ISSUE PAPER "D"

Unified Stormwater Sizing Criteria for Minnesota V.6 Final

Date: February 22, 2005

To: Minnesota Stormwater Manual Sub-Committee

From: CWP and EOR

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PREFACE

This version of the Unified Sizing Criteria Issue Paper was edited to reflect he discussion that occurred at the February 16, 2005 Manual Sub-Committee meeting. Some of the information requested or deemed to be needed to supplement this paper was not put into this version because of the time required. Instead it will be incorporated into the draft Manual for later review.

I. EXECUTIVE SUMMARY

The last decade has seen several fundamental shifts in how stormwater runoff is managed at development sites. These shifts are reflected in the trend toward expanded stormwater sizing criteria contained in recent state-wide design manuals and rules, including Wisconsin (2004), New Jersey (2004), Washington (2004), Pennsylvania (2005), New York (2003), Vermont (2002) and Maryland (2000). The six major shifts include:

1. A greater emphasis on on-site runoff reduction using innovative site design practices;
2. A unified approach to manage stormwater employing four to five defined sizing criteria;
3. Increased runoff volume requirements for water quality treatment and pollutant removal;
4. New requirements that promote greater infiltration and groundwater recharge at the site;
5. New storage and release requirements to protect urban stream channels from severe erosion; and
6. Explicit numeric guidance on how to appropriately use modeling tools to size stormwater management practices.

While many states have embraced these shifts in stormwater management, each has taken uniquely different approaches in how they are implemented on the ground. This issue paper reviews the following topics to address these major shifts in stormwater management in the State of Minnesota:

1. Overview of Unified Stormwater Sizing Framework
2. Recharge and Infiltration Criteria
3. Water Quality Criteria
4. Channel Protection Criteria

5. Overbank Flood Criteria
6. Extreme Storm Criteria
7. Modeling Assumptions of Development Scenarios

In addition, four detailed technical appendices are provided that review better site design (BSD) techniques, hydrologic modeling assumptions for design, specific recommendations for redevelopment sites, and guidance on performing acceptable downstream analysis for overbank and extreme flood control.

The main body of the issue paper outlines the current technical basis for each of the sizing criteria, examines what is currently required in Minnesota, evaluates alternative sizing criteria utilized in other communities, explores the pros and cons of each, and recommends a final criteria for potential inclusion in the manual. The recommended Minnesota stormwater sizing criteria are summarized in Table 1.

Our recommendations are based on five key factors that examine how each proposed criteria would be implemented in the real world. An ideal stormwater sizing criteria will:

1. Perform Effectively: Manage enough runoff volume to actually solve the stormwater problem it is intended to address.

2. Perform Efficiently: Manage just enough runoff volume to address the problem, but not over-control it. More storage is not always better, and can greatly increase construction costs. In most cases, the cost of a particular sizing criteria is a direct function of the storage volume required for a best management practice (Brown and Schueler, 1997). This paper models the impact of sizing criteria options on BMP storage volumes for a range of common development scenarios (Section VIII).

3. Be Simple to Administer: The criteria should be understandable, relatively easy to calculate with current hydrologic models, and workable over a range of development conditions and intensities. In addition, criteria should be clear and straightforward to avoid needless disputes between design engineers and plan reviewers when they are applied to development sites.

4. Promote Better Site Design: The criteria should be structured in a manner so that designers have real incentives to reduce storage volumes (and costs) by minimizing site impervious cover and applying better site design techniques. More detail on this approach will be provided in the forthcoming Issue Paper F.

5. Be Flexible to Respond to Special Site and Watershed Conditions. A "one size fits all" approach should be avoided in a state-wide stormwater management approach. Criteria need to be flexible (expanded or reduced) to account for unique water resource objectives, and to be modified or eliminated in certain development situations where they are inappropriate or infeasible.

This paper outlines recommendations for the ultimate adoption of a unified stormwater sizing criteria for Minnesota that best address the five factors above. The Stormwater Steering Committee has at least three mechanisms to implement the recommended sizing criteria, within the context of the 2003 MPCA General Permit (GP) for construction:

1. Adopt more stringent local criteria adopted as part of a Phase II NPDES MS4 post-construction storm water ordinance, watershed organization regulation and/or local drainage/floodplain ordinance;

2. Present supplemental state guidance to interpret or clarify existing criteria contained in the MPCA 2003 General Permit; and
3. Recommend changes in the Construction General Permit when it is renewed in 2008.

The initial recommendations for unified stormwater sizing criteria are summarized in Table 1.

Table 1: Recommended Stormwater Sizing Criteria for the Minnesota Stormwater Manual	
Criteria	**Recommendation**
Water Quality (WQ_v)	Retain the basic MPCA Rule contained in the 2003 Construction General Permit, with three important clarifications and while maintaining the recommended discharge rate requirement of 5.66 cfs/acre of pond surface as a maximum allowable rate: • Recommend an average of 12 hours of detention for pond BMPs with an acceptably sized and protected outlet (orifice) (design guidance to be contained in Volume 1 and Appendix B of the Manual); • Require a minimum volume of pre-treatment needed to protect non-pond BMPs from clogging and increase their longevity, which can be achieved through the addition of 0.10 watershed inches of dead storage and/or the installation of a locally approved pre-treatment practice; and • Recommend a minimum water quality storage volume of 0.2 watershed inches for non-pond BMPs, regardless of site impervious cover. Issue Paper E will recommend local adjustments to the WQv to achieve greater pollutant removal for sensitive lakes, trout streams or vulnerable wetlands. Guidance for local pollution loading rates used in these calculations will be contained in the Manual. For future program revisions beyond the scope of this Manual, the MPCA should consider implementation of TP Loading Calculations for phosphorus sensitive lakes, so that phosphorus accounting rules and load estimation methods can be further refined and tested.

Recharge (Re_v)	The recommended approach is to gradually introduce a recharge volume requirement for the state of Minnesota. To implement this, the State should: Offer stormwater credits for better site design techniques to promote recharge as a local option Present adjusted annual recharge volume requirements as a second local method to promote recharge, with methodology presented in an accompanying box in the Manual text. **Infiltration and recharge of polluted stormwater runoff is not always desirable at all development sites. Therefore, most communities qualify their recharge and/or infiltration requirements to reflect special site conditions, protect groundwater quality, and avoid common nuisance issues. For example, communities may require:** **Some form of pretreatment of stormwater runoff prior to infiltration for some land cover types and pollution source areas (e.g. parking lots)** **Recharge be restricted or prohibited at specific industrial, commercial and transport-related operations known to be stormwater hotspots. Issue Paper G will help define the range and type of development sites that will be classified as stormwater hotspots within Minnesota.** **Recharge be prohibited or otherwise restricted within the vicinity of sole source groundwater aquifers, wellhead protection areas, individual wells, structures and basins** **Recharge be avoided within certain geological zones such as karst and bedrock, and adjacent to steep or unstable slopes.** Recharge be reduced or waived for minor redevelopment projects that have previously compacted soil structures. For future program revisions beyond the scope of this Manual, the MPCA should consider imposing an annual recharge volume requirement statewide and work to develop an effective site-based recharge spreadsheet and design tool to implement the requirement.

Channel Protection (Cp_v)	The Manual should present effective options for protecting Minnesota's stream channels from bank erosion. It should discourage the use of two-year peak discharge control as an ineffective channel protection measure. Communities that provide effective channel protection measures are encouraged to drop their two-year peak discharge requirement (if they currently require 10-year peak discharge control for overbank flooding) as they adopt/revise local post-construction stormwater control ordinances. The State should recommend 24 hour extended detention of the 1-year, 24-hour design storm event as the best current channel protection option. Figure 1 illustrates how erosive flow can be avoided by this change from the 2-year peak criterion currently in common use. Alternatively, the recharge of all volume increases from pre- to post-development for a 2-year, 24-hour event may also be an effective channel protection measure and may be considered an option for trout stream protection (in Issue Paper E). There are some practical limitations to achieve any channel protection criteria on smaller sites (less than ten acres) because orifice diameters or weir sizes become extremely small and are prone to clogging. As a result, several state and localities allow the Cp_v to be waived at small sites (i.e., less than or equal to three acres of impervious cover). In addition, there are several discharge conditions where channel erosion is not expected to be a problem, such as direct discharges to 4th order or higher streams and rivers, and to lakes and reservoirs where the development area is less than 5% of the watershed area upstream of the development site. For future program revisions beyond the scope of this Manual, the MPCA should consider substituting the above change when the construction GP is revised in 2008, and also consider expanding coverage to all Special Waters or possibly even all state waters at that time.
Overbank Flood (Q_{p10})	The choice of what design storm(s) to target for overbank flood control is a local decision. The manual will present guidance that the combination 10 and 100 year peak discharge control is sufficient in most cases to address the range of peak discharges for overbank floods, provided control for more frequent events is in place. The Manual will provide more detailed guidance on the appropriate design assumptions for current hydrologic models.

Extreme Storm (Q_{p100})	The choice of methods and design storms to deal with extreme storms will continue to be a local decision within the purview of established programs. The Manual will contain links to obtaining information for these programs. The Manual will • encourage ultimate floodplain protection as cost-saving approach; • discourage the use of the 7.2 inch rain-on-snow scenario as a design option for snowmelt-related flooding; • present guidance on appropriate methods for downstream analysis; and • present guidance on the specific design assumptions to use in current hydrologic models (Appendix B and D) The Manual will clearly indicate that BMPs need to be designed to provide safe overflow of the 100-year peak discharge rate, even if 100-year control is not necessary (unless they are very small or are located off-line)
Better Site Design Credits	Several specific better site design techniques are recommended for evaluation as stormwater credits that may reduce on-site recharge and water quality requirement. The complete list will be further explored in Issue Paper F, but include: • Recommended for potential credit ❖ natural area conservation ❖ stream and shoreline buffers ❖ surface impervious cover disconnection ❖ rooftop disconnection ❖ grass channels • Possible credit but requires more research and investigation ❖ site reforestation ❖ prairie restoration ❖ soil compost amendments ❖ rooftop runoff storage (rain barrels) ❖ permeable pavers ❖ stormwater planters ❖ green rooftops • No explicit credit, but directly reduces sizing requirements ❖ Open space/cluster design ❖ Reduced street width ❖ Reduced sidewalks ❖ Smaller cul-de-sacs ❖ Shorter driveways ❖ Smaller parking lots

II. OVERVIEW OF THE UNIFIED STORMWATER SIZING FRAMEWORK

This section reviews key stormwater sizing concepts and terminology used in the issue paper, and outlines the unified framework for managing stormwater in the State of Minnesota. The section also briefly reviews the utility of better site design techniques to improve the performance of stormwater practices and reduce the overall cost of stormwater compliance.

Sizing Terminology Used in this Paper

The terminology and abbreviations used to define the various types of stormwater sizing criteria can be confusing at times, as different states and communities interpret them in a slightly different manner. The specific meanings of important terms used in this paper are described in Table 2.

Another source of confusion is how the five types of stormwater sizing criteria inter-relate. Each results in a unique storage volume that must be managed at the site. They are best understood visually as a layer cake that progresses in layers from bottom to top, with recharge volume being the narrowest layer contained within the water quality storage and the 100-year peak discharge control comprising the final layer at the top. Figure 1 generically shows how the four storage volumes interact in a stormwater pond. Note that the recharge storage is not explicitly shown because it is contained within the water quality (permanent pool plus temporary) storage volume.

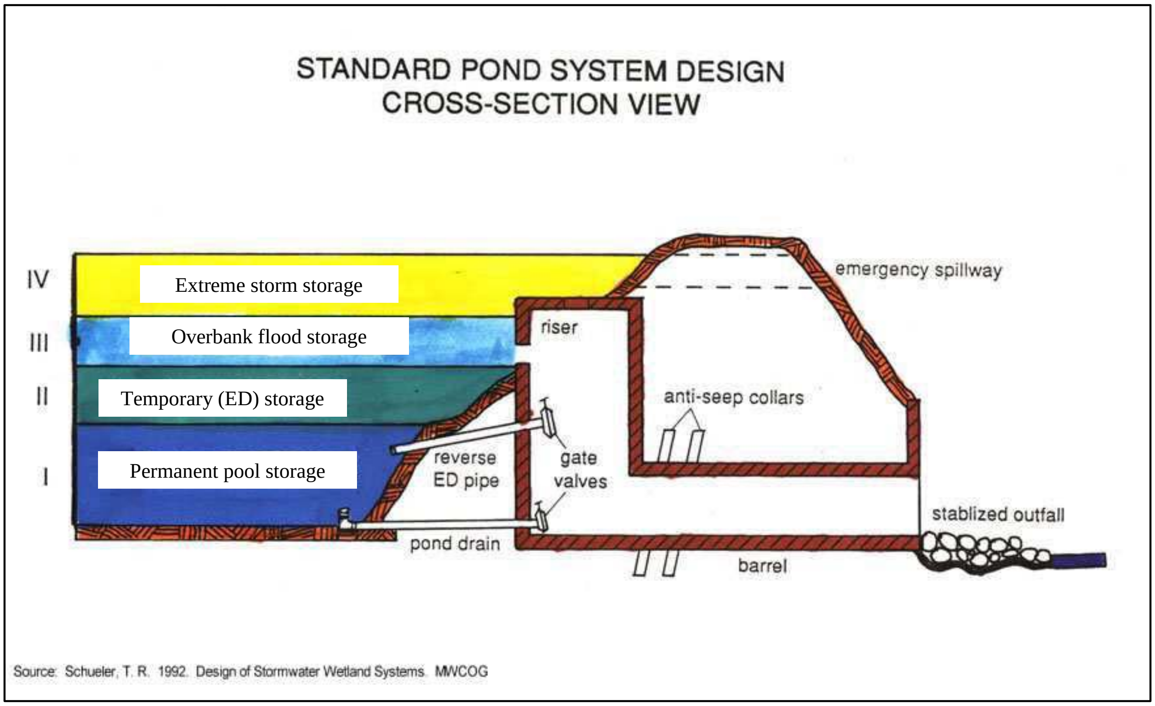
Table 2: Review of Key Stormwater Sizing Terminology

Term	Definition:
Water Quality (WQ_v)	Generic term for the storage used to capture, treat and remove pollutants in stormwater runoff. It is normally expressed as a volume (watershed-inches, and is denoted by WQ_v). The MCPA construction GP has a slightly different definition – it defines it as the volume of live storage above the permanent pool in a pond (i.e., above the dead storage) used for water quality, but not inclusive of flood storage. For non-pond BMPs, MPCA defines the water quality volume in the same manner as the general definition above.
Recharge (Re_v) (part of water quality volume)	Refers to volume of runoff which must be spread over pervious areas and otherwise infiltrated into the soil to promote groundwater recharge. The recharge volume is denoted as Re_v and is normally included as part of the water quality volume.
Channel Protection (Cp_v) (temporary pool storage)	Refers to runoff storage needed to control post development bankfull and sub-bankfull flow velocities so they do not increase erosion in downstream channels. Typically, detention and/or extended detention of intermediate sized storms (0.5 to 2.0 inches) are used for this purpose. The channel protection volume is denoted as Cp_v.

Overbank Flood (Q_{p10})	Refers to the runoff storage needed to prevent an increased frequency of floods that spill out of the channel and onto the floodplain where they may cause damage to conveyance systems, property and infrastructure. Overbank flooding is normally controlled by detention of post-development 10-year storm so that pre-development peak discharge rates are maintained. In this paper, overbank flood control is denoted by Q_{p10}, assuming that a 10-year frequency is adopted.
Extreme Storm (Q_{p100})	The greatest runoff storage is used to detain the peak discharges of infrequent but very large storm events to predevelopment levels. The 100-year design storm, which has a statistical recurrence interval of once every 100 years is used by most communities. Extreme floods can cause catastrophic damage and even loss of life, and the storage required to store and detain them is denoted as Q_{p100}.
Design Storm	An engineering term for a single rainfall event with a defined intensity, duration and statistical exceedance interval ranging from 0.5 years up to 100 years. These single event storms are based on long-term rainfall data, and are used in hydrologic models to predict the peak discharges and runoff volumes associated with each type of storm. Unless otherwise indicated, all design storms in this issue paper have a 24-hour duration and a Type II distribution.
Special Waters	A list of eight categories of sensitive waters and watershed areas specifically designated as “special waters” in Appendix B.1-8 of the MN Construction General Permit (2003). More guidance on special watershed-based stormwater criteria will be outlined in Issue Paper E, including specific stormwater criteria to protect: • Lakes and reservoirs • Trout Streams • Wetlands • Groundwater resources and • Impaired Waters These refinements are not considered in this Issue Paper
Better Site Design (BSD)	Better site design refers to the application of primarily non-structural practices at residential and commercial sites that reduce site impervious cover, conserve natural areas, and use pervious areas to more effectively treat stormwater runoff. Also known as low impact development. (LID).
Hydrologic Soil Group	HSG is an NRCS designation given to different soil types to reflect their relative surface permeability and infiltrative capability. Group A soils have low runoff potential and high infiltration rates greater than 0.3 in/hr. Group B soils have moderate infiltration rates (0.15 - 0.30 in/hr); Group C soils have low infiltration rates (0.05 - 0.15 in/hr) and Group D soils have high runoff potential with very low infiltration rates (0.0 - 0.05 in/hr) and consist chiefly of clay soils (TR-55, 1986).

New Development Vs. Redevelopment Sites	This paper sometimes distinguished sizing criteria depending on whether they apply to new development sites or redevelopment sites. The cost of complying with stormwater sizing criteria at redevelopment sites can be 2 to 10 times higher than at new development sites, and may be a barrier to smart growth. Therefore, Appendix C outlines some options for reducing stormwater requirements at redevelopment sites. All computations in this paper assume new development conditions.

Figure 1: Pond Cross-Section

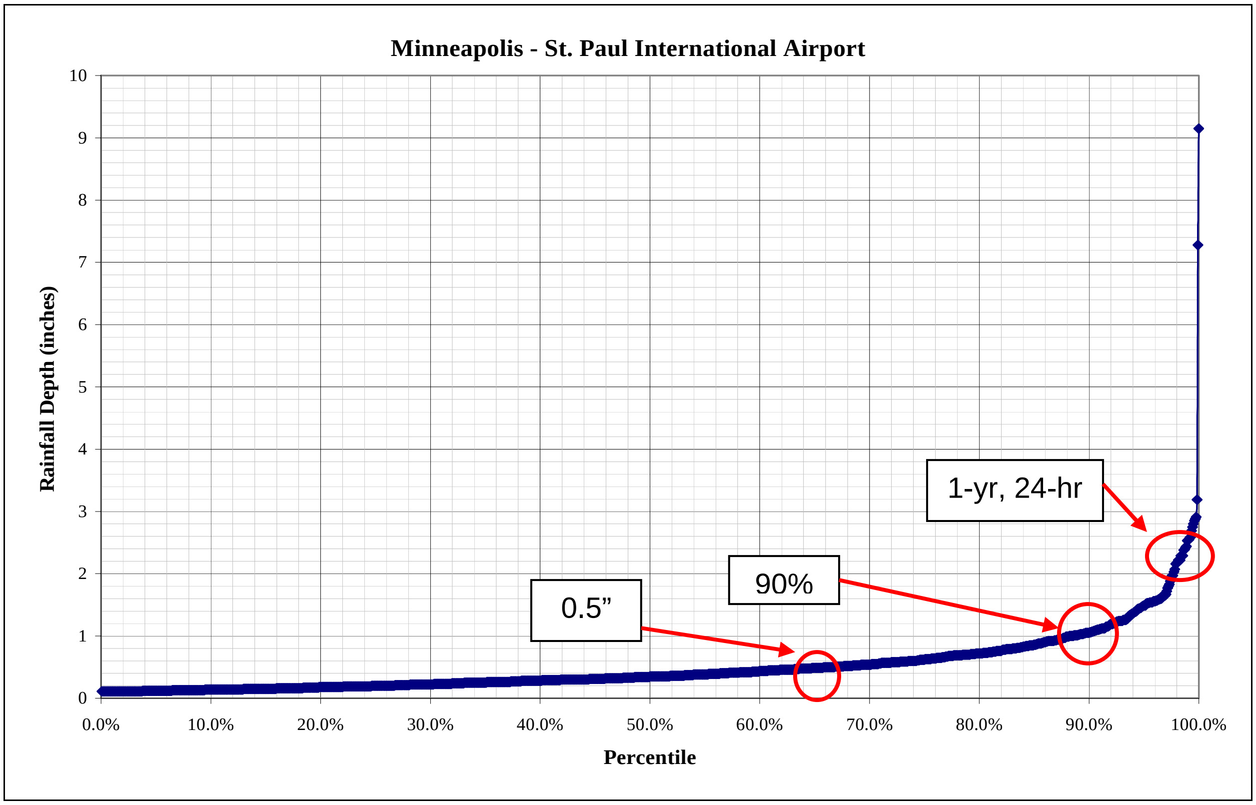


The Rainfall Frequency Spectrum

In the course of a year, anywhere from 35 to 50 precipitation events fall on Minnesota. Most events are quite small, but a few can be several inches in depth. A rainfall frequency spectrum describes the average frequency of the depth of precipitation events (adjusted for snowfall) that occur during a normal year. It is constructed by analyzing a long-term (30 to 50 year) record of daily precipitation events, so that the effects of unusually dry or wet years are smoothed out.

An example of a typical rainfall frequency spectrum (RFS) for the State of Minnesota is shown in Figure 2. The RFS, which was derived in Issue Paper B, shows that percent of rainfall events that are equal to or less than an indicated rainfall depth. As can be seen, the majority of storms are relatively small but a sharp upward inflection point occurs at about at inch of rainfall.

Figure 2. Rainfall Frequency Spectrum for Minnesota (Daily Precipitation Frequency for Minneapolis/St. Paul Airport , 1971-2000).



The unified sizing approach seeks to manage the entire frequency of rainfall events that are anticipated at a development site. The runoff frequency spectrum is divided into five basic management zones, based on their relative frequency, as follows:

Recharge: targets rainfall events less than or equal to the 50th percentile event which produce little or no runoff, but produce much of the annual groundwater recharge at the site.

Water Quality: targets rainfall events between the 10th and 90th percentile events that produce the majority of the stormwater pollutants at the site.

Channel Protection: targets storms in the 95th to 99.5th percentile that perform the most effective work on the channel and cause downstream erosion.

Overbank Floods: targets large and infrequent storm events that spill over to floodplain and cause damage to infrastructure, typically in the 99.9th percentile**.**

Extreme Storms: controls the largest, most infrequent and most catastrophic floods that are typically around the 99.99th percentile (e.g., more commonly known as the 100-year storm).

The goal of stormwater management at new development sites is to provide effective control within each of these five management zones to produce post-development conditions that most closely resemble predevelopment conditions.

A unified approach to sizing stormwater practices is recommended in Minnesota for several reasons:

- Communities and watershed organizations have adopted diverse and often confusing stormwater quantity and quality criteria across the State, and specific requirements for new development can differ widely from one city, county, watershed or region of the state. A unified state approach that still provides some local flexibility can provide a more consistent and effective approach to stormwater practice design.

- The unified approach establishes a common framework to address <u>all</u> stormwater problems caused at a development site created by the entire spectrum of rainfall events that can be anticipated.

- A unified approach standardizes the basic approach to stormwater design, by clearly outlining acceptable design assumptions and models to be used in the design process

- The unified approach also provides greater consistency in defining the exact site conditions and development scenarios that may be exempted from individual stormwater sizing criteria, at the same time it clearly indicates when sizing criteria need to be enhanced to provide a higher degree of water resource protection for waters in the State of Minnesota.

Role of Better Site Design in Stormwater Management

Better site design (BSD) refers to the application of non-structural practices at residential and commercial sites to reduce impervious cover, conserve natural areas, and use pervious areas to more effectively treat stormwater runoff (CWP, 1998). The use of BSD techniques has been promoted in both the MPCA manual (2002) and the Metropolitan Council manual (2001). When applied early in the design and layout process, BSD techniques can dramatically reduce the stormwater runoff and pollutants generated from a development site, and also sharply reduce the size and cost of both the stormwater conveyance system and stormwater management practices (CWP, 1999).

In recent years, several states have sought to encourage greater use of BSD techniques by creating a unified technique for the computation of stormwater credits that reduce the recharge, water quality or channel protection volume that must be provided at new development sites. Not all BSD techniques will qualify as stormwater credits; several directly produce a reduction in impervious cover that automatically reduces stormwater sizing requirements at the site without having to offer a formal credit. Credits may be applied at either the local, watershed or state-wide level.

This section presents a brief description of each better site design technique that can be applied to help reduce or manage stormwater runoff, and evaluates its general feasibility as a potential stormwater credit. Key recommendations on better site design techniques that may qualify for stormwater credits are summarized in Table 3. The entire range of BSD techniques are extensively reviewed in Appendix A, and the specific conditions and procedures by which stormwater credits would be submitted, reviewed and granted will be explored in Issue Paper F (March, 2005).

Table 3: Recommendations for Stormwater Credits for Various Better Site Design Techniques[1]			
Better Site Design Technique	Recommended as potential stormwater credit	Possible credit, but requires more research and investigation	No explicit credit, but directly reduces sizing requirements
1. Natural Area Conservation	●		
2. Site Reforestation/Prairie Restoration		●	
3. Stream and Shoreline Buffers	●		
4. Soil Compost Amendments		●	
5. Surface IC Disconnection	●		
6. Rooftop Disconnection	●		
7. Open Space/Cluster Design			●
8. Grass Channels	●		
9. Reduced Street Width			●
10. Reduced Sidewalks			●
11. Smaller Cul-de-Sacs			●
12. Shorter Driveways			●
13. Smaller Parking Lots			●
14. Rooftop Runoff Storage		●	
15. Permeable Pavers		●	
16. Stormwater Planters		●	
17. Green Rooftops		●	
[1.] more guidance on the recommended and possible stormwater credits will be provided in Issue Paper F			

1. *Natural Area Conservation* involves the identification and protection of natural resources and features that maintain the predevelopment hydrology at a site by reducing runoff, promoting infiltration and preventing soil erosion. Natural areas that are not disturbed during construction and are protected by a perpetual conservation easement may be eligible for a stormwater credit.

2. *Site Reforestation* involves reforestation of existing turf or barren ground at the development site with the explicit goal of establishing a mature forest canopy or prairie condition that intercepts rainfall, and maximizes infiltration and evapotranspiration. Capiella (2005) reviewed a range of research that demonstrates the considerable runoff reduction associated with forest cover compared to turf. Reforested sites protected by a perpetual conservation easement and maintained over a defined growing period may be eligible for a stormwater credit, although some additional investigation is needed to define over what time period it would be granted.

3. *Stream and Shoreline Buffers* are established (natural or graded) during the development process to provide a vegetative setback between development and streams, lakes and wetlands. Portions of the site reserved as buffers and maintained in native vegetation can help filter stormwater runoff, and these buffers (and certain adjacent site areas that directly contribute runoff to them) make sense as a possible stormwater credit. A perpetual conservation easement is also a good idea for these buffers.

4. *Soil Compost Amendments* refer to tilling and composting of new lawns and open spaces within a development site to recover soil porosity and reduce lawn runoff. This technique has not yet been widely applied in Minnesota, but could be a potential credit if the composting materially improves the hydrologic performance of highly compacted lawns (which has been demonstrated for in recent Wisconsin research).

5. *Surface Disconnection* is used to spread runoff generated from small parking lots, courtyard, driveways sidewalks and other impervious cover into adjacent pervious areas where it is filtered and infiltrated. By disconnecting small impervious surfaces from the storm drain system, the total volume and rate of runoff can be greatly reduced at a development site. A stormwater credit might be offered for surface disconnection if runoff can be spread over an acceptable pervious area with minimum dimensions and porosity.

6. *Rooftop Disconnection* in both residential and non-residential rooftops can offer an excellent opportunity to disconnect impervious surfaces and spread the rooftop runoff over lawns and pervious areas where it can be filtered and infiltrated. A stormwater credit may be considered for rooftop disconnections that are effectively spread over an acceptable pervious area**.**

7. *Open Space or Cluster Design* in residential development reduces average lot size within a subdivision in exchange for greater conservation of natural areas. This form of development, which may or may be a locally available option, also may reduce or disconnect impervious cover, and provide for greater on-site stormwater treatment. While no overall stormwater credit is recommended for open space designs, many of its individual elements are eligible for credit (e.g., grass channels, natural area conservation).

