Chapter 1
Factors in BMP Selection

Selection of appropriate methods for control of stormwater runoff requires an understanding of how rainfall, land management and pollutants on the ground interrelate. This chapter offers background information on hydrology (what happens to rainwater after it falls) and information on the most common surface water pollutants and their relationship to stormwater runoff. Cold-climate considerations for watershed management and the relationship between hydrology and watershed management are also discussed. Chapter 2 provides step-by-step guidance on selecting the best BMPs for a particular site.

Hydrology

Hydrology pertains to the movement of water. In the hydrologic cycle, rain or snow from clouds falls to the ground, and as water or snow melt: infiltrates or seeps into the ground, a process called percolation; is taken up by the trees and vegetation and is returned to the atmosphere through transpiration, or evaporation of water from all surfaces; or runs over the ground surface. Water that seeps into the ground travels underground until eventually reaching the groundwater table and possibly surface waters such as a lake, stream, or the ocean. This process, called groundwater recharge, helps maintain water flow in streams and wetlands and preserves water table levels that support drinking water supplies. The amount of recharge that occurs on a site is based on slope, soil type, vegetation and other cover, as well as precipitation and evapotranspiration rates. Sites with natural ground cover, such as forest, meadow, or shrubs, typically have greater recharge rates, less runoff, and higher transpiration than sites with pavement and buildings. The water that runs off the ground surface as overland flow is runoff. Through evaporation from surface waters, water is returned to the atmosphere, new clouds are formed, and the hydrologic cycle begins again (Fig. 1.1).

Introduction to Hydrologic Concepts

Stormwater runoff is a natural part of the hydrologic cycle. The volume and speed of runoff depends on the size of the storm (how much water falls in what amount of time) and the land features at the site. The size of the contributing drainage area, the slope of the land, the types of soils, and the surface conditions (such as woods or pavement) affect water movement. The contributing drainage area establishes the boundary limits for the movement of runoff - from the highest elevations to the lowest point. A watershed is a region that consists of one or more contributing drainage areas to a body of water.

In a natural, undeveloped setting, the ground's surface often is pervious, meaning water can percolate down into the soil. In developed areas,

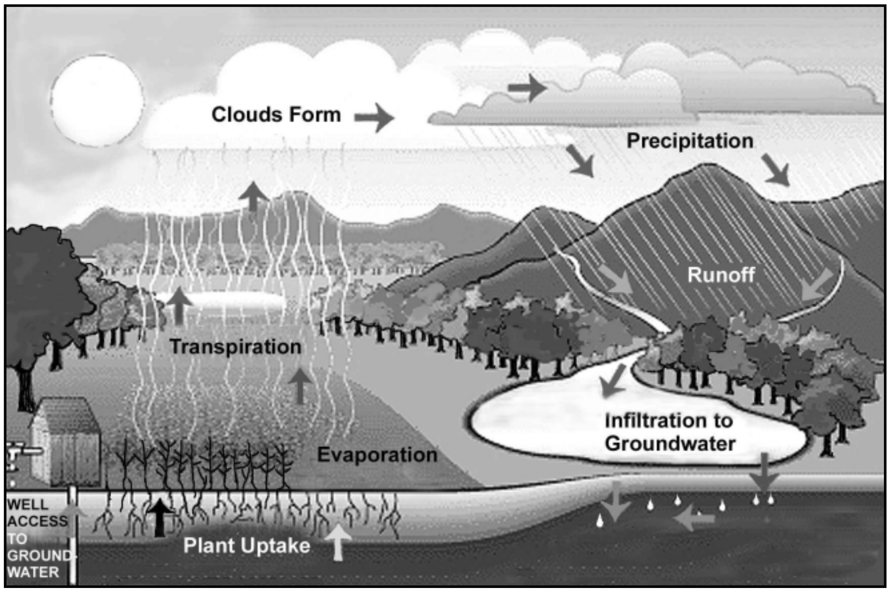


Figure 1.1: The Hydrologic Cycle
Adapted from US EPA, 2000

ground surfaces are often asphalt, concrete, and other materials that are impervious and prevent water from infiltrating into the soil. Water that cannot be absorbed into the ground becomes runoff. Water that falls during and immediately after a storm and flows over impervious surfaces or otherwise cannot be absorbed into the ground is called stormwater runoff.

Development - the construction of homes and other buildings, streets, parking lots, road gutters, storm sewers, paved channels and other man-made features - can alter the hydrology of the landscape and adversely affect water quality. Development changes land use and generally increases the amount of stormwater runoff from a site. Stormwater runoff can cause erosion and flooding. Development can change water flow and the percolation of water into the soil, which affects how much water can infiltrate into the ground to maintain water levels in streams, wetlands, and groundwater aquifers. Stormwater runoff also affects water quality, which can have adverse impacts on aquatic plants and animals. During development, vegetated and forested land with pervious surfaces are replaced by land uses with impervious surfaces. Impervious surfaces transform hydrology and impact aquatic habitats by changing the rate and volume of runoff and altering natural drainage features, including groundwater levels. Changes in water quantity begin with the initial site clearing and grading. Vegetation that intercepted rainfall and reduced runoff is removed. Natural depressions that provided temporary storage of rainfall are filled and graded. Soils are exposed and compacted resulting in

