

# Chapter 1 Introduction

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Designing stormwater best management practices (BMPs) that are effective at removing pollutants, acceptable to the public and affordable is not easy in any climate. Cold climates present additional challenges that make some traditional BMP designs less effective or unusable. Based on information gathered in a nationwide survey of cold climate BMP experts, stormwater challenges are evaluated and recommendations are made for BMP use in cold regions.

## **1.1 Cold Climate BMP Surveys**

Two surveys of stormwater experts in cold climates, an informal telephone survey and a formal write-in survey, were the primary sources for the recommendations made in this manual. The goal of these surveys was to gather information on current BMP practice in cold climates, problems encountered and any unique cold regions BMP designs.

### *1.1.1 Telephone Survey*

An informal telephone survey was conducted before the formal write-in survey. One hundred and forty individuals were contacted during this phase of the study. Most contacts were local or state government staff or consulting engineers. Initial contacts were from the Center for Watershed Protection's customer database, and these individuals were asked to recommend other people to contact.

The purpose of this telephone survey was threefold. First, the survey was used to obtain local and state BMP manuals. Second, it was used to develop a list of people to send the write-in survey, based on their interest and expertise. Finally, the telephone survey was used to obtain qualitative information, such as what types of BMPs are recommended and/or currently used in cold climates. This information was used to finalize the write-in survey.

### *1.1.2 Write-In Survey*

A six page write-in survey was sent to one hundred stormwater experts selected from the original contacts, based on their willingness to participate in the survey and their knowledge of stormwater BMPs. Fifty five people responded to the survey, from most of the cold and snowy regions in the United States (Figure 1.1). These individuals represent national and state agencies, local governments and private consultants. The survey results for all respondents, and a separate set of responses for very cold climates are included in Appendix A.

This survey was divided into five major sections. The first two sections were designed to determine if the survey respondents were from cold climates and had stormwater programs designed for water quality. A few participants had voluntary programs, such as some Soil and Water Conservation Districts. These respondents were included in the analysis as well. The second two sections asked general information about recommended BMPs and design considerations for cold climates. The fifth section included specific design questions regarding the pollutant removal capability of different BMPs and modifications to improve their performance in cold climates.

This survey was the primary source of information for the document, including specific design recommendations such as pipe sizes. In addition, it was used to target the information in the document to concerns that are the most important to designers in cold climates. Other research was conducted to establish sizing requirements based on design principles of snow hydrology and experiences of cold climate experts.

FIGURE 1.1 GEOGRAPHIC DISTRIBUTION OF SURVEY RESPONDENTS

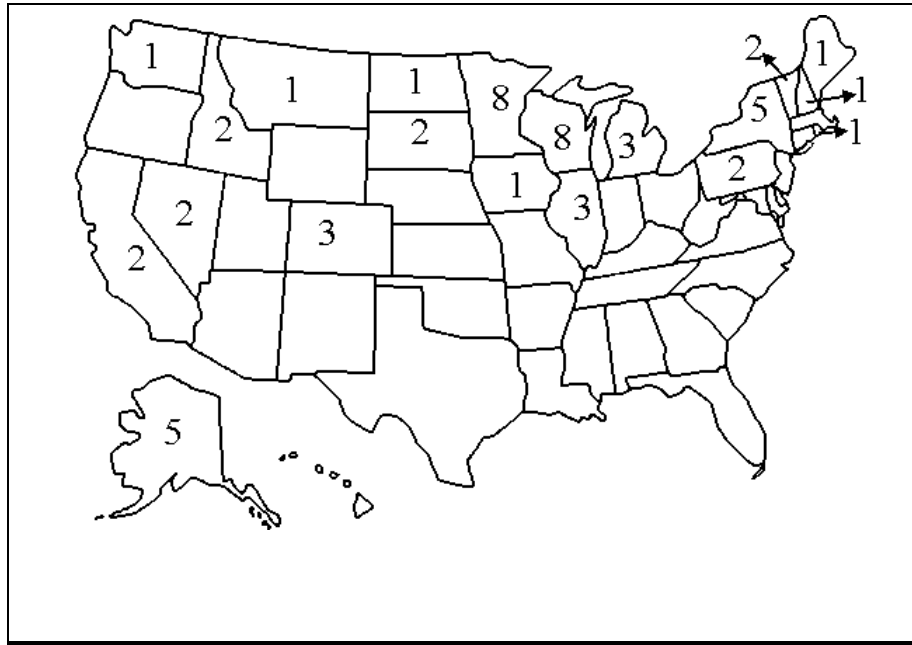
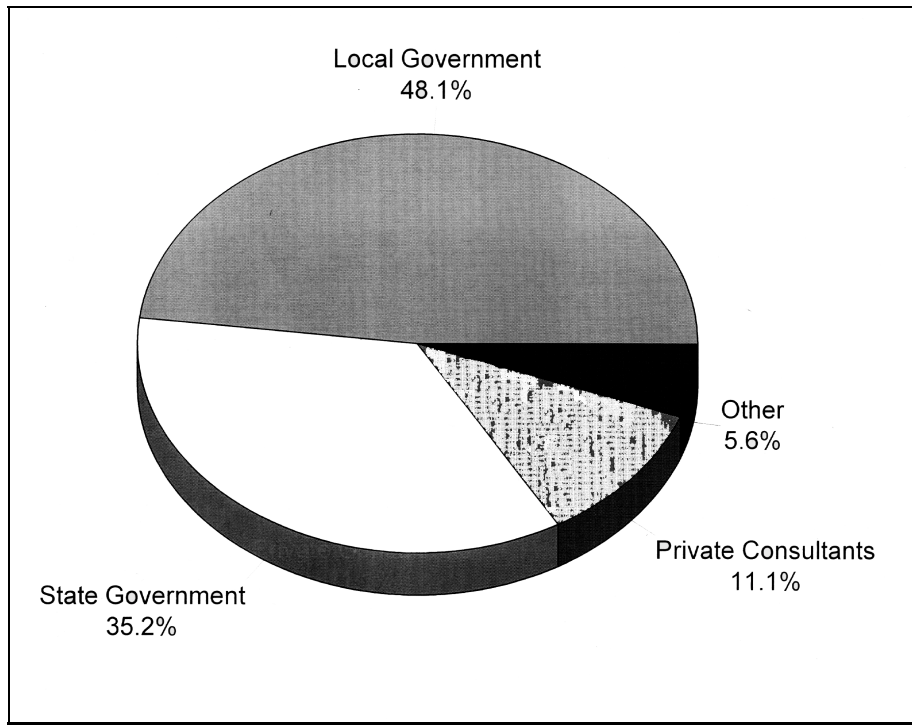


