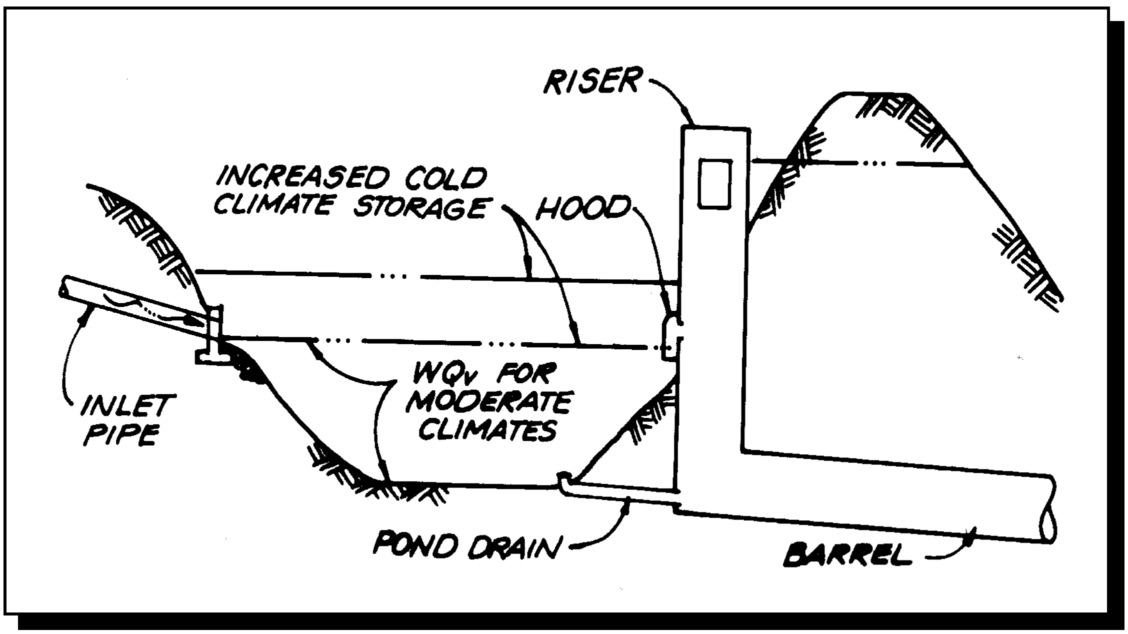
Traditional SMP sizing criteria are based on the hydrology and climatic conditions of moderate climates. These criteria are not always applicable to cold climate regions due to snowmelt, rain-on-snow and frozen soils. This chapter identifies methods to adjust both water quality (Section I.1) and water quantity (Section I.2) sizing criteria for cold climates.

I.1 Water Quality Sizing Criteria

The water quality volume is the portion of the SMP reserved to treat stormwater either through detention, filtration, infiltration or biological activity. Base criteria developed for SMP sizing nationwide are based on rainfall events in moderate climates (e.g., Schueler, 1992). Designers may wish to increase the water quality volume of SMPs to account for the unique conditions in colder climates, particularly when the 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. It is important to note that **the base criteria required by a region must always be met**, regardless of calculations made for cold climate conditions.

Figure I.1 Increased Water Quality Volume in Cold Climates



The goal of treating 90% of the annual pollutant load (Schueler, 1992), can be applied to snowmelt runoff and rain-on snow events. In the following conditions, cold climate sizing may be greater than base criteria sizing:

- Snowfall represents more than 10% of total annual precipitation. This value is chosen because, at least some portion of the spring snowmelt needs to be treated in order to treat 90% of annual runoff in these conditions. 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.

- The area is in a coastal or Great Lakes region with more than 3' of snow annually. In these regions, rain-on-snow events occur frequently enough to justify oversizing stormwater SMPs for water quality.

