ISSUE PAPER "B"

PRECIPITATION FREQUENCY ANALYSIS AND USE

Date: January 6, 2005

To: Minnesota Stormwater Manual Sub-Committee

From: EOR and CWP

I. ISSUES

The focus of this issue paper is to explore the wealth of precipitation data (rainfall and snowfall) that exists within the state of Minnesota. The team's objective has been to sort through the available information and present information to the Stormwater Steering Committee for input into the Minnesota Stormwater Manual. This paper describes our findings and highlights issues for SSC to consider in the general areas of small storm precipitation and snowmelt for water quality sizing, and large storm sizing for conveyance and flood protection.

The following issues are addressed in this paper:

ISSUE #1: Which water quality sizing option is most appropriate for Minnesota? We present several options that form the basis for later discussion when Issue Paper "D" on Unified Sizing Criteria is presented in February.

ISSUE #2: Is it appropriate to use a single state-wide rainfall value for water quality sizing of Best Management Practices? We display state-wide data and the variation associated with it.

ISSUE #3: Should infiltration be incorporated into snowmelt volume computations? We present data that designers could use to account for snowmelt infiltration.

ISSUE #4: Which set of precipitation data should be used for sizing stormwater facilities in Minnesota? The EOR/CWP Team recognizes that an update of Minnesota climatology

data for precipitation as proposed by the National Oceanic and Atmospheric Administration (NOAA) is very much needed. Until such time as that update is available, it appears as though Technical Publication 40 (TP-40, Hershfield, 1961) will be the standard reference for frequency analysis. The SSC, however, should recognize that TP-40 does not reflect some of the changing climatologic conditions evident in Minnesota since the early 1960s.

ISSUE #5: Should the value of 7.2 inches of runoff on frozen soils be the basis for analysis of a rain on snowfall event in Minnesota? We present findings that support the Issue #4 finding.

II. BACKGROUND

Water Quality vs. Quantity Storms

Engineers design and size stormwater structures for different purposes (water quality, peak rate control, discharge volume control) and to different levels of risk. Therefore, when designing structures that manage the rate, volume and quality of stormwater runoff, characterization of both small storm hydrology and large storm hydrology is pertinent.

Small storm hydrology is typically most important in the design of water quality protection whereas large storm hydrology is used to evaluate quantity related design for control of stormwater runoff rates and/or volumes. Small storms are focused on for water quality because research has shown that pollution migration associated with frequently occurring events accounts for a large percentage of the annual load. This is because of the “first flush” phenomenon of early storm wash-off and the large number of events with frequent return intervals (see Section III). Rain events between 0.5 inches and 1.5 inches are responsible for about 75% of the runoff pollutant discharges (MPCA, 2000).

The goal of establishing a set of criteria for stormwater management practice sizing is to try to mimic the pre-development hydrologic regime, from flood flows to groundwater recharge and pollutant loads. While it is unrealistic to expect to achieve an exact replication of pre-development hydrographs and pollutographs, implementing a variety of management tools (both structural and nonstructural) and source controls can go a long way toward that goal.

Unified Sizing Criteria

Ultimately, the Stormwater Steering Committee will be presented with a proposal which, if adopted, would establish state-wide criteria for the sizing of stormwater management systems. To understand how the precipitation information would fit into the proposed sizing criteria, we have prepared an overview of the five criteria used in other states (Table 1). The purpose of a unified sizing criteria is to provide a framework for sizing stormwater practices to remove pollutants in stormwater, maintain recharge, prevent channel erosion, reduce over-bank flooding, and pass extreme floods. The importance of each of these criteria in the overall

management of stormwater is briefly summarized below. Sizing criteria proposed for Minnesota will be the subject of issue paper "D" for MSC review on Feb, 16, 2005.

Table 1: Overview of Proposed Unified Sizing Criteria for Stormwater

Sizing Criteria	Description of Statewide Sizing Criteria
Water Quality Volume	Capture some of the annual pollutant load, as measured by certain indicator pollutants (e.g., TSS or total phosphorus). This criterion is based on a specified runoff amount or rainfall volume.
Recharge	Infiltrate a portion of annual rainfall based on predevelopment soil hydrologic soil group and site impervious cover.
Channel Protection	Provide extended detention or over-control for some small, frequent storm (i.e., 9-mos to 2-yr) to protect channels from erosive velocities and unstable conditions.
Overbank Flood Protection	Control post development peak discharge rate to predevelopment rate for large (i.e., 10-yr, 25-yr) storm event.
Extreme Storm	Evaluate the effect an extreme event (e.g., 100-year storm) has on the stormwater facility, adjacent property, and downstream facilities and property.

The remainder of this paper discusses standardizing precipitation data (rainfall and snowfall) for eventual use by stormwater designers and managers as they apply the final sizing criteria to a specific site.

> **ISSUE:** The question of whether to create a Minnesota unified sizing criteria will be the topic at the February 16, 2005 Stormwater Steering Committee meeting. Background information that the MSC can use to assist in making a decision is presented in this Issue Paper.