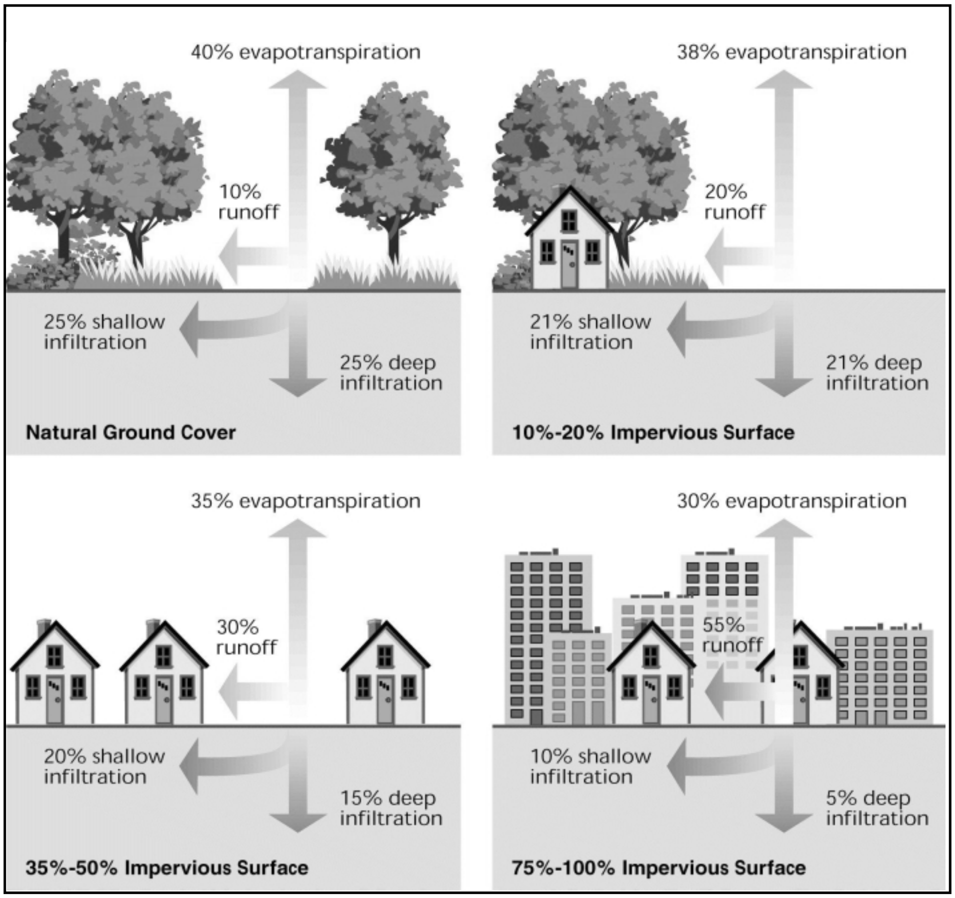
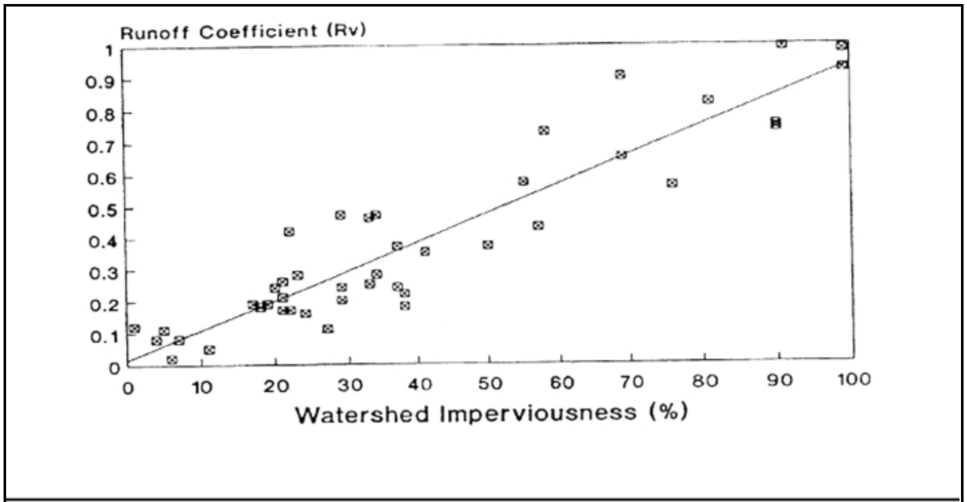


Figure 1.2: Relationship Between Impervious Cover and Surface Runoff

Source: Federal Interagency SRWG, 2000



The runoff coefficient (Rv) expresses the fraction of rainfall that is converted into runoff. The data points reflect over 35 monitoring stations in the U.S.

Figure 1.3: Relationship Between Impervious Cover and the Volumetric Runoff Coefficient

Source: Schueler, 1987 in Maryland, 1998

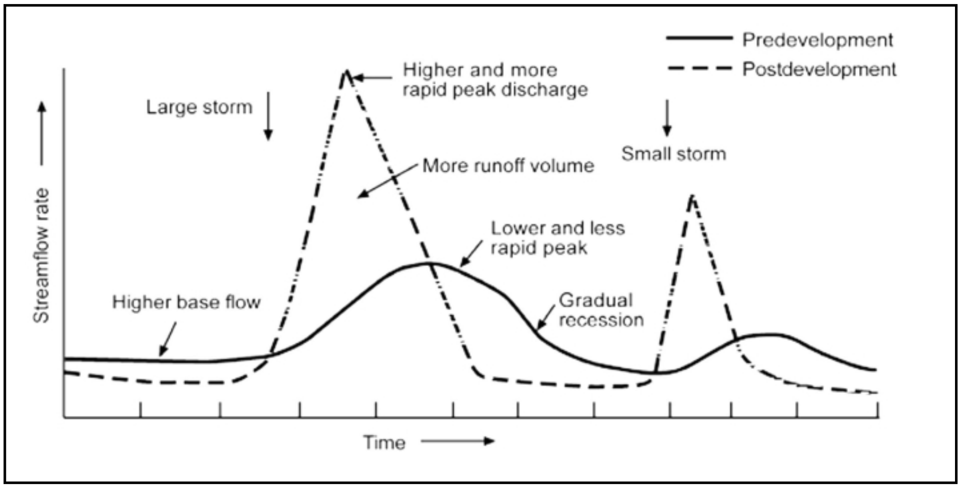


Figure 1.4: Changes in Stream Hydrology as a Result of Urbanization

Source: Schueler, 1992, in MPCA, 2000

increased sedimentation and decreased infiltration. Having lost much of its natural storage capacity, the cleared, graded site allows rainfall to rapidly become runoff. Once the development has been completed, the increase in impervious area (rooftops, roads, driveways, and parking lots) reduces the amount of rainfall that can be infiltrated, which increases the volume of runoff. Figure 1.2 shows the relationship of runoff, infiltration, and evaporation with varying degrees of impervious cover.