The following caveats apply to the sizing criteria presented in this section:

- These criteria are not appropriate for very deep snowpacks (i.e., greater than 4') because the volume to be treated would be infeasible, and often unnecessary.
- Sizing for snow storage areas is described in Appendix C.
- Snowmelt is a complicated process, with large annual variations. While the criteria presented here address the

affects of snowmelt and rain-on-snow, several simplifying assumptions are made. Where local data or experience are available, more sophisticated methods should be substituted.

I.1.1 Water Quality Volume for Snowmelt

In order to treat 90% of annual runoff volume, sizing for snowmelt events needs to be completed in the context of the precipitation for the entire year. In relatively dry regions that receive much of their precipitation as snowfall, the sizing is heavily influenced by the snowmelt event. On the other hand, in regions with high annual rainfall, storm events are more likely to carry the majority of pollutants annually. The sizing criteria for this section are based on three assumptions: 1) SMPs should be sized to treat the spring snowmelt event 2)Snowmelt runoff is influenced by the moisture content of the spring snowpack and soil moisture 3) No more than five percent of the annual runoff volume should bypass treatment during the spring snowmelt event and 4) SMPs can treat a snowmelt volume greater than their size.

- *SMPs should be sized to treat the spring snowmelt runoff event*

  Snowmelt occurs throughout the winter in small, low-flow events. These events have high concentrations of soluble pollutants such as chlorides and metals, because of "preferential elution" from the snowpack (Jeffries, 1988). Although these events have significant pollutant loads, the flows are very low intensity, and generally will not affect SMP sizing decisions.

  The spring snowmelt, on the other hand, is higher in suspended solids and hydrophobic elements, such as hydrocarbons, which can remain in the snowpack until the last five to ten percent of water leaves the snowpack (Marsalek, 1991). In addition, a large volume of runoff occurs over a comparatively short period of time (i.e., approximately two weeks). Most SMPs rely on settling to treat pollutants, and the pollutants carried in the spring snowmelt are more easily treated by these mechanisms. In addition, the large flow volume during this event may be the critical water quality design event in many cold regions.

- *Snowmelt runoff is influenced by the moisture content of the spring snowpack and soil moisture*

  Because of small snowmelt events that occur throughout the winter, losses through sublimation, and management practices such as hauling snow to other locations, the snowpack only contains a fraction of the moisture from the winter snowfall. Thus, the remaining moisture in the snowpack can be estimated by:

$$M=(0.1)S-L_1-L_2-L_3 \quad \text{Equation I.1}$$

Where:

M=Moisture in the Spring Snowpack (inches)
S=Annual Snowfall (inches)
L_1, L_2 and L_3 = Losses to Hauling, Sublimation and Winter Melt, respectively.

The volume of snow hauled off site can be determined based on available information on current plowing practices. In New York, sublimation to the atmosphere is not very important

The design examples in this section use a simple "rule of thumb" approach, to estimate winter snowmelt for simplicity (Table I.1). The method assumes that winter snowmelt is influenced primarily by temperature, as represented by the average daily temperature for January. One half of the snow (adjusted for plowing and sublimation) is assumed to melt during the winter in very cold regions (Average T_{max} <25degreesF) and 2/3 is assumed to melt during the winter in moderately cold regions (Average T_{max} <35degreesF). Winter snowmelt can be estimated using several methods, such as the simple degree-day method, or through more complex continuous modeling efforts.

Table I.1 Winter Snowmelt*

Adjusted Snowfall Moisture Equivalent	Winter Snowmelt (January T_{max}<25degreesF)	Winter Snowmelt (January T_{max}<35degreesF)
2"	1.0"	1.3"
4"	2.0"	2.7"
6"	3.0"	4.0"
8"	4.0"	5.3"
10"	5.0"	6.7"
12"	6.0"	8.0"

* Snowmelt occuring before the spring snowmelt event, based on the moisture content in the annual snowfall. The value in the first column is adjusted for losses due to sublimation and plowing off site.