III. WATER QUALITY EVENT: SMALL STORMS

Sizing BMPs for Water Quality

Water Quality Criteria Options

Traditional stormwater systems design has been based on protecting structures and property from the damaging effects caused by peak runoff rates generated by impervious surfaces. Rate, and rate control, continues to be an important feature in the larger storm criteria described above. Water quality sizing, however, is more closely tied to volume of stormwater runoff rather than rate. The reason for this is that the rate at which water enters a treatment facility is usually not critical to the treatment dynamics associated with the facility. Rather, the treatment effectiveness of most BMPs is a function of characteristics such as settling time and biologic uptake during quiescent periods, and achieving these depends upon exposing the runoff to an adequate volume that allows for these treatment systems to make a difference. Also, since pollution load is the product of flow volume times the pollutant concentration, the volume of water becomes more of a controlling factor than rate. The goal should be to capture and treat as much of the annual

average volume of runoff as feasible. Whether this is a realistic goal for Minnesota will be discussed as part of the Unified Sizing Criteria issue paper.

This leads to the question:

> ***Which rainfall event or runoff volume should be the basis of computing water quality volume?***

Six concepts are presented below:

<u>OPTION #1: 90% Rainfall Capture Rule:</u> The technical basis for the 90% capture rule is that the stormwater treatment practice is explicitly designed to capture and treat 90% of the annual rainfall from those rainfall events that produce runoff. Rainfalls less than 0.1" do not produce runoff and therefore were not included in the analysis. This option is based on rainfall depth, as opposed to runoff volume. As such, this sizing rule is not dependent on first flush (typically thought of as the first one-half inch of runoff from a site) assumptions.

Data used to generate the precipitation depth for the 90% capture rule are based on a regional analysis of the rainfall frequency spectrum. Figure 1 is an example of a rainfall frequency analysis from the Minneapolis/St. Paul Airport for the period of 1971 through 2000. The frequency curve illustrates that the 90th percentile rain event falls at the beginning of the "knee" of the curve. It is at this point that the theoretical optimization of treatment occurs. In other words, as you move past the "knee", the size of the treatment facility increases significantly with little increase in the total number of storms treated. The rainfall depth associated with the beginning of the knee of the curve (90th percentile) equates to 1.05 inches, while the true knee of the curve occurs at the 94th percentile, representing 1.4 inches of rainfall depth. Both of these values represent valid interpretations of the knee of the precipitation depth curve. Because the goal of the 90% capture rule is to select which the event that represents 90% of the annual cumulative precipitation depth (rather than 90% of the number of events) additional analysis is needed to determine which percentile event is most appropriate for application in Minnesota.

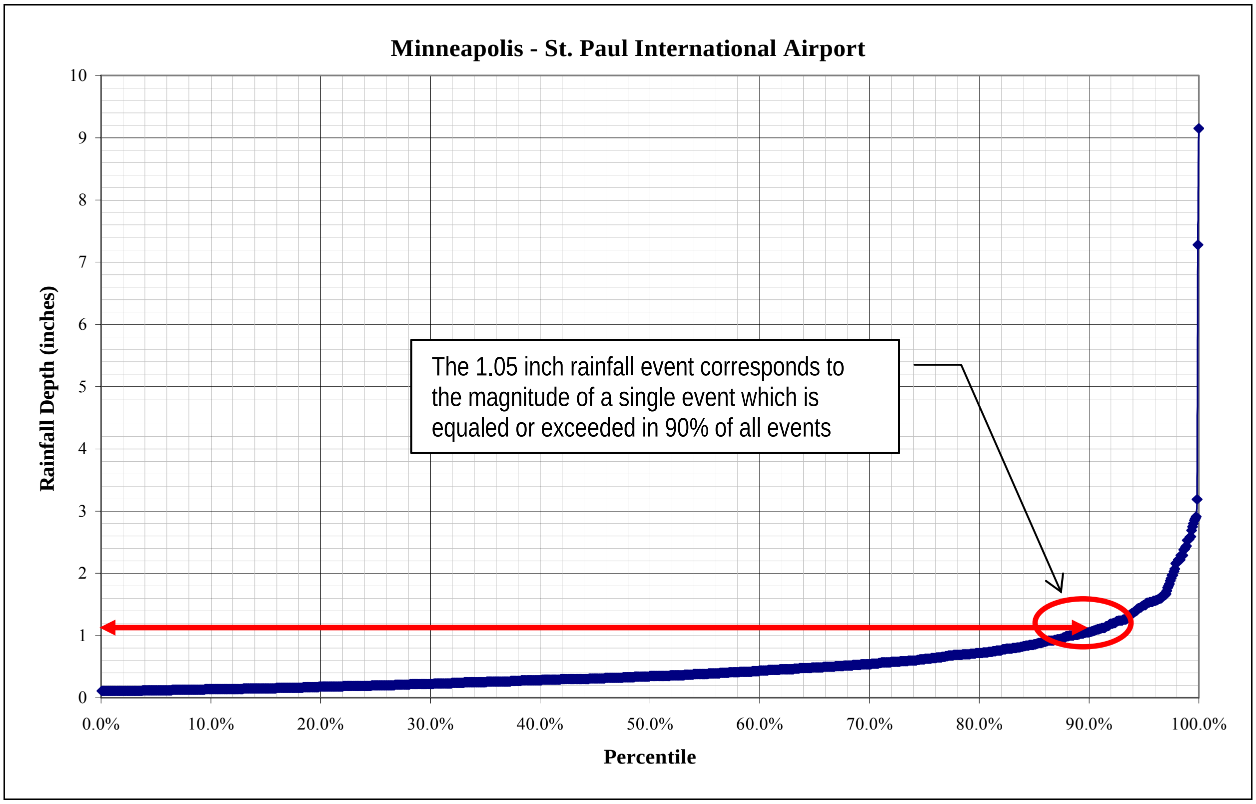

Figure 1: Precipitation Frequency for Minneapolis/St. Paul Airport (1971-2000)

The 1.05 inches of precipitation at the 90th percentile represents 67% of cumulative precipitation depth based on 30-years of record.