8. *Grass Channels* are preferable to curb and gutters as a conveyance system, where development density, topography, soils and slopes permit. While research has not demonstrated that grass channels or roadside ditches remove pollutants reliably enough to qualify as a stormwater management practice (Winer, 2000), they have been shown to reduce the total volume of runoff for smaller storms when compared to curbs and gutters. For this reason, grass channels are often considered a good candidate for a stormwater credit**.**

The next group of BSD techniques (9-13) reduces the creation of impervious cover during site design by downsizing the dimensions of streets, sidewalks, cul-de-sacs, driveways and parking lots. The ability to downsize these dimensions at a new development site depends greatly on current local development codes. If a community allows smaller dimensions for any of these standards in its local development codes, designers that take advantage of them can greatly reduce the amount of impervious cover at a development site. No explicit stormwater credit is generally offered when these BSD techniques are employed, since the designer will automatically get a direct reduction in stormwater sizing (since most sizing requirements are a direct function of site impervious cover). Details of these five techniques are contained in Appendix A.

9. *Reduced Street Width*
10. *Reduced Sidewalk Width*
11. *Smaller Cul-de-sacs*
12. *Shorter Driveways*
13. *Reduced Parking Lot Sizes*

14. *Rooftop Runoff Storage* involves the installation of cisterns or rain-barrels to capture and temporarily store rooftop runoff at confined sites, and gradually release it over pervious areas, or re-use it for irrigation or other purposes. Runoff storage is most practical for new commercial and industrial rooftops, but may require some significant cold-weather adaptations to perform effectively under Minnesota winter

conditions. Therefore, additional investigation is needed before developing a possible stormwater credit for this practice.

15. Permeable Pavers refers to a broad range of products including porous pavement, concrete and brick products, grass pavers, and various block pavers that enable some fraction of rainfall to be infiltrated into a sub-base underneath the paver. Permeable pavers are particularly well suited for high-density development projects such as courtyards, plazas and spill-over parking areas. Given the broad diversity of paver products and applications, and their uncertain longevity in cold-climates, more investigation is needed to determine how stormwater credits might be granted for this practice**.**

16. Stormwater Planters are self-contained landscaping areas employed in low- to high-density development projects to capture and temporarily store a fraction of rooftop runoff and filter it through the soil media. In most cases, stormwater planters cannot capture enough runoff to qualify as a stormwater management practice, but may possibly be eligible for a stormwater credit.

17. Green Rooftops are an emerging rooftop treatment practice where a thin planting media is established on roof surfaces and then planted with hardy, low-growing vegetation. Recent research has shown that green roofs can fully store and evapotranspire rainfall from small and medium events, but may not always qualify as a stormwater management practice because they may not be able to treat the entire water quality volume. In these cases, a generous stormwater credit may be offered for their use.

Stormwater Sizing Options Considered and Their Comparative Impact on Storage Volumes.

Table 4 generally describes the 22 different stormwater sizing criteria that were considered in the development of a unified stormwater sizing approach for the State of Minnesota. Succeeding sections provide much more detail on each sizing option and review the advantages and disadvantages of each option. Each succeeding section also recommends technical procedures and methods to apply individual sizing criteria, including exemptions and other special considerations, and makes an overall recommendation for each of the five sizing criteria.

<table>
<tr><th colspan="2">Table 4: Stormwater Sizing Options Reviewed in this Paper</th></tr>
<tr><th>Criteria</th><th>Sizing Options</th></tr>
<tr><td>Recharge (Re_v)
or
Infiltration
Current State Requirement:
None (#1)
(see Section III)</td><td>1. No recharge requirement
2. Allow stormwater credits that promote recharge and infiltration
3. Recharge requirement based on regional rates tied to HSG
4. 100% of predevelopment volume recharge based on on-site recharge analysis
5. Infiltrate the increase in runoff volume from pre- to post-development for the two-year, 24-hour storm</td></tr>
<tr><td>Water Quality
WQ_v

Current State Requirement: # 2
(see Section IV)</td><td>1. Half-Inch Rule (0.5 Inch * IC)
2. MPCA “Hybrid Rule” in 2003 GCP
3. 90% Capture Rule (1.1 inch * R_v)
4. Pitt Rule (1.5 inch * R_v)
5. Walker Rule (2.5 inch * R_v)
6. Post-development TP load = Pre-Development TP Load</td></tr>
<tr><td>Channel Protection (Cp_v)
Current State Requirement: #2 in a few Special Water categories
(see Section V)</td><td>1. Two-year design storm peak discharge control
2. One- and two-year design storm peak discharge and volume control
3. Two-year design storm peak discharge over-control
4. 24-hour extended detention of the one-year, 24-hour design storm
5. 0.5 to 50 year design storm peak duration matching
6. Distributed Runoff Control</td></tr>
<tr><td>Overbank Flood
(Q_{p10})
Current Local Requirement:
1 or 2
(see Section VI)</td><td>1. 10-year design storm peak discharge control
2. 10- and 25-year design storm peak discharge control</td></tr>
<tr><td>Extreme Storm
(Q_{p100})
Current Local Requirement: #1
(see Section VII)</td><td>1. 100-year design storm peak discharge control
2. No control, but exclude development from ultimate 100-year floodplain
3. Base peak discharge control on acceptable downstream hydrologic analysis</td></tr>
</table>

This section provides a general sense of the relative storage requirements for the spectrum of design storms that comprise the unified sizing criteria (recharge, water quality, channel protection, overbank flood, and extreme flood). The recharge volume does not require storage unless a specific infiltration facility is built to accommodate it. That is, water can be directly soaked into the ground without storage other than that needed for pre-treatment. The recharge volume (Re_v) represents a volume of water that will infiltrate into the ground and not need to be incorporated into the storage volume required in a pond. It is a sub-set of the water quality volume, representing the portion that is “reduced” in the watershed and therefore not in need of storage.

The example pie charts in Figures 3a and 4a show the comparative allocation of runoff volume for two common development scenarios in the state using: ¼” of infiltration as a possible example outcome of options #2-4 for Re_v; option #2 for WQ_v; option #4 for Cp_v; option # 1 for Q_{p10}; and option #1 for Q_{p100}. As can be seen, the majority of runoff volume that needs to be accounted for comes from overbank and extreme storms (56%), whereas only 2%, 21%, and 21% of total volume comes from to recharge, water quality and channel protection needs, respectively.

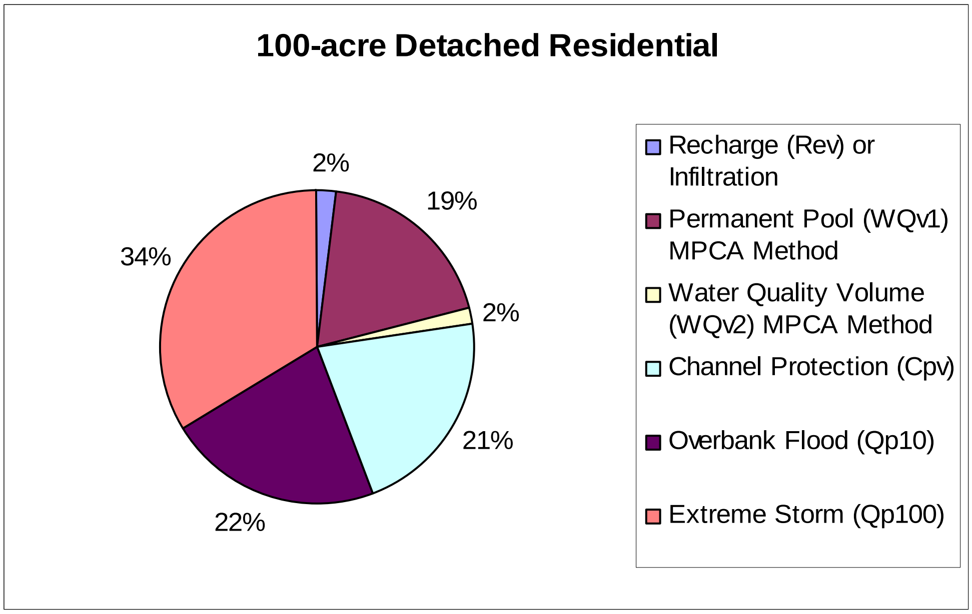
Note that the recharge assumption used in this example is a fairly modest one. Recharge is not currently required in most instances in Minnesota, although some watershed organizations do require it. The ¼" example used above is based on an assumption that one-quarter of the inch runoff in the MPCA Hybrid option can be infiltrated if rules 2-4 (Table 4) for recharge, or some combination of them, were adopted. Reference to a later graphic in this paper (Figure 12) shows that a ¼" event would represent about 40% of the events that occur in the metro area: this percentage, of course, varies across the state, but Issue Paper "B" showed that the variation is minimal.

Figures 3b and 4b use all of the same assumptions except for the recharge volume, which is instead converted to option 5 as an example of a high-end recharge requirement. In this example, all of the additional runoff from events up to the 2-year, 24-hour storm is infiltrated, resulting in the lack of any need for WQ_v storage. This option equates to the MPCA rule for minimizing increases in runoff volume to "Special Waters" and would apply currently under those conditions. Again, reference to Figure 12 later in this report shows that treating the 2-year, 24-hour event would address about 99% of the events.

The full collection of pie charts run for all of the design options is contained in Appendix E. Reviewing all of these charts simply shows that designing facilities for water quality and channel protection volumes represent smaller components than those needed for protection associated with high flows.

Figure 3. Sample Comparative Runoff Volumes for All Sizing Components (100-acre detached residential).

3a. Volume distribution with ¼" recharge assumption.



3b. Volume distribution with recharge of 2-yr, 24-hr volume increase.

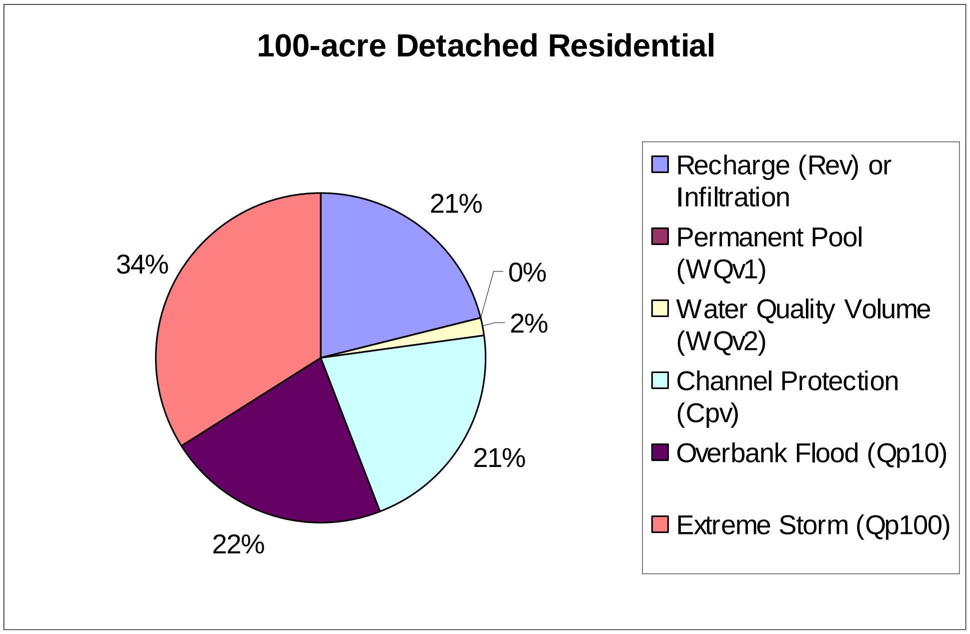
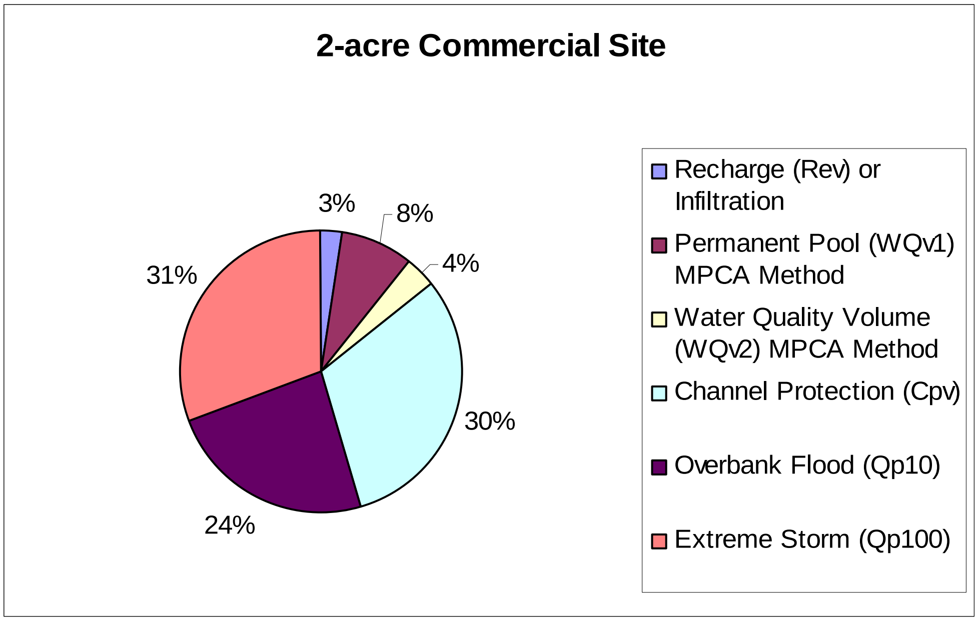
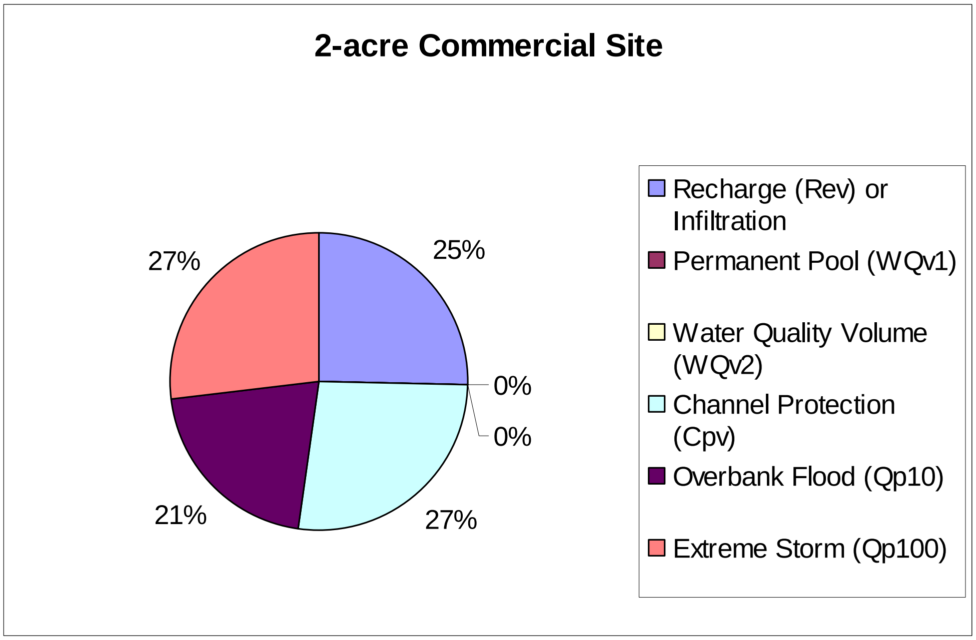


Figure 4. Sample Comparative Runoff Volumes for All Sizing Components (2-acre commercial).

4a. Volume distribution with ¼" recharge assumption.



4b. Volume distribution with recharge of 2-yr, 24-hr volume increase.



The next set of charts contrast the required storage volumes for different sizing options within a particular sizing criterion. The bar chart in Figure 5 compares the volume for two recharge sizing options relative to zero recharge, and Figures 6 and 7 compare the comparative water quality and channel protection storage volumes associated with the range of sizing options reviewed. These charts provide a general sense of the storage and cost implications of the various sizing options. A complete set of comparisons for four development scenarios is provided in Section VIII, along with the modeling assumptions used.

Figure 5. Comparative Volumes for Recharge (Re_v) Sizing Options.

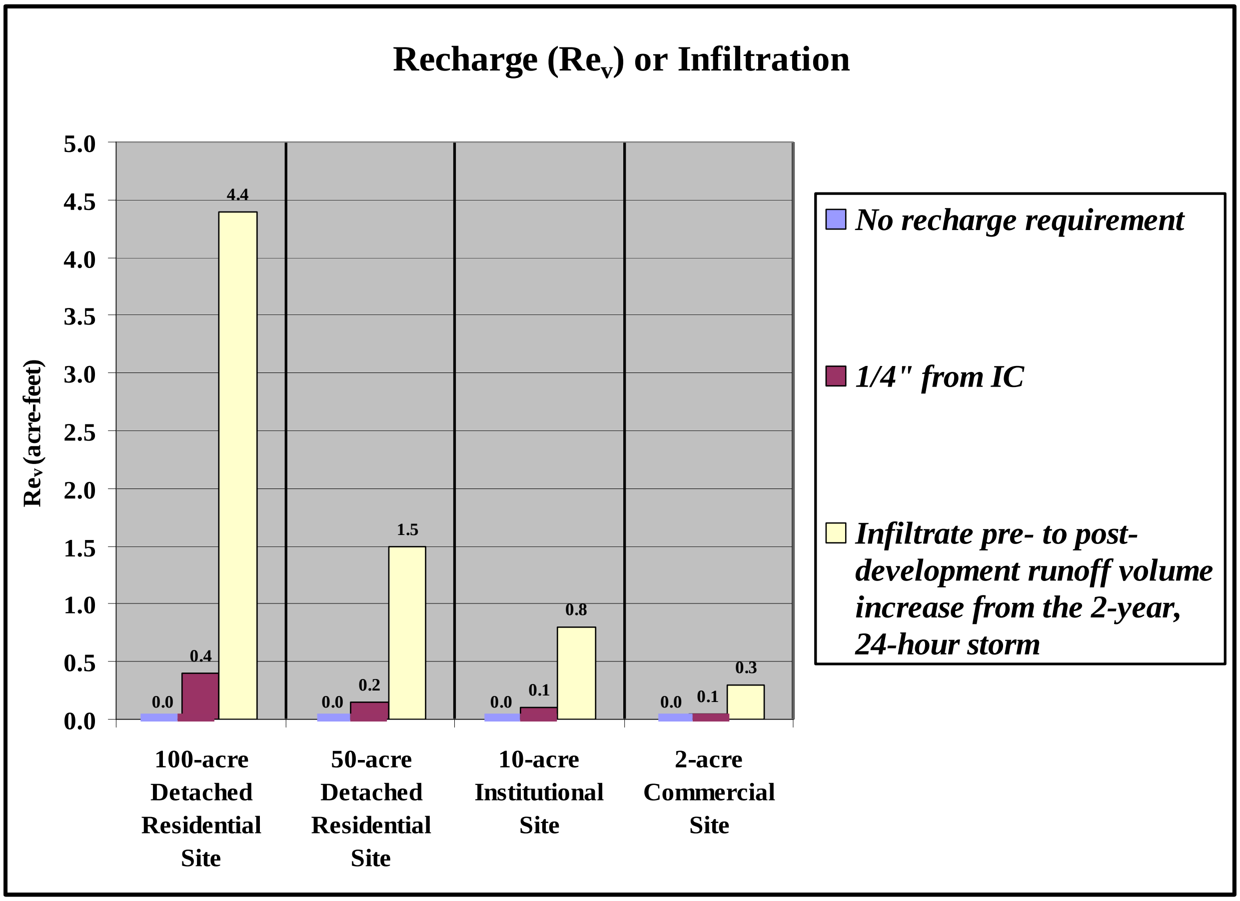


Figure 6. Comparative Volumes for Water Quality (WQ_v) Sizing Options.

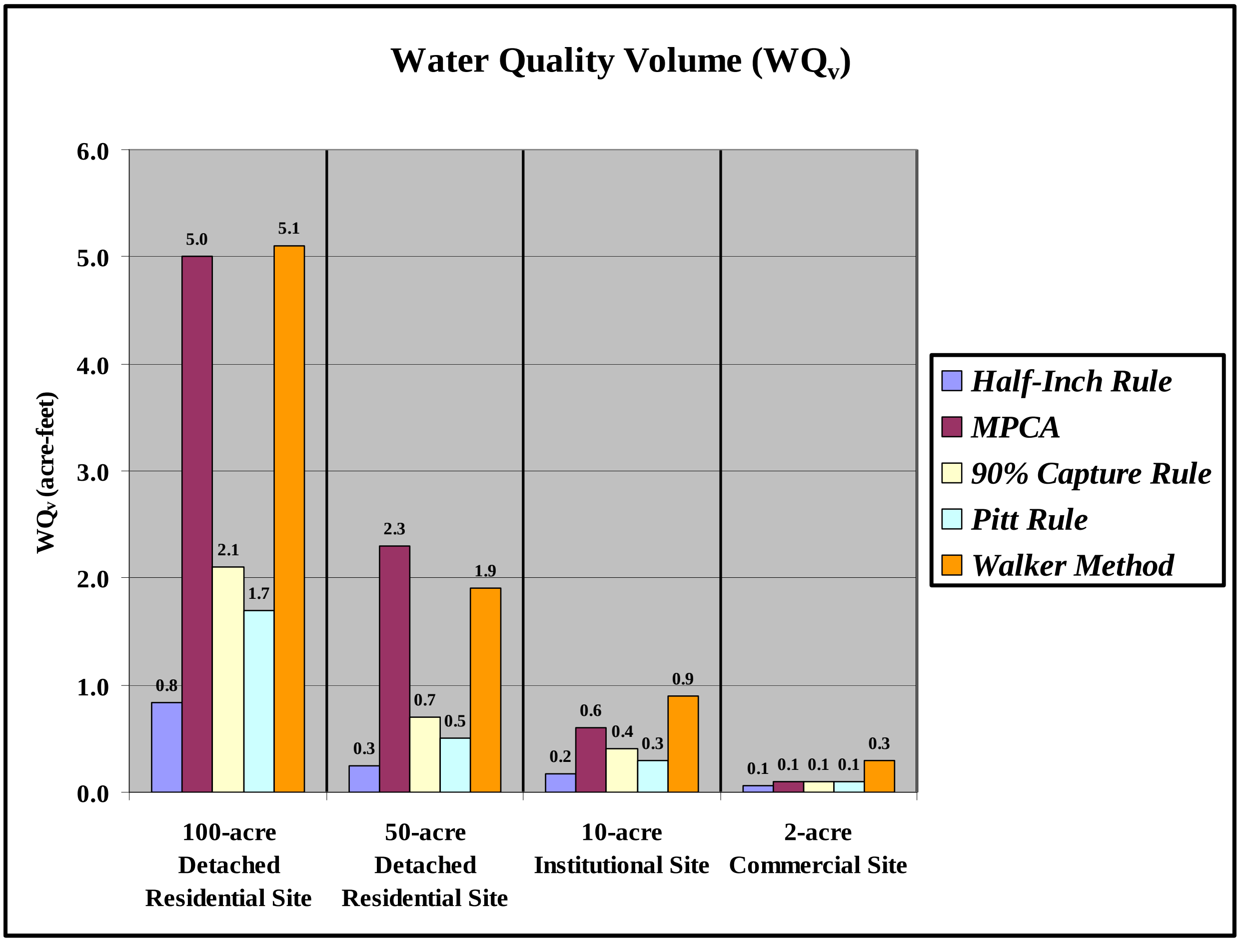
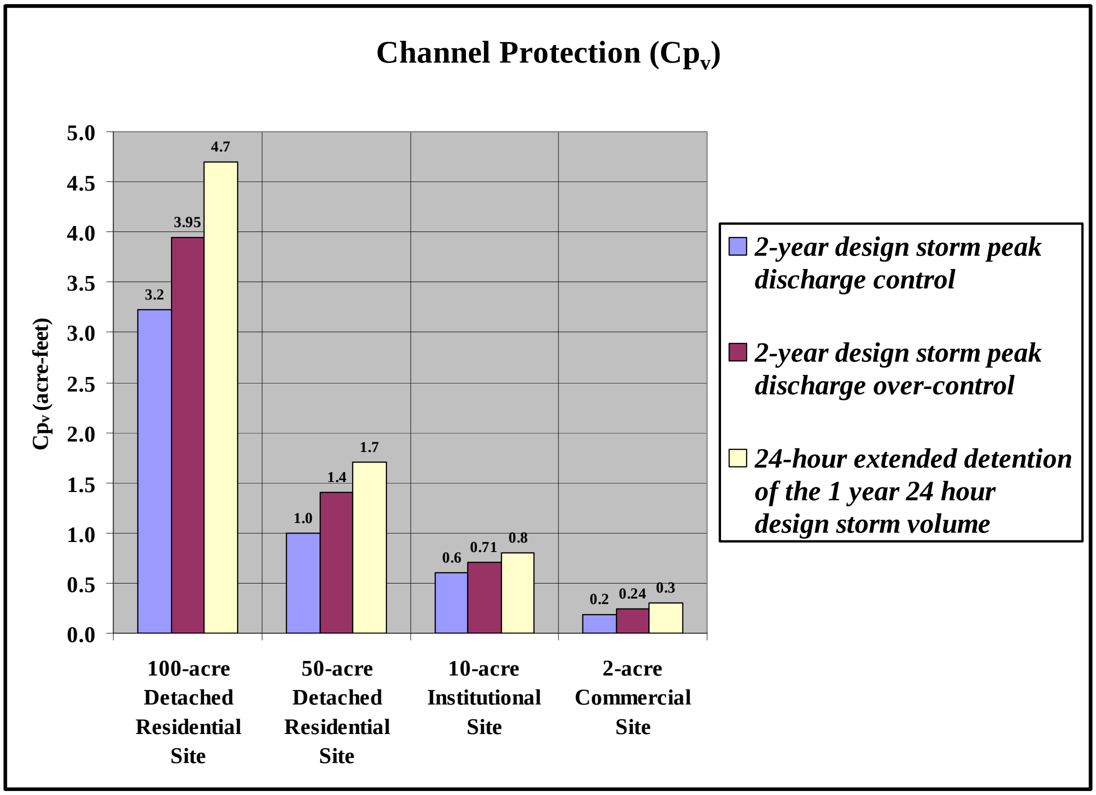


Figure 7. Comparative Volumes for Channel Protection (Cp_v) Sizing Options.



III. RECHARGE AND INFILTRATION CRITERIA (Re_V)

The intent of the recharge criteria is to maintain groundwater recharge rates at development sites to preserve existing water table elevations, thereby helping to support baseflow in streams and wetlands. Under natural conditions, the amount of recharge that occurs on a site is a function of slope, soil type, vegetative cover, precipitation and evapotranspiration. Sites with natural ground cover, such as forest and meadow, typically exhibit higher recharge rates, less runoff and greater transpiration losses than disturbed ground cover. Since development increases impervious surfaces, a net decrease in recharge rates is inevitable.

Recharge and/or infiltration criteria also offer additional benefits for many local or state stormwater management programs. These criteria can:

- Promote the desired trend toward more on-site infiltration/filtration of stormwater runoff;
- Enable local governments to offer stormwater credits that reduce the water quality storage volume;
- Provide real incentives to apply BSD or LID techniques at development sites;
- Reduce the size and cost of structural stormwater management practices required at the site, or downstream regional stormwater management practices; and
- Make designers consider stormwater management during initial site layout and much earlier in the overall design process.

Range of recharge and infiltration sizing criteria

The last five years has seen a remarkable proliferation of new recharge and infiltration sizing criteria throughout many states in the Northern Tier. Five basic criteria are reviewed that are ranked in increasing order of stringency. They are:

Option 1. Do not require recharge
Option 2. Use voluntary stormwater credits that promote recharge and infiltration
Option 3. Recharge sizing requirement based on regional rates tied to HSG
Option 4 Maintain 100% of predevelopment volume recharge based on on-site recharge analysis
Option 5. Infiltrate fraction of the runoff volume from the two-year, 24-hour storm

Each of the five recharge/infiltration options are briefly described below, along with their pros and cons:

Option 1. No recharge requirement

There are currently no recharge sizing requirements by the state of Minnesota (MPCA, 2002 and MC, 2001). While neither manual contains an explicit requirement for recharge or infiltration, both strongly promote them to sustain stream flows, and promote the use of BSD practices at new development sites. The 2002 MPCA manual edition does not contain explicit design guidance on small-site practices needed to infiltrate or recharge runoff (such as bioretention), although the MC (2001) manual does provide more design guidance for smaller site practices that can provide recharge. Some watershed districts in the State (ex. Rice Creek, Browns Creek) have established recharge criteria.