Snowmelt is converted to runoff when the snowmelt rate exceeds the infiltration capacity of the soil. Although the rate of snowmelt is slow compared with rainfall events, snowmelt can cause significant runoff because of frozen soil conditions. The most important factors governing the volume of snowmelt runoff are the water content of the snowpack and the soil moisture content at the time the soil freezes (Granger et al., 1984). If the soil is relatively dry when it freezes, its permeability is retained. If, on the other hand, the soil is moist or saturated, the ice formed within the soil matrix acts as an impermeable layer, reducing infiltration. Section I.1.3 outlines a methodology for computing snowmelt runoff based on this principle.

- *No more than 5% of the* ***annual runoff volume*** *should bypass treatment during spring snowmelt* In order to treat 90% of the annual runoff volume, at least some of the spring snowmelt, on average, will go un-treated. In addition, large storm events will bypass treatment during warmer months. Limiting the volume that bypasses treatment during the spring snowmelt to 5% of the annual runoff volume allows for these large storm events to pass through the facility untreated, while retaining the 90% treatment goal.

  The resulting equation is:

  $T=(R_s-0.05R)A/12$ (Equation I.2)

  Where:

  T = Volume Treated (acre-feet)
  R_s = Snowmelt Runoff [See Section I.1.3]
  R = Annual Runoff Volume (inches) [See Section I.1.2]
  A = Area (acres)

- *SMPs can treat a volume greater than their normal size.*

  Snowmelt occurs over a long period of time, compared to storm events. Thus, the SMP does not have to treat the entire water quality treatment volume computed over twenty four hours, but over a week or more. As a result, the necessary water quality volume in the structure will be lower than the treatment volume. For this manual, we have assumed a volume of ½ of the value of the computed treatment volume (T) calculated in equation I.2.

  Thus,

  $WQ_v = \frac{1}{2} T$ (Equation I.3)

I.1.2 Base Criteria/ Annual Runoff

The base criterion is the widely-used, traditional water quality sizing rule. This criterion, originally developed for moderate climates, represents the minimum recommended water quality treatment volume. In this manual, the runoff from a one inch rainfall event is used as the base criteria. The basis behind this sizing criteria is that approximately 90% of the storms are treated using this event. This value may vary nationwide, depending on local historical rainfall frequency distribution data. However, the one inch storm is used as a simplifying assumption. The base criteria included in this manual is chosen because it incorporates impervious area in the sizing of urban SMPs, and modifications are used nationwide. The cold climate sizing modifications used in this manual may be applied to any base criteria, however.

Runoff for rain events can be determined based on the Simple Method (Schueler, 1987).

$r = p(.05+.9I)$ (Equation I.4)

Where: r = Event Rainfall Runoff (inches)
p = Event Precipitation (inches)
I = Impervious Area Fraction

Thus, the water quality volume for the base criteria can be determined by:

$WQ_v = (0.05+.9I)\ A/12$ (Equation I.5)

Where: WQ_v =Water Quality Volume (acre-feet)
I= Impervious Fraction
A=Area (acres)

The Simple Method can also be used to determine the annual runoff volume. An additional factor, P_j, is added because some storms do not cause runoff. Assume $P_j = 0.9$ (Schueler, 1987). Therefore, annual runoff volume from rain can be determined by:

$R = 0.9\ P\ (0.05+.9I)$ (Equation I.6)