It is important to note that 1.05 inches of the precipitation depth of an individual storm which is in excess of 1.05 inches (the 90th percentile event) will still be managed by the BMP to some degree. For example, the total precipitation that was recorded at the Minneapolis/St. Paul airport over the past 30 years (not including snow records) totals 633 inches. The sum of all rainfall up to 1.05 inches, plus 1.05 inches of each precipitation event in excess of 1.05 inches totals 556 inches of precipitation. In total, 88% of the cumulative depth of rainfall (556/633) that occurred over the period of record used to assemble this data would be managed by a BMP sized to treat 1.05 inches. Further discussion of design features to assure proper treatment of large storms will be discussed in future issue papers.

A similar exercise of the 94th percentile rain event shows that 1.4 inches equates to 92% of the cumulative depth over the same 30-year period.

Finally, the general shape of the frequency curve will be similar from region to region; however, the location on the knee of the curve and the associated 90th percentile rainfall depth ranges between the 90th and 95th percentile event. For this reason, additional curves from areas of Minnesota are included in Appendix B.

OPTION #2 - One-inch times the site runoff coefficient: This approach applies an arbitrary rainfall depth that is approximately just under the 90th percentile of annual rainfall events for the six Minnesota stations that were analyzed. Runoff coefficient could either be standardized by a regulatory authority or left to the professional judgment of the site designers. The benefit to this approach is that it is a simplified analysis that produces results that are similar to the 90th capture option.

OPTION #3 - 1-yr, 24-hr frequency event: This approach applies the rainfall depth that has a 100% chance of being equaled or exceeded in any given year. Isopluvial curves representing the variation of this design event across Minnesota were generated and reported in the U.S. Weather Bureau's TP-40 (Figure 1-2, Appendix A). The value for the Twin Cities area equals 2.4 inches over a 24-hour period.

The Walker method recommends that the permanent pool in a water detention pond (also defined as water quality volume by the Center for Watershed Protection) be sized to contain 2.5 inches of rainfall (Walker, 1987). This is only slightly larger than the 1-year, 24 –hour event; therefore a separate recommendation of the Walker method was not included in this paper.

OPTION #4 - Half-inch rule: This runoff-based option is based on the first flush concept which states that the majority of the pollutants carried in urban runoff are carried in the first half-inch of runoff. The half-inch rule simply requires that one-half inch of runoff (not rainfall) be treated from the total area of the site. It is calculated by multiplying 0.5 inches by the total site area. While this method is simple to calculate, it is not a function of impervious cover, which removes an incentive to minimize the impervious cover at a site.

MPCA's General Permit for Construction Activities requires that wet detention basins contain a permanent storage volume (defined as "water quality volume" in Center for Watershed Protection publications) of 1800 cubic feet (c.f.) per acre of site for detention ponds. This computation is equal to the half-inch rule.

OPTION #5 - Half-inch per impervious area rule: This rule is a slight variant on the half-inch rule, where the water quality volume is defined as one-half inch times the impervious area of the site. The half-inch per impervious area rule provides an incentive to reduce impervious cover; however, the BMP size would be significantly less than the 90% rule and would not provide adequate treatment for a substantial portion of the annual pollutant load.

Presently, a modification of this half-inch rule is incorporated into the National Pollutant Discharge Elimination System (NPDES) General Permit for construction activity, issued by the Minnesota Pollution Control Agency (MPCA) on August 1, 2003. This permit defines the water quality volume as ½ inch of runoff from the new impervious surface. The NPDES General Permit also requires that this ½ inch of water quality volume is in addition to the 1800 c.f. per acre required for detention ponds (see Option #4). The ½ inch rule does directly apply to infiltration/filtration BMPs without additional water quality storage or treatment.

OPTION #6 – Pitt Method: Dr. Robert Pitt measured rainfall and pollutant distribution in a medium density residential area of Milwaukee, Wisconsin as part of the 1983 NURP program.

He found that rainfall between 0.5 inches and 1.5 inches are responsible for about 75% of the runoff pollutant discharges. MPCA recommends a value of 1.25 inches for the Upper Midwest, based on work by Dr. Pitt (MPCA, 2000).

Runoff at Example Site

The options presented above are based on either precipitation depth or runoff volume. The best method of comparing these two values would be to compute the water quality volume from a generic site. For this example we applied the above options to a single water quality event at a theoretical site with the following assumptions:

100-acre residential area
35% impervious surfaces
All impervious surfaces are "new"
Twin Cities precipitation data
Aggregate curve number = 72
Impervious surfaces curve number = 98
Pervious surfaces curve number = 49
Runoff coefficient = .30

Runoff volume was computed using SCS methodology in a HydroCAD model. Relative differences of the options outlined above are highlighted by their resulting range of water quality volumes. Results are summarized below in Table 2:

Table 2: Water Quality Sizing Option Comparison; 100-acre SFR development

Option	Description	Rainfall Depth	Runoff Depth	Water Quality Volume
1a	90% of annual rainfall events	1.05"		2.6 ac-ft
1b	94% of annual rainfall events	1.4"		3.3 ac-ft
2	1" times Runoff Coefficient	1"		2.5 ac-ft
3	1-yr/24-hour storm	2.4"		6.4 ac-ft
4	½" runoff over entire site (1800 c.f. per acre)		½"	4.2 ac-ft
5	½" runoff over impervious surfaces		½"	1.5 ac-ft
6	Pitt method	1.25"		3.0 ac-ft

This example is provided for purposes of comparing the water quality volume from a theoretical residential development site. Future issue papers, including "G": Cold Climate Considerations, "D": Unified Sizing Criteria; and "I": Engineering Specifications will discuss in greater detail considerations involved in applying this precipitation data to specific Best Management Practices.