Figure 1.3 shows the increase in the volumetric runoff coefficient (Rv), which expresses the fraction of rainfall volume that is converted into stormwater runoff, as a function of site imperviousness. As can be seen, the volume of stormwater runoff increases sharply with impervious cover. For example, a one acre parking lot can produce 16 times more stormwater runoff than a one acre meadow each year (Maryland, 1998, Schueler, 1994). The percentage of imperviousness in a watershed is a useful measure of land development impacts on streams and aquatic systems. Studies show that hydraulic and biological changes to streams occur when 10 to 20 percent of a watershed has impervious surfaces. Moreover, efforts to restore stream flow and water quality to pre-development conditions appear to be less successful when levels of impervious cover exceed 30 percent. (Massachusetts, 1997)

Drainage modifications also increase the velocity of runoff, which decreases the time required to convey it to the outlet of the watershed. Increased volume and increased velocity of runoff results in higher peak discharges and shorter times to reach peak discharge. This causes higher flows, flooding, erosion and adverse effects on habitat in natural streams. Figure 1.4 shows typical pre-development and post-development hydrographs for a watershed that is being developed for urban land uses. The areas below the hydrographs represent the volume of runoff. The increased volume of runoff after development is important because of the increased pollutant loading it can deliver as well as potential flooding and channel-erosion problems. Existing stream characteristics are a reflection of past conditions in the watershed. Under natural conditions and at bank-full capacity, studies have shown that streams can handle a flow approximately equal to the one-and-one-half- to two-year frequency peak discharge within their banks (Rosgen, 1994; Leopold et al., 1964). The frequency of bank-full events increases with urbanization, and might be expected to occur 2 to 8 times per year compared to less than once per year under natural conditions, causing the stream to enlarge its channel to reach a new equilibrium with the increased flows. In addition to regular flood damage, this condition causes previously stable channels to erode and widen. Much of the eroded material becomes bed load and can smother bottom-dwelling organisms. Sediment from streambank erosion eventually settles in streams, rivers and lakes, reducing their capacity and water quality. Base flow in streams is also affected by changes in hydrology from urbanization because a large part of base flow comes from shallow infiltration. Impervious cover reduces base flow, reducing the volume of water available for base flow in streams (MPCA, 2000). The problem may be further compounded by the installation of shallow ground water drainage systems to accommodate road or building construction. Lower recharge rates for groundwater in a watershed are generally reflected in lower stream base flows. Low rates of recharge also extend low flow durations; particularly during prolonged droughts. Typical alterations to the hydrologic regime as a result of development include, but are not limited to, increased runoff volume, imperviousness, flow frequency, duration, and peak runoff rate, reduced infiltration (groundwater recharge), modification of the flow pattern, faster time to peak (due to shorter time of concentration through storm drain systems), and loss of storage.

General Discussion of Design Hydrologic Events

Data for precipitation, including both snow and rain, are used in site planning and stormwater design. Precipitation occurs as a series of events characterized by different rainfall amount, intensity, and duration.

Frequency

Although precipitation events occur randomly, analysis of their distribution over a long period of time indicates that the frequency of occurrence of a given storm event follows a statistical pattern. This statistical analysis allows engineers and urban planners to further characterize storm events based on their frequency of occurrence or return period.

Storm events of specific sizes can be identified to support evaluation of designs. Storms with 2- and 10-year return periods are commonly used for subdivision, industrial, and commercial development design. The 1- and 2-year storm events are usually selected to protect receiving channels from sedimentation and erosion. The 5-

Table 1.1: Hydrologic Design Data

Metropolitan Area Precipitation Frequency Analysis: Comparison of TP40, Huff & Angel,
Metropolitan Council and Skaggs-Low Estimate

	Return Period						
Event Duration	**1 Year**	**2 Years**	**5 Years**	**10 Years**	**25 Years**	**50 Years**	**100 Years**
30 Minutes							
TP40	0.70	1.10	1.45	1.65	1.90	2.10	2.40
Huff & Angel	0.82	0.98	1.20	1.37	1.61	1.81	2.02
Skaggs-Low Estimate		0.99	1.37	1.66	2.07	2.40	2.76
1 Hour							
TP40	1.15	1.40	1.80	2.10	2.40	2.70	3.00
Huff & Angel	1.04	1.25	1.52	1.73	2.04	2.29	2.57
Skaggs-Low Estimate		1.26	1.63	2.11	2.62	3.05	3.51
2 Hours							
TP40	1.40	1.65	2.20	2.50	2.75	3.20	3.50
Huff & Angel	1.29	1.54	1.87	2.14	2.52	2.83	3.17
Metropolitan Council						2.7	2.9
Skaggs-Low Estimate		1.55	2.01	2.60	3.24	3.76	4.33
3 Hours							
TP40	1.50	1.75	2.25	2.65	3.00	3.40	3.70
Huff & Angel	1.42	1.70	2.07	2.36	2.78	3.12	3.49
Skaggs-Low Estimate		1.71	2.22	2.87	3.47	4.15	4.78
6 Hours							
TP40	1.75	2.20	2.60	3.20	3.50	4.00	4.50
Huff & Angel	1.66	1.99	2.42	2.77	3.26	3.66	4.10
Metropolitan Council						3.8	4.1
Skaggs-Low Estimate		2.01	2.78	3.37	4.19	4.87	5.60
12 Hours							
TP40	2.00	2.50	3.20	3.60	4.25	4.60	5.25
Huff & Angel	1.93	2.31	2.81	3.21	3.78	4.25	4.75
Skaggs-Low Estimate		2.33	3.23	3.90	4.86	5.64	6.50
18 Hours							
TP40							
Huff & Angel	2.09	2.49	3.04	3.47	4.09	4.59	5.13
Skaggs-Low Estimate		2.51	3.49	4.22	5.25	6.10	7.02
24 Hours							
TP40	2.35	2.75	3.55	4.20	4.70	5.40	6.10
Huff & Angel	2.22	2.65	3.23	3.69	4.35	4.88	5.46
Metropolitan Council						4.5	4.9
Skaggs-Low Estimate		2.67	3.71	4.49	5.58	6.49	7.47

Sources: Hershfield (1961), Huff & Angel (1992), Vinha et al. (1995) and Skaggs (1998) and 10-year storm events are selected for adequate flow conveyance design and minor flooding considerations. The 100-year event is used to define the limits of floodplains and for consideration of the impacts of major floods (Prince George's County, 1999).