Option 2. Use of voluntary stormwater credits that promote recharge and infiltration

This approach does not establish a formal recharge or infiltration requirement for development sites, but rather provides incentives or "credits" to reduce the required water quality volume (WQ_v) when certain approved site design and recharge practices are employed. Examples may include disconnection of rooftop runoff, use of grass swales and installation of permeable pavement surfaces. The credit approach requires development of guidance and procedures on how to compute, review and grant credits during site plan review. The forthcoming Issue Paper F will develop draft criteria for possible stormwater credits.

Advantages of Option 2

- This voluntary approach may be more acceptable to the regulatory and plan review community

Disadvantages of Option 2

- Experience in other States has shown that designers and plan reviewers are initially slow to utilize credits
- Some recharge practices may not be allowed by local development codes
- Skepticism by some plan reviewers about cheating
- May not be worth offering credits if the existing water quality sizing requirements do not fully capture enough treatment volume to ensure reliable pollutant removal (e.g., MPCA Rule 3: non-pond non-Special Waters in Section IV)

Option 3. Recharge requirement based on regional rates tied to HSG

Several States have adopted a simple recharge sizing criteria first advanced by Horsley (1996) for Massachusetts. The design approach determines the average annual recharge rate based on the prevailing hydrologic soil group (HSG) present at the site from NRCS Soil Surveys. Horsley recommended that annual predevelopment recharge rates should be maintained for specific hydrologic soils groups, as shown in Table 5. A similar analysis has not been done in Minnesota, so use of these numbers would need to be verified before proceeding.

Table 5:
Average Annual Recharge Rates for Different Hydrologic Soil Groups

Hydrologic Soil Group	Annual Recharge
A	18 inches/year
B	12 inches/year
C	6 inches/year
D	3 inches/year

The objective of the criterion is to mimic the average annual recharge rate for the prevailing hydrologic soil group(s) present at the development site. Therefore, the recharge volume can be determined as a function of annual predevelopment recharge for a given soil group, average annual rainfall volume, and amount of impervious cover at a site. Being a function of site impervious cover, the criterion provides incentive to planners and developers to reduce site imperviousness. Based on this approach, Massachusetts developed the recharge volume equations shown in Table 6.

Table 6:
Recharge Volume Equations for Different Hydrologic Soil Groups

Hydrologic Soil Group	Recharge Volume
A	0.40 inches x impervious area
B	0.25 inches x impervious area
C	0.10 inches x impervious area
D	waived

The Horsley recharge criteria would need to be adjusted for the State of Minnesota since they were derived in a more humid climate (annual average precipitation of 44 inches). Average annual precipitation for the state ranges from about 19 inches to 34 inches, with the majority of the state averaging about 25 inches (Figure 8 and Issue Paper B). In addition, published average annual turf evapotranspiration rates and lake evapotranspiration rates are essentially similar between the Northeast and Minnesota (Ferguson and Debo, 1990). Therefore, it is unclear how much the annual average recharge rates need to be adjusted downward for each hydrologic soil group to account for the fact that annual rainfall is 35% lower. State soils and climatologists should be consulted to determine if the annual recharge rates shown above need adjustment and whether regional values should be developed for the different parts of the State. Given the lower rainfall volume in Minnesota, the practical implication is that a fairly modest volume of infiltration is needed to maintain recharge rates for B and C soils, even if the development site is highly impervious.

Figure 8 *Minnesota Average Annual Precipitation (State Climatology Office, 2003)*

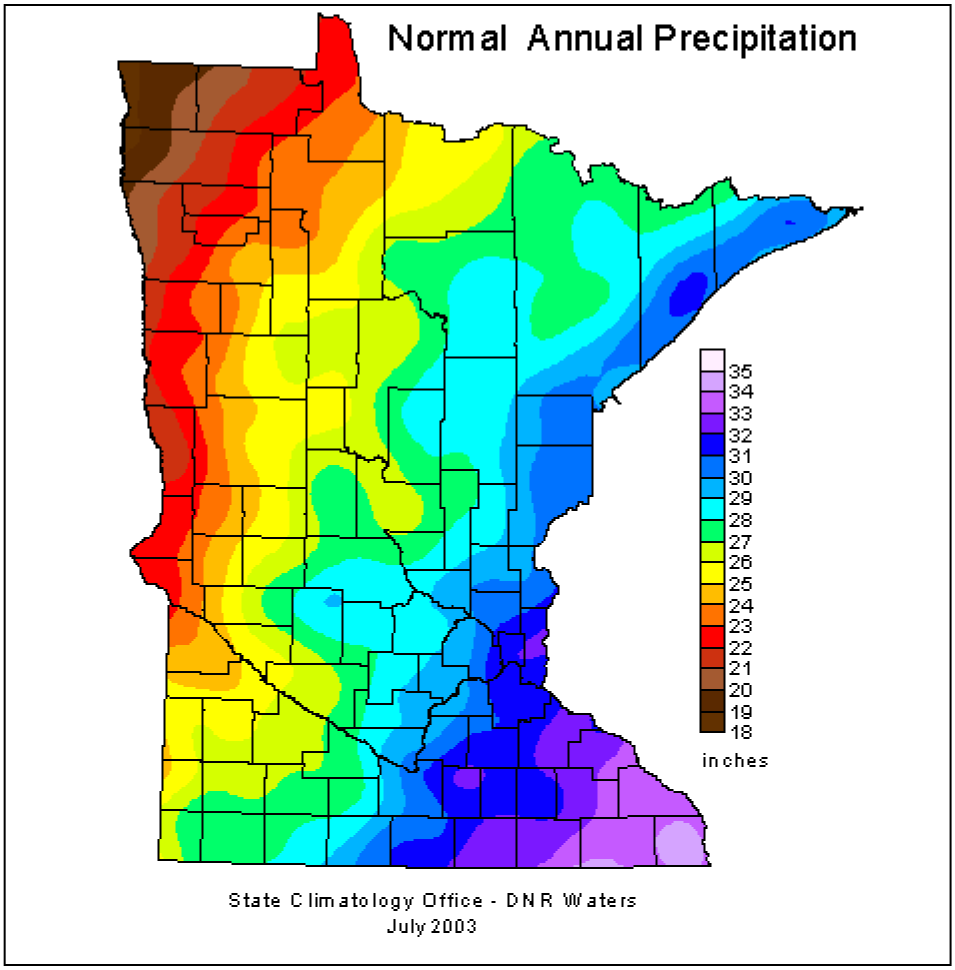
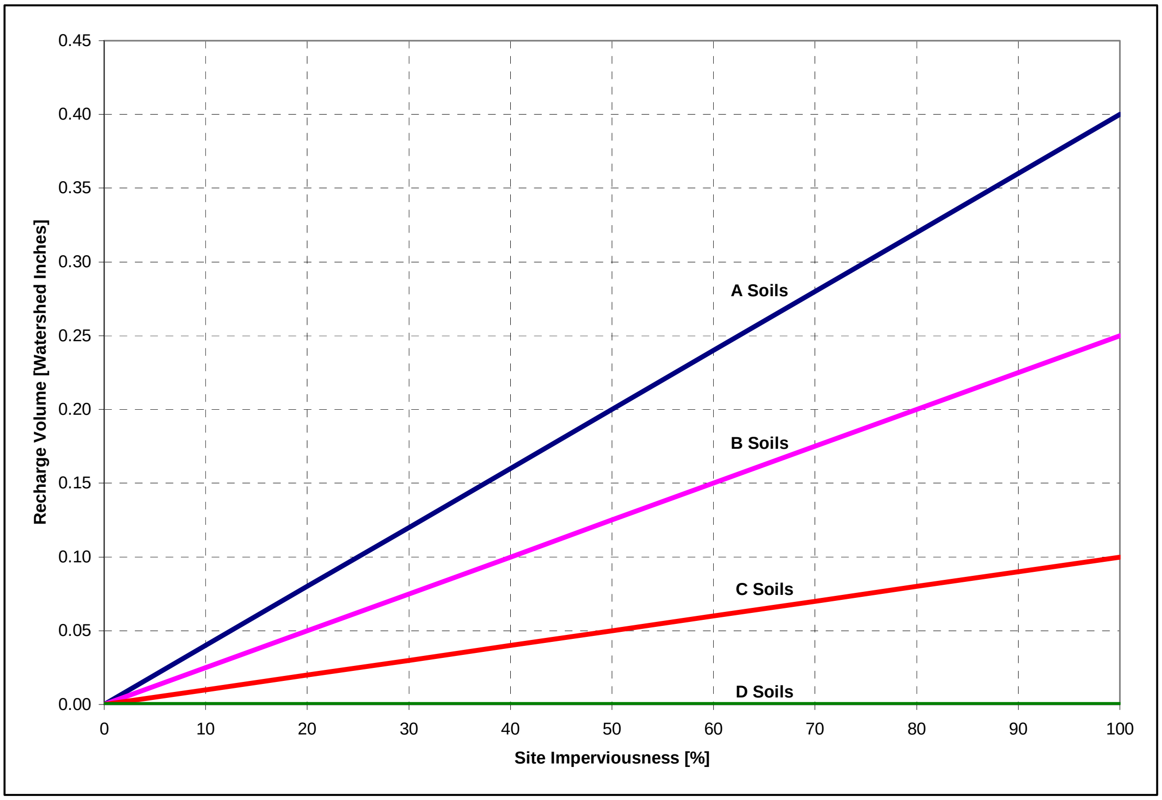


Figure 9 illustrates the unadjusted recharge volume criteria as a function of hydrologic soil group type and site impervious cover (expressed in watershed inches). The recharge volume is considered to be part of the total water quality volume provided at a site and is NOT an additional requirement (i.e., Re_v is contained within WQ_v). Recharge can be achieved either by a structural stormwater management practice (e.g., infiltration, bioretention, filters), BSD techniques, or a combination of both.

Only a limited number of stormwater management practices can meet the recharge requirement, including infiltration, bioretention, dry swales, and certain designs of filtration practices. Ponds and wetlands do not meet the criterion because the bottom of these facilities typically “seal up” as the result of sediment deposition over time or are already excavated to the groundwater table to sustain a permanent pool.

BSD techniques reduce the amount of impervious cover, disconnect impervious surfaces, facilitate infiltration and filtering or runoff within the site (e.g., filter strips and grass channels) and conserve natural areas that are already providing recharge (see Section II and Appendix A of this Issue Paper). A series of rules need to be developed to determine the allowable recharge deductions for each of these non-structural practices, which will be considered in the forthcoming Issue Paper F on stormwater credits.

Figure 9. Unadjusted Relationship Between Recharge Requirement and Site Impervious Cover.



Advantages of Option 3

- Recharge requirement is not additional volume to treat, but is included as part of the existing water quality volume for the site.

- Provides real incentive to employ better site design as it is a function of impervious cover

- The recharge volume is fairly modest for most combinations of soil type and impervious cover (about 0.05 to 0.50 watershed-inches) and is relatively easy to meet on most sites.

- The recharge volume is relatively straight-forward to compute and determine where it will be applied on a development site.

Disadvantages of Option 3

- The annual recharge rates for hydrologic soil groups may be somewhat lower in Minnesota, since it has less annual rainfall and the same basic annual evapotranspiration rates as the Northeastern states where it was first derived. State soil and groundwater experts should confirm whether the rates are acceptable or require adjustment before this approach is used in the State.

- Runoff infiltrated under this criterion may not always produce desired level of groundwater recharge. The criteria does not fully account for any losses of infiltrated water in the soil profile due to evapotranspiration and interflow. Under certain conditions in the growing season, these losses can sharply reduce the amount of annual recharge volume. Consequently, this recharge criterion may not produce the desired amount of deep recharge to sustain stream baseflow and maintain water table elevations.

Option 4. Maintain 100% of predevelopment recharge based on on-site recharge analysis

This recharge criterion is basically similar to Option 3, but it requires a detailed on-site recharge analysis to compute actual recharge rates at the site. New Jersey adopted this approach as part of its 2004 manual, and developed a statewide Groundwater Recharge Spreadsheet tool where designers enter basic information on pre- and post-development site land cover (forest, grass, impervious) and soil types for the site, along with the dimensions and locations of proposed recharge practices. The designer iteratively uses the spreadsheet until they can document that they have maintained 100% of the site's predevelopment annual recharge volume.

The New Jersey Recharge Method provides several technical improvements over the basic regional recharge criteria (Option 3). As noted earlier, the basic recharge criterion assumes that any runoff that is infiltrated or filtered over the ground will result in groundwater recharge. This obviously does not account for any losses while the runoff is in the ground due to evapotranspiration and interflow. Under certain conditions in the growing season, these losses can sharply reduce the amount of annual recharge volume that is actually achieved. Therefore, the NJ Spreadsheet Model incorporates simple soil water modeling to account for recharge losses due to evapotranspiration and interflow. Consequently, the NJ Method produces somewhat larger recharge volume requirements than Option 3 for the same combination of soil and impervious cover.

Advantages of Option 4

- Probably the best technical approach to maintaining annual recharge at development sites
- Spreadsheet tool allows designers to determine best locations for recharge practices on the site
- Based on very good statewide survey of actual groundwater recharge rates for specific soil types (not just the general hydrologic soil groups used in Option 3).

Disadvantages of Option 4

- Similar statewide data on groundwater recharge rates and soil types not available yet for Minnesota
-
- NJ spreadsheet tool cannot be imported to Minnesota without significant refinement and development
- Design approach is more complex and time consuming than other recharge options, and would require considerable training and support for both designers and plan reviewers on its proper use.

Option 5. Infiltrate the increase in runoff volume from pre- to post-development for the two-year, 24-hour storm (WI, PA)

Several states have recently established significant requirements for on-site infiltration of stormwater runoff. One of the most notable examples is the recent Wisconsin NR-151 runoff management rule (State of Wisconsin, 2004) which mandates that between 10 to 25% of the runoff volume produced from the two-year, 24-hour design storm be infiltrated, depending on the land use. In rough terms, the new rule requires from 0.1 to 0.75 watershed-inches of infiltration, depending on site land use and impervious cover. A second example is the State of Pennsylvania (2005) that recently proposed that the first half - inch of runoff from the two-year, 24-hour design storm be infiltrated at all development sites. Both States strongly promote on-site infiltration as the preferred stormwater management practice. Option 5 suggests that the increase in volume for a 2-year, 24-hour storm be infiltrated; that is, any increase in runoff be either directly soaked into the ground on-site or it be routed to an infiltration facility within the stormwater system.

Advantages of Option 5

- Infiltration requirements result in a sharp reduction in the volume of surface runoff leaving the site, and help maintain predevelopment hydrology for smaller storm events.
- May actually result in more annual recharge than would occur in the predevelopment condition.
- May substantially contribute to meeting a channel protection requirement

Disadvantages of Option 5

- The criterion promotes infiltration practices as the preferred or required stormwater best management practice that can only be used for recharge and water quality treatment purposes.
- Several states have experienced greater rates of BMP failure when large infiltration volumes are required on tight sites and marginal soils.
- More costly to implement than Option 3 and 4
- Potential groundwater quality concerns

<u>Exemptions and Modifications to Recharge and Infiltration Requirements</u>

Infiltration and recharge of polluted stormwater runoff is not always desirable at all development sites. Therefore, most communities qualify their recharge and/or infiltration requirements to reflect special site conditions, protect groundwater quality, and avoid common nuisance issues. For example, communities may require:

Some form of pretreatment of stormwater runoff prior to infiltration for some land cover types and pollution source areas (e.g. parking lots)

Recharge be restricted or prohibited at specific industrial, commercial and transport-related operations known to be stormwater hotspots. Issue Paper G will help define the range and type of development sites that will be classified as stormwater hotspots within Minnesota.

Recharge be prohibited or otherwise restricted within the vicinity of sole source groundwater aquifers, wellhead protection areas, individual wells, structures and basins

Recharge be avoided within certain geological zones such as karst and bedrock, and adjacent to steep or unstable slopes.

- Recharge be reduced or waived for minor redevelopment projects that have previously compacted soil structures.

Recommended Approach to Achieving Greater Recharge and Infiltration

The recommended approach to achieve greater recharge in the State is summarized in Table 7.

Table 7: Recommended Recharge Approach For Minnesota
The recommended approach is to gradually introduce a recharge volume requirement for the state of Minnesota. To implement this, the State should: • Offer stormwater credits for better site design techniques to promote recharge as a local option • Present adjusted annual recharge volume requirements as a second local method to promote recharge, with methodology presented in an accompanying box in the Manual text. **Infiltration and recharge of polluted stormwater runoff is not always desirable at all development sites. Therefore, most communities qualify their recharge and/or infiltration requirements to reflect special site conditions, protect groundwater quality, and avoid common nuisance issues. For example, communities may require:** **Some form of pretreatment of stormwater runoff prior to infiltration for some land cover types and pollution source areas (e.g. parking lots)** **Recharge be restricted or prohibited at specific industrial, commercial and transport-related operations known to be stormwater hotspots. Issue Paper G will help define the range and type of development sites that will be classified as stormwater hotspots within Minnesota.** **Recharge be prohibited or otherwise restricted within the vicinity of sole source groundwater aquifers, wellhead protection areas, individual wells, structures and basins** **Recharge be avoided within certain geological zones such as karst and bedrock, and adjacent to steep or unstable slopes.** o Recharge be reduced or waived for minor redevelopment projects that have previously compacted soil structures. For future program revisions beyond the scope of this Manual, the MPCA should consider imposing an annual recharge volume requirement statewide and work to develop an effective site-based recharge spreadsheet and design tool to implement the requirement.

IV. WATER QUALITY CRITERIA (WQ_v)

It is widely recognized that some degree of stormwater runoff treatment is needed to meet in-stream water quality standards and protect aquatic life and water resources. Extensive monitoring has revealed the presence of high concentrations of sediments, nutrients, bacteria, metals, COD, hydrocarbon and other pollutants in untreated stormwater runoff (for the most current summary, consult Pitt *et al*., 2004) and demonstrated their impact on stream and lake quality (CWP, 1999 and CWP, 2003). A range of stormwater management practices exist that can provide a high degree of removal for stormwater pollutants (for a comprehensive review, see ASCE, 2004 and Winer, 2001).

Several key management questions emerge when considering the optimal sizing for the water quality treatment volume in Minnesota:

- What is the major pollutant of concern to be treated?
- What is the desired degree of pollutant removal or outflow concentration?
- What depth of rainfall needs to be captured to ensure effective treatment? and how much can be bypassed?
- How effectively will it capture and treat snowmelt runoff?
- Does it provide effective treatment for all types and intensities of development?

Past state manuals have established a performance standard that the BMPs must provide a minimum degree of pollutant removal for a defined fraction of stormwater runoff events, which has been operationally defined as 80% TSS removal and 50% TP removal.

Range of Water Quality Sizing Criteria

Another clear trend in Northern Tier states in the past few years has been a number of efforts to increase the water quality volume for stormwater treatment and directly link it to the amount of impervious cover on the site. The criteria used should promote minimization of impervious cover as an incentive. Six basic water quality sizing options are reviewed in this section.

Option 1. Half-Inch Rule (0.5 inch * IC)
Option 2. MPCA "Hybrid Rule" in 2003 GCP
Option 3. 90% Capture Rule (1.1 inch * R_v)
Option 4. Pitt Rule (1.50 inch * R_v)
Option 5. Walker Rule (2.5 inch * R_v)
Option 6. Post-development TP load = Pre-Development TP Load

Special attention is focused on current Minnesota water quality volume criteria as contained in the 2003 MPCA Construction General Permit (see Box A).

Option 1. Half-Inch Rule (0.5 inch * IC)

This criteria 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. This simple rule defines the water quality volume as one-half inch times the impervious area (or IC = impervious cover) of the site. The half-inch per impervious area rule provides an incentive to reduce impervious cover; however, the required volume is significantly less than the 90% rule and does not provide adequate treatment for a substantial portion of the annual pollutant load. Reference to Issue Paper B shows that a half-inch would fully capture about 50-60% of the events that occur.

Advantages of Option 1

- Water quality sizing is extremely easy to calculate
- Results in the least storage volume and the lowest cost of all water quality sizing reviewed.
- Consistent with sizing requirements for non-pond BMPS in the current MPCA Construction Permit (i.e., non-pond BMPs located in non-special waters—See Box A)

Disadvantage of Option 1

- Recent research indicates that the first flush effect is weak or non-existent for many pollutants and storm events (Pitt *et al*., 2004).
- Poor removal during prolonged snowmelt events
- Only captures between 50 and 60% of storm events that occur in Minnesota each year, suggesting that that significant runoff volumes will be bypassed and receive little or no treatment
- BMPs may be undersized, and lack storage for pretreatment and the deposition of sediments

Option 2. MPCA "Hybrid Rule" in 2003 Construction GP

The current MPCA water quality volume criteria are referred to as a "hybrid rule" because it actually encompasses four different rules, depending on the type of BMP used and whether it drains to Special Waters. Together, the four different water quality sizing rules yield a wide range of potential storage volumes at development sites — with the smallest comparable to Option 1 and the largest comparable to Option 4. Some recommendations for clarifying and integrating the four criteria in the current and future editions of the General Permit are provided at the end of this section.

Box A. Description of current MN WQ_v in MPCA 2003 Construction General Permit.

The current MPCA water quality volume criteria is referred to as the “hybrid rule” because it actually encompasses four different rules, depending on the type of BMP used and the whether the development drains to special waters. Designers in the state have traditionally relied on ponds for water quality treatment, so the first water quality rule applies to ponds that do not drain to special waters. The design requirement volume has two additive components: dead (or permanent) storage of a half-inch per acre and live (or temporary) storage of one-half inch times the fraction IC for the site. Mathematically, the basic pond sizing equation is equivalent to:

Rule 1. WQv = [0.5 inch + (0.5 inch * IC)] *A

where: WQv is the required volume in acre-inches (divide by 12 to get acre-feet);
IC is the % new site impervious cover, expressed as a fraction; and
A is total watershed area (in acres) draining to the facility

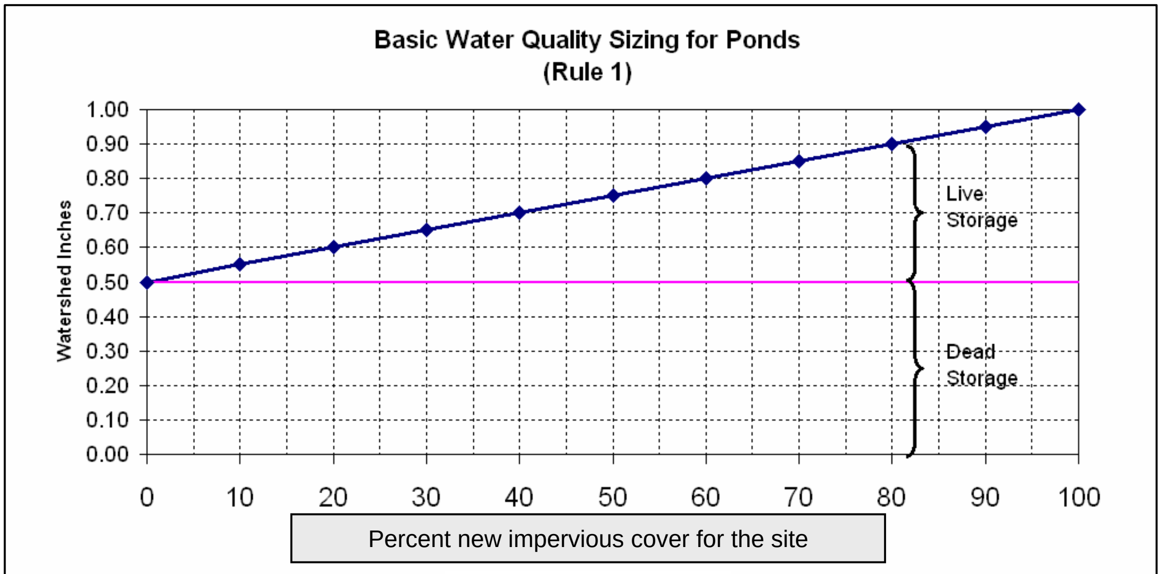


Figure 10.

Figure 10 (above) shows the relationship of the two water quality storage components (dead and live) in the basic pond sizing rule. In addition, the basic pond water quality sizing rule has a third requirement -- to have a live storage release rate no greater than 5.66 cfs per surface acre of pond area (as measured at the top of the live WQ storage “bounce” above the permanent pool). It is important to note that this is a geometrical requirement to achieve an overflow rate that ensures that a 5 micron (µm) sediment particle can be effectively settled within the pond, based on prior work by Pitt (1989). The 5.66 cfs release rate is not meant to be a specific extended detention requirement for the live storage component. Currently, there is no minimum extended detention time for the live storage, although establishing a minimum would seem to be advisable to assure adequate water quality treatment to occur.

The second MPCA water quality sizing rule pertains to ponds located within the “special waters” of the State, as defined in the permit. These facilities must have a greater live storage requirement -- one-inch times the fraction of new IC for the site, which results in water quality total storage equivalent to:

Rule 2. WQ_v = [0.5 inch + (1.0 inch * IC)] * A

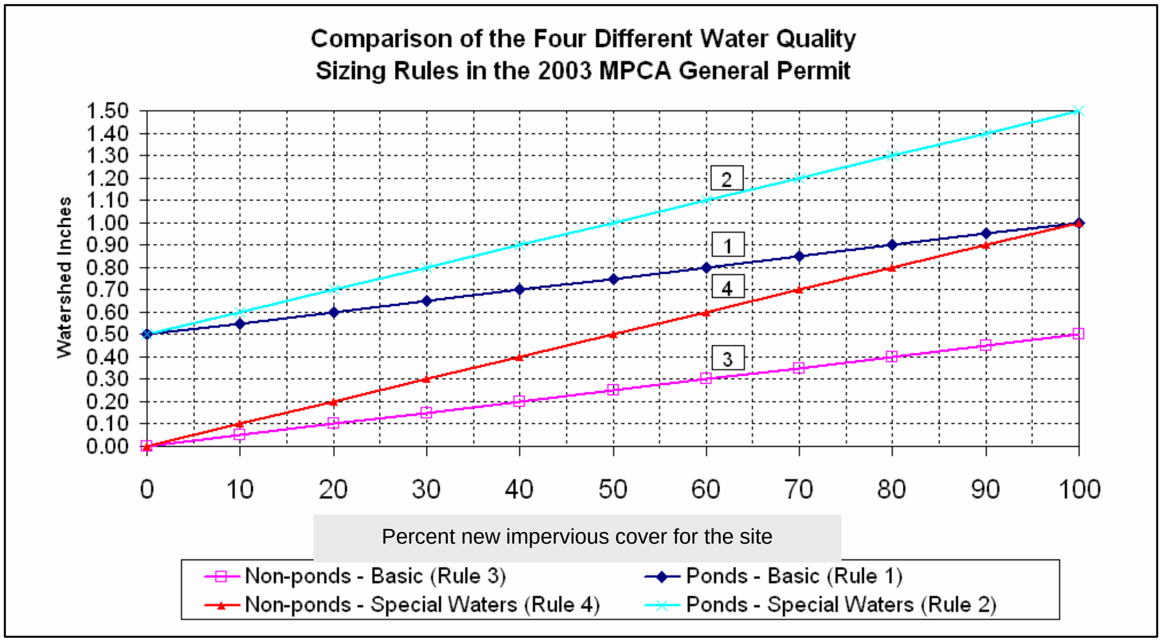
A third basic water quality sizing rule contained in the 2003 permit applies to non-pond BMPs such as infiltration, bioretention and filtering practices. These practices have no specific requirement for dead storage, although some unspecified degree of dead storage is presumed for pretreatment. The basic sizing equation for non-pond BMPs located in non-special waters is:

Rule 3. WQ_v = [0.5 inch * IC] * A

Non-pond BMPs located in special waters are required to have additional live storage, as shown below

Rule 4. WQ_v = [1.0 inch * IC] * A

The four water quality sizing rules are compared against each other in Figure 11 (below):



Option 3. 90% Capture Rule

The 90% capture rule is based on a regional analysis of the rainfall frequency spectrum, and is intended to capture and treat runoff produced from the 90th percentile annual rainfall event (determined in Issue Paper B to approximate 1.1" across Minnesota) multiplied by the runoff coefficient (R_v) and site area (A). This total volume is considered to be dead or permanent storage. To determine this volume:

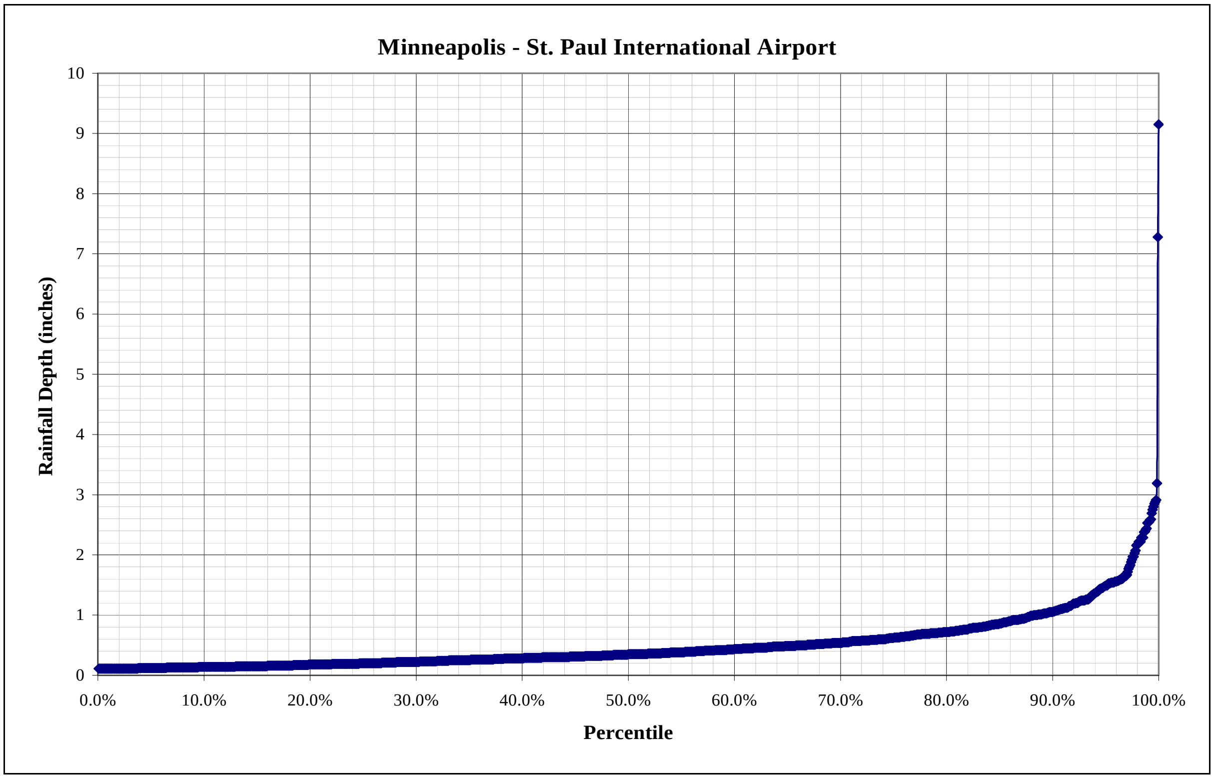
$$WQv = (1.1 \text{ inch} * R_v) * A$$

where: WQv expressed in acre-inches (divide by 12 to get acre-feet);
$R_v = 0.05 + 0.009(I)$;
I = percent impervious cover (%) (Schueler, 1987)

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 runoff events generated by the site. As such, this sizing rule targets the treatment of an annual load, as opposed to an event-based load such as the first flush approach (typically regarded as the first one-half inch of runoff from a site). In addition, the 90% rule results in an increasing volume with greater site impervious cover.

