City of Columbia Stormwater Utility: Review 2007 Stormwater Management and Water Quality Manual

PREPARED FOR: City of Columbia, MO

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1. Introduction

The City of Columbia, Missouri adopted a set of new stormwater regulations in 2007. Stream Buffer Requirements were added to Chapter 12A of the City Code of Ordinances on 1/2/07, and additional modifications to the stormwater requirements in the City Code were made

effective on 9/4/07. The City's "Stormwater Management & Water Quality Manual" (hereafter referred to as "the Manual") was approved by the Director of Public Works on 3/19/07. The City hired CH2M HILL in September, 2007 to perform an independent evaluation of the City's stormwater program, focusing on the current regulations, the current and future goals of the stormwater utility, and current and future stormwater utility funding.

Technical Memorandum #1 identifies and prioritizes current and future goals and objectives for the City's stormwater utility, along with recommendations for achieving those goals. The purpose of this technical memorandum is to provide recommendations on the 2007 Stormwater Management and Water Quality Manual dated March 2007 (hereafter referred to as "the Manual") on its adequacy and reasonableness relative to current best practices and technological advances. A cost-effectiveness evaluation was performed of the 100-year detention requirement, focusing on the appropriate design storm return periods to meet environmental protection objectives and regulations.

Some of the following recommendations, such as the stream assessment section, involve changes in items that are based on the Mid-America Regional Council and APWA Manual of Best Management Practices for Stormwater Quality (hereafter referred to as the MARC manual) or Section 5600 of the Kansas City Metropolitan Chapter of APWA Design Criteria (hereafter referred to as APWA 5600). Because the MARC manual and APWA 5600 are continuing, collaborative efforts with regular updates the City should present the recommendations to APWA and MARC and ask them to consider implementing the recommendations made in this memorandum. If the recommendations are adopted by APWA and MARC, the City can maintain consistency with the MARC manual and APWA 5600 releases.

The City should take steps to ensure that the Manual and stormwater ordinance are living documents, revisiting the contents annually and, when new updates to the MARC manual and APWA 5600 are available, evaluating them for consistency and potential inclusion. Changes to the Manual may also be necessary in the future as the regulatory climate continues to require more stringent regulations.

2. Detention Requirement (Chapter 6)

The Manual currently requires that *"the maximum release rate from any development and redevelopment shall be controlled by limiting the stormwater release rates for the 1%, 10%, 50%, and 100% storms to the predevelopment peak flow rates for the 1%, 10%, 50%, and 100% storms respectively."* These design storms translate to the 1-, 2-, 10- and 100-year storm events. This requirement was examined to determine if it is cost-effective and effective at preventing downstream flood and erosion damages. Assumptions were made for a typical residential development in the City of Columbia and a typical stream. A detention pond meeting the Manual requirements for the typical development was designed as well as ponds meeting water quality volume and channel protection volume requirements, and the outflow from the ponds was analyzed under different scenarios to determine the effectiveness of different levels of detention. Recommendations based on general cost-effectiveness and levels of protection were then made.

2.1 Pre- and Post-Development Conditions

Table 2.1 lists the assumptions that were made for the pre- and post-development scenarios.

TABLE 2.1.
Typical development hydrologic parameter assumptions

	Pre-Development	Post-Development
Area (Acres)	25	25
Hydrologic Soil Group	C	D
Land Use	Agricultural (Pasture), 0% Impervious	¼ Acre Lots, 35% Impervious
Curve Number	74	89
Runoff Calculation Method	NRCS Unit Hydrograph Method	NRCS Unit Hydrograph Method
Time of Concentration	20	15

2.2 Typical Detention Pond Designs

Detention ponds meeting the Manual requirements for the typical development were designed as well as ponds meeting water quality volume and channel protection volume requirements. All ponds were designed to have 4:1 side slopes and a 4-foot depth without freeboard.

2.2.1 Design Storm Detention Pond

A detention pond was designed to meet the Manual's requirements, which is to match the pre- and post- development runoff rates for the 1-, 2-, 10-, and 100-year 24-hour design storm events. A stair step weir configuration was used for the four-stage pond outlet.

A pond meeting the requirements of the Manual with a 4:1 side slope would have a footprint of 1.09 Acres, which increases to 1.35 acres of space when freeboard and the required access strip are included.

1-Year Storm Event Summary

Post-Development Peak Inflow:	54	cfs
Post-Development Peak Outflow:	16	cfs
Pre-Development Peak Flow:	22	cfs
Total Volume:	3.9	Ac-ft
Peak Storage:	1.5	Ac-ft

10-Year Storm Event Summary

Post-Development Peak Inflow:	111	cfs
Post-Development Peak Outflow:	54	cfs
Pre-Development Peak Flow:	66	cfs
Total Volume:	8.2	Ac-ft
Peak Storage:	2.8	Ac-ft

2-Year Storm Event Summary

Post-Development Peak Inflow:	67	cfs
Post-Development Peak Outflow:	20	cfs
Pre-Development Peak Flow:	34	cfs
Total Volume:	4.9	Ac-ft
Peak Storage:	1.9	Ac-ft

100-Year Storm Event Summary

Post-Development Peak Inflow:	164	cfs
Post-Development Peak Outflow:	111	cfs
Pre-Development Peak Flow:	113	cfs
Total Volume:	12.5	Ac-ft
Peak Storage:	3.6	Ac-ft

Peak flows for the pond configurations are shown above. The Total Volume represents the total runoff volume generated by the storm event, while the Peak Storage represents the runoff detained in the detention facility. Hydrographs and storage plots for each design storm event are shown in Appendix A.