FIGURE 1.2 TYPES OF ORGANIZATIONS REPRESENTED BY SURVEY RESPONDENTS



## **1.2 Cold Climate Identification**

The first step in using this manual is to decide whether cold weather design criteria apply in your case. The maps presented on the following pages (Figures 1.3 through 1.6) identify where modifications to standard BMPs are necessary, based on temperature, growing season and depth of snow. These data are readily available from the National Weather Service, or local weather stations, and adequately describe cold regions. Each map has a “very cold” (or snowy) and a “cold” (or snowy) band. The more severe climate bands represent areas where cold climate modifications are of particular concern. The data presented is intended to identify cold regions only, and should not be used in design calculations. Instead, local data should be used for this purpose. The depth of freeze is also referred to in some portions of this manual for design purposes. These data are not mapped because they vary widely based on soil type and soil moisture.

### **1.2.1 Temperature (Figure 1.3)**

The most obvious measure of cold climates is temperature. Two aspects of cold temperatures are important: extremely cold temperatures and sustained cold. Extreme cold can cause rapid freezing, which can cause pipes to burst. Sustained cold temperatures, on the other hand, result in the development of thick ice layers at the surface of some BMPs. In this manual, the average daily maximum temperature for January was used to represent cold climates. This data captures the temperature in the coldest month of the year, thus representing both sustained cold temperature (i.e., at least thirty days of freezing temperature) and extreme cold.

### **1.2.2 Length of Growing Season (Figures 1.4 and 1.5)**

Length of growing season is based primarily on temperature records, defined as the number of days between the last freezing day in Spring and the first freezing (32 F) day in Autumn. These data are useful in determining areas where alternative vegetation or special planting techniques are necessary. Much of the Southwestern United States has a short growing season. Because of the dramatic swings in temperature in these arid regions, a frost can occur during much of the year, despite high maximum temperatures. Map 1.5, which overlays short growing season and cold temperatures, more accurately describes the area focused on in this study.

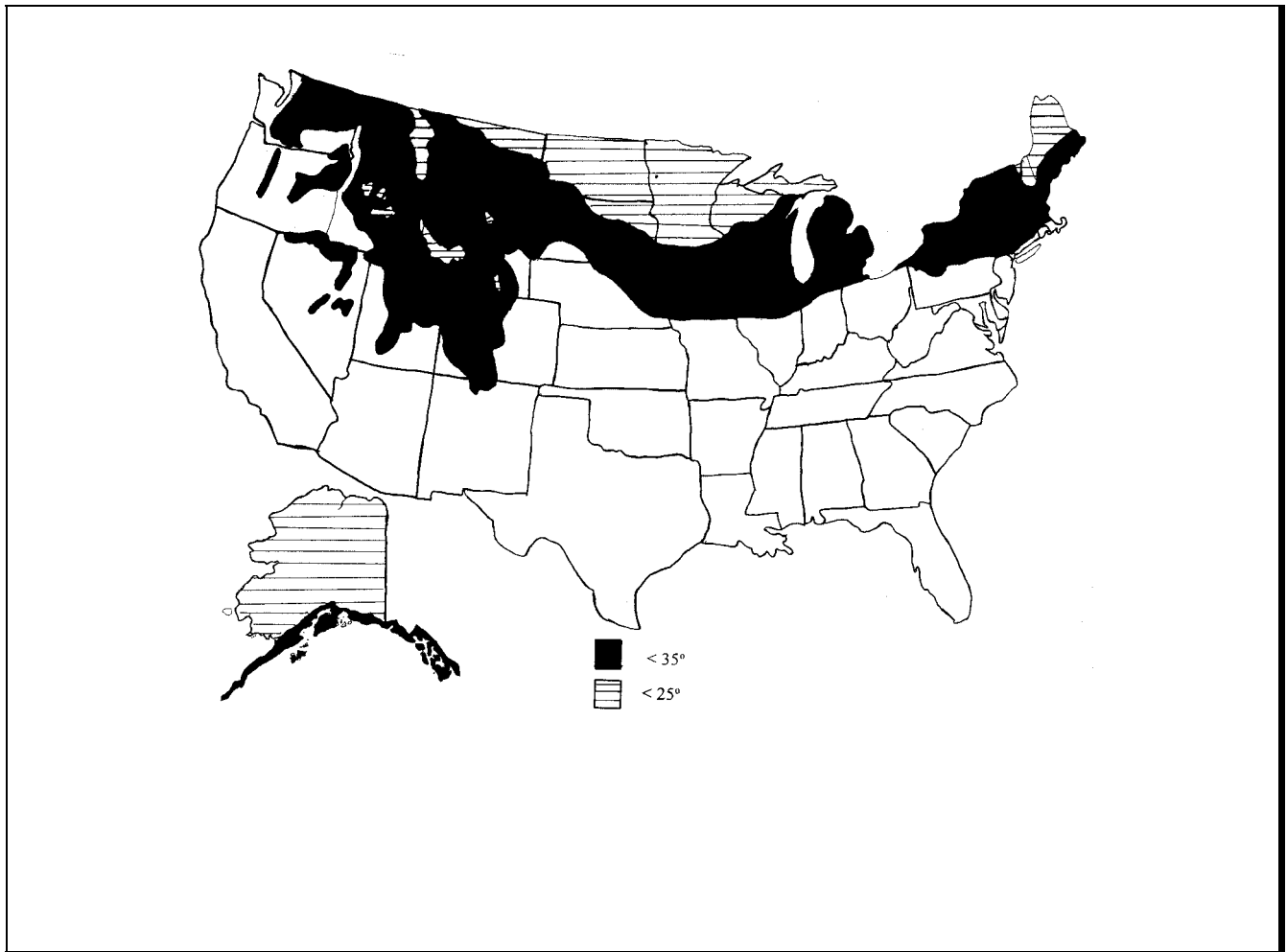
### **1.2.3 Snow Depth (Figure 1.6)**

The depth of snow identifies areas where snowfall is important in the hydrologic cycle. Areas with greater than 3' and greater than 5' of snow are identified. In these regions, snowfall represents at least 10% of the annual precipitation.