Figure 12 illustrates the rainfall frequency spectrum for the Minnesota-St Paul International Airport from 1971 to 2000, as derived earlier in Issue Paper B. The graph illustrates that the 90th percentile event falls within the "knee" of the curve where optimization of treatment volume occurs. Once one moves above the knee, the required treatment volume increases sharply with very modest increase in the total number of storms treated. It is also important to note that some portion of the runoff volume for storms in excess of the 90th percentile event will still be treated to some degree.

Figure 12 Rainfall Frequency for the Minnesota-St Paul International Airport for the 1971 to 2000.



The 90% rainfall event for the MSP Airport station is approximately 1.05 inches in depth. Based on similar analysis at six other rain gauges across Minnesota, a statewide value of 1.10 inches is recommended to define the 90% rainfall event. While total annual rainfall depth is variable across the state, the general shape of the rainfall frequency curve is remarkably similar from region to region (see Table 3 in Issue Paper B).

Advantages of Option 3

- Captures about 90% of runoff-producing storms each year that established as reliable threshold for runoff capture and treatment. Partial treatment is provided for larger storms above the 90% threshold.
- Ensures high degree of treatment at highly impervious commercial sites such as parking lots, gas stations, and convenience stores.
- Is relatively simple to compute, administer and review for most sites
- A single sizing criteria can be used across the state
- Is roughly comparable to non-pond Special Waters MPCA sizing rule (#4)

Disadvantages of Option 3

- The runoff coefficient is derived based on a national regression equation that is probably not as accurate as the source area runoff coefficients utilized in Option 4.

- The equation results in a relatively low water quality volume for sites less than 15% IC that may not fully capture runoff and nutrients from turf and lawn areas associated with low intensity development. Several states have instituted a minimum WQ_v value of 0.2 watershed inches to capture runoff from pervious surfaces on sites with low impervious cover.

Option 4. Pitt Rule (1.5 inch * R_v - temporary storage)

This water quality sizing rule was originally developed by Pitt (1989) to define effective water quality treatment for States in the Upper Midwest, and is incorporated into the Wisconsin Storm Water Manual (State of Wisconsin, 2002). Research by Wisconsin DNR indicates that practices designed with sufficient volume to capture and treat runoff from the 1.5 inch-four hour storm event would be capable of effective settling a sediment particle of 5 microns or greater. The Pitt storage is all live (or temporary) storage.

The actual water quality volume for a given development site is determined by multiplying 1.5 inch by a composite weighted volumetric runoff coefficient (R_v)representing up to 70 different source area types found at the site. The runoff coefficients were derived using extensive upper Midwestern runoff and water quality data (Milwaukee and elsewhere) within the context of the regionally calibrated Source Loading Assessment and Management Model (SLAMM, Pitt 1989b). The Pitt sizing rule can also generate a water quality hydrograph, which greatly assists in the design of multiple stage facilities and water quality flow splitters. The specific methods to compute this water quality sizing rule are clearly explained in State of Wisconsin (2002).

Advantages of Option 4

- The criterion is based on a large, robust and regionally derived dataset for both water quality and runoff coefficients.

- Pitt has derived more than 70 different runoff coefficients that define nearly every conceivable urban source area; this provides better site characterization than the nationally derived runoff coefficients based solely on impervious cover developed by Schueler (1987) used for Option 3.

Disadvantages of Option 4

- Requires more unit area storage volume compared to Options 1 to 3 (and thus higher compliance cost)
- The criterion is roughly comparable to the WQv pond, special waters criteria in the MPCA general permit (that is, requires more storage)
- May require training for designers and plan reviewers on the SLAMM model runoff coefficients

Option 5. Walker Rule: (2.5 inches * R_v - permanent storage)

The Walker rule was developed in the upper Midwest to maximize phosphorus removal to protect sensitive lakes from eutrophication. Unlike other sizing rules that primarily focus on particle settling, the Walker rule examines the retention time needed within a pond to promote maximum algal uptake of phosphorus and subsequent settling between storm events. To maximize phosphorus uptake, an average pond retention time of approximately two weeks time is required. Based on the distribution of storm events in the upper Midwest, Walker (1987) recommended a pond storage volume equivalent to 2.5 inches multiplied by the site runoff coefficient.

Advantages of Option 5

- The Walker Rule is the only water quality sizing rule that is explicitly designed to maximize phosphorus removal, which is a major concern for nutrient sensitive lakes throughout the state.

- Based on the Minnesota rainfall frequency spectrum (see Figure 12), the Walker rule would capture about 98% of all runoff producing events each year, resulting in very little bypass of untreated runoff. In addition, runoff from many storm events would be retained within the pond for several storm cycles that help improve phosphorus uptake.

- The prolonged detention times would presumably improve removal rates for other pollutants of concern (e.g., sediment, nitrogen, bacteria and soluble metals).

Disadvantages of Option 5

- The Walker Rule can only be applied to pond BMPs that possess a permanent pool to promote algal uptake of phosphorus. The Walker Rule cannot be applied to non-pond BMPs such as infiltration, bioretention and filtering practices that rely on other mechanisms to remove pollutants, including phosphorus.

- The Walker Rule can result in a much greater water storage volume than Options 1 to 4 and possibly even Option 6 under different development scenarios. This could increase the cost of compliance.

Option 6. Post-development TP load = Pre-Development TP Load

This option requires the designer to demonstrate that no increase in total phosphorus (TP) load occurs from pre-development to post-development conditions, and involves a site-based TP load calculation. The designer uses the Simple Method or equivalent (Schueler, 1987) to compute pre-development and post-development TP loads at the site and determine their pollutant removal requirement (in pounds). The designer must then propose a series of stormwater management practices that maximize the amount of phosphorus removal at the site. If a designer cannot meet the total removal requirement, they are allowed to pay an offset fee that is equivalent to the cost of providing equivalent TP removal elsewhere in the watershed. Option 6 clearly provides a major incentive to design for maximum phosphorus removal, which may be desirable for nutrient-sensitive lakes.

Option 6 has been applied to nutrient sensitive special areas to protect lakes and estuaries in Maine, Maryland, Virginia and New York, but has not been applied state-wide. The most comprehensive and up to date version of this approach is the Maryland Critical Area Applicants guide, which can be accessed at www.dnr.state.md.us/criticalarea/10percent_rule.html .

Advantages of Option 6

Specifically focuses on phosphorus as a pollutant of concern, which is major concern for Minnesota watersheds that contain sensitive lakes.

The method encourages designers to maximize total phosphorus removal at the site, yet provides for an offset fee if compliance cannot be attained.

Disadvantages of Option 6

- Only works if pollutant of concern is phosphorus, total suspended sediment or total flow volume; other pollutants lack enough monitoring data to establish loading and removal estimates (e.g., nitrogen, chloride, bacteria, metals).
- Not always enough scientific data to support all the phosphorus accounting rules (e.g., how to handle removal rates for a series of BMPs constructed in a row).
- Significant funds ($50K to 100K) would need to be expended to develop guidance manual describing Minnesota phosphorus accounting rules.
- Method requires much greater time for plan review and may create more disputes. In some cases, more effort is spent on BMP math to show compliance, and less effort is expended on the actual design of practices.
- May not address the unique stressors and impacts in watersheds containing trout streams, sensitive wetlands or bacteria impaired waters

Exemptions and Modifications to Water Quality Criteria

Most communities do not allow many exemptions to their basic water quality sizing criteria, although they may choose to reduce or exempt certain redevelopment and infill projects. Some guidance on handling water quality sizing in redevelopment situations is provided in Appendix C.

Water quality criteria can be modified in two instances. The first is when stormwater credits are offered to reduce water quality sizing when acceptable BSD techniques are applied on the site (see Issue Paper F). The second is when sizing criteria are increased to provide an enhanced level of treatment to protect a specific water resource in a designated watershed (e.g., a nutrient sensitive lake). Guidance on these potential modifications will be provided in Issue Paper E.

Comparison of WQ_v Sizing Criteria and Recommended Approach

It is instructive to compare the water quality storage volume required under each of the first five sizing options (Option 6 cannot be directly compared to other options). Figure 13 graphically depicts the water quality storage volume (expressed in watershed inches) as a function of impervious cover, with the four non-MPCA options plotted against the MPCA lines for rules 1, 2 and 4 that were previously shown in Figure 11. Based on this comparison, and the earlier review of existing and alternative water quality sizing criteria, several phased recommendations are made to improve pollutant removal (Table 8). Figure 14 illustrates the storage volume implications of the proposed modifications to the existing MPCA Hybrid Rule.

Figure 13. Comparison of Water Quality Volume Requirements Under Four Options.

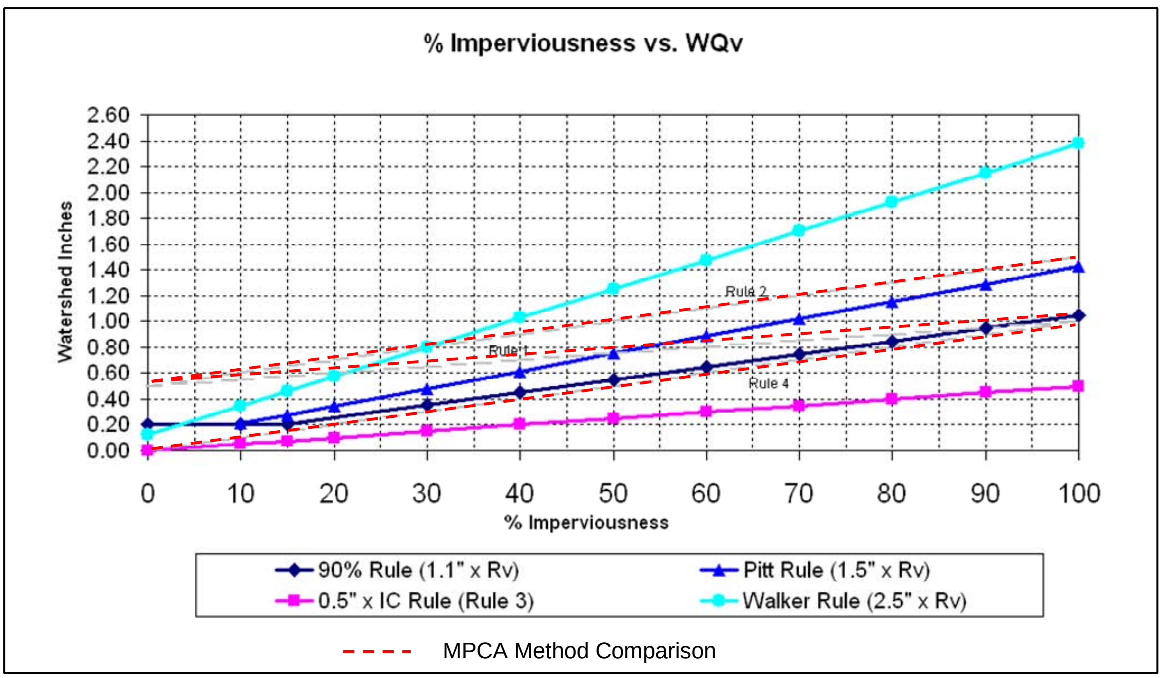
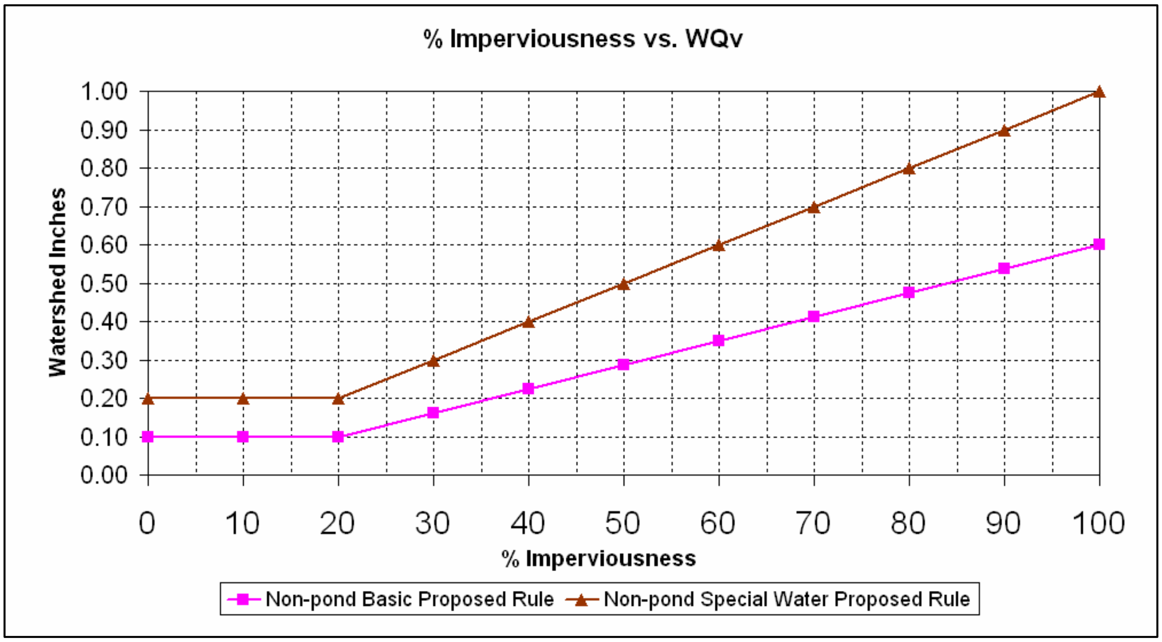


Table 8: Recommended Approach to Refine Water Quality Volume in Minnesota
Retain the basic MPCA Rule contained in the 2003 Construction General Permit, with three important clarifications and while maintaining the recommended discharge rate requirement of 5.66 cfs/acre of pond surface as a maximum allowable rate: • Recommend an average of 12 hours of detention for pond BMPs with an acceptably sized and protected outlet (orifice) (design guidance to be contained in Volume 1 and Appendix B of the Manual); • Require a minimum volume of pre-treatment needed to protect non-pond BMPs from clogging and increase their longevity, which can be achieved through the addition of 0.10 watershed inches of dead storage and/or the installation of a locally approved pre-treatment practice; and • Recommend a minimum water quality storage volume of 0.2 watershed inches for non-pond BMPs, regardless of site impervious cover. Issue Paper E will recommend local adjustments to the WQv to achieve greater pollutant removal for sensitive lakes, trout streams or vulnerable wetlands. Guidance for local pollution loading rates used in these calculations will be contained in the Manual. For future program revisions beyond the scope of this Manual, the MPCA should consider implementation of TP Loading Calculations for phosphorus sensitive lakes, so that phosphorus accounting rules and load estimation methods can be further refined and tested.

Figure 14: Proposed Modifications to MPCA Hybrid Rules 3 and 4.



V. CHANNEL PROTECTION CRITERIA (Cp_v)

The purpose of channel protection criteria is to prevent habitat degradation and erosion in urban streams due to increased frequency of bankfull and sub-bankfull stormwater flows. Channel protection criteria seek to minimize downstream channel enlargement and incision that is a common consequence of watershed urbanization (see Figure 15 and Schueler and Brown, 2004). As fields and forests are converted to impervious surfaces, the volume and frequency of runoff is increased significantly. Research indicates that urbanization causes channels to expand two to ten times their original size to adjust to the increased volume and frequency of runoff caused by impervious cover, as well as the increased conveyance efficiency of curbs, gutters and storm drains (Hammer, 1972; Moriwasa and LaFlure, 1979; Allen and Narramore, 1985; Trimble, 1997; Bledsoe, 2001; Finkebine *et al*., 2001; and Booth and Henshaw, 2001).

Accelerated channel erosion in urban streams produces significant impacts to stream habitat, water quality and public infrastructure (CWP, 2003), including:

- Sharp increases in total annual sediment yield due to bed and bank erosion
- Increased nutrient loads as nutrient-rich floodplain soils are eroded and transported downstream
- Degradation and simplification of stream habitat structure that contributes to declines in aquatic biodiversity
- Damage to bridge, culvert and sewer infrastructure and loss of property.

Figure 15. Undercut Portion of the Vermillion River.

<u>Range of Channel Protection Criteria Available</u>

To combat these problems, geomorphologists and stormwater managers have proposed a wide range of channel protection criteria, and have gradually developed a better understanding of the key hydrologic and sediment transport parameters needed to provide adequate downstream channel protection.

The six major sizing options that have been used to provide channel protection include:

Option 1. Two-year design storm peak discharge control
Option 2. One- <u>and</u> two-year design storm peak discharge and volume control
Option 3. Two-year design storm peak discharge over-control
Option 4. 24 hour extended detention of the 1-year, 24-hour design storm volume
Option 5. 0.5- to 50-year design storm peak duration matching
Option 6. Distributed runoff control

Option 1. Two-year design storm peak discharge control

Historically, two-year peak discharge control has been the most widely applied channel protection criterion used by localities in Minnesota, and many continue to use it today. This criterion seeks to ensure that the post-development peak discharge rate for the two-year design storm is maintained at pre-development rates. The reasoning behind this criterion is that the bankfull discharge for most streams has a recurrence interval of between one and two years, with approximately 1.5 years as the most prevalent (Leopold, 1964 and 1994), and maintaining this discharge rate should act to prevent downstream erosion.

Regrettably, recent research studies have indicated that two-year peak discharge control does not protect channels from downstream erosion and may actually contribute to erosion since banks are exposed to a longer duration of erosive bankfull and sub-bankfull events (MacRae, 1993 and 1996, McCuen and Moglen, 1988). Ponds that provide two-year peak discharge control release water above a critical discharge for a longer period of time that results in greater transport of sediment and bed-load (Figure 16). MacRae also documented that ponds employing two-year control can cause channel expansion by as much as three times the pre-development condition. The primary reason is that while the magnitude of the peak discharge does not change after development, the duration and frequency of erosive flows does. As a result, "effective work" on the channel is shifted to more frequent runoff events that range from the half-year event up to the 1.5-year runoff event (MacRae, 1993).

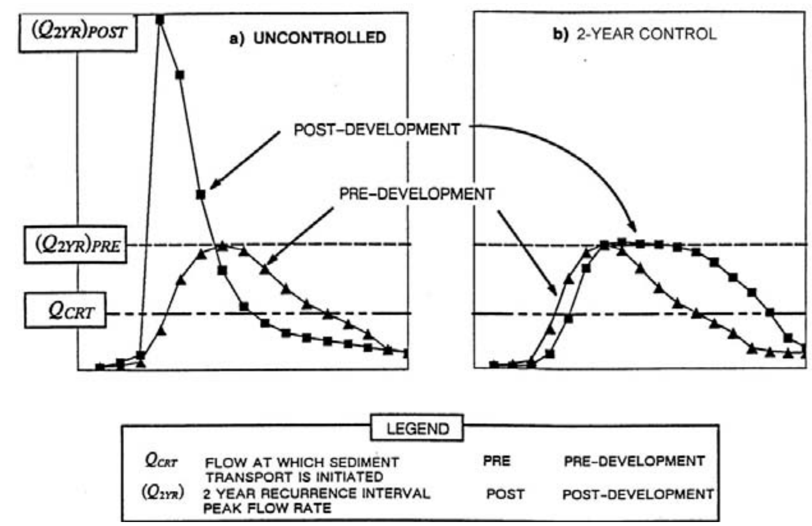


Figure 16. Effective Work Performed by Ponds With and Without Two-Year Peak Discharge Control (MacRae and Rowney, 1992)

Advantage of Option 1

- Consistent with local design practice in many communities in Minnesota

Disadvantage of Option 1

- Two-year peak discharge control may have modest value as an overbank flood control criteria, but is not recommended as a channel protection criterion. The criterion actually extends the duration of flows that exceed critical erosive velocities in the stream and may actually increase downstream channel erosion.

Option 2. One- and two-year design storm peak discharge volume control

This channel protection criterion is referred to in the Minnesota Construction General Permit (2003), but only applies to a very restricted subset of Special Waters designated in the permit. The intent of the criterion is to ensure that the post-development peak discharge rates and runoff volume for the one- and two-year design storm events are maintained at predevelopment levels. So far, very few development projects have been designed to comply with this criterion (Findorff, personal communication). Therefore, the exact hydrologic methods for maintaining predevelopment runoff volumes have not yet been established. Presumably, extended detention, infiltration and/or evaporation would be needed to reduce runoff volumes, but exactly how much reduction is needed and over what part of the storm hydrograph it would occur has not yet been specified.

Advantages of Option 2

- The criterion is referenced in the existing construction GP (albeit for only a very small number of designated Special Waters)

- Based on hydrologic considerations, the criterion appears to have the theoretical ability to maintain the magnitude and duration of predevelopment discharge rates, which should help to reduce downstream channel erosion.

Disadvantages of Option 2

- The principal disadvantage of the criteria is that there is no guidance on how to compute, design and verify how it would be met at actual development sites. The confusion stems from the fact that both detention and infiltration are needed to meet the criteria, yet models treat peak discharge control and volume reduction differently.

- The effect of the criteria in reducing channel erosion is only theoretical, and no hydraulic or hydrologic modeling has confirmed its benefits

Option 3. Two-year design storm peak discharge "over-control"

Two-year over-control was originally proposed by McCuen, (1979) and ratchets the post-development peak flow rate for the two-year design storm to less than 50% of its pre-development flow rate. This design approach recognizes the inherent limitations of two-year control, and emphasizes "over-control" of the two-year storm. Subsequent analysis by MacRae (1993), however, has indicated that the over-control criterion is still not fully capable of protecting the stream channel from erosion. Modeling by MacRae, (1993) suggests that over control may cause downstream channels to degrade (down-cutting where soft boundary material is present) or aggrade (builds up where firm boundary material is present), depending on the nature of bed and bank material.

Advantages of Option 3

- Relies on existing peak discharge control methods and models, suggesting that little additional training of design engineers and plan reviewers would be needed to institute the criteria.

Disadvantages of Option 3

- Modeling research has shown that over-control does not always provide full channel protection, particularly in the recessional limb of the post development hydrograph.

Option 4. 24-hour extended detention of the 1-year, 24-hour design storm volume

This design criterion calls for holding the runoff volume generated by the one-year, 24-hour rainfall to be gradually released over a 24-hour period. The stored runoff volume is then released in an extremely gradual manner so that critical erosive velocities are not exceeded over the entire storm hydrograph. As a very rough rule of thumb, storage capacity of about 60% of the one-year storm is needed to provide the required extended detention. The rainfall depth for the one-year, 24-hour storm varies across the State, but can be inferred from intensity-duration-frequency [IDF] curves. The one-year, 24-hour rainfalls range between 1.8 and 2.5 inches across the State of Minnesota (See Appendix of Issue Paper B). The 24-hour extended detention requirement is reduced to 12 hours in trout streams to prevent stream warming by the pond.

The premise of this criterion is that runoff would be stored and released in such a gradual manner that critical erosive velocities would seldom be exceeded in downstream channels. Modeling based on a Maryland development site demonstrated that 24-hour extended detention closely approximated the Distributed Runoff Control method (Option 6) for storms less than two inches of rainfall (Cappuccitti, 2000).

Advantages of Option 4.

- The 24-hour extended detention of the one-year storm event has been adopted or proposed by the States of Maryland, New York, Vermont, Georgia and Pennsylvania.
- The criterion makes it relatively easy to compute and verify the runoff volume and determine storage requirements at most development sites.
- Hydraulic and hydrologic modeling has demonstrated its channel protection benefits.
- Combines the need for a geomorphologically valid approach to stream erosion with a easy method to implement in the context of a statewide program
- Provides additional water quality treatment, especially for settleable contaminants

Disadvantages of Option 4.

- Requires significantly more storage volume compared to the two-year peak discharge sizing criteria currently in use in many Minnesota communities.
- May be hard to maintain extended detention release rates at smaller sites due to clogging of small diameter orifice.
- 24-hour detention may not be advisable in trout streams due to possible downstream warming in the pond.

Option 5. 0.5- to 50-year design storm peak duration matching (WA)

The State of Washington (2004) has adopted an extremely stringent channel protection criterion that requires the duration of post-development peak stormwater discharges match predevelopment durations for the entire range of storms between 50% of the one-year storm and the 50-year event. Designers must use a continuous hydrologic simulation models (ex., HSPF) to demonstrate compliance. As of 2004, hydrologic models such as TR-55 or P-8 that employ single event design storms are no longer allowed for design purposes. The goal of the peak duration matching criteria is to exactly replicate the pre-development frequency of peak discharge rates for all storm events that should provide a high level of channel protection.

Advantages of Option 5

- The peak duration matching criteria should theoretically provide a high level of channel protection (although the benefit has yet to be verified through field monitoring)

- The approach combines channel protection with overbank flood control into a single criterion

- Continuous simulation of hydrology is probably superior to single event modeling, since no simplifying design assumptions need to be made about rainfall durations, intensity and frequency, and the problems of back-to-back storms and antecedent soil moisture are explicitly dealt with.

Disadvantages of Option 5

- Requires development, calibration and verification of regional continuous simulation models over a 30 to 50 year rainfall period in the State of Minnesota, which would require a multi-million dollar investment to create the needed design tool.