MPCA General Permit for Construction Activities

As described above, the MPCA Permit for Construction Activities divides water quality volume into two components: permanent pool plus live storage. For a wet detention basin (Part III.C.1 of the permit) the basin must have a permanent volume of 1800 cubic feet (approximately ½ inch) of storage below the outlet pipe (dead storage) for each acre drained to the basin. The basins are also required to release the water quality volume (live storage) of ½ inch of runoff from the new impervious surfaces at no more than 5.66 cubic feet per second per acre of surface area of the pond. This corresponds to a combination of option #4 and option #5 where a certain volume is captured as dead storage and the live storage is determined by the amount of impervious surface. When designing an infiltration or filtration system, the water quality volume is ½ inch of runoff from new impervious surfaces. This approach can serve to create an inventive to reduce the impervious surface and thereby reduce the amount of live storage required by this permit.

> **ISSUE #1:** Which rainfall based water quality sizing option is most appropriate for Minnesota?

Minnesota Rainfall Analysis

Rainfall Analysis

The next question investigated by the team was:

> ***Is there a regional variation in rainfall depth?***

The rainfall frequency analysis was expanded statewide for six locations to determine the 90^{th} percentile annual rainfall depth for all of Minnesota. The six stations analyzed were Minneapolis/St. Paul International Airport, St. Cloud Airport, Rochester Airport, Cloquet, Itasca, and the Lamberton SW Experiment Station (shown in Figure 2).

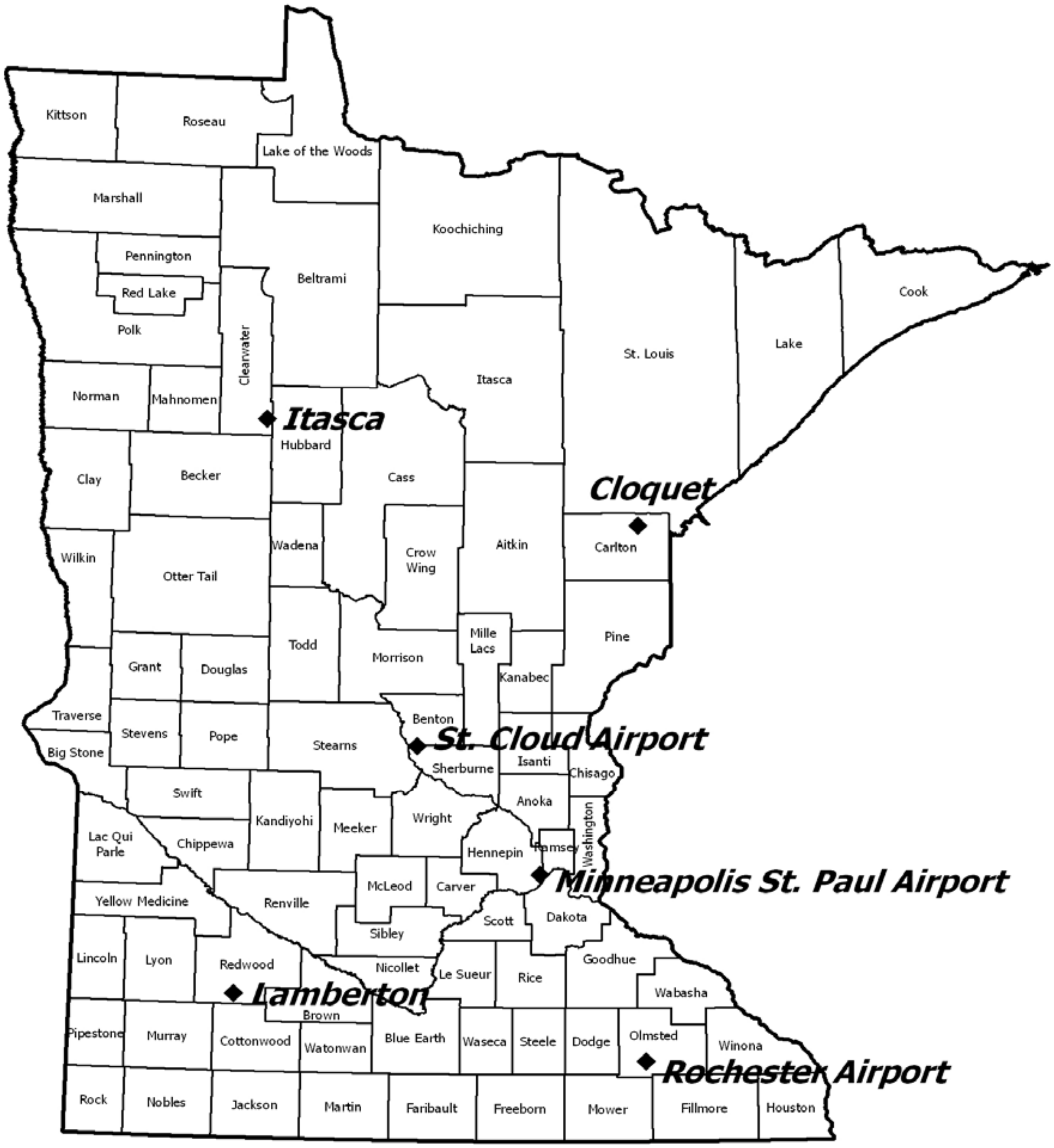

Figure 2: Precipitation Frequency Analysis-Station Locations

The following describes the protocol for this analysis:

- Daily precipitation and snowfall record were obtained from the MN State Climatology Group (http://climate.umn.edu/doc/historical.htm).