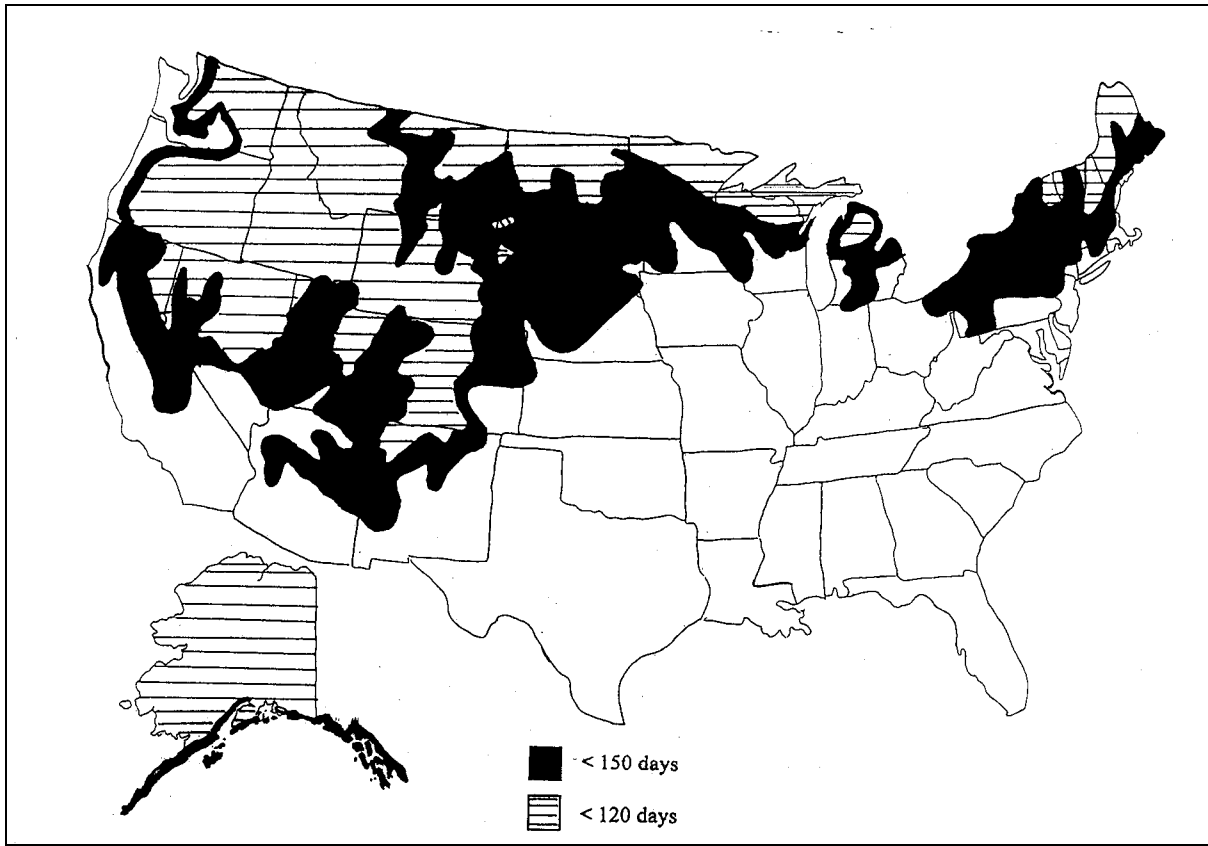
### **1.2.4 Depth of Freeze**

The depth of freeze is an important design parameter for laying pipes and installing underground systems. Installing these structures “below the frost line” protects them from frost heave, and prevents water from freezing in pipes or underground permanent pools. The depth of freeze varies depending on land cover, climate, soils and soil moisture. Most communities use a design depth of freeze for laying pipes. This is the value referred to for design recommendations in this manual.