- The method has only been employed in one state (Washington) that has less intense and smaller storm events than Minnesota. Consequently, while the required channel protection storage volume under this criteria cannot be precisely quantified, it is certain to be much larger than other channel protection criteria reviewed in this issue paper

- Most of the hydrology gages needed to calibrate and verify simulation models have drainage areas in excess of ten square miles, whereas most development sites range from ten to 100 acres in size. This creates a scaling problem that may affect the parameterization of the models, and possibly their accuracy.

- This criterion requires extensive and complex modeling in design; and will be initially difficult to administer and review

Option 6. Distributed Runoff Control

The distributed runoff control (DRC) criteria was first developed by MacRae (1993) and is now an accepted channel protection criteria option for larger development sites in Ontario, Canada and the States of New York and Vermont. It is the most stringent of the “over-control” options. The DRC entails both detailed stream assessments and hydraulic and hydrologic modeling to determine the hydraulic stress and erosion potential of bank materials. The criterion states that channel erosion is minimized if the erosion potential of the channel bank materials are maintained constant to pre-development conditions over the range of flows at which sediment transport of bed or bank material begins (i.e., mid-bankfull to bankfull flow events). The DRC field assessment examines downstream channel parameters generally within a reach length of similar geomorphic characteristics at the location most susceptible to erosion. The DRC hydrograph attempts to mimic the pre-development hydrograph for the area above Q_{crt} shown in Figure 17.

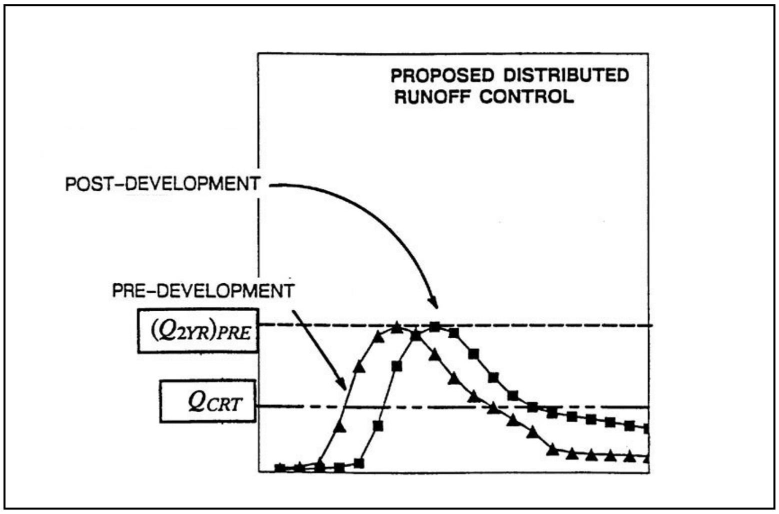


Figure 17. Distributed Runoff Control (DRC) vs. Predevelopment Hydrograph (MacRae and Rowney, 1992)

Advantages of Option 6

- The DRC is the only design method that specifically looks at downstream geomorphic characteristics and sediment transport, both of which are extremely important to understand current and future channel erosion processes. All of the other channel protection methods only evaluate hydrology.

- Initial use on Ontario and Vermont sites indicates that it appears effective in reducing downstream channel erosion.

Disadvantages of Option 6

- The current design method is fairly complex, and requires a thorough stream assessment by a well-trained geomorphologist. Extensive training for design engineers and plan reviewers would be needed to implement the option and designs would initially be quite hard to review and administer. A shift to the DRC method would sharply increase design costs, since downstream field assessments are not currently performed in normal stormwater design.

- The basic approach works best for larger development sites (50+ acres) that drain to a single headwater stream. Application of DRC to smaller sites is very problematic.

Exemptions and Modifications to Channel Protection Criteria

There are some practical limitations to achieve any channel protection criteria on smaller sites (less than ten acres) because orifice diameters or weir sizes become extremely small and are prone to clogging. As a result, several state and localities allow the Cp_v to be waived at small sites (i.e., less than or equal to three acres of impervious cover).

In addition, there are several discharge conditions where channel erosion is not expected to be a problem, such as direct discharges to:

- 4^{th} order or higher streams and rivers
- lakes and reservoirs where the development area is less than 5% of the watershed area upstream of the development site.

Recommended Channel Protection Criteria and Modeling Approach

The recommended options for providing greater channel protection are summarized in Table 9.

Table 9. Recommended Approach to Developing Channel Protection Criteria for Minnesota
The Manual should present effective options for protecting Minnesota's stream channels from bank erosion. It should discourage the use of two-year peak discharge control as an ineffective channel protection measure. Communities that provide effective channel protection measures are encouraged to drop their two-year peak discharge requirement (if they currently require 10-year peak discharge control for overbank flooding) as they adopt/revise local post-construction stormwater control ordinances. The State should recommend 24 hour extended detention of the 1-year, 24-hour design storm event as the best current channel protection option. Figure 1 illustrates how erosive flow can be avoided by this change from the 2-year peak criterion currently in common use. Alternatively, the recharge of all volume increases from pre- to post-development for a 2-year, 24-hour event may also be an effective channel protection measure and may be considered an option for trout stream protection (in Issue Paper E). There are some practical limitations to achieve any channel protection criteria on smaller sites (less than ten acres) because orifice diameters or weir sizes become extremely small and are prone to clogging. As a result, several state and localities allow the Cp_v to be waived at small sites (i.e., less than or equal to three acres of impervious cover). In addition, there are several discharge conditions where channel erosion is not expected to be a problem, such as direct discharges to 4^{th} order or higher streams and rivers, and to lakes and reservoirs where the development area is less than 5% of the watershed area upstream of the development site. For future program revisions beyond the scope of this Manual, the MPCA should consider substituting the above change when the construction GP is revised in 2008, and also consider expanding coverage to all Special Waters or possibly even all state waters at that time.

VI. OVERBANK FLOOD PROTECTION CRITERIA (Q_{p10})

The purpose of overbank flood protection is to prevent flood damage to conveyance systems and infrastructure and reduce minor flooding caused by an increased frequency and magnitude of overbank floods. Overbank floods exceed the bankfull capacity of the channel, and spill over to the floodplain where they can damage property and structures. The key management objective is to protect downstream structures (houses, businesses, culverts, bridge abutments, etc.) from increased flows and velocities from upstream development.

The return frequency for the overbank design storm is chosen to match up with local requirements for the design of culverts, bridges, and storm drain systems. In general, storage requirements for the 25-year return design storm are much greater than for the 10-year design storm

Range of Design Criteria for Overbank Flood Protection

Many Minnesota localities typically require that post-development peak discharge from the 10-year and/or 25-year 24-hour design storm event be controlled to predevelopment levels. This translates into three basic options:

Option 1. 10-year design storm peak discharge control
Option 2. 10- and 25-year design storm peak discharge control
Option 3. 25-year design storm peak discharge control

Modeling has shown that control of the 10-year storm coupled with control of the 100-year storm effectively attenuates storm frequencies between these two events (e.g., the 25-year storm). Even without attenuation of the 100-year event, 10-year control provides a significant control for the 25-year storm (approximately 70 to 80%).

Consequently, most communities across the country have adopted the 10-year design storm control for overbank protection, since it requires smaller storage volume and provides some de-facto control for the 25-year storm. The basic decision on the appropriate overbank flood design turns on whether the 10- or 25-year design storm has historically or currently been used as the basis for the design of conveyance systems, bridges, and culverts under the ultimate condition.

Some localities may exempt a development project from overbank flood control if development is excluded from the downstream ultimate 100-year floodplain and the downstream conveyance systems and infrastructure are also designed for the ultimate 10-year storm event.

Recommended Design Guidance for Overbank Flood Criteria

Recommended local guidance for overbank flood criteria is summarized in Table 10.

Table 10: Recommended Guidance on Overbank Flood Control Criteria
The choice of what design storm(s) to target for overbank flood control is a local decision. The manual will present guidance that the combination 10 and 100 year peak discharge control is sufficient in most cases to address the range of peak discharges for overbank floods, provided control for more frequent events is in place. The Manual will provide more detailed guidance on the appropriate design assumptions for current hydrologic models.

VII. EXTREME FLOOD CONTROL CRITERIA (Q_{p100})

The three primary purposes of extreme flood control criteria are to:

1. Maintain the boundaries of the predevelopment 100-year floodplain
2. Reduce flooding risks to life and property damage from infrequent but very large storm events
3. Protect the physical integrity of a stormwater management practice itself.

Range of sizing methods to address Extreme Storms

Nationally, many localities require storage to control the post development 100-year, 24-hour peak discharge rate (Q_{p100}) to predevelopment rates. We recommend that localities carefully reassess this requirement since it produces the largest storage volumes and greatest cost of any stormwater sizing criteria. Consequently, two options are presented where 100-year peak discharge control requirements may be adjusted or reduced.

Option 1. No control, but exclude development from ultimate 100-year floodplain
Option 2. Base extreme storm controls on acceptable downstream analysis

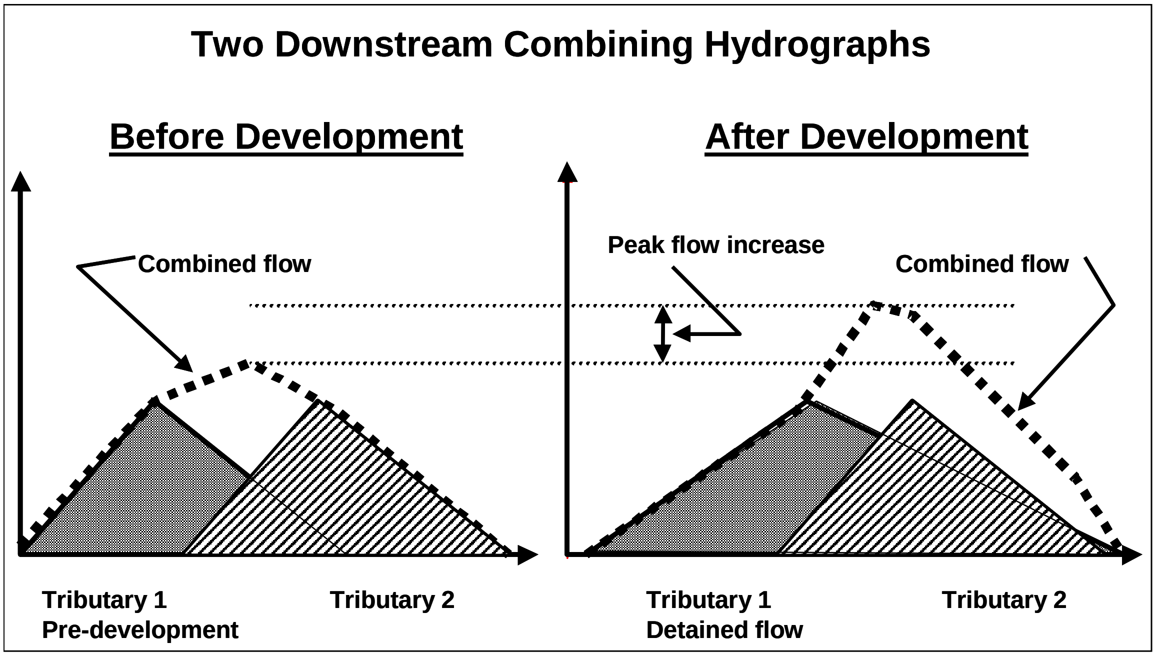
Option 1. No control, but exclude development from ultimate 100 year floodplain

This approach accomplishes the goal of extreme flood control by excluding development from the downstream ultimate 100-year floodplain through their floodplain ordinance. Designers may also need to show through an acceptable downstream analysis that no downstream structures exist within the 100-year floodplain and that bridges and other infrastructure can safely pass the storm.

Option 2. Base extreme peak discharge control on acceptable downstream analysis

Hydrologists have often noted that extreme flood criteria may not always provide full downstream control from the out-of-bank events, due to differences in timing of individual peak discharges in the downstream portion of the watershed. Depending on the shape and land use of a watershed, it is possible that upstream peak discharge may arrive at the same time a downstream structure is releasing its peak discharge, thus increasing the total discharge (see Figure 18). As a result of this "coincident peaks" problem, it is often necessary to evaluate conditions downstream from a site to ensure that effective out-of-bank control is being provided. Some guidance on appropriate procedures for downstream analysis is provided in Appendix D.

Figure 18 Graphical Depiction of Coincident Peak Phenomena (Ogden, 2000).



Debo and Resse (1992) proposed the concept of the 10% rule as the point to which a downstream analysis should extend. This is operationally defined as the downstream point where the development site represents 10% of the total contributing drainage area of a watershed. They contend that the hydrologic effects of upstream stormwater detention stabilize and remain constant further downstream.

A typical downstream analysis will require a hydrologic investigation of the site area draining to a proposed detention facility and of the contributory watershed to the location of the 10% rule for the 10- and 100-year storms. As a minimum, the analysis should include the hydrologic and hydraulic effects of all culverts and/or obstructions within the downstream channel and assess whether an increase in water surface elevations will impact existing buildings or other structures. The analysis should compute flow rates and velocities for pre-developed conditions and proposed conditions both with and without the detention facility.

<u>Exemptions and Modifications to Extreme Storm Criteria</u>

A local community may elect to waive the Q_{p100} criteria when a development project:

- Directly discharges to a large reservoir or lake,
- Directly discharges to a 4^{th} order or larger stream or river
- Is smaller than five acres in area
- Is a redevelopment or infill project that does not increase total impervious surface

- A regional flood model indicates that 100-year control is not needed at a particular site.

Some Minnesota communities base their extreme storm design on a rain-on-snow scenario, rather than a specific design storm approach. Under this scenario, some communities have applied a rule that runoff from as much as 7.2 inches or equivalent rainfall need to be controlled to predevelopment levels. As noted in Issue Paper B, there is little basis for this rule in Minnesota rainfall records or experience, and it clearly results in costly over-control.

Recommended Guidance for Managing Extreme Storms

The recommended guidance for managing extreme storms is summarized in Table 11.

Table 11: Summary of Proposed Approach in the Manual for Dealing with Extreme Storms
The choice of methods and design storms to deal with extreme storms will continue to be a local decision within the purview of established programs. The Manual will contain links to obtaining information for these programs. The Manual will • encourage ultimate floodplain protection as cost-saving approach; • discourage the use of the 7.2 inch rain-on-snow scenario as a design option for snowmelt-related flooding; • present guidance on appropriate methods for downstream analysis; and • present guidance on the specific design assumptions to use in current hydrologic models (Appendix B and D) The Manual will clearly indicate that BMPs need to be designed to provide safe overflow of the 100-year peak discharge rate, even if 100-year control is not necessary (unless they are very small or are located off-line)

VIII. MODELING OF OPTIONS FOR TYPICAL SITES

Each of the sizing criteria described in this paper will generate a different runoff volume to be contained in the site BMP. To further complicate comparisons, each sizing criteria option will produce a different result based on the characteristics of a development. To sort through all the concepts, a simple hydrologic model was constructed to compute the volume of runoff that would be contained in the site BMP for each sizing criteria option (recharge, water quality, channel protection, overbank and extreme storm). Four development scenarios were created for the purpose of understanding how the BMP sizing would differ among a range of land uses. The following describes the procedures, assumptions and results.

Description of Development Scenarios

Four development scenarios were selected for analysis:

- 100-acre detached single family residential, 20% impervious cover
- 50-acre detached single family residential, 12% impervious cover
- 10-acre institutional, 40% impervious cover
- 2-acre commercial, 70% impervious cover

For purposes of comparison, the background conditions were assumed to be constant. All sites consist of HSG soil type B. All impervious surfaces are new. Curve number for impervious surface is 98 and 61 for pervious surfaces. Predevelopment conditions assumed to be meadow in good condition, with Curve Number 58. The input parameters are shown in Table 12.

Table 12. Pre- and Post-Development Input Parameters

	Development Scenario			
	100-acre Detached Residential Site	50-acre Detached Residential Site	10-acre Institutional Site	2-acre Commercial Site
Pre-Development Input Parameters				
Percent Impervious	0%	0%	0%	0%
Curve Numbers	58	58	58	58
Time of Concentration [minutes]	81	61.4	32.2	16.9
Post-Development Input Parameters				
Percent Impervious	20%	12%	40%	70%
Curve Numbers	98/61	98/61	98/61	98/61
Time of Concentration [minutes]	15	15	15	7

<u>Brief description of simplified modeling approach</u>

To generate the volumes for each option and scenario evaluated, either a HydroCAD model was used or a hand-calculation was performed. The results of these analyses are presented in Table 13.

HydroCAD Model
The HydroCAD model was used to compute the following results:

1. Water Quality Volume – The HydroCAD model was used to determine the water quality volume for the following criteria: Walker and Pitt.

2. Peak Flow Rate Analysis – The HydroCAD model was used to determine the volume of storage required to meet the following peak flow rate criteria for Channel Protection (Cp_v), Overbank Flood (Qp_{10}) and Extreme Storm (Qp_{100}): 2-year design storm peak discharge control, 2-year design storm peak discharge over-control, 24-hour extended detention of the 1-year 24-hour design storm, 10-year design storm peak discharge control and 100-year design storm peak discharge control. A generic pond and outlet structure was configured for each development scenario to determine the storage volume required to meet the peak flow rate requirement.

3. Detention Time for the Water Quality Criteria - A final analysis of the detention time was done for the MPCA Hybrid Option. Depending upon which sizing variables were chosen (particularly pond shape and outlet pipe size) detention times varied widely. However, the rate of discharge from the water quality events was tested in all cases to ensure they did not exceed the 5.66 cfs per pond acre requirement contained in the MPCA General Permit for Construction Activities. Ideally, detention times for the final design should equal or exceed 12 hours to get satisfactory water quality treatment.

Table 13. Summary of Volume Requirements for the Various Design Criteria

Criteria	Development Scenario: 100-acre Detached Residential Site	50-acre Detached Residential Site	10-acre Institutional Site	2-acre Commercial Site
Recharge (Re_v) or Infiltration				
No recharge requirement	0.0	0.0	0.0	0.0
¼" over new impervious area (half of MPCA WQv requirement)	0.40	0.13	0.09	0.03
Recharge requirement based on regional rates tied to HSG	--	--	--	--
Infiltrate pre- to post-development runoff volume increase from the 2-year, 24-hour storm (MPCA rule for Special Waters)	4.4	1.47	0.83	0.28
Water Quality Volume (WQ_v)				
Half-Inch Rule	0.83	0.25	0.17	0.06
MPCA	5.0	2.3	0.6	0.1
90% Capture Rule	2.1	0.7	0.4	0.1
Pitt Rule	1.7	0.5	0.3	0.1
Walker Method	5.1	1.9	0.9	0.3
Channel Protection (Cp_v)				
2-year design storm peak discharge control	3.2	1.0	0.6	0.2
2-year design storm peak discharge "over-control"	4.0	1.4	0.7	0.2
24-hour extended detention of the 1 year 24 hour design storm volume	4.7	1.7	0.8	0.3
Overbank Flood (Qp_{10})				
10 year design storm peak discharge control	4.8	1.7	0.7	0.2
Extreme Storm (Qp_{100})				
100 year design storm peak discharge control	7.4	2.9	0.9	0.3

It should be noted that three of the water quality sizing options described in this issue paper apply a runoff coefficient (R_v) to the impervious surface to compute the runoff volume under the half-inch rule, MPCA method and 90% capture rule. Ease of application is the primary reason this procedure was used. The analysis performed for this issue paper used Curve Numbers to create a more exact comparison of the options being considered. The Minnesota Stormwater Steering Committee could still recommend use of a runoff coefficient computation technique.

In this analysis, a composite CN was not used. Runoff from pervious and impervious areas for each development scenario was computed separately. The difference between composite CN runoff volumes vs. separate computations for each land cover is most noticeable for the water quality criteria options. The separate computation reflects the typical site approach currently taken by designers: pervious surfaces are typically higher than and drain towards the impervious surfaces. Impervious surfaces are connected, which are then connected to the site BMP. These computations generate the greatest possible amount of runoff from these generic sites. Better site design techniques, discussed in Appendix A would result in lesser volumes of runoff.

Hand Calculation
A hand calculation was performed to determine the water quality volume required for the following criteria: half-inch rule (0.5" x Total Watershed Area), MPCA method (1800ft^3/acre of site plus one half-inch over new impervious) and 90% capture rule ((1.1" x runoff coefficient (R_v) x total site area (ac)).

<u>Impacts on storage volume for each of Five Sizing Criteria</u>

Two techniques were used (in Section II) to compare the results of this analysis: pie charts to compare the relative volume of each criterion within a site BMP and bar charts to compare the relative volumes for each option.

Pie Charts (Figures 3 and 4, Section II)

The runoff volumes plotted for the recharge volume (Re_v), water quality volume (WQ_v), channel protection (Cp_v), overbank conveyance (Qp_{10}) and extreme storms (Qp_{100}) were based on the recommendations contained in this paper. The volumes for overbank conveyance (Qp_{10}), extreme storms (Qp_{100}), channel protection (Cp_v) and recharge volume (Re_v) are the same for each scenario plotted. The criterion used for the channel protection (Cp_v) volume is the 24-hour extended detention of the 1 year 24 hour design storm (approximately 2.4") volume, and the criterion used for the recharge volume (Re_v) is the difference in runoff volume between pre- and post-development for the 2-year 24-hour storm. As a result, the variable for each pie chart is the water quality option. One pie chart was prepared for each development scenario. As the charts illustrate, recharge volume is a subset of the water quality volume; that is, the <u>total</u> water quality volume for each pie chart is the sum of the recharge volume and the water quality volume.

Illustrative examples of the pie chart series were included in Section II of this paper. All of the pie charts are contained in Appendix E.

Bar Charts (Figures 5-7, Section II)

A series of bar charts were developed to contrast the required storage volumes for different sizing options within a particular sizing criterion. A bar chart was developed for the following sizing options: recharge volume (Figure 5), water quality volume (Figure 6), and channel protection volume (Figure 7). These charts provide a general sense of the storage and thus cost implications of the various sizing options.

<u>Water Quality Modeling Results</u>

Water Quality Modeling

An evaluation of the pollutant removal capability for each water quality volume criteria (1/2" rule, MPCA method, 90% Capture Rule, Pitt Rule and Walker Method) and each development scenario was performed using both PONDNET (Walker) and P8 (Walker). A summary of this evaluation is provided later in this section (Table 15). The following section describes the methodology used to make this pollutant removal comparison.

<u>PONDNET Methodology</u>

To perform the PONDNET evaluation for each of the ponds a separate spreadsheet was developed for each development scenario and water quality scenario.

For each of the scenarios modeled, the volume used to determine the percent phosphorous removal is the water quality volume calculated using the criteria identified below. The water quality model assumes that the basins are not managed for infiltration and that the water at the normal water level (NWL) remains at the NWL for the next precipitation event.

1. ½" Rule - 0.5" x IC*
2. MPCA Method - 1800ft^3/acre of site + [1/2" x new impervious area]
3. 90% Capture Rule - (1.1" x runoff coefficient (R_v) x total site area(ac))
4. Pitt Rule – 1.25" x CN x Area
5. Walker Method – 2.5" x CN x Area

*For the above equations: IC = acres of impervious cover
R_v = 0.05 + 0.009I where I = percent impervious cover
CN = runoff curve number

In order to make the water quality results comparable the same runoff coefficient was used for each development scenario. The runoff coefficient was computed using the following formula: R_V = 0.009I + 0.05 where I is equal to the percent impervious cover. The runoff coefficients used for each PONDNET calculation are provided in Table 14.

In addition to using a constant runoff coefficient for each development scenario, the mean depth of the pond was held constant to make the water quality results comparable. Again, the mean depths assumed for each development scenario are provided in Table 14.

Table 14. Input Parameters for the PONDNET model.

	100-acre development scenario	50-acre development scenario	10-acre development scenario	2-acre development scenario
Percent Impervious	20	12	40	70
Runoff Coefficient	0.23	0.158	0.41	0.68
Constant Mean Depth [feet]	3.0	2.5	2.0	2.0

The annual precipitation depth and the phosphorous concentrations for each development scenario were held constant between the PONDNET model and the P8 model. These values are discussed in the P8 section below.

P8 Methodology

Four separate P8 models were constructed to evaluate the various methods for sizing the water quality ponds. As with the PONDNET evaluation, the models were set up for each development scenario and the pond configurations varied for each water quality volume criteria. Again, the water quality model assumes that the basins are not managed for infiltration and that the water at the normal water level (NWL) remains at the NWL for the next precipitation event.

In order to make the water quality results comparable to those generated in the PONDNET model, the following modifications were made:

1. The subwatersheds were given the same runoff coefficients assigned to the subwatersheds in PONDNET. The runoff coefficient was computed using the following formula: $R_v = 0.009I + 0.05$ where I is equal to the percent impervious cover.

2. The water quality volume calculated using the ½" Rule, Walker Method, Pitt Rule and 90% Capture Rule was defined as the dead storage or the permanent pool. Live storage was defined above the dead storage to handle the bounce generated in the detention pond.

3. The surface area at the NWL was defined by keeping the depth constant, as was done in the PONDNET analysis. Surface area of the permanent pool was defined as the corresponding flood volume/1.5 feet.

4. The outlet for each of the development scenarios was modified to increase the performance of the ponds. The following outlet structures were defined in the P8 analysis:

100-acre Detached Residential	24" RCP
50-acre Detached Residential	18" RCP
10-acre Institutional Site	15" RCP
2-acre Commercial Site	10" RCP

The precipitation data used for this analysis is the Minneapolis-St. Paul Airport rainfall file for 1995. This was selected to represent an "average" precipitation year. The annual rainfall depth for this year was 26.54 inches. This is the annual rainfall depth used in the PONDNET evaluation. The P8 simulation was run from 10/01/94 to 9/30/1995.

The particle-size file used to evaluate pollutant removal rates for the water quality ponds is called "Monroe.par". This particle-size file was developed by Roger Bannerman and is based on monitoring data from a 223 acre residential watershed that was 34 percent impervious in Madison, Wisconsin. The data was collected from 1993 to 1997. The phosphorous concentrations generated in P8 for each development scenario were used in the PONDNET model.

Results

A summary of the water quality analysis is provided in Table 15.

Table 15. Summary of the Water Quality Analysis.

Criteria	PondNET Results – Percent Reduction Phosphorous Loads Development Scenario				P8 Results – Percent Reduction Phosphorous Loads Development Scenario			
	100-acre Detached Residential Site	50-acre Detached Residential Site	10-acre Institutional Site*	2-acre Commercial Site*	100-acre Detached Residential Site	50-acre Detached Residential Site	10-acre Institutional Site	2-acre Commercial Site
	Percent Removal	Percent Removal	Percent Removal	Percent Removal	Percent Removal	Percent Removal	Percent Removal	Percent Removal
Half-Inch Rule	46.0	45.7	48.0	53.1	36.0	36.3	38.9	43.8
MPCA	65.0	63.0	57.7	57.8	54.8	56.0	51.3	51.0
90% Capture Rule	57.9	55.0	54.8	53.1	47.7	46.8	47.4	43.8
Pitt Rule	50.9	51.6	52.2	53.1	46.4	42.7	41.4	43.8
Walker Method	65.1	62.1	59.9	60.4	54.9	55.0	54.0	53.8

The results of the PONDNET analysis indicate that the percent phosphorous removal for each of the water quality volume criteria is fairly consistent (approximately within seven percentage points). The water quality criteria appear to provide all development densities and development sizes with a relatively equal level of pollutant removal capacity. The least consistent of the five criteria is the ½" Rule which has a variation of 7.4 percentage points. The most consistent is the Pitt Rule and then the 90% Capture Rule.

It is clear that the equations that are based on the percent impervious cover have higher removal rates as the percent impervious increases. For example, the half-inch rule (which is completely based on the total impervious area) has increasing removal rates for increasing percent imperviousness. For the other equations, which are more sensitive to the total area of the site, the removal rate increases as the development size increases. As a result, the elements that have the most significant impact on percent removal are total area and percent impervious area.

The results of the P8 analysis also indicate that the percent phosphorous removal for each of the water quality volume criteria is fairly consistent (approximately within eight percentage points). Again, the least consistent of the five criteria is the ½" Rule which has a variation of 7.8 percentage points. The most consistent is the Walker Method and then the 90% Capture Rule.

A review of the P8 results indicates that there is some variation in the results within a given water quality volume criterion: there is not a consistent trend up or down as displayed in the PONDNET results. The reason for this is that P8 is model is more sensitive to surface area that it is to pond volume. The main parameter of P8 is the area at the NWL of the permanent pool.