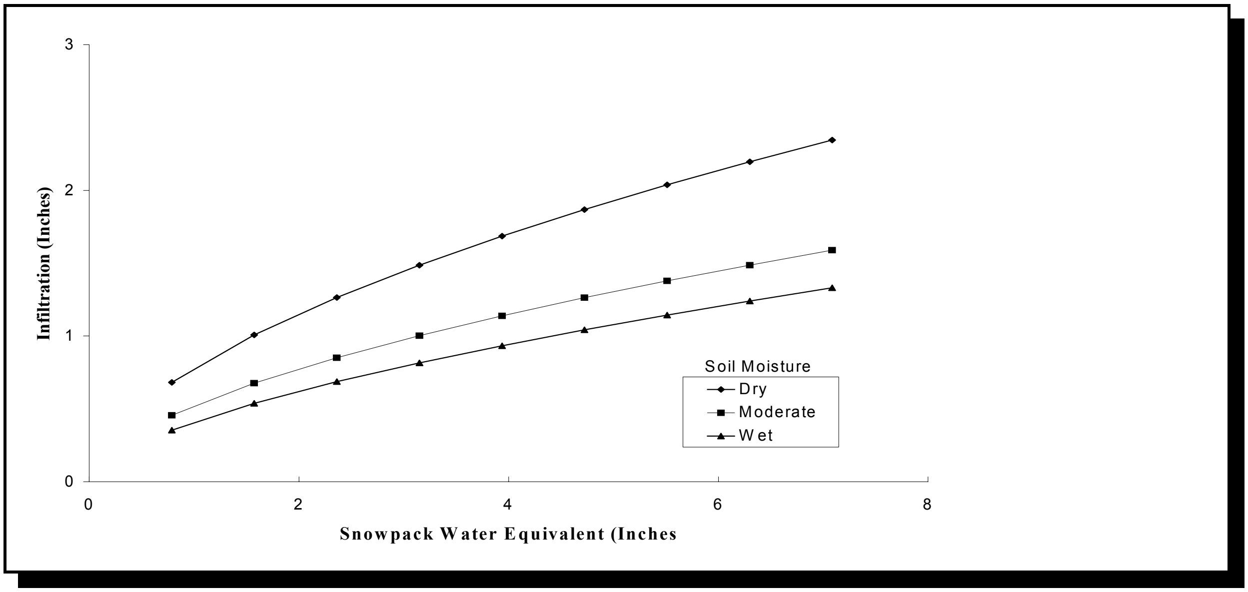
Where: R = Annual Runoff (inches)
P = Annual Rainfall (inches)

I.1.3 Calculating the Snowmelt Runoff

To complete water quality sizing, it is necessary to calculate the snowmelt runoff. Several methods are available, including complex modeling measures. For the water quality volume, however, simpler sizing methods can be used since the total water quality volume, not peak flow, is critical. One method, modified from Granger et al. (1984) is proposed here. Other methods can be used, particularly those adjusted to local conditions.

According to Granger et al. (1984) the infiltration into pervious soils is primarily based on the saturation of the soils prior to freezing. While saturated soils allow relatively little snowmelt to infiltrate, dry soils have a high capacity for infiltration. Thus, infiltration volumes vary between wet, moderate and dry soil conditions (Figure I.2).

Figure I.2 Snowmelt Infiltration Based on Soil Moisture



Assume also that impervious area produces 100% runoff. The actual percent of snowmelt converted to runoff from impervious areas such as roads and sidewalks may be less than 100% due to snow removal, deposition storage and sublimation. However, stockpiled areas adjacent to paved surfaces often exhibit increased runoff rates because of the high moisture content in the stockpiled snow (Buttle and Xu, 1988). This increased contribution from pervious areas off-sets the reduced runoff rates from cleared roads and sidewalks.

The resulting equation to calculate snowmelt runoff volume based on these assumptions is:

R_S = [runoff generated from the pervious areas] + [runoff from the impervious areas]

R_s = [(1 - I)(M-Inf)] + [(I)(1)(M)] (Equation I.7)

where:

R_S = Snowmelt Runoff

I = Impervious Fraction

M = Snowmelt (inches)

Inf = Infiltration (inches)

Sizing Example 1: Snowpack Treatment

Scenario:
50 Acre Watershed
40% Impervious Area
Average Annual Snowfall= 5'=60"
Average Daily Maximum January Temperature= 20 degrees
Average Annual Precipitation = 30"
20% of snowfall is hauled off site
Sublimation is not significant
Prewinter soil conditions: moderate moisture.

Sizing Example 1: Snowpack Treatment

Step 1: Determine if oversizing is necessary
Since the average annual precipitaiton is only ½ of average annual snowfall depth, oversizing is needed.