- The number of stations analyzed was limited to six and selected to provide representative geographical coverage of the state. Selected stations also had at least 30 years of daily precipitation record available (1971-2000).

- The analysis was conducted under two scenarios: (1) evaluating the total precipitation (rain and snow) record and (2) evaluating the rainfall record only. The second analysis was performed because, while snowfall is a part of the precipitation record, it does not produce runoff immediately. (Snowmelt runoff is addressed in a later section.) Thus, the 90th percentile storm event can be calculated by eliminating snowfall from the precipitation record. A simplified assumption was used for the second analysis (rainfall only), whereby any day that had recorded snowfall was discarded from the analysis. This analysis reduces the total number of records from which the frequency analysis was developed.

For both analyses, all precipitation depths of 0.1 inches or less were discarded. This is based on the assumption that the majority of precipitation events that are 0.1 inches or less generally will not generate a measurable amount of runoff. While the actual depth may vary from site to site, 0.1 inches is frequently used as the cutoff point in rainfall

- frequency analysis in Minnesota (ex. USDA-SCS Hydrology Guide for Minnesota).

The results of the frequency and volume analysis for the 90th percentile at six stations are summarized in the following Tables 3 and 4. Graphs illustrating the results of each individual station are provided in Appendix B.

Table 3. Summary of Precipitation Frequency Analysis

Location (MN Station No.)	Region of State	Period of Record	90% Rainfall w/ snow	90% Rainfall w/o snow	95% Rainfall w/o snow
Mpls./St. Paul Airport (215435)	East Central	1971-2000	0.98"	1.05"	1.49"
St. Cloud Airport (217294)	Central	1971-2004	1.00"	1.07"	1.39"
Rochester (217004)	Southeast	1971-2000	1.01"	1.12"	1.55"
Cloquet (211630)	Northeast	1971-2000	1.01"	1.13"	1.47"
Itasca (214106)	Northwest	1971-2000	0.95"	1.05"	1.42"
Lamberton (214546)	Southwest	1971-2000	1.03"	1.09"	1.48"
Average			1.00	1.09	1.46
Range			+/- 0.04	+/- 0.04	+/- 0.08

Review of the station graphs (Appendix B) reveals surprising consistency among the six stations chosen to represent regional precipitation across the State. As illustrated in Table 3, the rainfall depth (last columns) which represents 90% and 95% of runoff producing events was approximately 1.09 inches (+/- 0.04 inches) and 1.46 inches (+/- 0.08 inches) respectively.

Data from each station was analyzed to determine what percentage of rainfall would be treated by a BMP if the water quality sizing was based on Option #1:
Using the technique following in Section III, Option #1, the data was analyzed to determine the total precipitation depth related to the 90th percentile rainfall event for each of these 6 Minnesota stations. Table 4 following is a summary of the results:

Table 4. Percentage of Cumulative Rainfall Depth Contained in 90% of all Rainfall Events

Location (MN Station No.)	90% Rainfall Depth w/o snow	% Total Cumulative Rainfall Depth in BMP
Mpls./St. Paul Airport (215435)	1.05”	88
St. Cloud Airport (217294)	1.07”	89
Rochester (217004)	1.12”	88
Cloquet (211630)	1.13”	88
Itasca (214106)	1.05"	87
Lamberton (214546)	1.09”	88
Average	1.09”	88
Range	+/- 0.04	+/- 1

> **<u>ISSUE #2:</u>** Is it appropriate to use a single state-wide rainfall value for water quality sizing of Best Management Practices? The small amount of areal variability shown in Table 3 supports a single state-wide value.

<u>Snowmelt Analysis</u>

The CWP’s *Stormwater BMP Design Supplement for Cold Climates* (Caraco and Claytor, 1997) states:

> “BMPs should also be sized to treat the spring snowmelt runoff event.”

Special consideration is essential for snowmelt runoff in Minnesota. The question to answer is:

> ***What is the best method to determine the volume of snowmelt that must be treated by a site Best Management Practice?***

Snowmelt occurs throughout the winter in small, low-flow events and generally will not affect BMP sizing decisions. The spring snowmelt, on the other hand, can be the single largest water and pollutant loading event in the year. Most BMPs do not address the volume of meltwater nor its poor quality. Instead, they are typically designed to reduce peak flow during rainfall and rely mostly on settling to treat pollutants, which is not

always the way to treat soluble pollutants that can be a significant problem related to spring snowmelt.

In Minnesota, this spring snowmelt occurs over a comparatively short period of time (i.e., approximately two weeks) in March or April of each year – depending on the region of the state. The large flow volume during this event may be the critical water quality design event in much of the state. BMPs, therefore, should be sized to address the volume of runoff from this spring snowmelt event.

The goal of treating 90% of the annual pollutant load can also be applied to snowmelt runoff and rain-on-snow events. Cold climate sizing could be greater than rainfall-based criteria sizing when snowfall represents more than 10% of total annual precipitation (Caraco and Claytor, 1997), as occurs in all of Minnesota.