As Table 15 indicates, the percent removal rates for phosphorous are higher for PONDNET than they are for P8. This difference in results can be attributed to the fact that PONDNET is an empirical model (based on measured data points) while P8 is a physically based model (based on particle distribution size and sedimentation processes). Another difference between the models is that P8 simulates live storage and PONDNET does not. The inflow to a detention pond in PONDNET completely replaces the volume of water that was in the detention pond at the beginning of the rainfall event. This allows the pollutant-laden water to undergo a longer period of treatment before the next "batch" of stormwater enters the system. Conversely, P8 is probably more representative of the physical processes that are actually happening. Inflow to a detention pond in P8 "pushes" some of the water out of the pond while some of the stormwater mixes with the water that remains in the pond until the next rainfall event. As a result, the percent removal is lower for the P8 model than for the PONDNET model.

The difference in removal rates between PONDNET and P8 is not a concern given that the difference is based on how the individual model computes removal rates. The main point is that depending upon which model an applicant chooses to use for a water quality analysis, the amount of land dedicated to water quality volume will be different. In Table 15, the relative differences among criteria can be compared because the input assumptions are the same for each.

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Appendix A.

Review of Better Site Design Techniques

Appendix A: Better Site Design Techniques

Better site design (BSD) refers to the application of non-structural practices at residential and commercial sites to reduce impervious cover, conserve natural areas, and use pervious areas to more effectively treat stormwater runoff (CWP, 1998). The use of BSD techniques has been promoted in both the MPCA manual (2002) and the Metropolitan Council manual (2001). When applied early in the design and layout process, BSD techniques can dramatically reduce the stormwater runoff and pollutants generated from a development site, and also sharply reduce the size and cost of both the stormwater conveyance system and stormwater management practices (CWP, 1999). In recent years, several states have sought to encourage greater use of better site design techniques by offering stormwater credits that reduce the recharge, water quality or channel protection volume that must be provided at new development sites.

The 1998 Center for Watershed Protection publication *Better Site Design: a handbook for changing development rules in your community* presents these techniques and is the source of much of the information in this appendix. The Stormwater Manager's Resource Center, another Center for Watershed Protection source used in compiling this information, is located online at www.stormwatercenter.net.

This appendix presents a description of each better site design technique that can be applied to help reduce or manage stormwater runoff, and evaluates its general feasibility as a potential stormwater credit. This is summarized in Table 3 in the body of the memo. These techniques were introduced in Issue Paper A, decision matrix 2. The following questions were posed in that paper:

- Does this techniques reduce the volume of stormwater runoff?
- Does it reduce the runoff…
  - By preserving natural hydrology?
  - By infiltrating runoff?
  - By reducing the amount of site imperviousness?
- Would this credit qualify for a recharge credit? For a water quality credit?

Each better site design technique was recommended as a potential stormwater credit, classified as a possible credit pending further investigation, or not recommended for a credit. In the latter case, when no credit is recommended, better site design techniques are their own rewards. Techniques that reduce the impervious cover of a site reduce the required recharge and water quality volume as methods to calculate these criteria are based on impervious cover. Therefore, less structural controls are necessary on sites that utilize better site design.

1. Natural Area Conservation

Natural Area Conservation involves the identification and preservation of natural resources and features that can be instrumental in the protection of water resources. The conservation area should be set aside in a permanent conservation easement with a prescribed set of uses or activities that restrict future development. Site resources to protect include areas of undisturbed vegetation, floodplains and riparian areas, ridge tops and steep slopes, natural drainage pathways, intermittent and perennial streams, wetlands, and porous or erodible soils.

The benefits of natural area conservation include reduced runoff, infiltration of stormwater, runoff storage and reduced flooding, prevention of soil erosion, and capture and filtering out of pollutants in stormwater runoff. Undisturbed, un-compacted soils promote infiltration by attenuating runoff due to storage in the pores created by tree roots and in the organic matter. Forested areas intercept rainfall in their canopy, reducing the amount of rain that reaches the ground, and use water through tree roots and increasing space available for water storage in the soil. Additionally, trees and native vegetation prevent erosion by stabilizing soil, filter sediment and pollutants from runoff, and take up nutrients such as nitrogen.

Natural area conservation is recommended as a potential stormwater management credit for areas on site that are not disturbed during construction and are instead protected by a perpetual conservation easement that specifies the management of native vegetation.

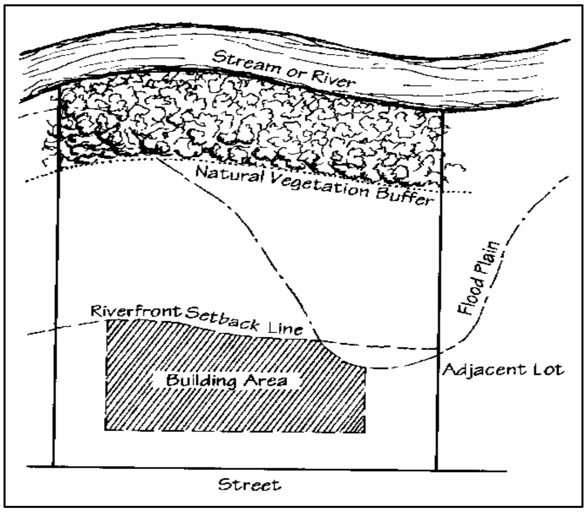


Figure A-1. Example of Site Resource Protection and Conservation

2. Site Reforestation

Site Reforestation involves reforestation of existing turf or barren ground at the development site with the explicit goal of establishing a mature forest canopy or prairie vegetation that intercepts rainfall and maximizes stemflow, infiltration, and evapotranspiration. Reforestation is accomplished through active replanting or natural regeneration.

The benefits of site reforestation include reduced runoff, infiltration of stormwater, runoff storage and reduced flooding, prevention of soil erosion, and capture and filtering out of pollutants in stormwater runoff. Soils in forested areas promote infiltration by attenuating runoff due to storage in the pores created by tree roots and in the organic matter. Forested areas intercept rainfall in their canopy, reducing the amount of rain that reaches the ground, and use water through tree roots and increasing space available for water storage in the soil. Additionally, trees and native vegetation prevent erosion by stabilizing soil, filter sediment and pollutants from runoff, and take up nutrients such as nitrogen. Capiella (2005) reviewed a range of research that demonstrates the considerable runoff reduction associated with forest cover compared to turf.

Reforested sites protected by a perpetual conservation easement and maintained over a defined growing period may be eligible for a stormwater credit, although some additional investigation is needed to define over what time period it would be granted.

3. Stream and Shoreline Buffers

The primary function of stream and shoreline buffers is to physically protect and separate a stream, lake or wetland from future disturbance or encroachment. By providing setbacks from water features during development, potential pollution can be avoided. If properly designed, buffers can provide stormwater management and act as a right-of-way during floods, sustaining the integrity of stream ecosystems and habitats. Technically buffers are a type of natural area conservation, function as an integral part of the aquatic ecosystem, and can also function as part of an urban forest.

For optimal stormwater treatment, a buffer should be composed of three lateral zones: a stormwater depression area that leads to a grass filter strip that in turn leads to a forested buffer. The captured runoff within the stormwater depression can be spread across a grass filter designed for sheetflow conditions for the water quality storm. The grass filter then discharges into a wider forest buffer designed to fully infiltrate the surface runoff.

Stream and Shoreline buffers can be considered part of natural area conservation; additional credit extends to certain adjacent areas that contribute runoff to the buffer.

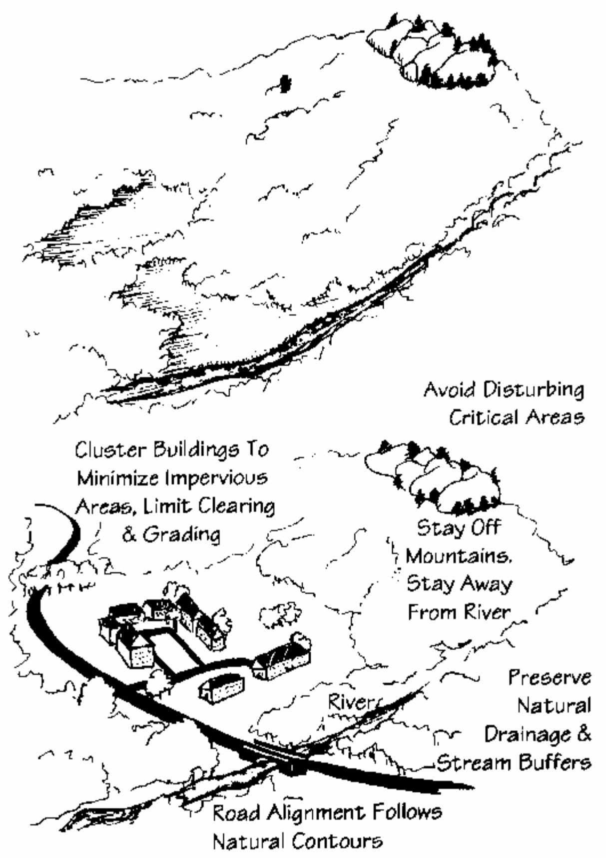


Figure A-2 Fit the design of a site to the terrain, preserving natural areas and buffers

4. Soil Compost Amendments

Soil Compost Amendments refer to tilling and composting of new lawns and open spaces within a development site to recover soil porosity lost due to compaction as a result of past construction, soil disturbance and ongoing human traffic. The soil compost amendment process seeks to recover the porosity and bulk density of soils by incorporating soil amendments or conditioners into the lawn, such as compost, top soil, lime and gypsum (McDonald, 1999).

Soil compost amendments improve the hydrological properties of the lawn or landscaped area by promoting more storage and infiltration, and producing less runoff. In addition, reduced runoff from amended soils may also reduce nutrient and sediment loading to surface waters.

This technique has not yet been widely applied in Minnesota, but could be a potential credit if the composting materially improves the hydrologic performance of highly compacted lawns (which has been demonstrated for in recent Wisconsin research).

5. Impervious Surface Disconnection

Surface Disconnection is used to spread runoff generated from small parking lots, courtyard, driveways sidewalks and other impervious cover into adjacent pervious areas where it is filtered and infiltrated. These pervious areas, with grass or natural vegetation, can be used to infiltrate runoff, reduce runoff velocity, and remove pollutants. Minimum design standards regarding the length of the pervious area, slope, soil characteristics and contributing drainage area are necessary to prevent the reconnection of this runoff to the storm drain system. Impervious surface disconnection techniques primarily involve diversion of runoff to a vegetated filter strip or pervious area.

By disconnecting small impervious surfaces from the storm drain system, the total volume and rate of runoff can be greatly reduced at a development site. A stormwater credit might be offered for surface disconnection if runoff can be spread over an acceptable pervious area with minimum dimensions and porosity.

6. Rooftop Disconnection

Both residential and non-residential rooftops can offer an excellent opportunity to disconnect impervious surfaces and spread the rooftop runoff over lawns and pervious areas where it can be filtered and infiltrated. Alternately, residential downspouts can be directed to a dry well, an underground rock-filled trench, similar to an infiltration trench. Practices that store rooftop runoff, such as cisterns and rain barrels, are discussed in BSD technique number 14.

Downspout disconnection can infiltrate runoff, reduce runoff velocity, and remove pollutants. A stormwater credit may be considered for rooftop disconnections that are effectively spread over an acceptable pervious area.

7. Open Space or Cluster Design

This form of residential development reduces average lot size within a subdivision in exchange for greater conservation of natural areas. With dwelling units concentrated in a compact area, less grading and lower construction costs can be benefits of this approach. The minimum lot sizes, setbacks and frontage distances for the residential, commercial, industrial or mixed-use zone are relaxed in order to create the open space at the site. This form of development, if available as an option under local zoning codes, also may reduce or disconnect impervious cover and provide for greater on-site stormwater treatment.

Open space and cluster designs can reduce overall impervious cover in comparison to the conventional subdivisions that they replace and provide more undisturbed open space with the benefits of natural area conservation discussed above.

While no overall stormwater credit is recommended for open space designs, many of its individual elements are eligible for credit (e.g. grass channels, natural area conservation).

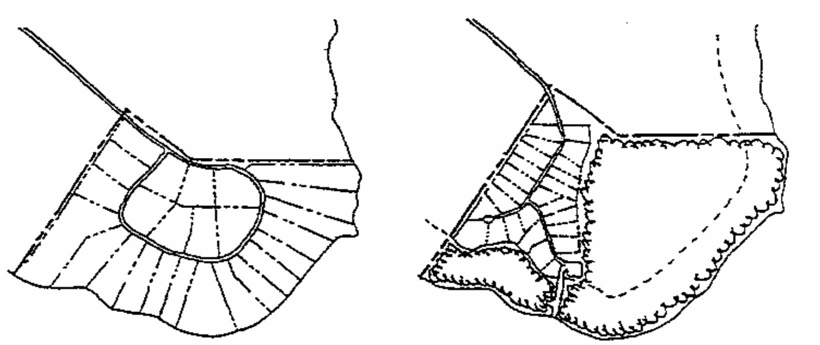


Figure A-3. Conventional Development Versus Cluster Design with Conservation Area

Source: Conservation Design for Stormwater Management. Delaware Department of Natural Resources and Environmental Control

8. Grass Channels

Grass Channels are preferable to curb and gutters as a conveyance system, where development density, topography, soils and slopes permit. Buildings and roads should be sited to utilize the natural grading and drainage system, avoid the unnecessary disturbance of vegetation and soils, and preserve natural drainageways.

Structural drainage systems and storm sewers are designed to be hydraulically efficient in removing stormwater from a site. However, they also tend to increase peak runoff discharges, flow velocities, and the delivery of pollutants to downstream waters. The alternative – the use of natural open channels - allows for more storage of stormwater flows on-site, lower stormwater peak flows, a reduction in erosive runoff velocities, infiltration of a portion of the runoff volume, and some capture and treatment of stormwater pollutants. While research has not demonstrated that grass channels or roadside ditches remove pollutants reliably enough to qualify as a stormwater management practice (Winer, 2000), they have been shown to reduce the total volume of runoff for smaller storms when compared to curbs and gutters.

Stormwater credits should be awarded for the use of grass channels, due to their ability to reduce the volume of runoff through infiltration and provide some detention through decreased velocities.

Reduced Impervious Cover

The next group of better site design techniques reduces the creation of impervious cover during site design by downsizing the dimensions of streets, sidewalks, cul-de-sacs, driveways and parking lot dimensions. The ability to downsize these dimensions at a new development site depends greatly on current local development codes. If a community allows smaller dimensions for any of these standards in its local development codes, designers that take advantage of them can greatly reduce the amount of impervious cover at a development site. No explicit stormwater credit is generally offered when these better site design techniques are employed, since the designer will automatically get a direct reduction in stormwater sizing (since most sizing requirements are a direct function of site impervious cover).

9. Reduced Street Width

In localities with flexible road section standards, streets should be designed for the minimum pavement width needed to support travel lanes, on-street parking, and emergency access, which can be as narrow as 22 to 26 feet. Even narrower access streets or shared driveways can be used when only a handful of homes need to be served. Currently, many communities require wide residential streets that are 32-40 feet wide, providing two parking lanes and two moving lanes which amount to more parking than is actually necessary.

10. Reduced Sidewalks

In localities with flexible sidewalk requirements, the amount of impervious cover can be reduced by modifying the placement and width of sidewalks in ways that do not impair pedestrian mobility. Placing sidewalks on only one side of the street or designing sidewalks to the minimum required width results in reduced impervious cover. Disconnection of impervious cover can be achieved by grading sidewalks to drain to pervious areas, such as lawns or buffers, rather than the gutter and storm drain system.

11. Smaller Cul-de-sacs

Impervious cover can be reduced by minimizing the number of residential street cul-de-sacs and incorporating landscaped areas. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Alternatives to the traditional 40' radius cul-de-sac as a turnaround include the 30' radius cul-de-sacs, hammerheads, and loop roads.

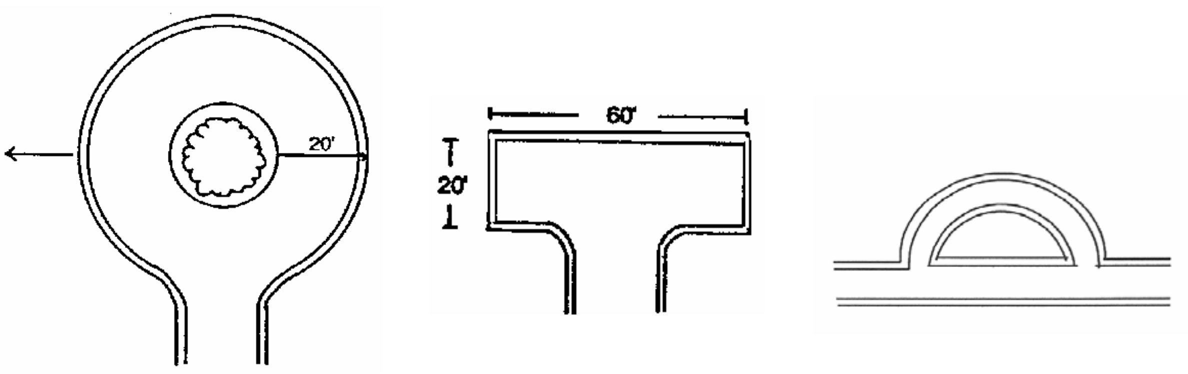


Figure A-4: Alternative turnarounds include (a) cul-de-sac with landscaped island (b) hammerhead and (c) loop road.

12. Shorter Driveways

Front yard setback requirements usually dictate driveway length. To reduce the impervious cover on the site with shorter driveways, use the minimum available setback or apply for a variance. Shared driveways, providing access to the street for up to six homes, also reduce the impervious cover on a site.

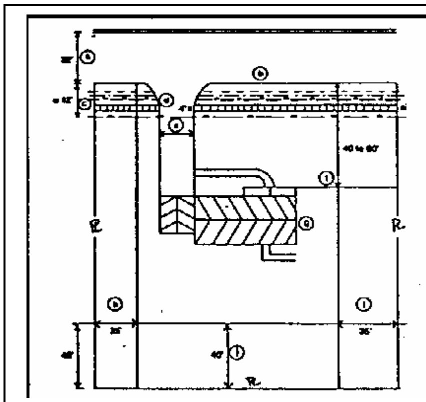


Figure A-5: Driveway length is dictated by setbacks.

13. Smaller Parking Lots

Smart parking lots can be produced using sound better site design techniques as follows:

- Minimizing the stall dimensions
- Providing compact car spaces
- Incorporating efficient parking lanes
- Reducing minimum parking demand ratios
- Creating stormwater "islands" in traffic islands or landscaping areas to treat runoff using bioretention, filter strips or other practices
- Taking advantage of incentives for shared parking arrangements
- Structured parking.

These better site design techniques can reduce and disconnect impervious cover, but do not qualify as a direct stormwater credit.

14. Rooftop Runoff Storage

Rooftop Runoff Storage involves the installation of cisterns or rain-barrels to capture and temporarily store rooftop runoff at confined sites, and gradually release it over pervious areas or use for irrigation. Runoff storage is most practical for new commercial and industrial rooftops. However, residential rain barrels are effective if homeowners are interested and have a use for the stored water.

Rooftop runoff storage decreases runoff by retaining a portion of the flows for later use and indirectly promotes groundwater recharge by applying runoff to pervious areas.

This technique achieves impervious surface disconnection but it may require some significant cold-weather adaptations to perform effectively under Minnesota winter conditions. Therefore, additional investigation is needed before developing a possible stormwater credit for this practice.

15. Permeable Pavers

Permeable Pavers refers to a broad range of products including porous pavement, concrete and brick products, grass pavers, and various block pavers that enable some fraction of rainfall to be infiltrated into a sub-base underneath the paver. Permeable pavers can replace asphalt and concrete for driveways, parking lots and walkways, and are particularly well suited for high density development projects such as courtyards, plazas and spill-over parking areas. Porous asphalt and pervious concrete are pavement surfaces with an underlying stone reservoir that temporarily stores surface runoff before infiltrating into the subsoil. Porous asphalt and pervious concrete appear the same as traditional pavement from the surface, but are manufactured without "fine" materials, and incorporate void spaces to allow infiltration. Paving blocks or grass pavers are concrete interlocking blocks or synthetic fibrous grid systems with open areas designed to allow grass to grow within the void areas. Paving blocks make the surface more rigid and gravel or grass planted inside the holes allows for infiltration. Depending on the use and soil types, a gravel layer can be added underneath to prevent settling and allow further infiltration.

Permeable pavers can replace impervious surfaces, creating less stormwater runoff by allowing parking lot runoff to infiltrate directly into the soil and receive water quality treatment.

Given the broad diversity of paver products and applications, and their uncertain longevity in cold-climates, more investigation is needed to determine how stormwater credits might be granted for this practice.

16. Stormwater Planters

Stormwater Planters are self-contained landscaping areas employed in high density development projects to capture and temporarily store a fraction of rooftop runoff and filter it through the soil media.

Stormwater planters generally receive runoff from adjacent rooftop downspouts in highly urban areas such as central business districts. Stormwater planters reduce runoff by infiltrating runoff and through plant uptake. Water quality is improved as runoff passes through the planter and pollutants are captured on planter soils.

In most cases, stormwater planters cannot capture enough runoff to qualify as a stormwater management practice, but may possibly be eligible for a stormwater credit.

17. Green Rooftops

Green Rooftops are an emerging rooftop treatment practice where a thin planting media is established on flat roof surfaces and then planted with hardy, low-growing vegetation. The vegetation can range from turfgrass to shrubs or even trees, depending on the climate and the load-bearing capacity of the roof. A green rooftop typically consists of several layers, including a waterproofing membrane, insulation, protection layer, drainage layer, filter mat, soil layer, and vegetation. Green rooftops may have an internal drainage network that directs an overflow away from the roof to inhibit ponding.

Recent research has shown that green roofs can fully store and evapotranspire rainfall from small and medium events, but may not always qualify as a stormwater management practice because they may not be able to treat the entire water quality volume. In these cases, a generous stormwater credit may be offered for their use.

Appendix B.

Summary of Acceptable Hydrological Models for Stormwater Design and Recommended Hydrologic Basis for Design

A. Recommended Hydrological Models for Stormwater Design

The purpose of this section is to describe computer program packages in hydrology that are generally available to hydrologists and engineers. While new programs being developed each year, this paper focuses on those programs that are considered industry standards and are more readily available to the engineering consulting world.

The programs covered in this section deal with surface water quantity and quality. Models are grouped into the following classes: single-event rainfall-runoff and routing models, continuous stream flow simulation models, flood-hydraulics models and water quality models. The following information is provided:

1. Model overview
2. Specific hydrologic application strengths
3. Required model input
4. Model limitations
5. Model acquisition

Single Event Rainfall-Runoff and Routing Models

Technical Release No. 20 (TR-20)

Technical Release No. 20: Computer Program for Project Formulation Hydrology (TR-20) was developed by the hydrology branch of the U.S. Soil Conservation Service in 1964. TR-20 is a single-event rainfall-runoff model that is typically used with a design storm for rainfall input. There is no provision for recovery of initial abstraction or infiltration during periods of no rainfall within an event. The program computes runoff hydrographs, routes flows through channel reaches and reservoirs, and combines hydrographs at confluences of the watershed stream system. Runoff hydrographs are computed using the SCS runoff equation and the SCS dimensionless unit hydrograph. A rainfall-runoff analysis can be performed on as many as 200 subwatersheds or reaches and 99 structures in any one continuous run. TR-20 does not provide for losses of runoff in the transmission of the flood hydrograph dues to seepage or other causes of flood water loss.

TR-20 is currently being re-written by the Natural Resources Conservation Service (NRCS). The revised program, Win TR-20, will have a windows-base input editor. A Beta Test version is available on the NRCS web-site.

http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr20.html

Technical Release 55 (TR-55)

Technical Release 55 (TR-55) Urban Hydrology for Small Watersheds was developed by the U.S. Natural Resources Conservation Service (NRCS) in 1975 as a simplified procedure to calculate storm runoff volume, peak rate of discharge, hydrographs and storage volumes. In 1998, Technical Release 55 and the computer software were revised to what is now called WinTR-55. The changes in this revised version of TR-55 include: upgraded the source code to Visual Basic, changed the philosophy of data input, developed a Windows interface and output post-processor, enhanced the hydrograph-generation capability of the software and flood routing hydrographs through stream reaches and reservoirs.

WinTR-55 is a single-event rainfall-runoff small watershed hydrologic model. The model is an input/output interface which runs WinTR-20 in the background to generate, route and add hydrographs. The WinTR-55 generates hydrographs from both urban and agricultural areas at selected points along the stream system. Hydrographs are routed downstream through channels and/or reservoirs. Multiple sub-areas can be modeled within the watershed. A rainfall-runoff analysis can be performed on up to ten sub-areas and up to ten reaches. The total drainage area modeled can not exceed 25 square miles. WinTR-55 was not designed to model storm sewer systems and should not be used to evaluate these flow conditions.

WinTR-55 is available on the NRCS web-site.

http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr55.html

HEC-1

HEC-1 is a rainfall-runoff model developed by the U.S. Army Corps of Engineers. HEC-1 is a single storm event, lumped parameter model that includes several options for modeling rainfall, losses, unit hydrographs, and stream routing. The model is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component models an aspect of the precipitation-runoff process within a portion of the basin. A component may represent a surface runoff entity, a stream channel, or a reservoir. Representation of a component requires a set of parameters which specify the particular characteristics of the component and mathematical relations which describe the physical processes. The result of the modeling process is the computation of stream flow hydrographs at the desired locations in the river basin.

The HEC-1 program is available to the public and can be downloaded from the U.S. Army Corps of Engineers web-site at:
http://www.hec.usace.army.mil/software/legacysoftware/hec1/hec1-download.htm.

Continuous Stream Flow Simulation Models

HydroCAD

HydroCAD is a computer aided design program for modeling the hydrology and hydraulics of stormwater runoff. Runoff hydrographs are computed using the SCS runoff equation and the SCS dimensionless unit hydrograph. There is no provision for recovery of initial abstraction or infiltration during periods of no rainfall within an event. The program computes runoff hydrographs, routes flows through channel reaches and reservoirs, and combines hydrographs at confluences of the watershed stream system. HydroCAD has the ability to simulate backwater conditions by allowing the user to define the backwater elevation prior to simulating a rainfall event.

HydroCAD is a proprietary model and can be obtained from HydroCAD Software Solutions LLC. http://www.hydrocad.net/

SWMM

The Storm Water Management Model (SWMM) was originally developed for the Environmental Protection Agency (EPA) in 1971 by Metcalf and Eddy, Inc., Water Resources Engineers, Inc. and the University of Florida. SWMM is a dynamic rainfall-runoff simulation model, primarily but not exclusively for urban areas, for single-event or long-term (continuous) simulation.

The Storm Water Management Model (SWMM) is a comprehensive computer model for analysis of quantity and quality problems associated with urban runoff. Both single-event and continuous simulation can be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations. Extran Block solves complete dynamic flow routing equations (St. Venant equations) for accurate simulation of backwater, looped connections, surcharging, and pressure flow. Modeler can simulate all aspects of the urban hydrologic and quality cycles, including rainfall, snow melt, surface and subsurface runoff, flow routing through drainage network, storage and treatment. Statistical analyses can be performed on long-term precipitation data and on output from continuous simulation. SWMM can be used for planning and design. Planning mode is used for an overall assessment of urban runoff problem or proposed abatement options.

The SWMM program is available to the public and can be downloaded from the U.S. Environmental Protection Agency's website at:
http://www.epa.gov/ceampubl/swater/swmm/index.htm

Flood-Hydraulics Models

HEC-2

HEC-2 is a rainfall-runoff model developed by the U.S. Army Corps of Engineers to compute steady-state water surface elevation profiles in natural and constructed channels. HEC-2 uses the standard step method for water surface profile calculations assuming that flow is one-dimensional, gradually varied steady flow. Subcritical and supercritical flow profiles may be evaluated. The water surface profile through structures such as bridges, culverts, weirs and other types of structures can be computed.

The HEC-2 program is available to the public and can be downloaded from the U.S. Army Corps of Engineers web-site at:
http://www.hec.usace.army.mil/software/legacysoftware/hec1/hec1-download.htm.