Step 2: Determine the annual losses from sublimation and snow plowing.
Since snow hauled off site is about 20% of annual snowfall, the loss from snow hauling, L_1, can be estimated by:

$L_1 = (0.2)(0.1)S$
Where: L_1 = Water equivalent lost to hauling snow off site (inches)
S = Annual snowfall (inches)
0.1 = Factor to convert snowfall to water equivalent

Therefore, the loss to snow hauling is equal to:
$L_1 = (0.2)(0.1)(60")$
$L_1 = 1.2"$

Since sublimation is negligible, $L_2 = 0$

Step 3: Determine the annual water equivalent loss from winter snowmelt events
Using the information in Step 2, the moisture equivalent in the snowpack remaining after hauling is equal to:

(60")0.1-1.2" = 4.8"

Substituting this value into Table I.1, and interpolating, find the volume lost to winter melt, L_3.

$L_3 = 2.4"$

Step 4: Calculate the final snowpack water equivalent, M
$M = (0.1)S-L_1-L_2-L_3$ (Equation I.1)
S = 60"
$L_1 = 1.2"$
$L_1 = 0"$
$L_3 = 2.4"$

Therefore, M = 2.4"

Step 5: Calculate the snowmelt runoff volume, R_s
$R_s = (1-I)(M-Inf)+ I(M)$ Equation I.7
M =2.4"
I =0.4
Inf =0.8" (From figure I.2; assume average moisture)
Therefore, R_S = 1.9"

Step 6: Determine the annual runoff volume, R
Use the Simple Method to calculate rainfall runoff:
R=0.9(0.05+0.9*I)P (Equation I.6)
I=0.4
P=30"
Therefore, R=11"

Sizing Example 1: Snowpack Treatment	
Step 7:	Determine the runoff to be treated Treatment, T should equal: $T = (R_s - 0.05*R)\ A/12$ (Equation I.2) R_s=1.9" R =11" A = 50 Acres Therefore, T=5.6 acre-feet
Step 8:	Size the SMP The volume treated by the base criteria would be: WQ_v=(.05+.9*.4)(1'/12")(50 acres) = 1.7 acre-feet (Equation I.5) For cold climates: WQ_v=1/2(T) = 2.8 acre-feet (Equation I.3) The cold climate sizing criteria is larger, and should be used to size the SMP.

I.1.4 Rain-on-Snow Events

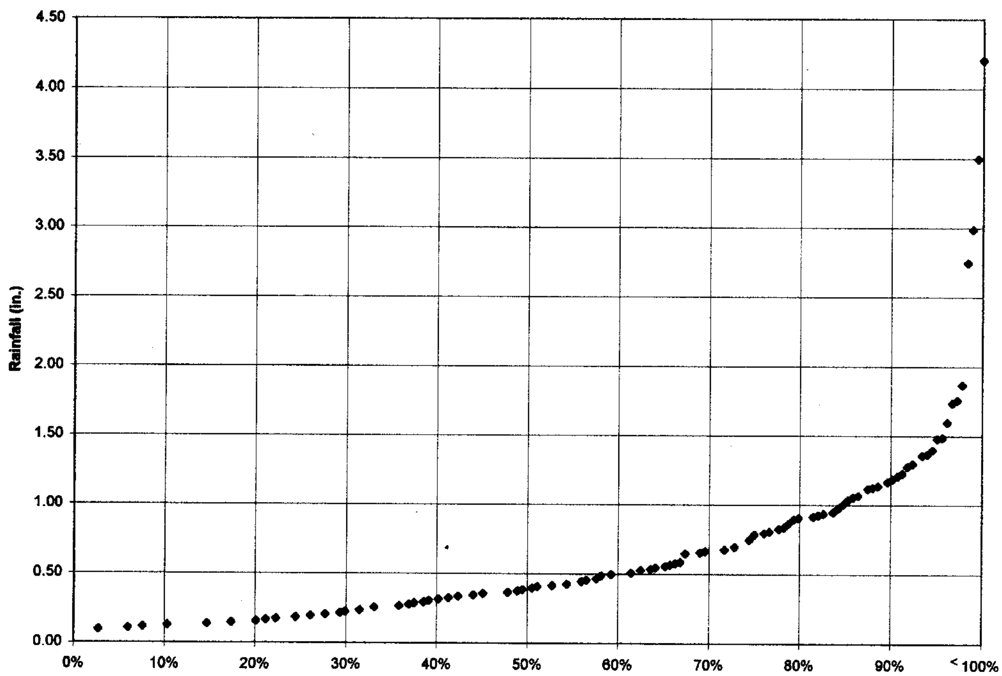
For water quality volume, an analysis of rain-on-snow events is important in coastal regions. In non-coastal regions, rain-on-snow events may occur annually but are not statistically of sufficient volume to affect water quality sizing, especially after snowpack size is considered. In coastal regions, on the other hand, flooding and annual snowmelt are often driven by rain-on-snow events (Zuzel et al., 1983). Nearly 100% of the rain from rain-on-snow events and rain immediately following the spring melt is converted to runoff (Bengtsson, 1990). Although the small rainfall events typically used for SMP water quality do not produce a significant amount of snowmelt (ACOE, 1956), runoff produced by these events is high because of frozen and saturated ground under snow cover.