One of the more confusing phrases used in meteorology and hydrology is "the 100-year storm." The phrase implies that an intense rainstorm dubbed as a 100-year event brings rainfall totals heretofore unseen for 100 years, and not to be experienced again for another century. This is a logical, but incorrect conclusion to draw from the phrase. A 100-year storm drops rainfall totals that had a one percent probability of occurring at that location that year. Encountering a 100-year storm on one day does not change the chances of observing the same amount of precipitation the very next day (Minnesota Climatology Working Group). Similarly, a "50-year-storm" has a two percent (1/50) chance of occuring in a given year, a "25-year storm" has a four percent (1/25) chance of occurring and a "ten-year storm," a ten percent (1/10) chance

Duration

The storm duration that is critical for a watershed depends on the watershed size, shape, and slope; the volume of storage available in the system; and the outlet capacity. The critical duration is determined by routing several different duration storms of a given frequency through the stormwater system and determining which duration event produces the greatest peak discharge and/or flood elevation. A small watershed with little available storage will have a critical storm of shorter duration than a large watershed with abundant storage. (Barr, 1991)

Hydrologic Events: Rainfall vs. Snowmelt

In many moderate climates, most of the runoff on an annual basis is generated by rainfall events that are distributed relatively evenly throughout the year. During rainfall events runoff occurs immediately, mostly from impervious surfaces. For snowfall, on the other hand, precipitation is stored during the year in the snowpack, and then released during snowmelt events, usually during the spring. The runoff from snowmelt is often increased because of saturated or frozen soils present during the spring melt, and nearly the entire watershed can contribute to runoff. This shift in the hydrologic cycle is important for BMP design because the critical runoff event may be this snowmelt event rather than the storm events typically used in sizing BMPs both for flooding and water quality.

Flows caused by rain-on-snow events can create significant flooding. These rain events fall on relatively impervious soils because of frozen conditions, and warm rains can cause rapid melting of the snowpack. (Center for Watershed Protection, 1997)

Table of Hydrologic Design Data

Several published studies have analyzed precipitation frequency distributions for various storm durations in the Twin Cities metropolitan area (Hershfield, 1961; Huff and Angel, 1992; Vinha et al., 1995; Skaggs, 1998). Precipitation frequency distribution information provides the basis for design of nearly all water drainage and storage projects throughout Minnesota.

Table 1.1 compares the Twin Cites metropolitan area precipitation estimates for various frequencies and storm durations, based on the latest editions of four published studies. Technical Publication No. 40 (TP40) utilized older hourly precipitation data from National Weather Service stations, which include approximately 20 stations in the Twin City metropolitan area, to develop frequency distributions (Hershfield, 1961). The Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992) utilized a longer period of record of precipitation data, which included just one National Weather Service station (the Minneapolis-St. Paul airport) in the Twin

City metropolitan area, to develop frequency distributions for nine regions in Minnesota (Section 6 data is shown in Table 1.1). The Metropolitan Council (Vinha et al., 1995) assembled rainfall frequency data from 23 National Weather Service stations in the vicinity of the Twin City metropolitan area. Six of these stations collected hourly precipitation data, while the rest collected data on a daily basis. Skaggs (1998) utilized data from the Minnesota high density precipitation network between 1958 and 1997 to develop low and high frequency distribution estimates for the Twin City metropolitan area.

The low estimates were intended to pertain to a 20 km by 20 km area while the high estimates were expected to occur *at some point* in the Twin Cities area. Table 1.1 only contains the low estimates from Skaggs (1998), as the high estimates are generally twice as high as the values shown for the other three studies. Hershfield (1961), Huff and Angel (1992), and Skaggs (1998) used standard inflation and deflation factors to transform daily precipitation values for maximum 24 hour and shorter durations, respectively. Skaggs (1998) utilized extreme value statistical distributions while the other three authors used graphical or empirical curve-fitting techniques to complete the rainfall frequency analyses. Table 1.1 shows that the low estimates from Skaggs (1998) are larger than estimates from the other three studies, with the differences increasing with increasing return period. Generally, the Metropolitan Council estimates (Vinha et al., 1995) are slightly lower than estimates from the other three studies.

Variability in Prescribed Hydrologic Design Events

Urbanization will increase the runoff volume from each storm event, thereby increasing the erosive force of the flows in the channel and can significantly upset the sediment load equilibrium that was established over many years. While the significance of large flood events should not be underestimated, the smaller flows with an approximately nine-month to two-year return period frequency can be very erosive. Often, these smaller flows have not been given sufficient consideration. Several states have developed policies regarding volume controls (Maryland, 1998) and erosive flow controls (Washington State Department of Ecology, 1992). Hydrologic studies need to look at flood, peak flow and total flow conditions, while keeping in mind that small-storm hydrology is a critical component for protection of property, water quality and habitat.

Rationale for Variability

Traditionally, the response of watersheds to urban development has been measured in terms of changes in the flow regime, with management efforts focused on the prevention of property damage from flooding as previously described. Stormwater management efforts historically followed the design storm concept described earlier and focused almost exclusively on runoff collection systems such as curbs and gutters, and pipe conveyance systems which discharged directly to receiving water bodies. Stormwater quantity (peak discharge rate) management was incorporated as BMPs to address concerns about downstream flooding and stream bank erosion. Typically these BMPs, usually ponds or detention basins were located at the lowest point of the site and at the end of the network of inlets and pipes.

Stormwater quantity controls have been set by states or local government agencies to prevent site and downstream flooding and erosion. A typical design criteria requires that "the post development peak discharge for a 2- and 10- year frequency storm event be maintained at a level equal to or less than the respective 2- and 10-year pre-development peak discharge rates, through the use of stormwater management structures that control the timing and rate of runoff." This requirement is based on the design storm concept described earlier under in this section. The selection of the 2-year return frequency storm is based on a belief that the 1.5- to 2-year storm dictates the shape and form of natural channels (Leopold, 1964; Leopold et al. 1968). The selection of the 10-year storm is based on consideration of possible property damage due to local flooding and stream bank erosion.