**FIGURE 1.3 NORMAL DAILY MAXIMUM TEMPERATURE ( ° F) FOR JANUARY**  
**(SOURCE: U.S. DOC, 1975)**



**FIGURE 1.4 MEAN LENGTH OF FREEZE-FREE PERIOD (DAYS), i.e. GROWING SEASON**  
(SOURCE: U.S. DOC, 1975)



**FIGURE 1.5 OVERLAY OF MAXIMUM JANUARY TEMPERATURE AND GROWING SEASON  
(SOURCE: U.S. DOC, 1975)**

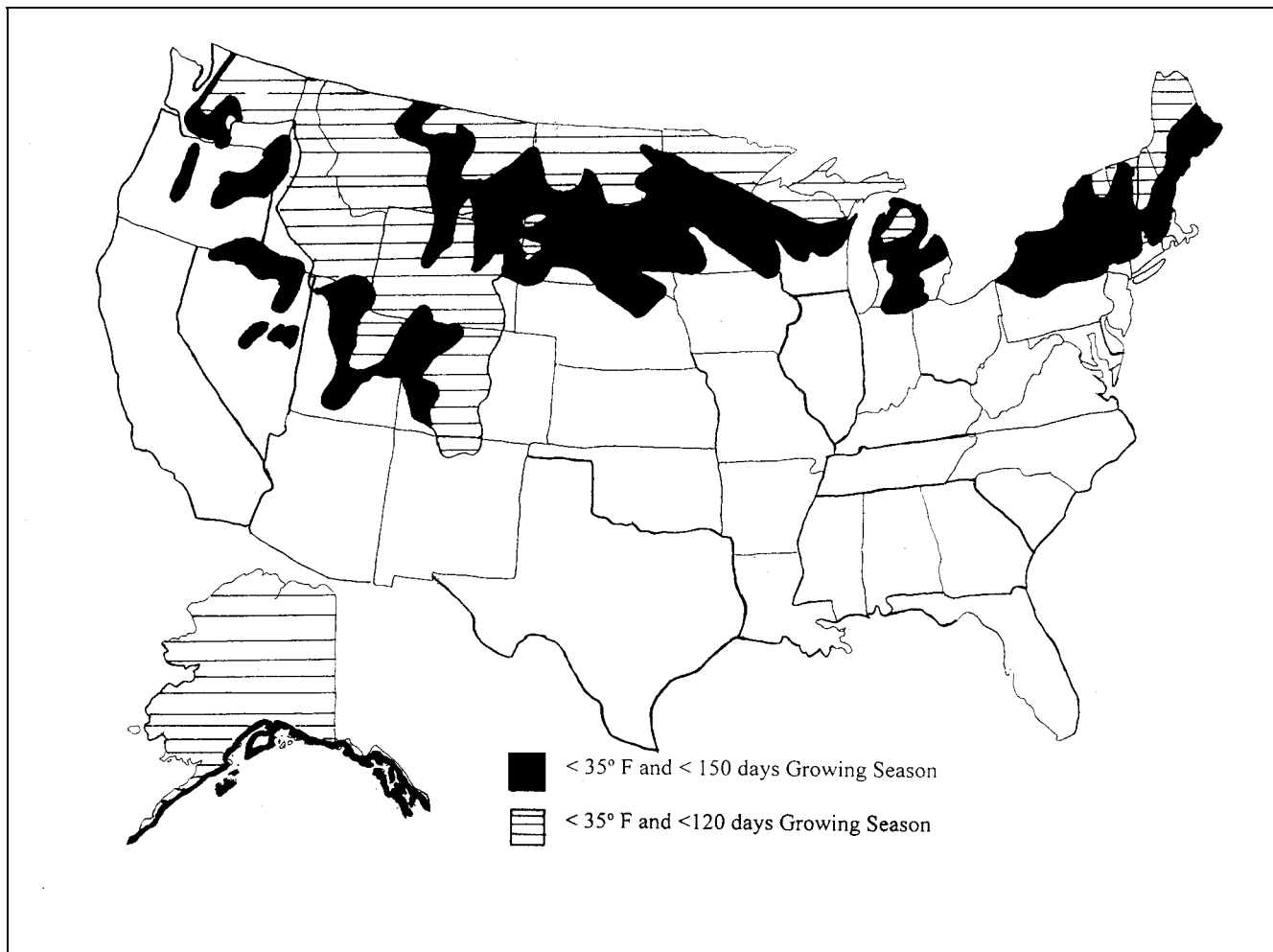
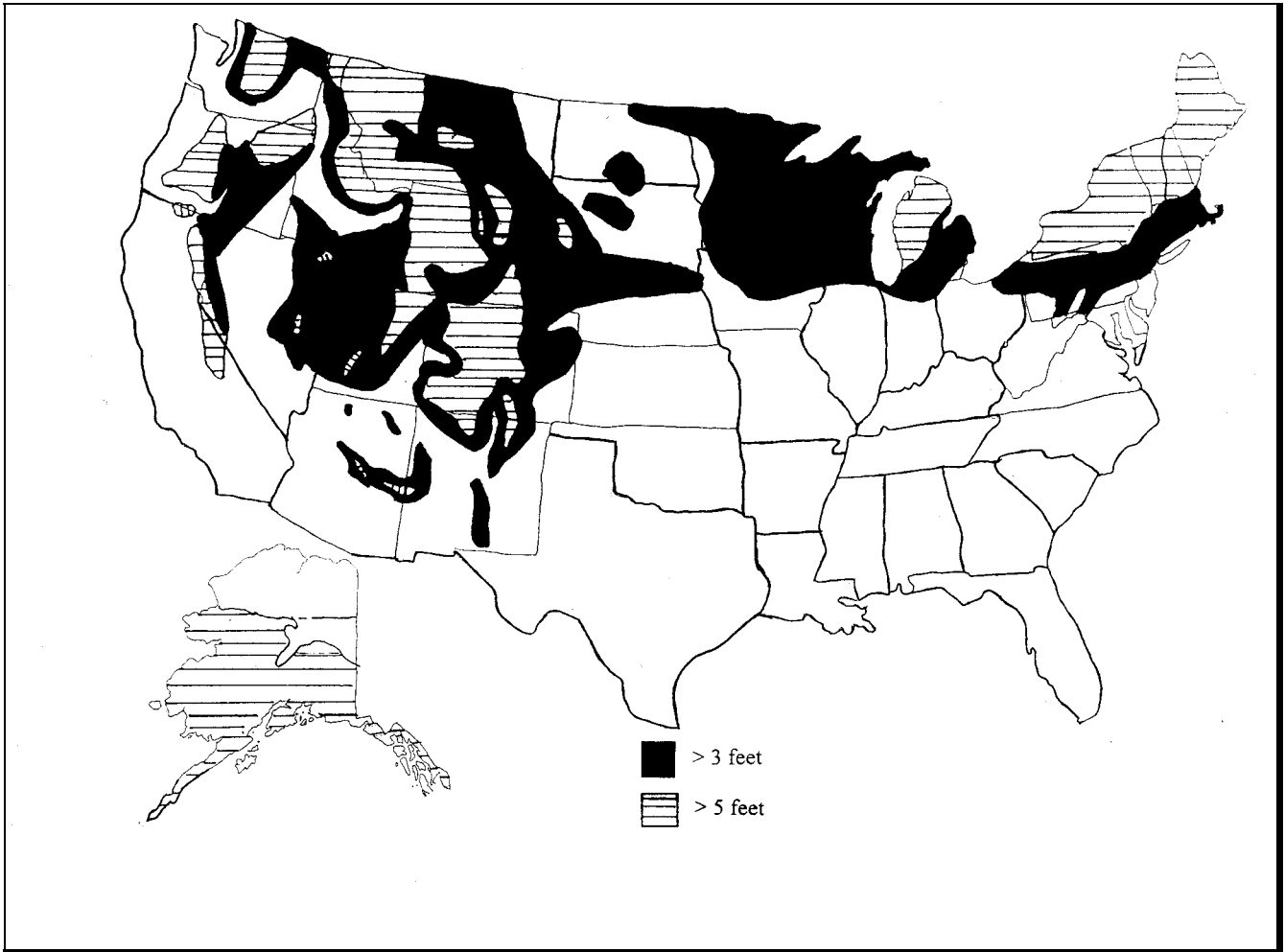


FIGURE 1.6 MEAN ANNUAL SNOWFALL (FEET)  
(SOURCE: U.S. DOC, 1975)



### **1.2.5 Moderate Climate Definition**

Many of the base design criteria discussed in this manual are appropriate for “moderate” climates. Moderate climates do not have extremely cold or dry characteristics and are defined by the following characteristics:

- 1) Annual precipitation between 30" and 45"
- 2) Growing season greater than five months
- 3) Average daily maximum temperature for January greater than 35 °F
- 4) Less than three feet of snow annually.

### **1.3 Cold Climate Design Challenges**

Why should a designer care about cold or snowy conditions? How do they affect BMP performance? Each of the measurable cold climate traits described in section 1.2 influences effectiveness (or ineffectiveness) of stormwater BMPs (Table 1.1). Most problems were rated “Always a Design Concern” by more than 30% of stormwater professionals (CWP, 1997; Figure 1.7). Thus, it is generally recognized that cold climates can influence the performance of stormwater BMPs.