The "Mean Annual Snowfall" Figure C-1 in Appendix C illustrates that this rule applies to all parts of Minnesota, therefore, presentation of the procedure used to estimate Minnesota's average annual snow depth follows. Other procedures for estimating the water quality treatment volume based on annual snow depth are described in the CWP (Caraco and Claytor, 1997), which is available as a free download from the CWP web page at http://www.cwp.org/cold-climates.htm.

A review of snowmelt research, available data, and current treatment standards was conducted to evaluate and devise an appropriate snowmelt volume recommendation for Minnesota. Snowmelt analysis is typically reviewed over a 10-day period. The average annual date that this snowmelt is expected to conclude is available from the Minnesota State Climatology Office and is shown in Figure C-2.

The average snowmelt volume was estimated using the following equation:

Average snowmelt volume (depth/unit area)	=	Average snow pack depth at the initiation of the snowmelt period	x	Typical snow pack water equivalent at time of melt	-	Estimated infiltration volume likely to occur during a 10-day melt period.

Due to the range in snowfall that typically occurs in Minnesota (lowest in the southwest and highest in the northeast), it is not feasible to establish a standard value for use in computing the volume of snowmelt. Therefore a series of maps have been prepared that will allow the designer to focus on their region of the state to determine both the average depth of snowpack existing at the start of spring snowmelt, plus the water content of the snowpack during the month of March (Figure C-3). These maps are contained in Appendix C.

The last part of this equation allows designers to subtract winter infiltration from the volume of snow that would melt and be contained by the site BMP. This leads to the question:

Should designers assume that a portion of the snowpack will infiltrate?

Research in cold climates by Baker (1997), Buttle and Xu (1988), Bengtsson (1981), Dunne and Black (1971), Granger *et al.* (1984) and Novotny (1988) shows that infiltration does in fact occur during a melt at volumes that vary considerably depending upon multiple factors including: moisture content of the snow pack, soil moisture content at the time the soil froze, plowing, sublimation, vegetative cover, soil properties, and other snowpack features. For example, snowmelt investigations by Granger *et al*. (1984) took measurements from 90 sites, located in Saskatchewan Canada, representing a wide range of land use, soil textures, and climatic conditions. From this work (Figure 3 reproduced below), general findings showed that even under conservative conditions (wet soils, ~35% moisture content, at the time of freeze) about 0.4 inches of water infiltrated during the melt period from a one-foot snowpack with a 10% moisture content (1.2 inches of equivalent moisture) in areas with pervious cover. This would not apply to impervious surfaces.

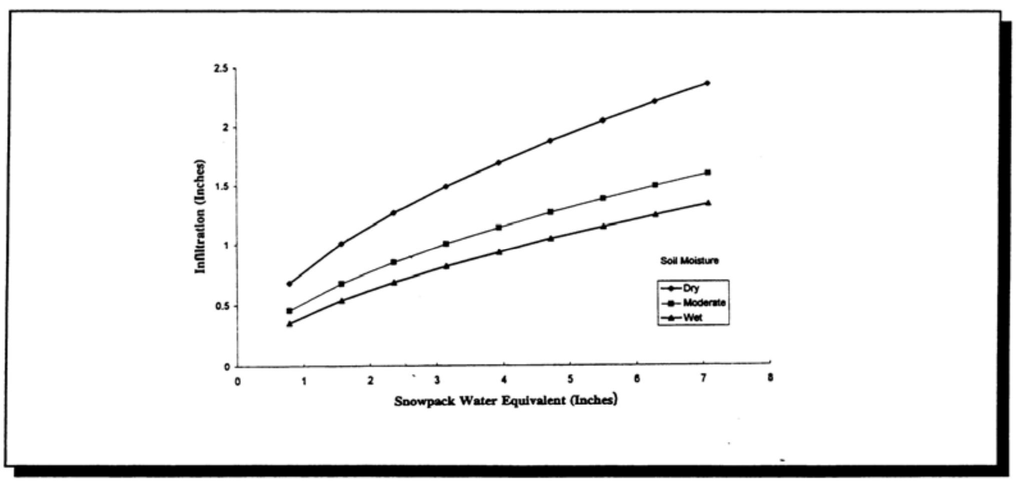

Figure 3: Snowmelt Infiltration Based on Soil Moisture (Granger et al., 1984)

> **<u>ISSUE #3:</u>** Should infiltration be incorporated into snowmelt volume computations? Sufficient studies exist to support infiltration of snowmelt.

Sample Water Quality Volume Computation

For purposes of determining the volume of runoff or snowmelt that should be managed by the site (BMPs), designers must make two water quality volume computations: snowmelt and rainfall runoff. The BMP would then be sized for the larger of the two results. Areas with low snowfall will likely find that the rainfall based computations are

the larger value, while those areas with greater snowpack will find that snowmelt is larger.

Snowmelt: Using data from St. Paul approximations above (Figures C-2 and C-3) and the land use characteristics of the previous example, the average snowmelt runoff volume (Vs) can be estimated as follows:

Vs = (7" depth)(10 % moisture content)(100 acres)(1/12) – (0.4" infiltrated)(65 acres)(1/12)
Vs = 3.7 acre-feet

Rainfall: Using the results from the various Options in Table 2, the water quality volume from rainfall runoff (Vr) falls in the following range, depending upon which option is chosen:

Vr = 1.5 to 6.4 acre-feet

Comparing the snowmelt runoff value of 3.7 acre-feet with the various options for rainfall runoff (1.5 to 6.4 acre-feet) exemplifies the importance in selecting a water quality sizing option. In some cases snowmelt would be selected as the design parameter for computing the volume, whereas other options lead to rainfall as the critical design parameter. More discussion on the various options for selection criteria will occur when Issue Paper "D" on Unified Sizing Criteria is presented to the MSC.