More recently, stormwater management efforts have recognized that runoff from urban areas was more polluted than runoff from undeveloped areas and was degrading the water quality of the receiving streams and other water bodies. Designers and modelers discovered that the design storm approach used for peak discharge control was not appropriate for water quality control issues, since water quality issues were related to the annual volume of runoff which consists of many small storms. For the most part this problem was addressed by modifying and improving traditional BMPs with extended detention, forebays, wetlands, permanent pools and numerous other design improvements to improve the pollutant removal effectiveness. Also the concept of controlling the "first flush" was introduced. A "first flush" event is defined as the first half inch of runoff from an impervious surface, and is expected to carry with it most of the pollutant load associated with stormwater. In terms of a typical storm hydrograph, the "first flush" represents a small portion of a storm's total discharge, but a larger percentage of the total loading for a particular contaminant.

Examples

Recognizing the need for BMP design that will protect and improve the integrity of unique water resources across Minnesota, watershed management organizations have developed different variations of design criteria with respect to hydrologic events. Some examples of the variability in hydrologic design requirements for these BMPs follow.

Design criteria from "Protecting Water Quality in Urban Areas" (MPCA, 2000), provides detailed recommendations for wet detention storage. Some of the key recommendations include the following:

- Outflow discharge should be no larger than 5.66 cfs per acre of basin area for the 1.25-inch event.
- Maximum treatment area velocity criteria for 2.4-, 2.8-, 4.0-, and 6.0-inch events.
- Discharges to erodible channels or streams should be limited to one-half the 2-year and the same as the 10-year and 100-year pre-urban rates.

The Minnehaha Creek Watershed District rules require water quality treatment and rate control for most development, and volume control for landlocked areas. For rate control, the rules specify that the rate of stormwater runoff must be restricted to the rate that existed before the development for runoff-producing events of critical duration with return frequencies of 1, 10, and 100 years in the subwatershed in which the site is located. Volume control is required when the receiving area of runoff is landlocked and not capable of handling the increased volume of runoff, in which case back-to-back 100-year runoff events will be used to analyze holding capacity and freeboard for the receiving area.

Check with the municipality or WMO in your project area for criteria.

Relationship of Hydrology and Watershed Management

Duration and Frequency Effects on the Runoff Hydrograph

A runoff hydrograph is a continuous plot of instantaneous discharge versus time. It results from a combination of physiographic and climatic conditions in a watershed and represents the integrated effects of climate, hydrologic losses, surface runoff, interflow, and ground water flow (Bedient and Huber, 1988). Important physiographic factors include size and shape of the drainage area, nature of the stream network, slope of the land and the main channel, storage detention in the watershed (Sherman, 1932), imperviousness, and soil types. Climatic factors that influence the hydrograph shape and volume of runoff include rainfall intensity and pattern, areal distribution of rainfall over the basin, duration of the storm event (Bedient and Huber, 1988) and antecedent conditions.

Design Hydrograph and BMP Selection

Flow-Related Issues

Maintaining the preexisting hydrologic conditions is recommended in all cases, but especially for water bodies that are highly or moderately susceptible to stormwater impacts. The relationship between any storm event, no matter how small or how large, and runoff volumes must be thoroughly understood. Best management practices (BMPs) that address the full range of hydrologic conditions should be employed to minimize impacts.

Snow melt runoff events pose a problem in that a large volume of water occurs at the end of the winter when many impediments, such as frozen ground for infiltration basins or frozen permanent pools and clogged outlets for pond systems, may be at their worst. Thus, the effectiveness of these BMPs is often compromised during this critical runoff event. (CWP, 1997)

Pollutants of Concern

Stormwater runoff carries a variety of contaminants that affect water quality. These contaminants come from different residential, commercial, and industrial land uses within a watershed. People's daily activities leave pollutants, such as pesticides, fertilizers, animal wastes, sediments, nutrients and heavy metals, on the surface of the ground. Stormwater runoff carries the pollutants on the ground into nearby water bodies and waterways. As development increases and activities change and intensify, the concentrations and types of contaminants also increase. Although all land uses can affect water quality, in undeveloped areas natural processes can lessen the impacts of contaminants or even remove contaminants from runoff through infiltration and evaporation. Impervious areas reduce the opportunity for natural processes to treat stormwater. Therefore, stormwater runoff must be adequately controlled and treated to reduce pollutants before it is discharged to surface water, groundwater, or wetlands. A summary of the principal pollutants found in runoff, their sources, and related impacts is provided in Table 1.2.

Several mechanisms constitute the genesis of stormwater quality in urban areas, most notably buildup/washoff, erosion of solids and atmospheric deposition. In an impervious urban area, it is usually assumed that a supply of constituents is built up on the land surface during dry weather preceding a storm. Such a buildup may or may not be a function of time and factors such as traffic flow, dry fallout and street sweeping. With the storm the material is then washed off into the drainage system. The physics of the washoff may involve rainfall energy, as in some erosion calculations, or may be a function of bottom shear stress in the flow as in sediment transport theory. Most often, however, the magnitude of pollutant washoff or erosion is proportional to flow raised to some power. Therefore, longer antecedent dry periods, high rainfall intensity and runoff volumes result in higher pollutant loadings. A final source of pollutants is in the precipitation itself. Precipitation can contain surprisingly high concentrations of many constituents (Huber, 1981).

An evaluation of rainfall and pollutant runoff distributions for Milwaukee and Minneapolis-St. Paul show three distinct rainfall categories (Pitt, 1998):

- Common rains less than approximately 0.5 inch have relatively low pollutant discharges (less than 25 percent of the annual pollutant mass discharges from residential areas), but occur very often (on about 95 days a year in Minneapolis-St. Paul). These are key rains when evaluating runoff-associated water-quality violations, especially for bacteria and heavy metals. These pollutants in the storm water exceed water-quality standards for almost all rains.

