disturbance until construction of the swale begins to prevent soil compaction by heavy equipment. Dry swale locations should never be used as the site of sediment basins during construction, as the concentration of fines will prevent post-construction infiltration. To prevent sediment from clogging the surface of a dry swale, stormwater should be diverted away from the practice until the drainage area is fully stabilized.

The construction sequence for dry swales is similar to that used for bioretention (for further details see section 4.5). Three key steps should be emphasized. First, the contributing drainage area has been fully stabilized prior to dry swale construction. Second, designers should check elevations at driveway culverts and check dams to ensure ponding depths are achieved. Lastly, the swale channel and side slopes should be rapidly stabilized using biodegradable geotextile blankets and seeding before bringing the swale "on line".

Construction Inspection
Common construction pitfalls can be avoided by careful construction supervision that focuses on the following aspects:

Erosion and Sediment Control
- Dry swale locations should be blocked from construction traffic and should not be used for erosion and sediment control.
- Proper erosion and sediment controls should be in place for the drainage area during construction, including sediment fencing around the swale.

Materials
- Gravel for the underdrain should be clean and washed; no fines should be present in the material.
- Underdrain pipe material should be perforated and of the correct size.
- A cap should be placed on the upstream (but not the downstream) end of the underdrain.
- Filter media should be tested to confirm that it meets specifications.
- Mulch composition should be correct.
- Matting, if used, should be correct specification, and durable enough to last at least 2 growing seasons.

Elevations
Elevations of the following items should be checked for accuracy:
- Depth of the gravel and invert of the underdrain
- Inverts for inflow and outflow points
- Filter depth after media is placed
- Ponding depth provided between the surface of the filter bed and the overflow structure
- Mulch depth

Landscaping and Stabilization
- Correct vegetation should be planted.
- Pretreatment area should be stabilized.
- Drainage area should be stabilized prior to directing water to the swale.

The following items should be checked after the first rainfall event, and adjustments should be made as necessary:

- Sheet flow should occur as designed.
- Outfall protection/energy dissipation at concentrated inflow should be stable.
- Ponded water on the surface of the swale should drain within 24 hours of the end of the storm event. The filter media bed should fully drain within 72 hours.
- Sediment accumulation should not be present.

4.9.3 Maintenance and Construction Costs

Inspection and Maintenance

Maintenance of dry swales mostly involves maintenance of the vegetative cover as well as periodic inspection for less frequent maintenance needs. Generally, routine maintenance will be the same for any other landscaped area; weeding, pruning, mowing and litter removal. Inspections annually and after every major storm event (> 25 mm), will determine whether corrective action is necessary to address gradual deterioration or abnormal conditions.

For the first six months following construction, the site should be inspected after each storm event greater than 10 mm, or a minimum of twice. Subsequently, inspections should be conducted in the spring of each year and after rainfall events greater than 25 mm. Two or three growing seasons may be required to establish vegetation to the desired level. During this period, erosion and sediment control practices, such as mats or blankets, should be used to help protect swale structure.

The expected lifespan of infiltration practices is not well understood, however, it can be expected that it will vary depending on pretreatment practice maintenance frequency, and the sediment texture and load coming from the catchment.

Routine Inspection and Maintenance

Routine inspection and maintenance activities, as shown in Table 4.9.5, are necessary for the continued operation of dry swales. Suggested inspection items and corrective actions are provided in Table 4.9.6.

Table 4.9.5 Suggested routine inspection and maintenance activities for dry swales

Activity	Schedule
▪ Inspect for vegetation density (at least 80% coverage), damage by foot or vehicular traffic, channelization, accumulation of debris, trash and sediment, and structural damage to pretreatment devices.	After every major storm event (>25 mm), quarterly for the first two years, and twice annually thereafter.
▪ Regular watering may be required during the first two years while vegetation is becoming established;	As needed for the first two years of operation.
▪ Mow grass to maintain height between 75 to 150 mm; ▪ Remove trash and debris from pretreatment devices, the swale surface and inlet and outlets.	At least twice annually. More frequently if desired for aesthetic reasons.
▪ Remove accumulated sediment from pretreatment devices, inlets and outlets; ▪ Trim trees and shrubs; ▪ Replace dead vegetation, remove invasive growth, dethatch, remove thatching and aerate (PDEP, 2006; ▪ Repair eroded or sparsely vegetated areas; ▪ Remove accumulated sediment on the swale surface when dry and exceeds 25 mm depth (PDEP, 2006); ▪ If gullies are observed along the swale, regrading and revegetating may be required.	Annually or as needed