**FIGURE 1.7 IMPORTANCE OF COLD CLIMATE CHALLENGES FOR BMP DESIGN**  
(SOURCE: CWP, 1997)

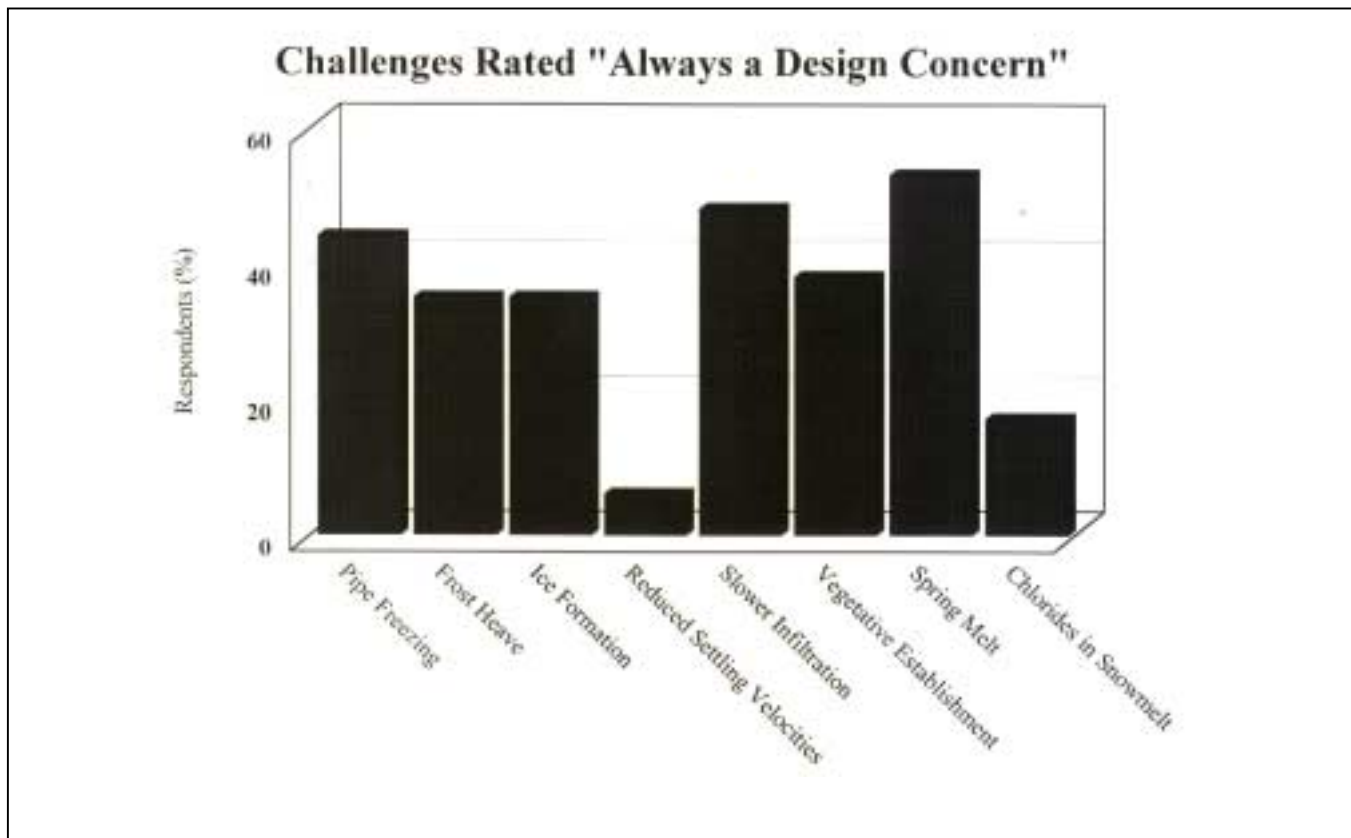




TABLE 1.1 COLD CLIMATE DESIGN CHALLENGES

Climatic Condition	BMP Design Challenge
Cold Temperatures	<ul style="list-style-type: none"> <li>• Pipe freezing</li> <li>• Permanent pool ice-covered</li> <li>• Reduced biological activity</li> <li>• Reduced oxygen levels during ice cover</li> <li>• Reduced settling velocities</li> </ul>
Deep Frost Line	<ul style="list-style-type: none"> <li>• Frost heaving</li> <li>• Reduced soil infiltration</li> <li>• Pipe freezing</li> </ul>
Short Growing Season	<ul style="list-style-type: none"> <li>• Short time period to establish vegetation</li> <li>• Different plant species appropriate to cold climates than moderate climates</li> </ul>
Significant Snowfall	<ul style="list-style-type: none"> <li>• High runoff volumes during snowmelt and rain-on-snow</li> <li>• High pollutant loads during spring melt</li> <li>• Other impacts of road salt/deicers</li> <li>• Snow management may affect BMP storage</li> </ul>