Additional Information
More snowfall and snowmelt data can be found in the following report sponsored by the Minnesota Department of Transportation:

http://www.climate.umn.edu/snow_fence/Components/SWE/marswe.htm#

IV. LARGER STORMS: WATER QUANTITY EVENTS

Design engineers typically make use of precipitation exceedance probability to calculate the risks of design failure for channel protection, over-bank flooding, and extreme flooding. A storm magnitude of a return period (T) has the probability of being equaled or exceeded in any given year is equal to 1/T. For example a "100-year" event has a chance of being equaled or exceeded in *any* given year of 1/100 or 0.01 or 1%.

Precipitation Trends in Minnesota

According to Dr. Mark Seeley, University of Minnesota, sufficient data exist to support recently observed trends of climate change in Minnesota. Notable changes over the last 30 years include:

- warmer winters
- higher minimum temperatures
- increased frequency of tropical dew points
- greater annual precipitation with:
  - more snowfall
  - more frequent heavy rainstorm events
  - more days with rain

The increasing precipitation and snowfall trends (illustrated in Figures D-1 and D-2 of Appendix D) suggest the need for an updated Minnesota precipitation study.

NOAA has proposed a comprehensive precipitation analysis for the upper Midwest, including Minnesota. Its analysis would follow procedures used in the Ohio Valley. As of this November 2004, the NOAA study has not yet been funded.

Best Available Data for Minnesota

The most commonly referenced precipitation frequency study in Minnesota is the U.S. Weather Bureau's 1961 Technical Publication 40 (TP-40, Hershfield, 1961). Although the document is viewed by some as outdated and not reflective of the climatic changes noted in the previous section, and complaints are made that the design event magnitudes underestimate recent trends, the document remains the leading reference for design purposes.

Later work by others to update, test and/or validate the TP-40 findings (see Appendix E for comparison and reference information) include precipitation frequency studies conducted by the Midwest Climate Center (Huff and Angels' 1992 Bulletin 71), Metropolitan Council's Precipitation Frequency Analysis for the Twin Cities Metropolitan Area (study updates in 1984, 1989, and 1995), and Mn/DOT's November 1998 study (Intensity of Extreme Rainfall over Minnesota) in coordination with Richard Skaggs from the University of Minnesota. Issues regarding the studies are summarized in Appendix E.

> ***Should TP-40 continue to be used as the basis for sizing of stormwater systems, or should designers use the more recent work by the Midwest Climate Center?***

Despite existing doubts regarding the adequacy of TP-40, use of the newer studies has not taken hold. This is in part because the studies are limited in scope (not appropriate for the entire state), viewed as being carried out by a possibly biased source, or questions and uncertainty about the various study methods and statistical analysis techniques

remain. Therefore, until a large enough study, by an independent source (unbiased group or agency) is conducted, TP-40 will likely remain the dominant source for Minnesota precipitation magnitude and return frequency.

Isopluvial maps showing precipitation depths corresponding to the following 24-hour return events over the entire state from TP-40 are included (Appendix A).

- 1-Year design storm
- 2-Year design storm
- 5-Year design storm
- 10-Year design storm
- 25-Year design storm
- 100-Year design storm

The complete TP-40 document is available on line through the National Weather Service website at: http://www.nws.noaa.gov/ohd/hdsc/temp_currentpf.htm#TP40 .

For comparison, isopluvial precipitation frequency maps corresponding to the 24-hr return events given by Bulletin 71 are included in Appendix F.

- 2-Year design storm
- 5-Year design storm
- 10-Year design storm
- 25-Year design storm
- 100-Year design storm

In addition to the frequency analysis studies, an impressive source of historical (and current) precipitation data for Minnesota exists at the Minnesota Climatology Working Group website at: http://www.climate.umn.edu/ . Additional data sources are listed in Appendix G.

> **ISSUE #4:** Which set of precipitation data should be used for sizing stormwater facilities in Minnesota? The variations between TP-40 and the Midwest Atlas, and the need to reflect changing climatic conditions may suggest that the MSC support the study proposed by NOAA.

Rainfall Distribution

Storm distribution is a measure of how the intensity of rainfall varies over a given period of time. For example, in a given 24 hour period, a certain amount of rainfall is measured. Rainfall distribution describes how that rain fell over that 24 hour period; that is,, whether the precipitation occurred over a 1 hour period or over the entire 24 hours.

The standard rainfall distribution used in Minnesota is the Natural Resource Conservation Services (NRCS) recommended Type II rainfall distribution for urban areas (Figure 4).

This is a synthetic event, created by the NRCS, of a 24-hour duration rainfall event in which the peak intensity falls in the center of the event (at 12 hours).

The advantage of using the synthetic event is that it is appropriate for determining both peak runoff rate and runoff volume. While a 24-hour event is longer than necessary to determine peak runoff rates, the synthetic distribution has a short segment of intense rainfall nested into it. Drawbacks of using a synthetic event are that they rarely occur in nature and are difficult to explain.

Further information regarding rainfall distribution can be found in Minnesota Department of Transportations Drainage Manual and Hydrology Guide for Minnesota prepared by the Soil Conservation Service (now the NRCS).