Table 4.9.6 Suggested inspection items and corrective actions for dry swales

Inspection Item	Corrective Actions
Vegetation health, diversity and density	• Remove dead and diseased plants. • Add reinforcement planting to maintain desired vegetation density. • Prune woody matter. • Check soil pH for specific vegetation. • Add mulch to maintain 75 mm layer.
Sediment build up and clogging at inlets	• Remove sand that may accumulate at the inlets or on the filter bed surface following snow melt. • Examine drainage area for bare soil and stabilize. Apply erosion control such as silt fence until the area is stabilized. • Check that pretreatment is properly functioning. For example, inspect filter strips for erosion or gullies. Reseed as necessary.
Ponding for more than 48 hours	• Check underdrain for clogging and flush out. • Apply core aeration or deep tilling • Mix amendments into the soil • Remove the top 75 mm of filter media soil • Replace filter media soil

Installation and Operation Costs

Very limited information is available regarding dry swale construction costs. Due to similarities in design, dry swale construction costs are likely comparable to those for bioretention. In a study by the Center for Watershed Protection to estimate and compare construction costs for various stormwater BMPs, the median base construction cost for bioretention was estimated to be $62,765 (2006 USD) per impervious hectare treated with estimates ranging from $49,175 to $103,165 (CWP, 2007b). These estimates do not include design and engineering costs, which could range from 5 to

40% of the base construction cost (CWP, 2007b). However, since dry swales serve as a conveyance measure, their cost is offset by the savings in curb and gutter, inlets, and storm sewer pipe as well as the reduction in other stormwater best management practices needed downstream.

4.9.4 References

American Association of State Highway and Transportation Officials (AASHTO). 2002. Geotextile Specification for Highway Applications. AASHTO M 288-00. Washington DC.

Amrhein, C., Strong, J.E., and Mosher, P.A. 1992. Effect of de-icing salts on metal and organic matter mobilization in roadside soils. *Environmental Science and Technology*. Vol. 26, No. 4, pp. 703-709.

Bauske, B., Goetz, D. 1993. Effects of de-icing salts on heavy metal mobility. *Acta Hydrochimica Hydrobiologica*. Vol. 21. pp. 38-42.

Center for Watershed Protection (CWP). 2007a. *National Pollutant Removal Database – Version 3.* September 2007. Ellicott City, MD.

Center for Watershed Protection (CWP). 2007b. Urban Stormwater Retrofit Practices: Manual 3 in the Urban Subwatershed Restoration Manual Series. Ellicott City, MD.

City of Portland. 2004. *Portland Stormwater Management Manual*. Prepared by the Bureau of Environmental Services (BES). Portland, OR.

Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. Center for Watershed Protection. Ellicott City, MD.

Davis, A.P. 2007. Field performance of bioretention: Water Quality. *Environmental Engineering Science*. Vol. 24. No. 8. pp. 1048-1064.

Davis, A. 2008. Field performance of bioretention: hydrology impacts. *Journal of Hydrological Engineering*. Feb 2008. 90-96.

Davis, A., M. Shokouhian, H. Sharma and C. Minami. 2001. Laboratory Study of Biological Retention for Urban Stormwater Management. *Water Environment Research.* 73(5): 5-14.

Davis, A., M. Shokouhian, H. Sharma and C. Minami. 2006. Water Quality Improvement through Bioretention Media: Nitrogen and Phosphorus Removal. *Water Environment Research.* 78(3): 284-293.

Davis, A., M. Shokouhian, H. Sharma, C. Minami and D. Winogradoff. 2003. Water Quality Improvement Through Bioretention: Lead, Copper, and Zinc Removal. *Water Environment Research.* 75(1): 73-82.

Davis, A., W. Hunt, R. Traver, and M. Clar. 2009. Bioretention Technology: Overview of Current Practice and Future Needs. *Journal of Environmental Engineering*. 135(3): 109-117

Diblasi, C.J., Li, H., Davis, A.P. and Ghosh, U. 2009. Removal and Fate of Polycyclic Aromatic Hydrocarbon Pollutants in an Urban Stormwater Bioretention Facility. *Environmental Science and Technology*. Vol. 43. No. 2. Pp. 494-499.

Dietz, M.E. and J.C. Clausen. 2006. Saturation to Improve Pollutant Retention in a Rain Garden. *Environmental Science &Technology.* 40(4): 1335-1340.

Ermilio, J. 2005. *Characterization study of a bio-infiltration stormwater BMP*. M.S. Thesis. Villanova University. Department of Civil and Environmental Engineering. Philadelphia, PA.

Emerson, C., Traver, R. 2004. The Villanova Bio-infiltration Traffic Island: Project Overview. *Proceedings of 2004 World Water and Environmental Resources Congress (EWRI/ASCE).* Salt Lake City, Utah, June 22 – July 1, 2004.

Granato, G.E., Church, P.E., Stone, V.J. 1995. Mobilization of Major and Trace Constituents of Highway Runoff in Groundwater Potentially Caused by De-icing Chemical Migration. *Transportation Research Record*. No. 1483.