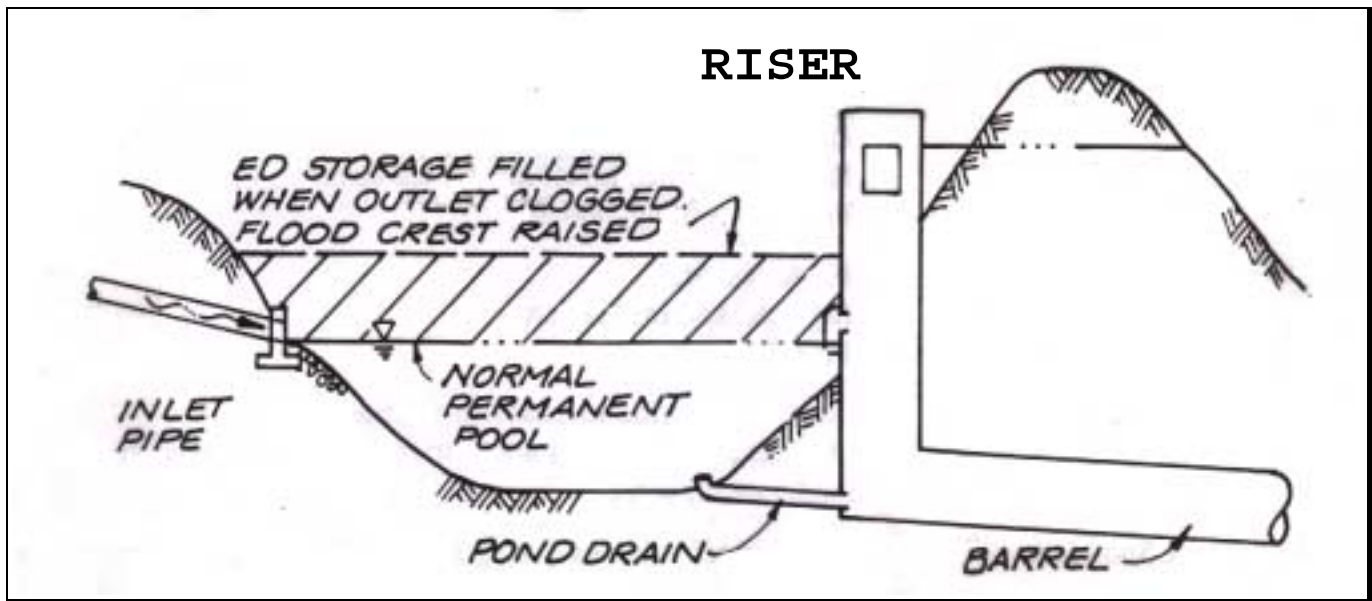
### 1.3.1 Pipe Freezing

Most BMPs, with the exception of vegetative filter strips, rely on some piping system at the inlet, and many also have an outlet or underdrain pipe. Frozen pipes can crack due to ice expansion, creating a maintenance or replacement burden. In addition, pipe freezing reduces the capability of BMPs to treat runoff for water quality and can create the potential for flooding.

Frozen pipes can cause stormwater to bypass the BMP untreated. Figure 1.8 illustrates the effect of pipe freezing on a simplified wet extended detention pond. In a properly functioning system, the low-flow orifice allows drawdown of the smaller storms over a 24-hour period, and the larger orifice controls the peak discharge of larger storm events. When the low-flow orifice (usually a small diameter pipe) is clogged with ice, the smaller design event fills the detention area. Thus, the treatment volume available for subsequent events may be partially or fully lost, reducing residence time and, consequently, treatment.

Another more immediate concern is that clogged outlets or inlets to BMP systems may increase the likelihood of flooding. In the scenario described above, the pond volume available to treat flood events was filled with the water from smaller storms. A large storm or snowmelt event could result in serious flooding because of this loss of storage. When ice clogs inlets, flooding can occur because storm events become backed up in the drainage system, flooding the contributing area.

FIGURE 1.8 INFLUENCE OF PIPE FREEZING ON DETENTION STORAGE



### 1.3.2 Ice Formation on the Permanent Pool

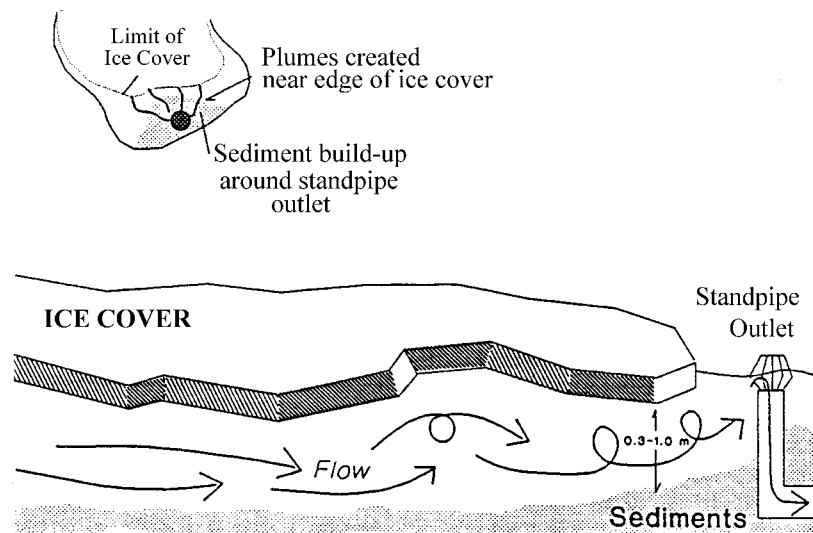
The permanent pool of pond and wetland systems serves several purposes. First, the water in the permanent pool slows down incoming runoff, allowing increased settling. In addition, the biological activity in this pool can act to remove nutrients, as growing algae, plants and bacteria require these nutrients for growth. In some systems, such as sand filters, a permanent pool can act as a pretreatment measure, settling out larger sediment particles before full treatment by the BMP.

Ice cover on the permanent pool causes two problems. First, the treatment pool's volume is reduced. Ice can take up as much to three feet of permanent pool space, often about half the depth and volume. Second, since the permanent pool is frozen, it acts as an impermeable surface. As a result, runoff entering an ice-covered pond has two possible options, neither of which provides sufficient pollutant removal (Oberts, 1994). In the first, runoff is forced under the ice, causing scouring of bottom sediments. In the second, runoff flows over the top of the ice, receiving very little treatment at all (Figure 1.9). The sediment that does settle on the top can easily be resuspended by subsequent runoff events.

### 1.3.3 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.

FIGURE 1.9 EFFECT OF ICE COVER ON FLOW THROUGH PONDS  
(SOURCE: OBERTS, 1990)



#### 1.3.4 Reduced Oxygen Levels in Bottom Sediments

In cold regions, oxygen exchange between the air-water interface in ponds and lakes is restricted by ice cover. In addition, warmer water sinks to the bottom during ice cover because it is denser than the cooler water near the surface. Water is densest at 39 °F (Wetzel, 1975). Thus, although biological activity is limited in cooler temperatures, most decomposition takes place at the bottom, sharply reducing oxygen concentrations in bottom sediments (Wetzel, 1975). In these anoxic conditions, positive ions retained in sediments can be released from bottom sediments, reducing the BMP's ability to treat these nutrients or metals in runoff. For example, Higgins et al. (1991) attribute phosphorous releases from a treatment pond to the lack of oxygen in bottom sediments of a six foot deep treatment pond.

#### 1.3.5 Reduced Settling Velocities

Settling is the most important removal mechanism in many BMPs (Schueler, 1994). As water becomes cooler, its viscosity increases, reducing particle settling velocity. In fact, particle settling velocity is about 50% faster with water temperatures at 68 °F than at 40 °F (Figure 1.10). This reduced settling velocity obviously influences pollutant removal in any BMP that relies on settling. Very few survey respondents considered this parameter important for BMP design, though. This is probably because most BMPs are designed for specific flow events, and not based on the time required for particles to settle.