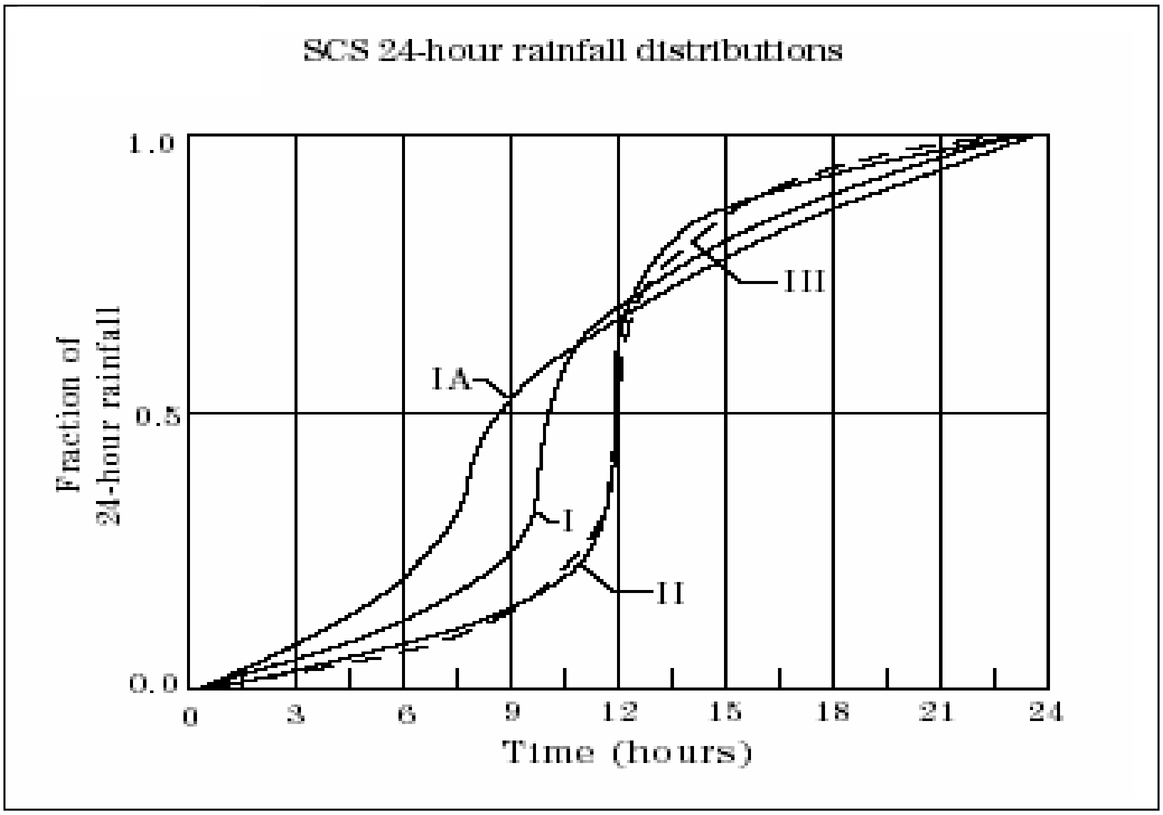

Figure 4: SCS Rainfall Distributions (from NRSC TR-55)

Rainfall on Snow in Minnesota

Because a spring melt event generates a large volume of water over an extended period of time, evaluation of the snowmelt event for channel protection and over-bank flood protection is generally not as important as the extreme event analysis. This warrants

attention because of the possibility that a major melt flooding event could, and sometimes does, happen somewhere in the state.

How should the volume of rainfall plus snow depth be computed?

Extreme Flood Event

Conservative design for extreme storms can be driven by either a peak rate or volume event depending upon multiple hydraulic factors. Therefore, depending upon the situation, either the 100-yr, 24-hr rain event or the 100-yr, 10-day snowmelt runoff event can result in more extreme conditions. For this reason, both events should be analyzed in to determine conservative sizing criteria.

Protocol for simulation of the 100-yr, 24-hr rainfall event is well established in Minnesota. Commonly reported high water elevations (HWL) and peak discharge rates are the result of storm magnitudes given by the TP-40 frequency analysis and the SCS Type II storm distribution. The MSC should consider waiting until a statewide reassessment of precipitation frequency is conducted before changing this standard.

Protocol has also been established for the analysis of HWL and peak discharge resulting from a 7.2 inch 100-yr, 10-day snowmelt runoff event. However, this event (unlike the 100-yr, 24-hr rainfall runoff event) has received a considerable amount of criticism. Although not well documented, it is thought that the theoretical snowmelt event was devised by assuming a six inch 100-yr, 24-hr rainfall event during a 10-day melt period in which one foot of snow (with a 10% moisture content) exists at the onset. A typical assumption accompanying the event is that of completely frozen ground (no infiltration) during the melt period for which the result is 100% delivery of volumes.

Criticisms of this event have included the following points.

- The probability of a six inch rainfall in March (when the melt typically occurs) is less than that of a 100-yr return frequency. Note: the largest recorded precipitation event occurring at the Minneapolis/St. Paul International Airport (station 215435) in March between 1891 and 2001 equaled only 4.75 inches (http://mcc.sws.uiuc.edu/Precip/MN/215435_psum.html). Perhaps the 4.75" of rainfall should be added to a theoretical one-foot melt at 10% moisture equivalent, for a total water equivalent of 5.95 inches.

- No infiltration during the entire 10 day melt (warming) period is unrealistic.

ISSUE #5: Should the value of 7.2 inches of runoff on frozen soils be the basis for analysis of a rain on snowfall event in Minnesota?

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