Water Quality Models

PONDNET

The PONDNET model (Walker 1987) is an empirical model developed to evaluate flow and phosphorous routing in Pond Networks. The following input parameters are defined by the user in evaluating the water quality performance of a pond: watershed area (acres), runoff coefficient, pond surface area (acres), pond mean depth (feet), period length (years), period precipitation (inches) and phosphorous concentrations (ppb). The spreadsheet is designed so that the phosphorous removal of multiple ponds in series can be evaluated.

A copy of PONDNET may be requested from William W. Walker at the following web-site: http://wwwalker.net/.

P8

P8, Program for Predicting Polluting Particle Passage through Pits, Puddles & Ponds (Walker), is a physically-based model developed to predict the generation and transport of stormwater runoff pollutants in urban watersheds. The model simulates runoff and pollutant transport for a maximum of 24 watersheds, 24 stormwater best management practices (BMPs), 5 particle size classes, and 10 water quality components. The model simulates pollutant transport and removal in a variety of BMPs including swales, buffer strips, detention ponds (dry, wet and extended), flow splitters, and infiltration basins (offline and online). Model simulations are driven by a continuous hourly rainfall time series. P8 has been designed to require a minimum of site-specific data, which are expressed in terminology familiar to most engineers and planners. An extensive user interface providing interactive operation, spreadsheet-like menus, help screens and high resolution graphics facilitate model use.

A copy of P8 may be obtained from William W. Walker at the following web-site: http://wwwalker.net/.

BASINS

The Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) model is a multipurpose environmental analysis system developed by the U.S. Environmental Protection Agency's (EPA's) Office of Water. The model was originally introduced in 1996 and has had subsequent releases in 1998 and 2001. BASINS allows for the assessment of large amounts of point and non-point source data in a format that is easy to use and understand. BASINS incorporates a number of model interfaces that it uses to assess water quality at selected stream sites or throughout the watershed. These model interfaces include;

QUAL2E	A water quality and eutrophication model
WinHSPF	A watershed scale model for estimating in-stream concentrations resulting from loadings from point and non-point sources
SWAT	A physical based, watershed scale model that was developed to predict the impacts of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land uses and management conditions over long periods of time.
PLOAD	A pollutant loading model.

BASINS may be obtained on the following EPA web-site: http://www.epa.gove/waterscience/basins/. The EPA's Office of Science and Technology provides technical support to users of the BASINS system. This technical support can be obtained at the following web-site: http://www.epa.gov/ost/basins.

B. Hydrologic Basis for Design

The basis for hydrologic and hydraulic evaluation of development sites should be as follows:

Water Quality Volume - WQ_v

- Impervious cover is measured from the site plan and includes all impermeable surfaces (i.e., paved and gravel roads, rooftops, driveways, parking lots, sidewalks, pools, patios, and decks).
- The final WQ_v shall be treated by an acceptable Stormwater BMP from the list presented in Issue Paper A (and the final Manual).
- Where non-structural practices are employed in the site design, the WQ_v volume can be reduced in accordance with stormwater credits outlined in Issue Paper F.
- Off-site areas shall be assessed based on their "pre-developed condition" for computing the water quality volume (i.e. treatment of only on-site areas is required).

- When computing peak discharges for the WQ_v storm for flow splitter design, the principles of "Small Storm Hydrology" shall be employed (Pitt, 1994).
- The water quality requirement can be met by providing 12 or 24 hour extended detention of the WQ_v (provided a "micro-pool" is specified).
- When evaluating percent pollutant removal, the MPCA should consider providing runoff coefficients for various pre- and post-development land use conditions. This should be done to streamline

Recharge Volume - Re_v

- The MPCA may want to consider providing infiltration rates for the design of stormwater management facilities based upon collection of published infiltration rate data.

Channel Protection Volume - Cp_v

- The models TR-55 or TR-20 (or approved equivalent) shall be used for determining peak discharge rates.
- Off-site areas shall be modeled as "present condition" for the one-year storm event.
- The length of overland flow used in time of concentration (t_c) calculations is limited to no more than 100 feet for post-developed conditions.
- Detention time for the one-year storm is defined as the center of mass of the inflow hydrograph and the center of mass of the outflow hydrograph.
- The $Cp_{v.}$ Storage volume shall be computed using the detention lag time between hydrograph centroids developed by Harrington (1987).
- Cp_v is not required at sites where the resulting diameter of the Cp_v orifice is too small. A minimum of one acre of impervious cover is necessary to apply the Cp_v requirement (this results in about a 1" minimum orifice size).

Overbank and Extreme Flood Control (Qp_{10} and Qp_{100})

- The models TR-55 and TR-20 (or approved local equivalent) will be used for determining peak discharge rates.
- The standard for characterizing pre-development land use for on-site areas shall be woods, meadow, or pasture. For agricultural land, use a curve number representing pasture. The MPCA should strongly consider providing curve numbers for pre-development agricultural conditions. This will avoid the use of curve numbers that misrepresent what occurs in reality when agricultural land use is converted to residential development for example.
- Off-site areas should be modeled as "present condition."
- For safe passage of the 100-year event, off-site areas should be modeled as "ultimate condition."
- The length of overland flow used in time of concentration calculations is limited to no more than 150 feet for predevelopment conditions and 100 feet for post development conditions.

Appendix C.

Stormwater Sizing for Redevelopment Projects

The following language was adapted from several recent manuals and deals with an approach to adjust stormwater sizing criteria for redevelopment projects so that it does not increase compliance costs to the point that it acts as a barrier to smart growth.

The first issue is how to define what is meant by infill and redevelopment, which may be different in each locality. One accepted definition is that redevelopment is "any construction, alteration, or improvement that disturbs greater than or equal to 5,000 square feet of existing impervious cover performed on sites where the existing land use is commercial, industrial, institutional, or residential."

The second issue is to provide some greater flexibility in how redevelopment projects can comply with basic stormwater sizing criteria. This is done by proposing stormwater management guidance that a redevelopment will:

(a) provide a reduction in impervious area; or

(b) implement stormwater management practices; or

(c) A combination of both (a) and (b) to result in an improvement to water quality.

More specifically, and unless otherwise specified by an approved and adopted basin plan, all redevelopment projects shall reduce existing site impervious area by at least 20 percent; or, where site conditions prevent the reduction of impervious area, stormwater management practices shall be implemented to provide water quality control for at least 20 percent of the site's impervious area.

When a combination of impervious area reduction and stormwater management practice implementation is used for redevelopment projects, the combination of impervious area reduction and the area controlled by a stormwater management practice shall equal or exceed 20 percent.

The MPCA may allow practical alternatives where conditions prevent impervious area reduction or on-site stormwater management. Practical alternatives include, but are not limited to:

(a) Fees paid in an amount specified by the approving agency and then dedicated to stormwater management;
(b) Off-site stormwater treatment practice implementation for a drainage area comparable in size and percent imperviousness to that of the project;
(c) Watershed or stream restoration; or
(d) Stormwater retrofitting.

The recharge, channel protection storage volume, overbank, and extreme flood protection volume requirements specified in the Manual do not apply to redevelopment projects unless specified in an approved and adopted basin plan.

Appendix D.

Guidance on Downstream Analysis for Overbank and Extreme Storms

Debo and Resse (1992) proposed the concept of the “10% rule” as the point to which a downstream analysis should extend. This is operationally defined as the downstream point where the development site represents 10% of the total contributing drainage area of a watershed. They contend that the hydrologic effects of upstream stormwater detention stabilize and remain constant further downstream. Under the 10% rule, a 10 acre development site would require the downstream analysis at the point where the total accumulated drainage area is 100 acres.

While the 10% rule is useful in establishing a limit for assessment, stormwater program managers still have some basic issues that need to be addressed. For example,

- Is a downstream analysis always required?
- Should a downstream analysis be required on a case-by-case basis?
- Is a certain site size threshold required to trigger the analysis?
- What should the analysis include (culverts, channel erosion, flooding, etc.)?
- What data requirements are necessary for the analysis and what methods should be employed?

The following recommendations are provided to help answer these questions.

A downstream analysis is probably warranted for projects over 50 acres that posses more than 25% impervious cover or when deemed appropriate by the reviewing authority when existing conditions are already causing a problem (e.g., known drainage or flooding conditions or existing channel erosion is evident).

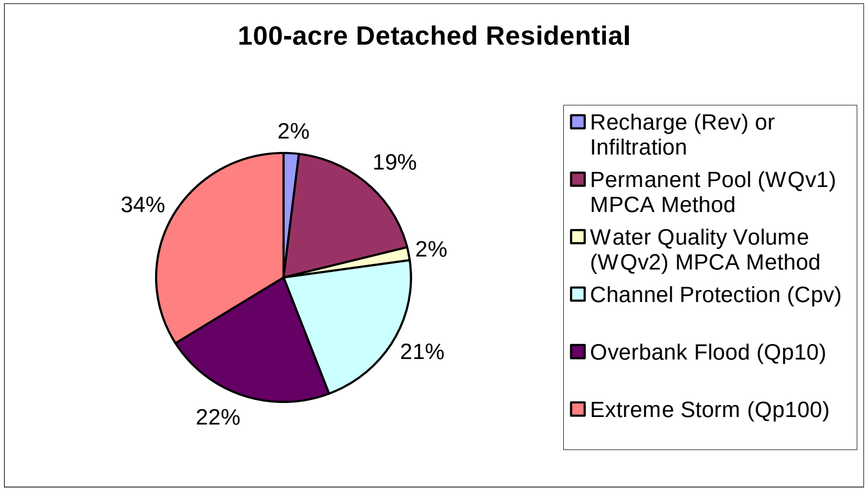
A typical downstream analysis will require a hydrologic investigation of the site area draining to a proposed detention facility and of the contributory watershed to the location of the 10% rule for the 10- and 100-year storms. A hydraulic analysis of the stream channel below the facility to the location of the 10% rule will also be necessary (e.g., a HEC-RAS water surface profile analysis). Depending on the magnitude of the impact and the specific conditions of the analysis, additional information and data may be necessary such as collecting field run topography, establishing building elevations and culvert sizes or investigating specific drainage concerns or complaints.

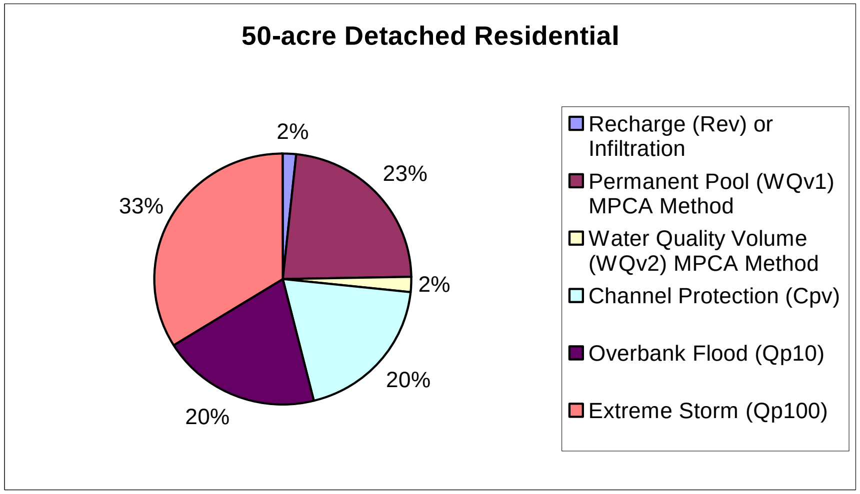
As a minimum, the analysis should include the hydrologic and hydraulic effects of all culverts and/or obstructions within the downstream channel and assess whether an increase in water surface elevations will impact existing buildings or other structures. The analysis should compute flow rates and velocities for pre-developed conditions and proposed conditions both with and without the detention facility. If flow rates and velocities (for Qp_{10} and Qp_{100}) with the proposed detention facility increase by less than 5% from the pre-developed condition, and no existing structures are impacted, then no additional analysis is necessary. If the flow rates and velocities increase by more than 5%, then the designer must either redesign the detention structure, evaluate the effects of no detention structure, or propose corrective actions to the impacted downstream areas. Additional investigations may be required by the approving authority on a case-by-case basis depending on the magnitude of the project, the sensitivity of the receiving water resource, or other issues such as past drainage or flooding complaints. Special caution should be employed where the analysis shows that no detention structure is required. Stormwater designers must be able to demonstrate that runoff will not cause downstream flooding within the stream reach to the location of the 10% rule.

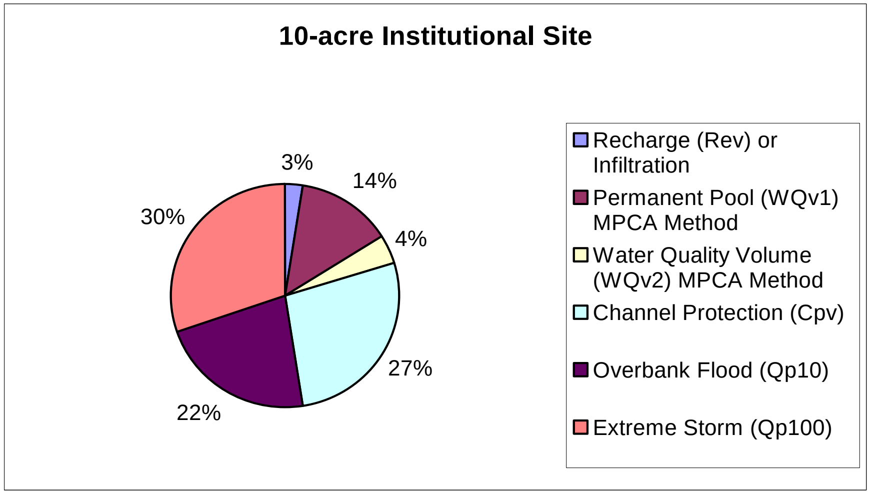
Appendix E.