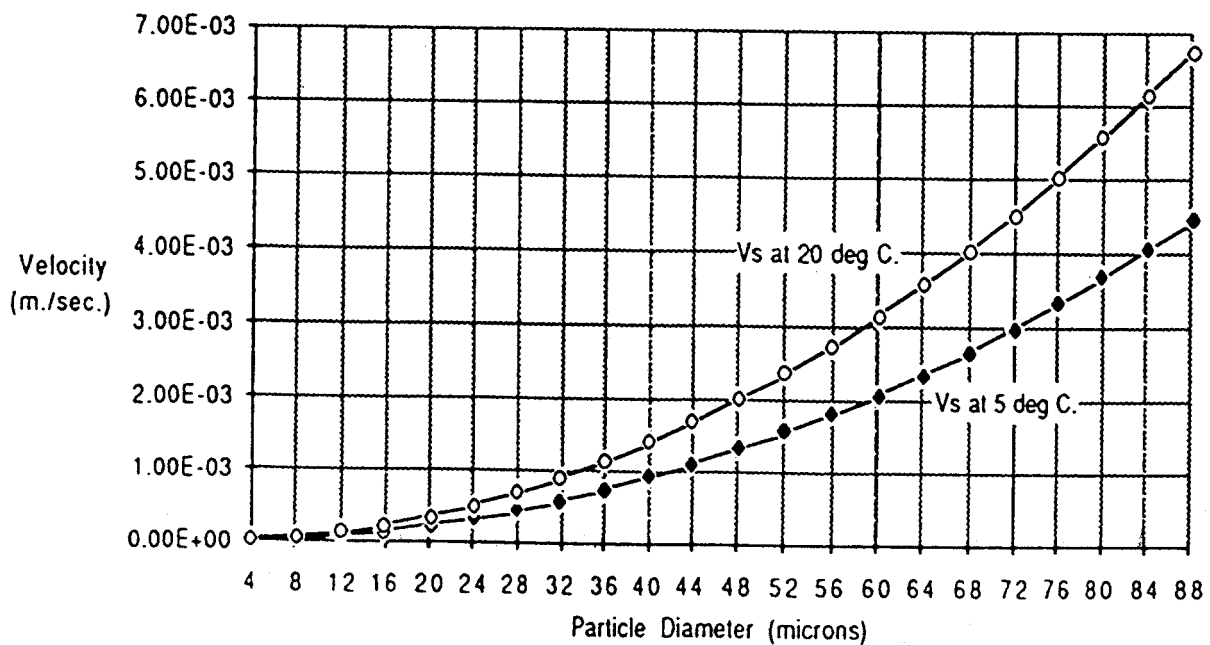
#### 1.3.6 Frost Heave

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 (Holtz and

Kovacs, 1981). Subsurface water migrates toward the surface layer, forming layers of frozen material that cause the soil to rise or heave in some sections. This upward soil water migration is most significant in fine-grained soils because of their high capillary pressure. Since this freezing does not occur uniformly, structures can crack as they are influenced by this uneven pressure.

The primary risk associated with frost heave is the damage of structures such as pipes or concrete materials used to construct BMPs. Another concern is that infiltration BMPs can cause frost heave damage to other structures, particularly roads. The water infiltrated below the soil surface can flow under a permanent structure and then refreeze. The sudden expansion associated with this freezing can cause damage to above ground structures.

**FIGURE 1.10 EFFECT OF WATER TEMPERATURE ON SETTLING VELOCITY**  
(SOURCE: JOKELA AND BACON, 1990)

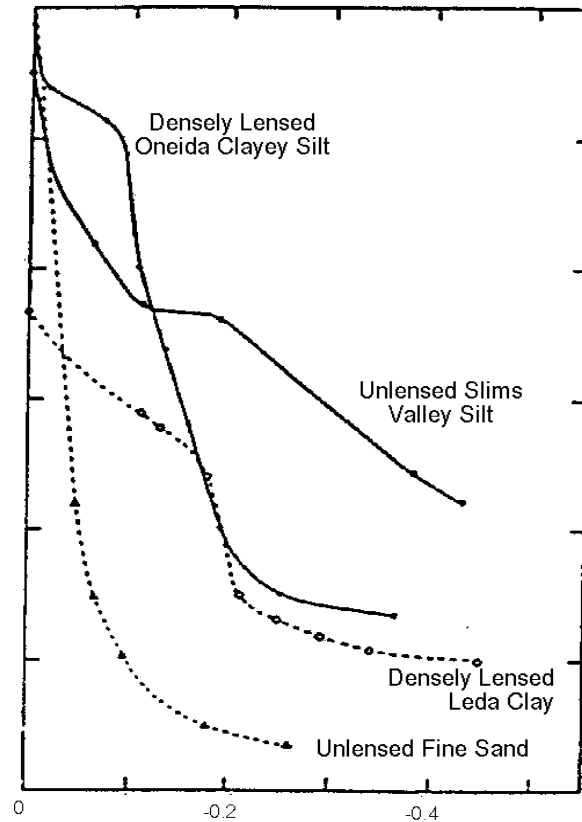


### 1.3.7 Reduced Soil Infiltration

The rate of infiltration in frozen soils is limited, especially when ice lenses form (Figure 1.11). There are two results of this reduced infiltration. First, BMPs that rely on infiltration to function are ineffective when the soil is frozen. In cold climates, this can be a significant portion of the year. Second, runoff rates from snowmelt are elevated because the ground underneath the snow is frozen.

FIGURE 1.11 INFILTRATION IN FROZEN SOILS

(SOURCE: KANE AND CHACO, 1990)



### 1.3.8 Short Growing Season

For some BMPs, such as bioretention facilities, wetlands and grass filter strips, vegetation is central to the proper functioning of the BMP. When the growing season is shortened, establishing and maintaining this vegetation becomes more difficult. First, during construction of a BMP system, the

“envelope” for planting grass, wetland vegetation or other plant material is reduced. Second, some plant species that succeed in moderate climates with a nearly seven month growing season may not succeed when the growing season is reduced. Thus, different plant species may be more appropriate for these BMPs. (See Table 4.5 for a plant listing).

### ***1.3.9 High Runoff Volumes During Spring Melt***

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 (Westerstrom, 1990). 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 ground conditions, and warm rains can cause rapid melting of the snowpack. In the Sierra Nevada region, for example, most flood events are caused by rain-on-snow events (Bergman, 1983).

Another compounding problem is that this 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.

### ***1.3.10 High Pollutant Loading During the Spring Melt***

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 build-up 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.