AVAILABILITY OF POTENTIAL POLLUTANTS ON THE LAND SURFACE

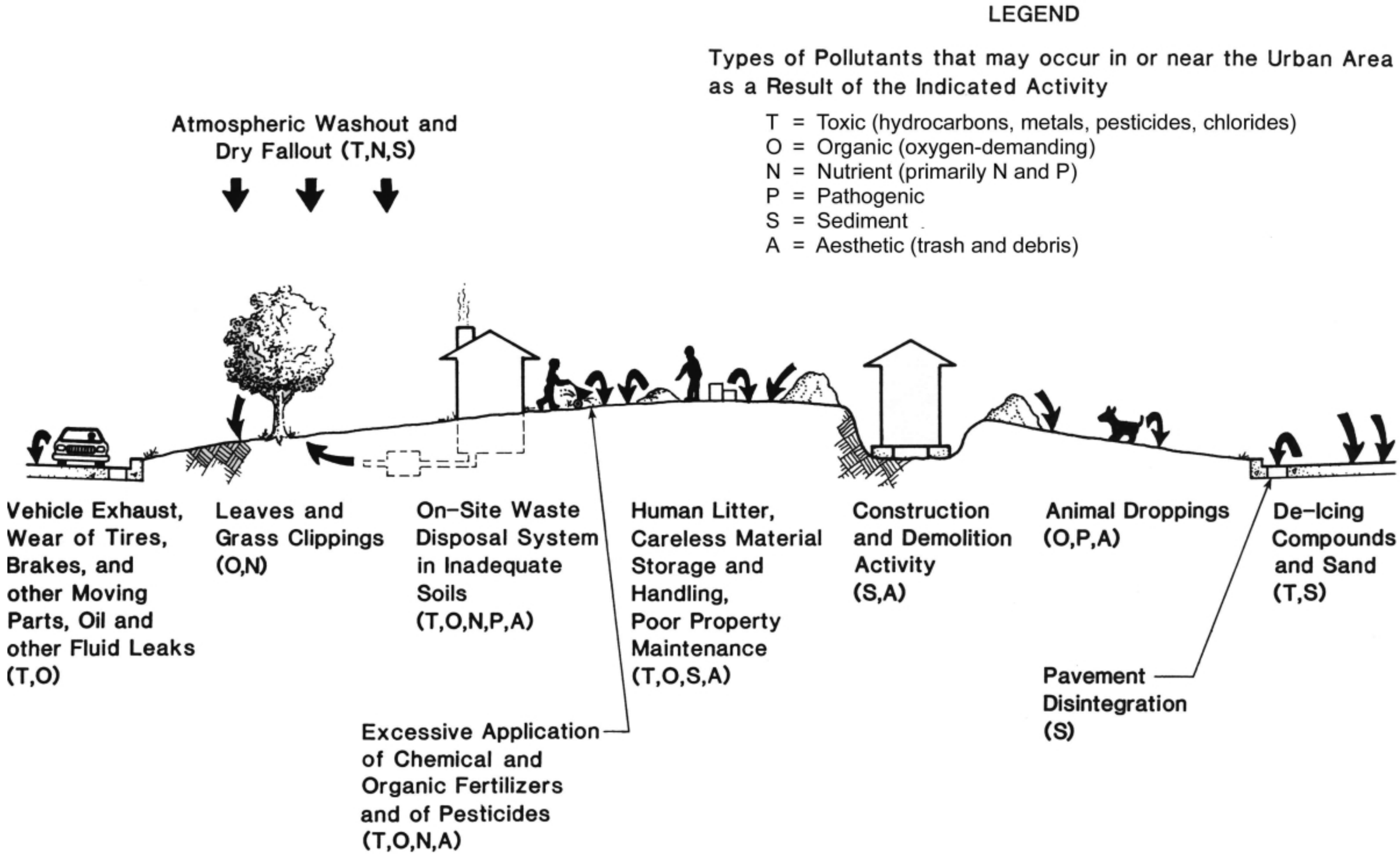


Figure 1-5
Source: Walesh, 1989

- Rains between 0.5 and 1.5 inches are responsible for about 75 percent of the annual runoff-pollutant mass discharges from residential areas, and are the key rains that need to be addressed when concerned with mass discharges of pollutants.
- Rains greater than 1.5 inches occur rarely (on only about two days a year in Minneapolis-St. Paul) and are needed for designing and evaluating storm drainage systems. However, these rains are only responsible for relatively small portions of the annual pollutant mass discharges. In Minnesota, more than 90% of the precipitation events are less than 1.0 inch. These rainfall events also account for the majority (about 65%) of the cumulative runoff quantity and proportionately large amounts of the pollutant loading associated with these rainfall events. The pollutant loading is more closely associated with total runoff volume than with peak runoff rates.

The spring melt event is important in terms of pollutant loading as well as hydrology. The snowpack has high pollutant concentrations because it represents the buildup of pollutants over an entire season. According to Oberts (1982) about 65% of sediment, organic, nutrient and lead loads can be attributed to the spring melt event. In addition, cyanide concentrations are high in snowmelt runoff because of cyanide added to salt to prevent clumping.

The rate of accumulation for polycyclic aromatic hydrocarbons (PAHs) is slightly elevated during the winter because of home heating, such as fireplaces, and the inefficiency of automobiles in cold weather. Chloride loadings are the highest in snowmelt events because of the use of sodium chloride and magnesium chloride as deicers. Much of the chloride melt occurs during the quick melting of snow on pavement throughout the winter season. Chlorides are also in plowed snow piles, and can be significant during the spring melt event (CWP, 1997).

Stormwater Pollutants

Urban stormwater runoff carries a variety of pollutants that affect water quality. These contaminants are generated through the activities in different residential, commercial, and industrial land developments within a watershed. During storm or snowmelt events, these pollutants quickly wash off and are carried to downstream waters. As development increases and activities change and intensify, the concentrations and types of contaminants increase accordingly.

The principal pollutants found in urban runoff are:

Nutrients

Urban runoff has elevated concentrations of both phosphorus and nitrogen, which can promote nuisance algal blooms in streams, rivers and lakes (known as eutrophication). In particular, excess phosphorus is known as a major factor in the decline of many of Minnesota’s water bodies.

Sediments

Sources of sediment include particles washed off of impervious surfaces and the eroded from streambanks and construction sites. Both suspended and deposited sediments can have adverse effects on the aquatic life in streams, rivers and lakes. Sediments can also transport other, attached pollutants.

Organic Materials

Organic matter, such as grass clippings, leaves and seeds, carried with runoff during storm events, can cause an oxygen deficit in downstream waters. As organic matter decomposes, it consumes oxygen. Low levels of oxygen in water bodies can have an adverse effect on aquatic life.