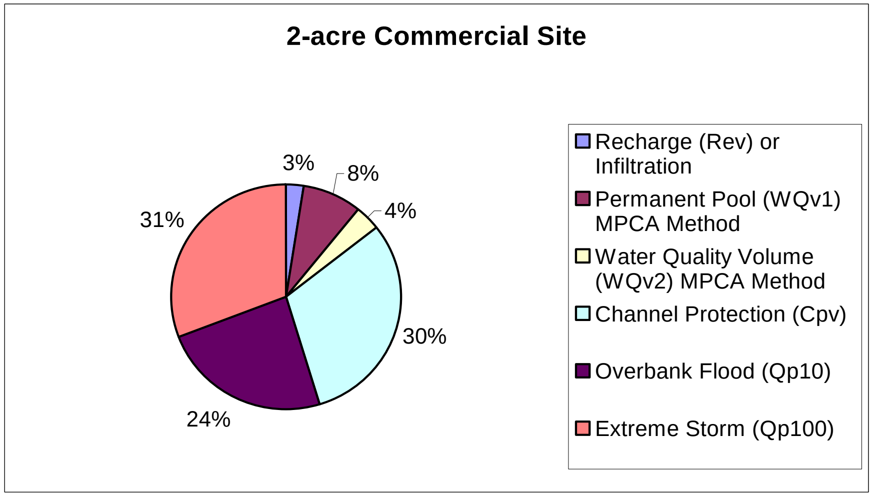
Hydrologic Model Results
Pie Charts

MPCA Hybrid Method with 1/4" Recharge

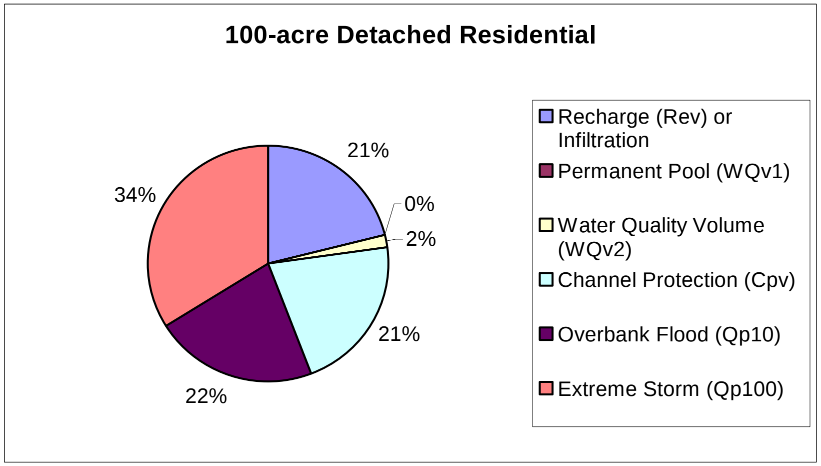


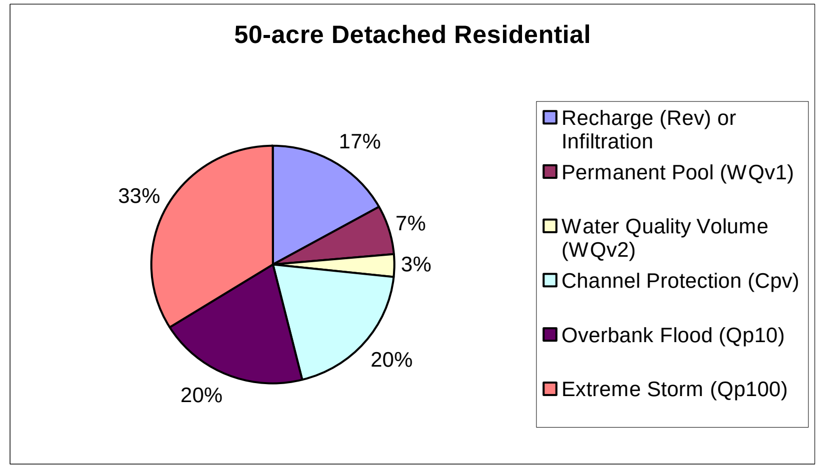


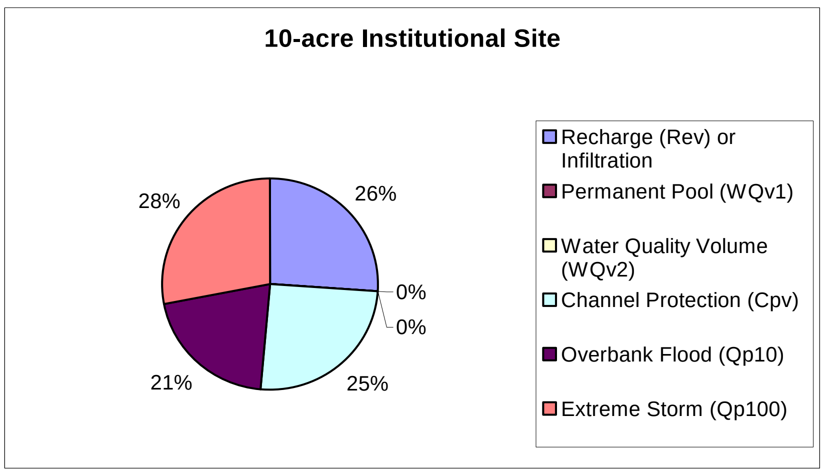


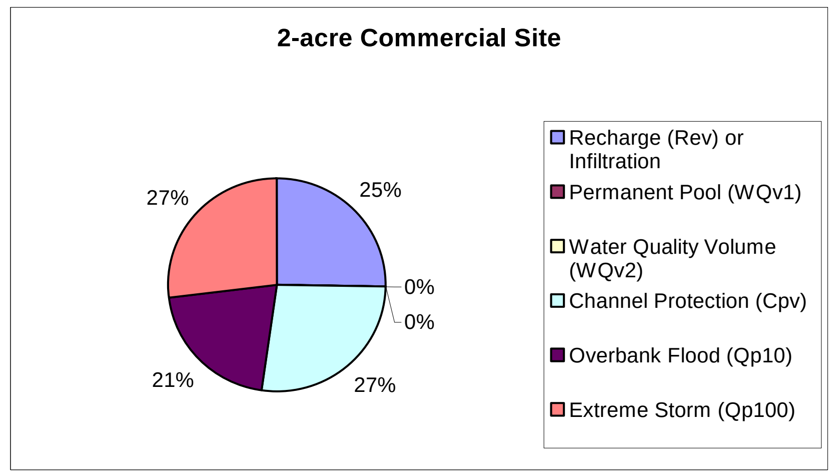


MPCA with No Net Increase for 2-year 24-hour Event

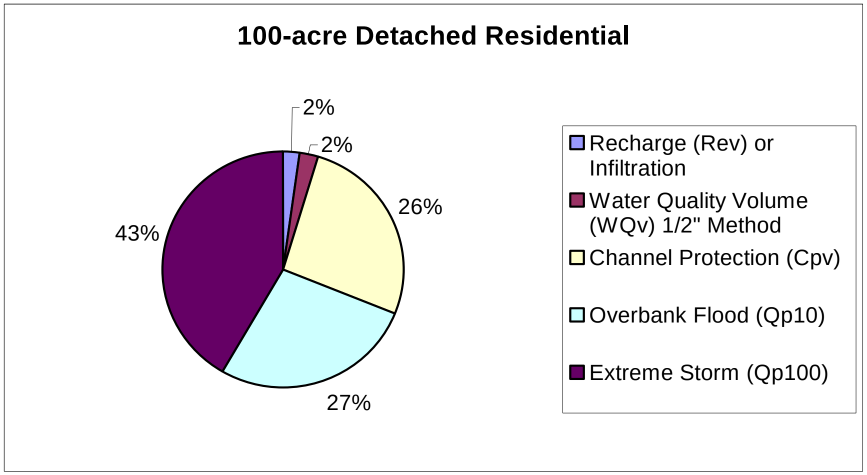


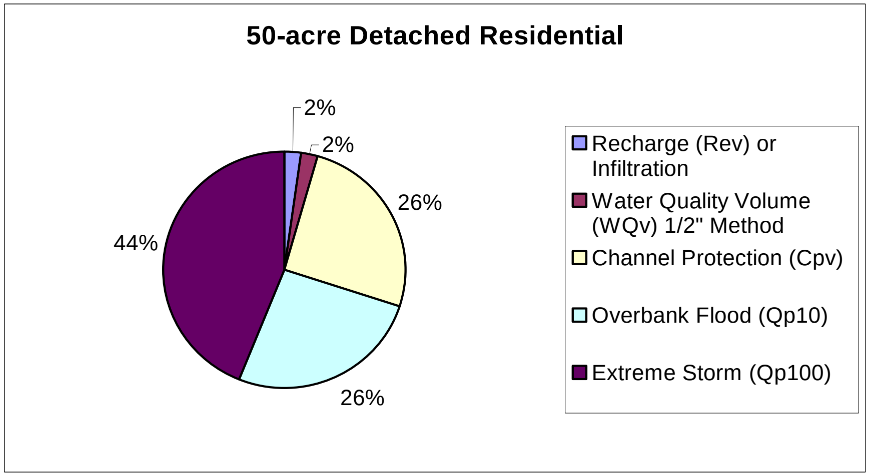


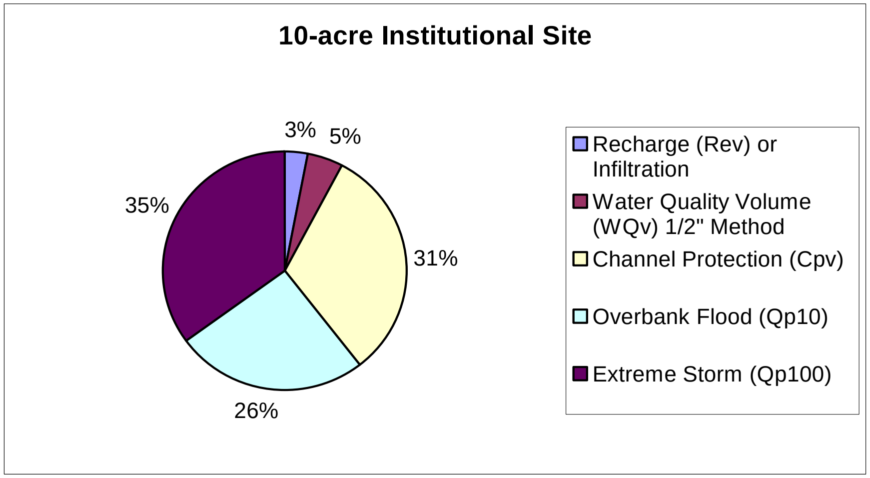


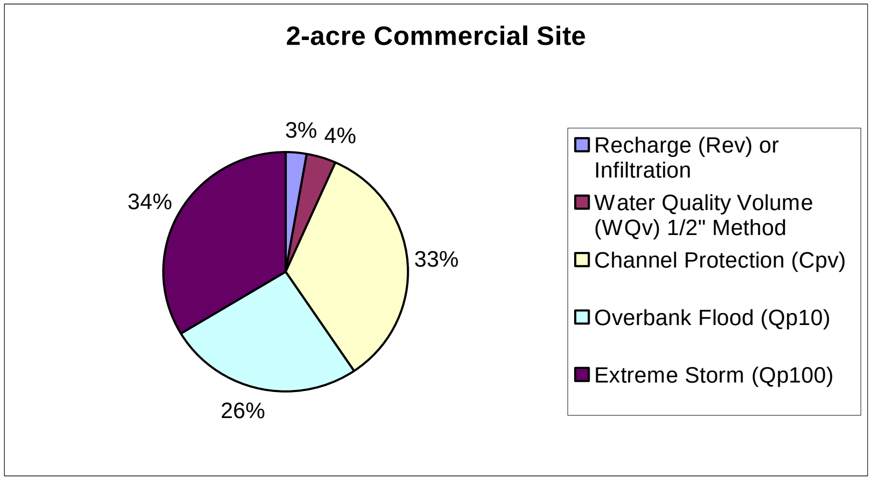


HALF INCH with 1/4" Recharge

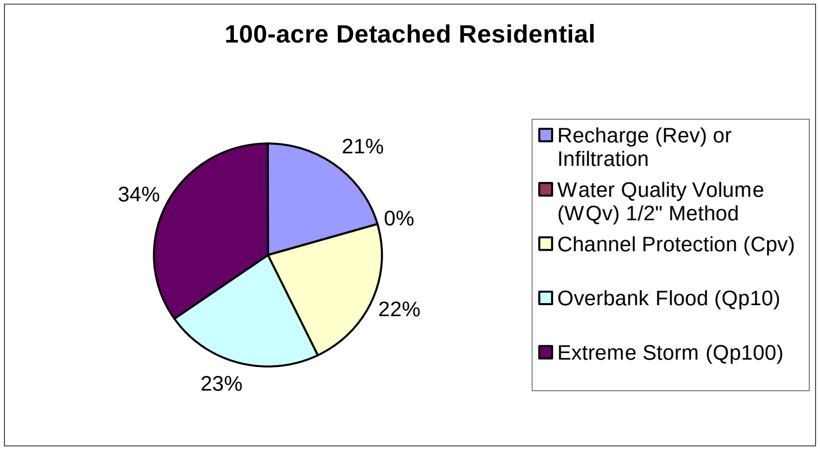


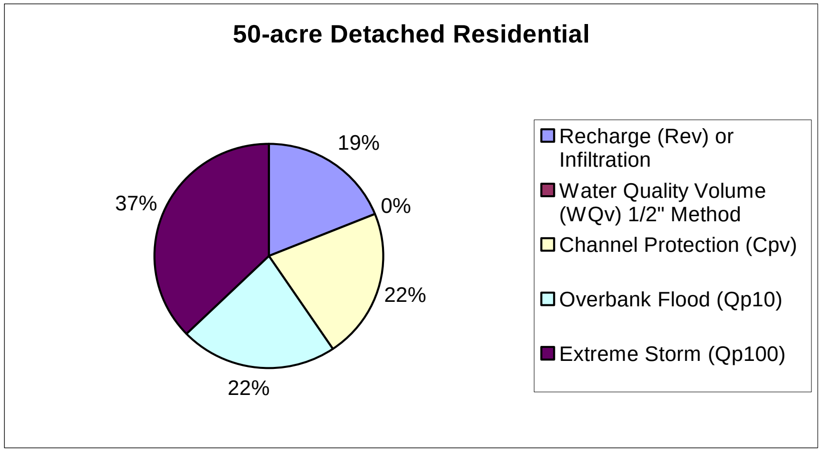


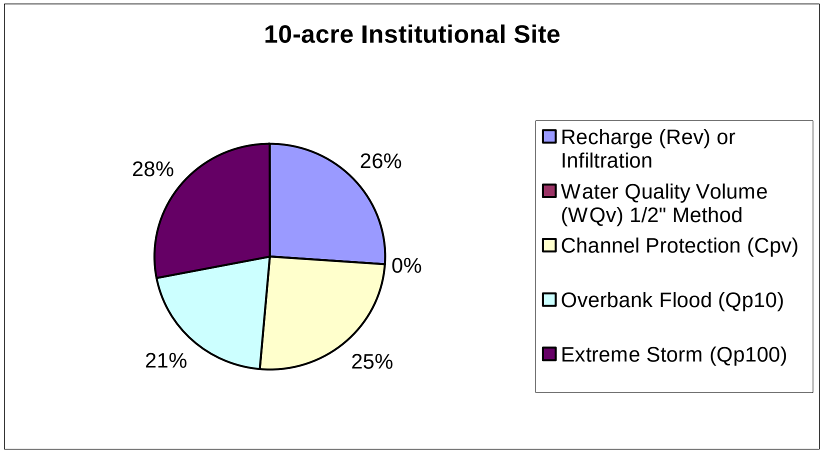


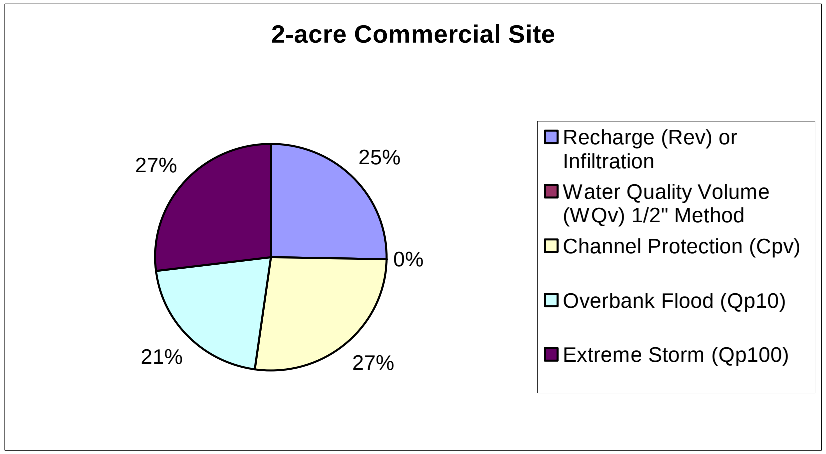


HALF INCH with No Net Increase for 2-year 24-hour Event

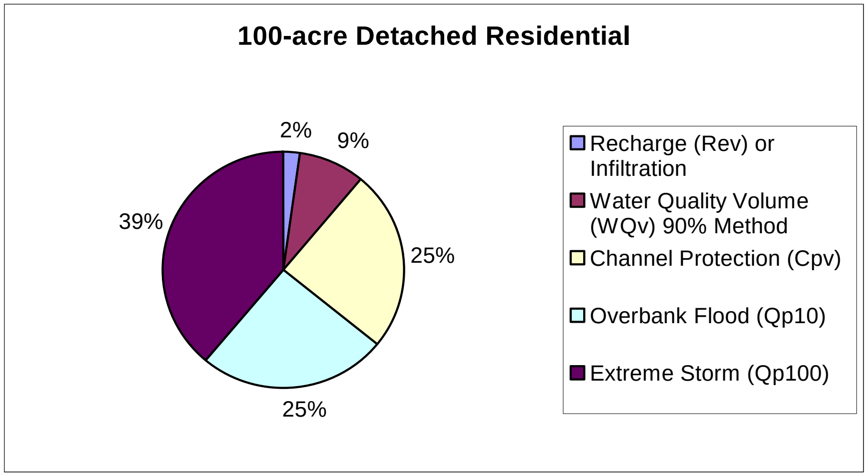


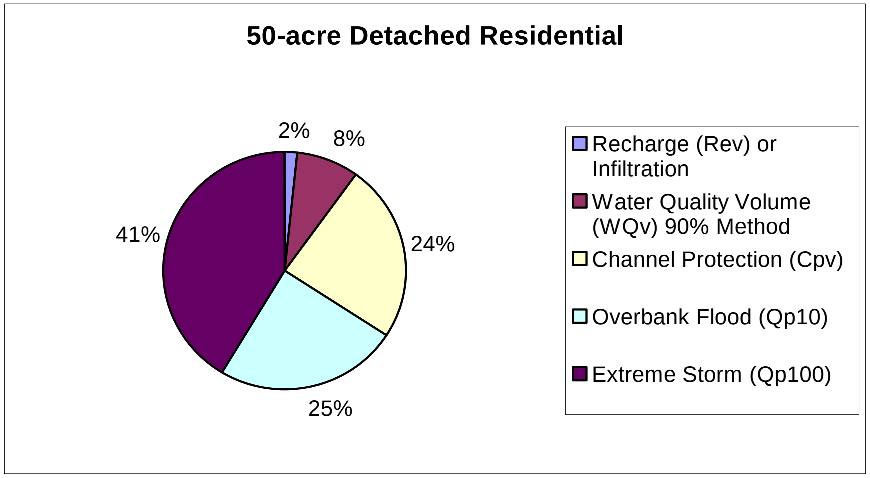


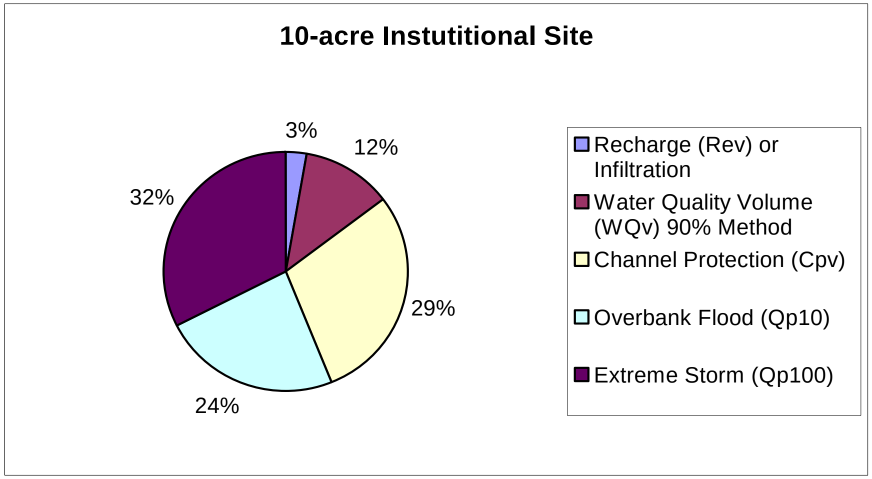


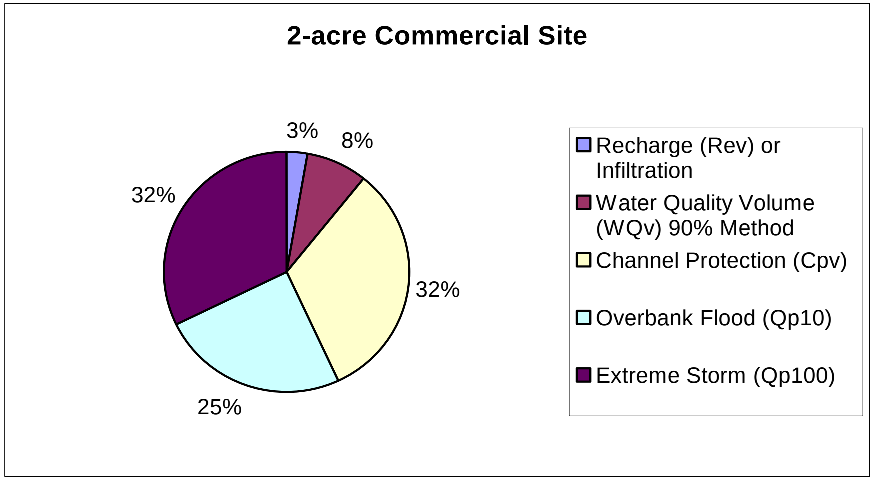


90% with 1/4" Recharge

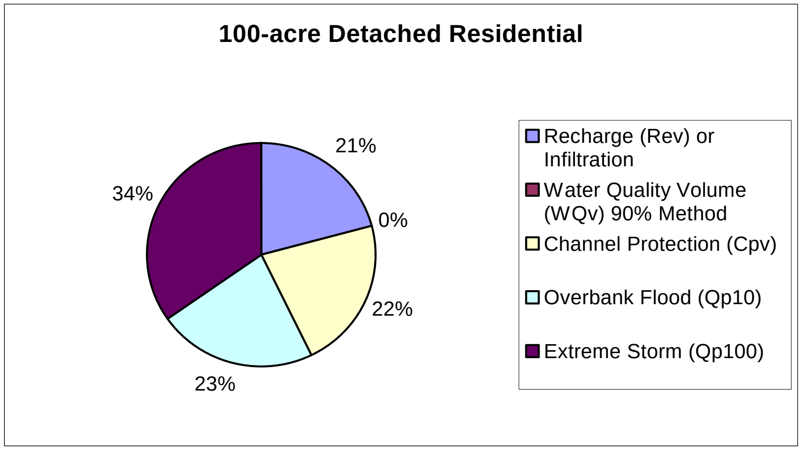


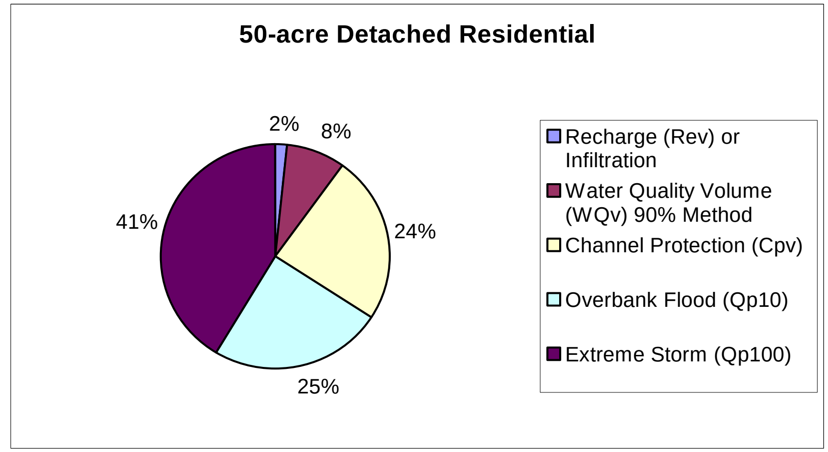


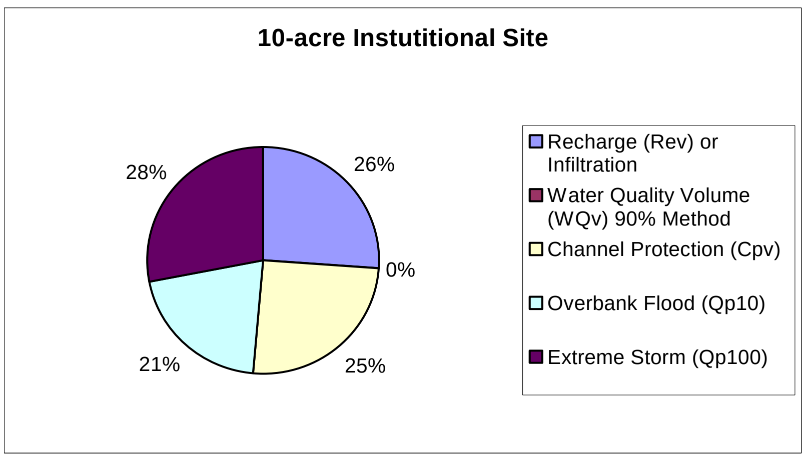


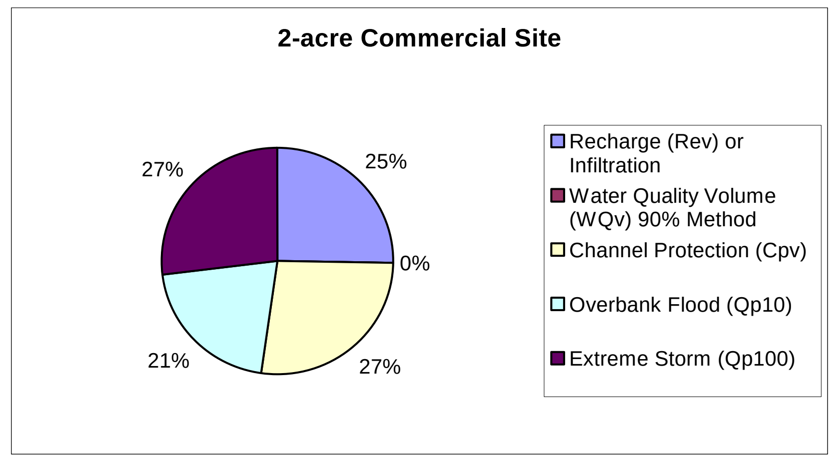


90% with No Net Increase for 2-year 24-hour Event

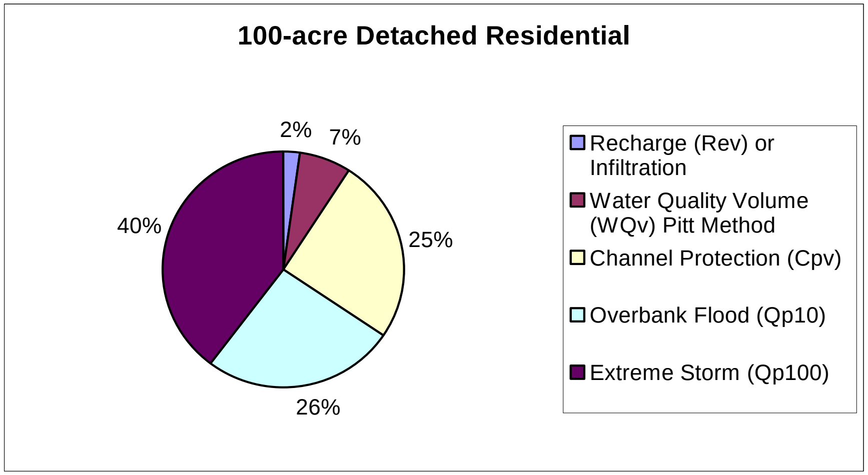


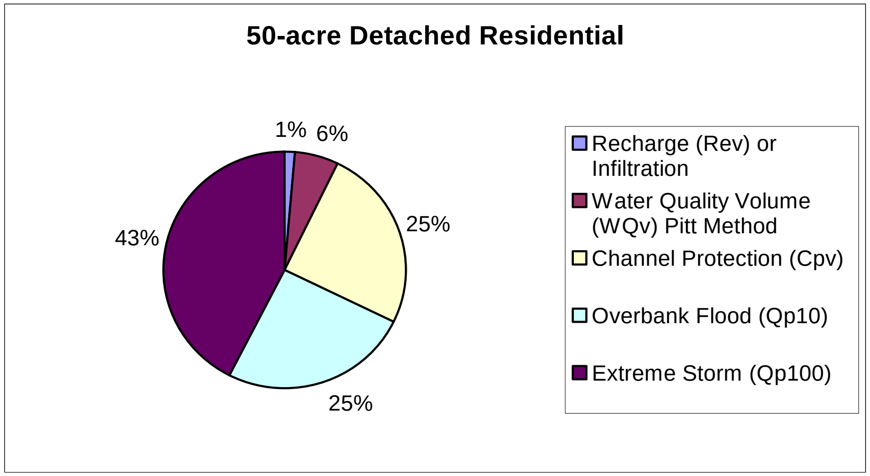


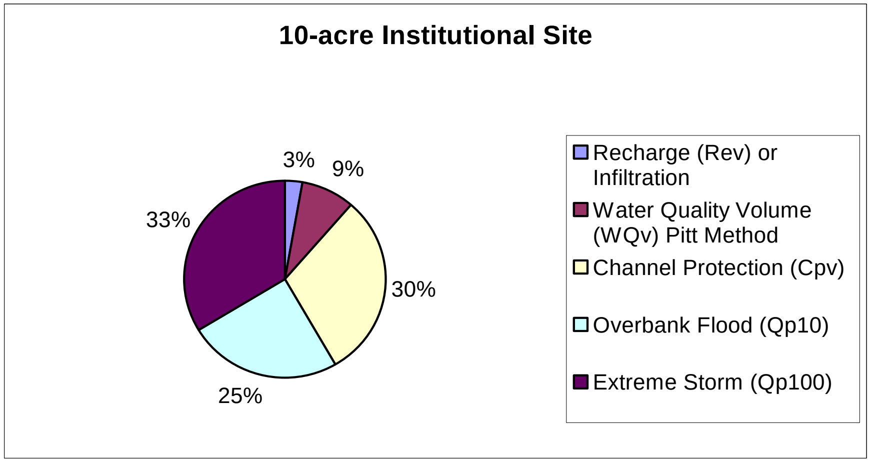


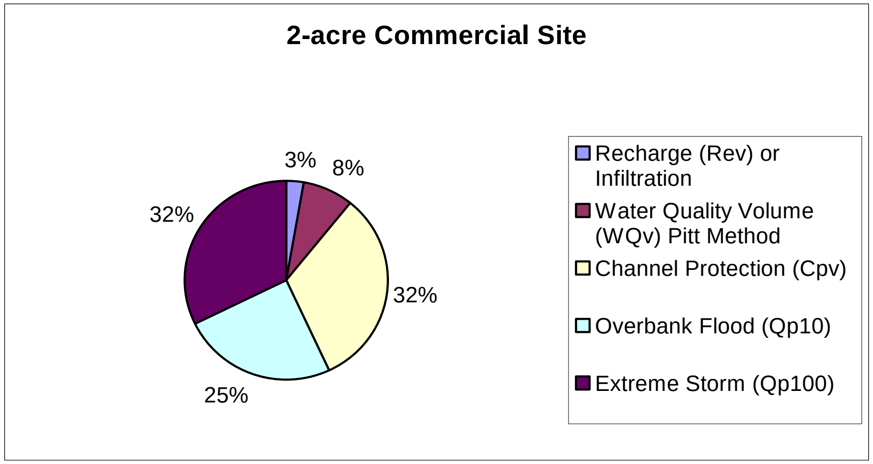


Pitt   Pitt with 1/4" Recharge

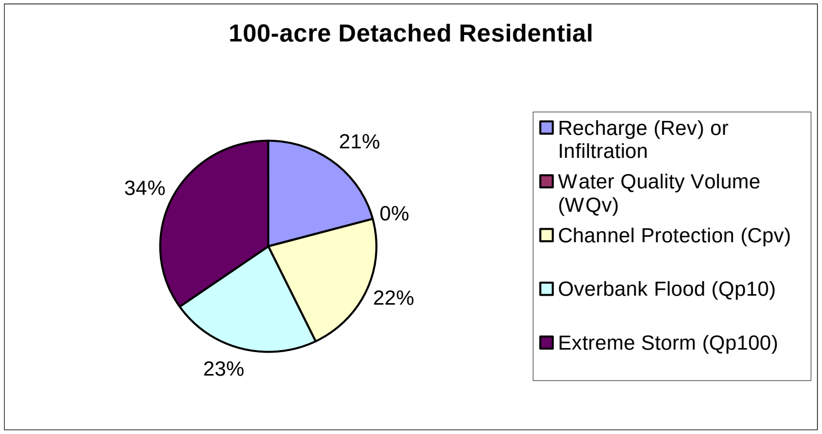


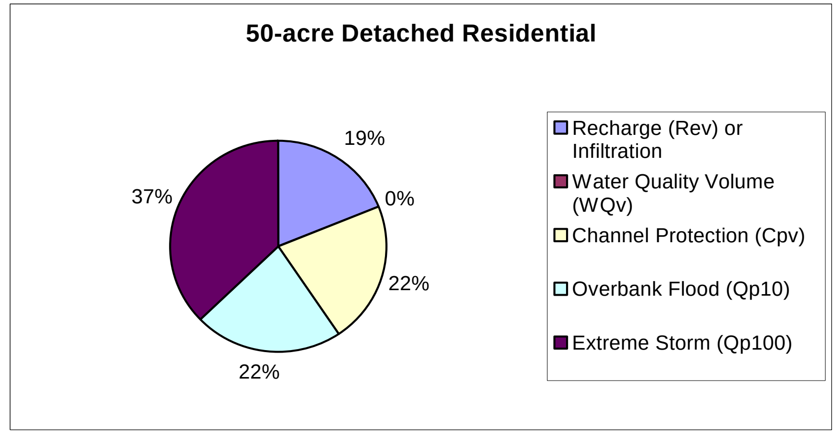


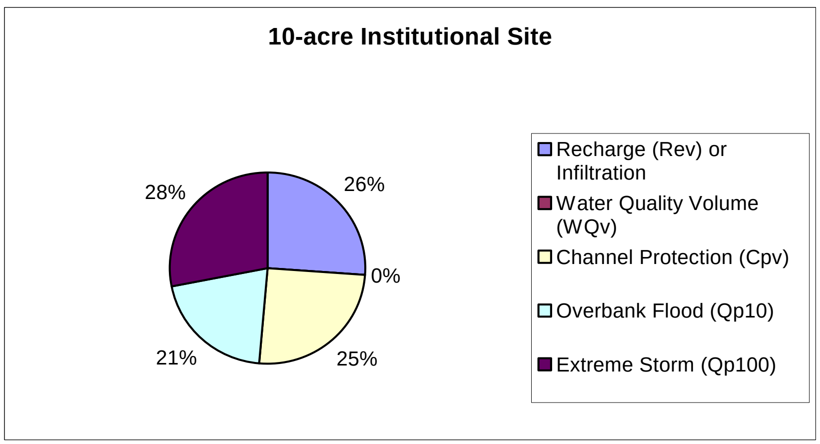


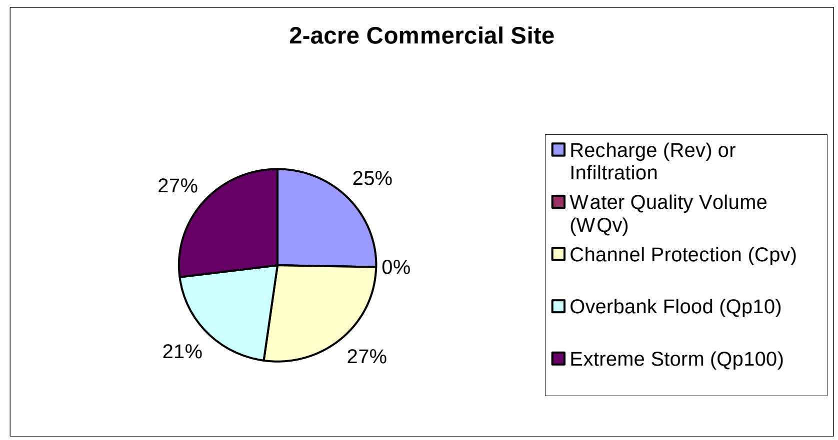


Pitt with No Net Increase for 2-year 24-hour Event

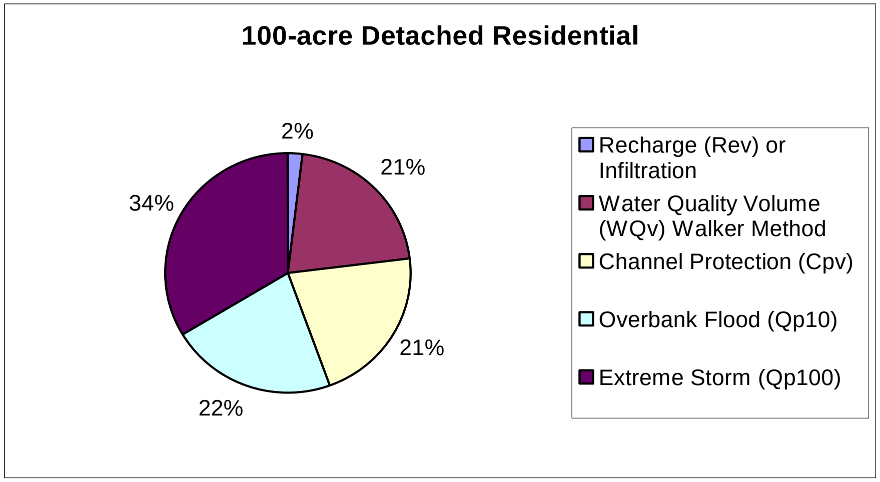


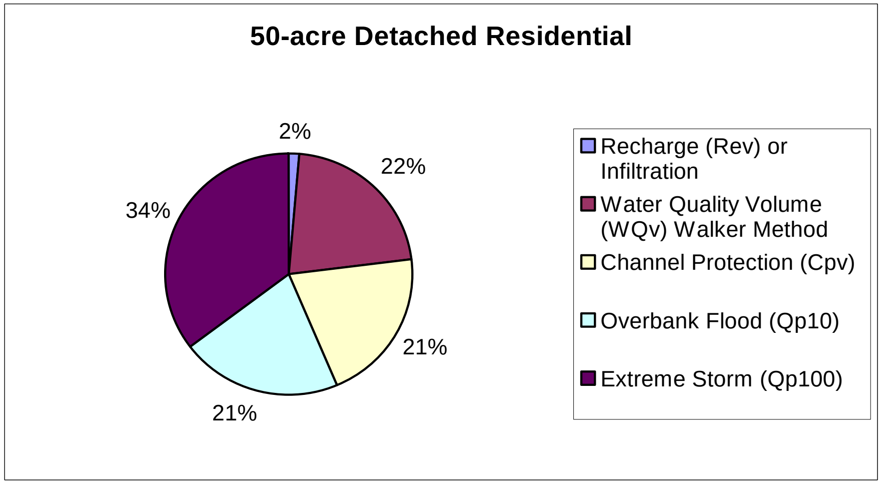


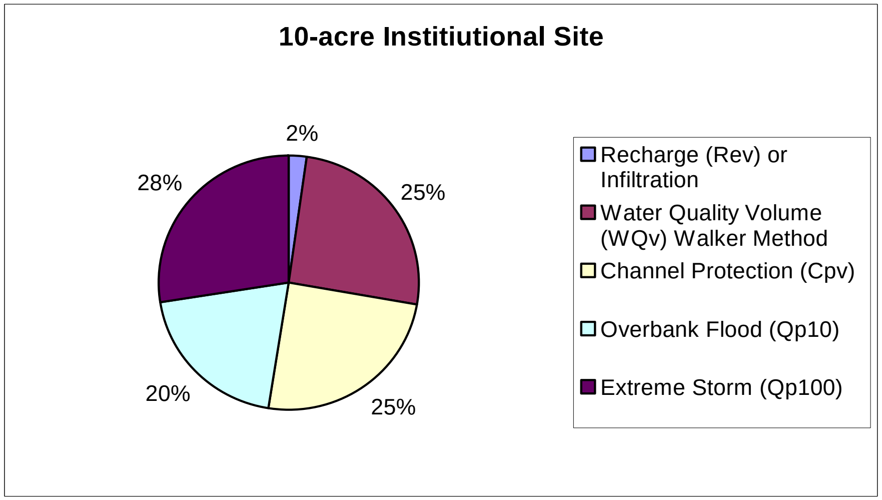


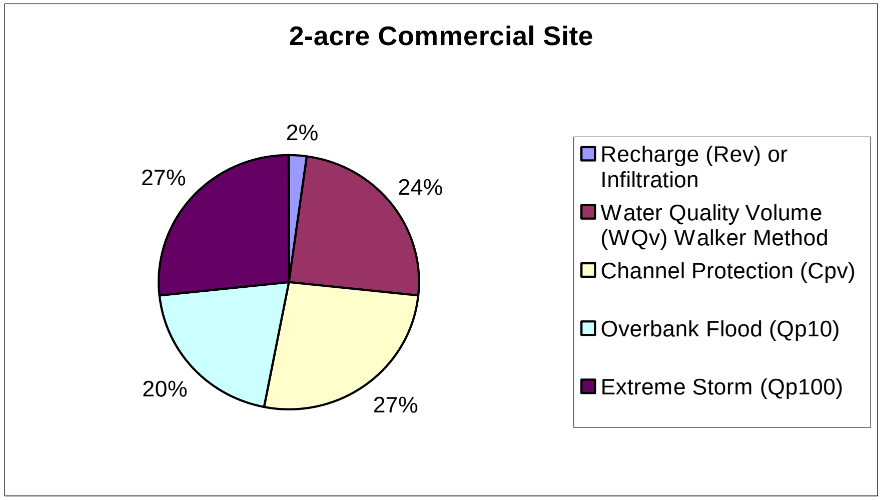


Walker with 1/4" Recharge









Walker with No Net Increase for 2-year 24-hour Event