Polycyclic aromatic hydrocarbons (PAHs) in runoff from the snowpack can exceed drinking water standards (Marsalek, 1990). 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.

Chloride loadings are the highest in snowmelt events because of the use of sodium chloride and magnesium chloride as deicers. Much of this 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. In general, water quality impacts of chlorides are minimal, but they can have some impacts (Oberts, 1994a). One study (Demers and Sage, 1990) shows significant impacts on macroinvertebrate species diversity in four small Adirondack streams. Runoff containing chlorides is dense and tends to sink to the bottom of lakes. This layer of water can remain

at the bottom for a long period, resulting in an anoxic zone near the lake bottom. For example, the Irondequoit Bay in Monroe County, New York, experienced incomplete mixing of the water column in 1986, which was attributed to the high road salt use in the region (MCEMC, 1987).

### ***1.3.11 Roadside Impacts of Road Salt/ Sand on Roadside Vegetation***

Although most respondents to the Center's Survey were not concerned with water quality issues related to road salt application (Figure 1.7), there are some other impacts that may affect BMP design, especially at roadsides or in areas where plowed snow is stored. Salt can damage vegetation or change species composition. One respondent noted that salt-water species tend to dominate wetlands near roadsides. Sodium in road salts can damage soil structure, creating less permeable and arable soils (Jones and Jeffrey, 1992). These impacts may make roadside swales less effective, or influence the rate of runoff from the soil near roadsides.

### ***1.3.12 Snow Management***

An age old concern in snowy climates is where to put snow. Snow management can influence water quality and impact decisions in the selection of urban BMPs. The old method of dumping snow into rivers is now discouraged because of water quality concerns. Placing snow on pervious surfaces can help to decrease peak runoff rates from snowmelt and encourage infiltration. Some stormwater BMPs, such as infiltration basins and filter strips, show promise for snow storage. It is important to note, however, that snow with large amounts of sand can result in smothering or filling the capacity of stormwater BMPs. In addition, high salt concentrations in roadside snow can kill vegetation in swales or other vegetative BMPs.

## **1.4 Designing Better BMPs for Cold Climates**

Despite the somewhat grim picture depicted above, stormwater BMP designs can be modified for cold climates. The remainder of this report outlines criteria for sizing BMPs in cold climates and modifications to traditional BMP designs to make them more effective in cold regions.

While a few BMPs are not recommended in cold climates, most can be applied in at least some cold climate conditions (Table 1.2). The opinions of stormwater experts were incorporated to develop this table (CWP, 1997). Each expert was asked which BMPs he or she recommended for cold climates (Figure 1.12).

It is obvious when comparing Table 1.2 and Figure 1.12 that the information in the table is not determined solely from information in the survey. There are two reasons for the differences between this information. First, more specific BMPs are included in this manual than in the original survey. For example, few respondents recommended sand filters, but a few commented that underground sand filters in particular were recommended.

Some BMPs were recommended or not recommended based on more information than cold climate conditions. For example, infiltration was often not recommended because of soils conditions. The dry ED pond, which is classified as easily applied to cold climates, is not highly recommended. This BMP was not recommended because of its pollutant removal annually, and not because of cold climate challenges. Grass swales and filter strips were very highly recommended, but were classified as moderately effective because of the reliance of this BMP on infiltration and vegetative growth.

**TABLE 1.2 APPLICABILITY OF BMPS TO COLD CLIMATE CONDITIONS**

Type	BMP	Classification	Notes
<b>Ponds (Chapter 3)</b>	Wet Pond	◐	Can be effective, but needs modifications to prevent freezing of outlet pipes. Limited by reduced treatment volume and biological activity in the permanent pool during ice cover.
	Wet ED Pond	●	Some modifications needed to conveyance structures needed. Extended detention storage provides treatment during the winter season.
	Dry ED Pond	◐	Few modifications needed. Although this practice is easily adapted to cold climates, it is not highly recommended overall because of its relatively poor warm season performance.
<b>Wetlands (Chapter 4)</b>	Shallow Marsh	○	In climates where significant ice formation occurs, shallow marshes are not effective winter BMPS. Most of the treatment storage is taken up by ice, and the system is bypassed.
	Pond/Wetland System	◐	Pond/Wetland systems can be effective, especially if some ED storage is provided. Modifications for both pond and wetland systems apply to these BMPS. This includes changes in wetland plant selection and planting.
	ED Wetland	●	See Wet ED Pond. Also needs modifications to wetland plant species.
<b>Infiltration (Chapter 5)</b>	Porous Pavement	○	This practice is restricted in cold climates. It cannot be used on any pavement that is sanded, because the pavement will clog.
	Infiltration Trench	◐	Can be effective, but may be restricted by groundwater quality concerns related to infiltrating chlorides. Also, frozen ground conditions may inhibit the infiltration capacity of the ground.
	Infiltration Basin	◐	See infiltration trench.



TABLE 1.2 APPLICABILITY OF BMPs TO COLD CLIMATE CONDITIONS (CONTINUED)

Type	BMP	Classification	Notes
<b>Filtering Systems (Chapter 6)</b>	Surface Sand Filter	○	Frozen ground considerations, combined with frost heave concerns, make this type of system relatively ineffective during the winter season.
	Underground Sand Filter	●	When placed below the frost line, these systems can function effectively in cold climates.
	Perimeter Sand Filter	○	See Surface Sand Filter
	Bioretention	◐	Problems functioning during the winter season because of reduced infiltration. It has some value for snow storage on parking lots, however.
	Submerged Gravel Wetland	◐	Some concerns of bypass during winter flows. Has been used in relatively cold regions with success, but not tested in a wide range of conditions.
<b>Open Channel Systems (Chapter 7)</b>	Grassed Channel	◐	Reduced effectiveness in the winter season because of dormant vegetation and reduced infiltration. Valuable for snow storage.
	Dry Swale	◐	Reduced effectiveness in the winter season because of dormant vegetation and reduced infiltration. Very valuable for snow storage and meltwater infiltration.
	Wet Swale	◐	Reduced effectiveness in the winter season because of dormant vegetation. Can be valuable for snow storage.
	Vegetated Filter Strip	◐	See Dry swale.

ED: Extended Detention

- Easily applied to cold climates; can be effective during the winter season.
- ◐ Can be used in cold climates with significant modifications; moderately effective during the winter season.
- Very difficult to use in cold climates. Generally not recommended.

FIGURE 1.12 BMPS RECOMMENDED IN COLD CLIMATES