Table 1-2

Stormwater Pollutant	Examples of Sources	Related Impacts
Nutrients: Nitrogen, Phosphorus	Animal waste, fertilizers, failing septic systems	Algal growth, reduced clarity, other problems associated with eutrophication (oxygen deficit, release of nutrients and metals from sediments)
Sediments: Suspended and Deposited	Construction sites, other disturbed and/or non-vegetated lands, eroding banks, road sanding	Increased turbidity, reduced clarity, lower dissolved oxygen, deposition of sediments, smothering of aquatic habitat including spawning sites, sediment and benthic toxicity
Organic Materials	Leaves, grass clippings	Oxygen deficit in receiving water body, fish kill.
Pathogens: Bacteria, Viruses	Animal waste, failing septic systems	Human health risks via drinking water supplies, contaminated swimming beaches
Hydrocarbons: Oil and Grease, PAHs (Napthalenes, Pyrenes)	Industrial processes; automobile wear, emissions & fluid leaks; waste oil.	Toxicity of water column and sediment, bioaccumulation in aquatic species and through food chain
Metals: Lead, Copper, Cadmium, Zinc, Mercury, Chromium, Aluminum, others	Industrial processes, normal wear of auto brake linings and tires, automobile emissions & fluid leaks, metal roofs	Toxicity of water column and sediment, bioaccumulation in aquatic species and through the food chain, fish kill
Pesticides: PCBs, Synthetic Chemicals	Pesticides (herbicides, insecticides, fungicides, rodenticides, etc.), industrial processes	Toxicity of water column and sediment, bioaccumulation in aquatic species and through the food chain, fish kill
Chlorides	Road salting and uncovered salt storage	Toxicity of water column and sediment
Trash and Debris	Litter washed through storm drain networks	Degradation of the beauty of surface waters, threat to wildlife

Pathogens

Pathogen concentrations in urban runoff (commonly quantified in terms of fecal coliform) frequently exceed public health standards for water contact recreation in urban areas. Pathogens in runoff can also lead to increased health risks in drinking water.

Hydrocarbons

Vehicles leak substances, including gasoline, oil and lubricants, that contain a wide variety of hydrocarbon compounds, some of which are toxic at low concentrations to aquatic organisms.

Metals

Metals are routinely found in stormwater runoff, and can be toxic to aquatic organisms. Metals can also accumulate sediments of streams, rivers and lakes and up the food chain of organisms.

Pesticides

Both currently used and recently banned insecticides and herbicides are sometimes detected in urban streams at levels that approach or exceed toxicity thresholds for aquatic organisms.

Chlorides

Salts that are applied to roads and parking lots during winter months accumulate in meltwater and are delivered to downstream water bodies at concentrations that many freshwater organisms cannot tolerate.

Trash and Debris

Considerable quantities of trash and debris are washed through storm drain networks, accumulating in downstream water bodies and diminishing their natural beauty.

These pollutants, their sources, and related impacts are summarized in Table 1-2 and Figure 1-5.

Cold Climate Considerations

Winter hydrologic conditions—ice, snow and snowmelt—present special considerations for runoff management. An extensive review of BMP selection and design in cold climates was performed by the Center for Watershed Protection (Stormwater BMP Design Supplement for Cold Climates, 1997). In this review, the major considerations for cold-climate snowmelt and stormwater management were identified as:

- Pipe Freezing
- Ice Formation on the Permanent Pool
- Reduced Biological Activity
- Reduced Oxygen Levels During Ice Cover
- Reduced Settling Velocities
- Frost Heave
- Reduced Infiltration
- Short Growing Season
- High Runoff Volumes During Spring Snowmelt
- High Pollutant Loading During Spring Snowmelt

- Snow Management
- Special Maintenance

Pipe Freezing

Most BMPs rely on some piping system at the inlet and outlet, Frozen pipes can crack due to ice expansion, creating a maintenance or replacement burden. In addition, frozen pipes reduce the treatment capability of BMPs (by restricting or completely blocking the inflow or outflow to the BMP) and can increase the potential for flooding.

Many authorities have recommendations for the sizing and location of inlets and outlets to avoid ice clogging and freezing (CWP, 1997).

Ice Formation on the Permanent Pool

In BMPs that have a permanent pool of water, ice formation causes two problems. First, the permanent pool's volume is reduced. Ice can take up as much as three feet of permanent pool space, often about half the depth and volume. Second, the intended movement of runoff through the pond is compromised. Specifically, runoff entering an ice-covered pond has two options, neither of which provides sufficient pollutant removal (Oberts, 1994). In one case, runoff is forced under the ice, causing scouring of bottom sediments. In the other case, runoff flows over the top of the ice, receiving very little treatment at all. The sediment that does settle on the top can easily be resuspended by subsequent runoff events.

Some authorities recommend that the permanent pool volume be increased by an amount equal to the expected volume of the ice cover (Ontario Ministry of the Environment, 1999) or that extended storage be incorporated into the pond's design. Another option is to increase the depth of the pond at the inlet and outlet, creating more room for ice to collapse. These features will usually result in designs that are robust enough to handle winter and spring runoff conditions.

Pond structures should be carefully selection to withstand ice conditions: Once ice begins to melt and break apart, ice movement can cause damage to structures in the pond. For example, standpipe outlets are particularly susceptible to ice damage.

Reduced Biological Activity

Many BMPs rely on biological mechanisms to help reduce pollutants, especially nutrients and organic matter. For example, wetland systems rely on plant uptake of nutrients and the activity of microbes at the soil/root zone interface to break down pollutants. In cold temperatures, microbial activity is sharply reduced when plants are dormant during longer winters, limiting these pollutant removal pathways.

Reduced Oxygen Levels in During Ice Cover

In cold regions, oxygen exchange between the air-water interface in ponds and lakes can be restricted by ice cover. In addition, warmer water sinks to the bottom during ice-cover because it is denser than the cool water near the surface. Thus, although biological activity is limited in cooler temperatures, most decomposition takes place at the bottom, sharply reducing oxygen concentrations in bottom sediments. In these anoxic conditions, nutrients and metals retained in the sediments can be released, reducing the BMP's treatment efficiency.

Reduced Settling Velocities

Settling is the most important removal mechanism in many BMPs. As water becomes cooler, its viscosity increases, reducing particle velocity. In fact, particle settling velocity is about 50% faster with water temperatures at 68 degrees F than at 40 degrees F. This reduced settling velocity influences pollutant removal in any BMP that relies on settling.