Many water quality volume sizing rules are based on treating a certain frequency rainfall event, such as treating the 1-year, 24-hour rainfall event. The rationale for treating 90% of the pollutant load (Schueler, 1992) can also be applied to rain-on-snow events, as shown in the following example.

Sizing Example 2: Rain-on-Snow	
Step 1:	Develop a rain-on-snow data set. Find all the rainfall events that occur during snowy months. Rainfall from December through April were included. Please note that precipitation data includes both rainfall and snowfall, and only data from days without snowfall should be included. Exclude non-runoff-producing events (less than 0.1"). Some of these events may not actually occur while snow is on the ground, but they represent a fairly accurate estimate of these events.
Step 2:	Calculate a runoff distribution for rain-on-snow events Since rain-on-snow events contribute directly to runoff, the runoff distribution is the same as the precipitation distribution in Figure I.3.

Sizing Example 2: Rain-on-Snow

Figure I.3 Rainfall Distribution for Snowy Months



Step 3: Calculate a rainfall distribution for non-snow months.
Develop a distribution of rainfall for months where snow is not normally on the ground. The rainfall distribution for May through November is included in Figure I.4.

Sizing Example 2: Rain-on-Snow

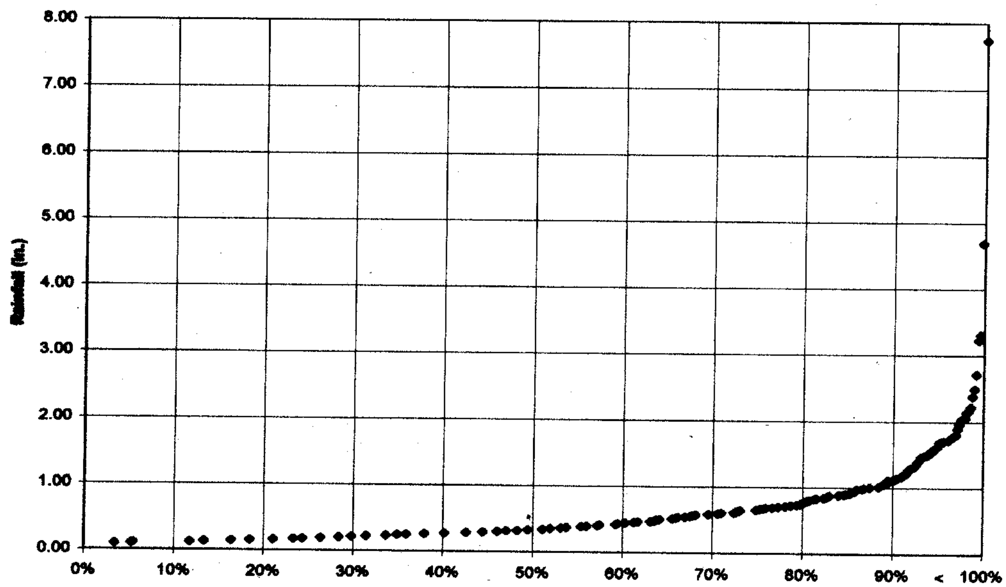


Figure I.4
Rainfall Distribution for Non-Snowy Months

Step 4: Calculate the runoff distribution for non-snow months.
Use a standard method to convert rainfall to runoff, particularly methods that are calibrated to local conditions. For this example, use the Simple Method. Runoff is calculated as:

$r=(0.05+0.9\ I)p$ (Equation I.4)

For this example, I=0.3 (30% impervious area), so:

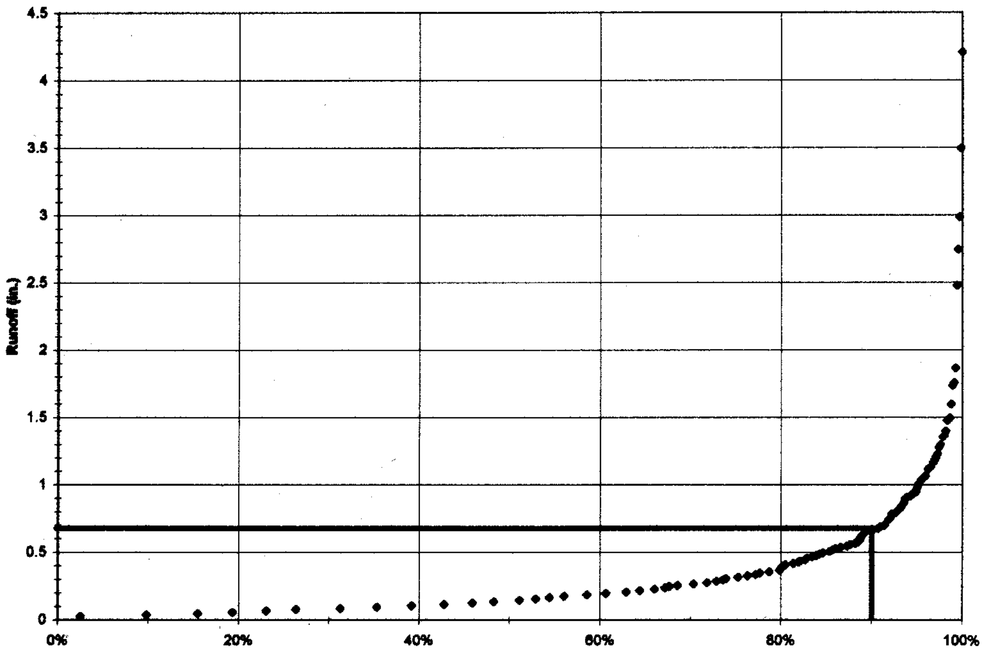
$r=0.32\ p$

The runoff distribution for non-snow months is calculated by multiplying the rainfall in Figure I.4 by 0.32.

Step 5: Combine the runoff distributions calculated in Steps 2 and 4 to produce an annual runoff distribution. The resulting runoff distribution (Figure I.5) will be used to calculate the water quality volume.

Sizing Example 2: Rain-on-Snow

Figure I.5 Annual Runoff Distribution



Step 6: Size the SMP.
In this case, use the 90% frequency runoff event (Figure I.4), or 0.65 watershed inches. This value is greater than the base criteria of 0.32 watershed inches (1" storm runoff). Therefore, the greater value is used.

WQ_v=(0.65 inches) (1 foot/12 inches) (50 acres) = 2.7 acre-feet

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