Horner, R., H. Lim and S. Burges. 2003. Hydrologic monitoring of the Seattle ultra-urban stormwater management project. University of Washington. Department of Civil and Environmental Engineering. Water Resources Series. Technical Report 170.

Howard, K.W.F. and Beck, P.J. 1993. Hydrogeochemical implications of groundwater contamination by road de-icing chemicals. *Journal of Contaminant Hydrology*. Vol. 12. pp. 245-268.

Hsieh, C.H. and A.P. Davis. 2005. Multiple-Event Study of Bioretention for Treatment of Urban Storm Water Runoff. *Water Science and Technology.* 51(3-4): 177-181.

Hunt, W.F. and W.G. Lord. 2006. Bioretention Performance, Design, Construction, and Maintenance. *North Carolina Cooperative Extension Service Bulletin.* Urban Waterways Series. AG-588-5. North Carolina State University. Raleigh, NC.

Hunt, W.F., A.R. Jarrett, J.T. Smith, and L.J. Sharkey. 2006. Evaluating Bioretention Hydrology and Nutrient Removal at Three Field Sites in North Carolina. *ASCE Journal of Irrigation and Drainage Engineering.* 132(6): 600-608.

Jefferies, C. 2004. Sustainable drainage systems in Scotland: the monitoring programme. Scottish Universities SUDS Monitoring Project. Dundee, Scotland

Li, H., Sharkey, L.J., Hunt, W.F., and Davis, A.P. 2009. Mitigation of Impervious Surface Hydrology Using Bioretention in North Carolina and Maryland. *Journal of Hydrologic Engineering*. Vol. 14. No. 4. pp. 407-415.

Low Impact Development Center. 2003a. Bioretention Specification. http://lowimpactdevelopment.org/epa03/biospec.htm (last accessed Sept. 2009)

Minnesota Pollution Control Agency (MPCA). 2005. *The Minnesota Stormwater Manual*.
Newman, A.P., Coupe and Robinson, K. 2006a. *Pollution Retention and Biodegradation within Permeable Pavements*. In: Proceedings of the 8th International Conference on Concrete Block Paving. November 6-8, 2006. San Francisco. California.

Muthanna, T.M., Viklander, M., Blecken, G., Thorolfsson, S.T. 2007. Snowmelt pollutant removal in bioretention areas. *Water Research*. Vol. 41. pp. 4061-4072.

Ontario Ministry of the Environment (OMOE). 2003. Stormwater Management Planning and Design Manual. Ontario, Canada.

Pennsylvania Department of Environmental Protection (PDEP). 2006. *Pennsylvania Stormwater Best Management Practices Manual*. Prepared by Cahill Associates Inc., Harrisburg, PA.

Pitt, R., Clark, S. and Field, R. 1999. Groundwater contamination potential from stormwater infiltration. *Urban Water*. Vol. 1., pp. 217-236.

Roseen, R.M., Ballestro, T.P., Houle, J.J., Avelleneda, P., Wildey, R. and Briggs, J. 2006. Storm water low-impact development, conventional structural and manufactured treatment strategies for parking lot runoff. Transportation Research Record: *Journal of the Transportation Research Board*, pp. 134-147.

Roseen, R.M., Ballestro, T.P., Houle, J.J., Avelleneda, P., Briggs, J., Fowler, G., and Wildey, R. 2009. Seasonal Performance Variations for Storm-Water Management Systems in Cold Climate Conditions. *Journal of Environmental Engineering*. Vol. 135. No. 3. pp. 128-137.

Smith, D.R. 2006. *Permeable Interlocking Concrete Pavements: Selection, Design, Construction, Maintenance.* Interlocking Concrete Pavement Institute. Washington, D.C.

Smith, R and W. Hunt. 2007. *Pollutant removals in bioretention cells with grass cover*. Proceedings 2nd National Low Impact Development Conference. Wilmington, NC. March 13-15, 2007.

Stagge, J. 2006. Field evaluation of hydrologic and water quality benefits of grass swales for managing highway runoff. Master of Science Thesis, Department of Civil and Environmental Engineering, University of Maryland.

Toronto and Region Conservation (TRCA). 2008b. *Performance Evaluation of Permeable Pavement and a Bioretention Swale, Seneca College, King City, Ontario.* Prepared under the Sustainable Technologies Evaluation Program (STEP). Toronto, Ontario.

Toronto and Region Conservation (TRCA). 2009b. *Review of the Science and Practice of Stormwater Infiltration in Cold Climates*. Prepared under the Sustainable Technologies Evaluation Program (STEP). Toronto, Ontario.

United States Department of Defense. 2004. *Unified Facilities Criteria: Engineering Use of Geotextiles*.