Frost Heave

Frost heaving is a rising of the soil surface during cold periods. One of the sources of frost heaving is the expansion of pore water as it freezes under the ground's surface. An additional, and perhaps more important source is the formation of ice lenses, or layers of ice, below the soil surface. The primary risk associated with frost heave is the damage of structures such as pipes or concrete materials used to construct BMPs.

The CWPs Stormwater BMP Design Supplement for Cold Climates (CWP, 1997) addresses minimum depth of cover and backfilling practices to reduce the potential for pipe freezing and frost heave.

Reduced Infiltration

The rate of infiltration in frozen soils can be limited, especially when ice lenses form. As a result, BMPs that rely on infiltration to function may be ineffective when soil is frozen, which in cold climates can be a significant portion of the year. It is important to note, however, that some frozen soils can continue to infiltrate water year-round, depending on soil porosity and water content.

Short Growing Season

Vegetation is central to the proper functioning of some BMPs (wetlands and grass filter strips, for example). When the growing season is shortened, establishing and maintaining this vegetation is more difficult. During construction of a BMP system, the "envelope" for planting grass, wetland vegetation or other plant material is reduced. Also, the range of usable plants is more limited in cold climates than in more moderate climates. Finally, many plants are dormant during the winter months. This results in decreased efficiency for BMPs in which plants are used to help attenuate or filter runoff.

High Runoff Volumes During Spring Snowmelt

Ground freezing throughout the tributary watershed effectively increases the watershed's imperviousness which, in turn, increases the runoff volume that reaches BMPs. Runoff volume from spring snowmelt events can be very large, often the largest-volume event of the year. Another compounding problem is that this large volume of water occurs at the end of the winter when many impoundments may be at their worst, such as frozen ground for infiltration basins or frozen permanent pools and clogged outlets for pond systems. Thus the effectiveness of these BMPs is often compromised during this critical runoff event.

Designers may wish to increase the capacity of BMPs to account for the unique conditions in colder climates, particularly when the volume of spring snowfall represents a significant portion of the total rainfall. Spring snowmelt, rain-on-snow and rain-on-frozen ground may warrant higher treatment volumes.

Many regions have a goal to treat 90% of the annual runoff volume. Therefore, if snowfall represents more than 10% of the total precipitation in these regions, at least some portion of the spring snowmelt needs to be treated in order to meet the treatment goal. Using the rule of thumb that the moisture content of snowfall has about 10% moisture content, this rule can be simplified as: Oversize when average annual snowfall depth is greater than or equal to annual precipitation depth.

High Pollutant Loading During Spring Snowmelt

Snowmelt runoff events in cold climates may convey high concentrations of urban runoff pollutants to stormwater ponds and other receiving waters. Winter maintenance operations involve snow plowing, sanding, and salting of roadways, parking lots, sidewalks and other impervious areas. Snow piles can build up over the winter months, generating concentrated releases of pollutants during spring snow melt conditions. Therefore, five months of winter pollutant accumulation may be available for rapid release in the spring. Typical pollutants found in snowmelt are:

- Sand (sediments)
- Salt (chlorides)
- PAHs
- Cyanide
- Trash and Debris

Sand

Large quantities of sand are applied to roadways during the winter months. By the end of winter, sand has accumulated onto streets and snow piles and will be carried with snowmelt to receiving water bodies if proper maintenance activities are not employed. Sediments (including sand) represent the largest volume of pollutants impacting receiving water bodies. The effect of sediments are discussed in the previous section of this report.

Salt (Chlorides)

Chloride loadings are the highest in snowmelt events because of the use of sodium chloride and magnesium chloride as deicers. In general, confirmed water quality impacts of chlorides are minimal; however, there is some current discussion on whether there should be more concern and research about the impact of chlorides transported into surface and ground waters.

It is estimated that most of the transport of deicing chemicals is caused by the concentrated runoff that can be created by inadequate storage facilities (MPCA, 2000). Also, because of the current concern over the movement of chlorides into the environment, any reduction in chloride runoff that can be achieved through the proper storage or reduced application rate is recommended.

The MPCA recommends the following practices when storing or using deicing chemicals (MPCA, 2000):

- Store compounds on sheltered (protected from precipitation and wind), impervious pads
- Watch the weather in anticipation of snow storm events, to estimate storm durations, temperatures, and conditions to better plan the amount of deicing chemical that will be needed
- Properly calibrate equipment so that the planned application is delivered
- Limit salt application on low-traffic areas and straight, level areas. Critical areas, such as intersections, hills or major roads, will need higher levels of service.

PAHs

Polycyclic aromatic hydrocarbons (PAHs) in runoff from the snowpack can exceed drinking water standards. The rate of accumulation is slightly elevated during the winter because of home heating, such as fireplaces, and the inefficiency of automobiles in cold weather. In addition, these hydrophobic materials remain in the snowpack until the end of snowmelt, resulting in “shock” loadings.

Cyanide

Cyanide concentrations can be high in snowmelt runoff because of cyanide added to salt to prevent clumping.

Trash and Debris

Trash and debris usually accumulate in snow piles during snow plowing operations. During the winter, these materials can be blown off of snow piles. During snowmelt, they can be carried into receiving waters.

Snow Management

Proper management of snow, in terms of snow removal and storage, can prevent or minimize the major runoff and pollutant loading impacts. The following list outlines some recommendations for snow storage (MPCA, 2000):

- Plowed snow should not be directly discharged to lakes, streams or wetlands.
- Storage locations should be outside of direct drainage into surface waters.
- Plowed snow should be placed in pervious areas where it can slowly infiltrate.
- Snow should not be piled in wooded areas, around trees, or in vegetated buffer zones due to concerns about sediment and/or salt damage to vegetation.
- Snow piles should be monitored for debris that could be windblown.
- Sediments should be contained as snow melts, and removed from the snow storage areas every spring.

Special Maintenance

BMPs designed to function effectively in summer are often disrupted by winter and spring events. Inspection and maintenance during spring runoff should be a consistent feature of stormwater treatment systems in cold climates. In terms of the tributary watershed, intensive street and catch basin cleaning in early spring in anticipation of spring snowmelt events.

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