2.2.2 Water Quality Storm and Channel Protection Volume Detention Pond

A second pond was sized based on the water quality volume specified by the Manual and a channel protection volume. Because the City's manual does not contain guidance on incorporating water quality detention into a traditional detention facility, the pond was sized to

release the water quality volume over a 40-hour period per the newly updated March 2008 MARC manual. The volume required for a 40-hour release of the water quality volume was 0.5 acre-feet.

Channel protection volume is additional to water quality volume. Because the City does not currently have a channel protection volume requirement, criteria from the Metropolitan St. Louis Sewer District (MSD) was used. MSD requires the 1-year, 24-hour storm to be released with 24-hour extended detention. The 24-hour detention time is defined as the interval between the center of mass of the inflow hydrograph and the center of mass of the outflow hydrograph. The volume required for detention of the channel protection volume is 2.6 acre-feet.

A pond incorporating only water quality storm event and channel protection volume retention and release with a 4:1 side slope would have a footprint of 0.85 Acres, which increases to 1.04 acres of space when freeboard and the required access strip are included. Hydrographs and storage plots for each design storm event are shown in Appendix B.

2.2.3 Detention Pond Scenario Summary Table

The basic geometry of the two modeled detention ponds is summarized in Table 2.2.

TABLE 2.2
Detention Pond Size Summary

	1-, 2-, 10- and 100-year Design Storm Detention	Water Quality and Channel Protection Volume Detention (No additional design storm detention)
Depth (without freeboard)	4	4
Side slopes	4:1	4:1
Bottom length (ft)	443	243
Bottom width (ft)	68	103
Top length (ft)	475	275
Top width (ft)	100	135
Impoundment area (no freeboard or access strip) (acres)	1.09	0.85
Max impoundment area with freeboard and access strip (acres)	1.41	1.04

2.3 Detention Ponds and Downstream Channel Shear Effects

Open channels in the City are subject to severe erosion problems. The shear stress created by the flow acting on the channel bed and bank materials is the parameter often used as a measure of a stream's ability to retain the soil particles in the channel bed and banks. Critical shear stress is the shear stress required to mobilize sediments stored on the channel bed and banks and delivered to the channel from upstream. When the shear stress is greater than the critical

shear stress for the bank material, erosion ensues and channel degradation will likely result. Assumptions were made to represent a typical channel in the City of Columbia and the shear stress resulting from a variety of flow conditions was calculated. Typical channel information is shown in Table 2.3.

TABLE 2.3
Typical channel physical parameters

Parameter	Value	Description
z1	2	channel side slope 1
z2	2	channel side slope 2
b	1.56	bottom width (ft)
slope (ft/ft)	0.040	slope along flow line of channel
Manning's n	0.035	Manning's roughness factor

2.3.1 Precipitation Analysis and Average Year of Rainfall

Precipitation data that was recorded from the Columbia Municipal Airport (1948-1969) and Columbia Regional Airport (1969-2007) was used to determine an average year of rainfall. Approximately 59 years of hourly precipitation data (September 1, 1948 through August 1, 2007) was run through the XP-SWMM rainfall utility to determine individual storm events. A minimum six-hour dry period was used to separate precipitation into separate storm events. A total of 5916 storm events ranging from 0.01 inches to 5.97 inches were determined.

The storm event data was sorted into several individual 'bins' based upon a range of the total volume of precipitation in the event. Sorting the events into these bins evaluated the data into a summary of the average precipitation and duration of events in each range. Table 2.4 displays the results of the annual summary of storm events.

TABLE 2.4
Annual storm event summary

Bin ID	Lower Limit (in)	Upper Limit (in)	# Storms	Average Rain (Magnitude, inches)	Average Number storms per year	Percent of Total Rainfall in Bin[1]	Average Annual Rainfall (in)	Average Duration (hr)
1	0.00	0.25	3655	0.078	60.92	13.3%	4.74	3.6
2	0.25	0.50	957	0.366	15.95	16.4%	5.84	7.8
3	0.50	0.75	441	0.620	7.35	12.8%	4.56	9.6
4	0.75	1.00	282	0.869	4.70	11.5%	4.08	12.0
5	1.00	1.25	184	1.122	3.07	9.7%	3.44	12.5
6	1.25	1.50	128	1.379	2.13	8.3%	2.94	14.7
7	1.50	1.75	94	1.623	1.57	7.1%	2.54	15.9
8	1.75	2.00	52	1.871	0.87	4.6%	1.62	17.3

TABLE 2.4
Annual storm event summary

Bin ID	Lower Limit (in)	Upper Limit (in)	# Storms	Average Rain (Magnitude, inches)	Average Number storms per year	Percent of Total Rainfall in Bin[1]	Average Annual Rainfall (in)	Average Duration (hr)
9	2.00	2.25	32	2.137	0.53	3.2%	1.14	15.8
10	2.25	2.50	24	2.402	0.40	2.7%	0.96	14.5
11	2.50	2.75	19	2.587	0.32	2.3%	0.82	20.8
12	2.75	3.00	18	2.879	0.3	2.4%	0.86	23.9
13	3.00	6.00	30	4.044	0.5	5.7%	2.02	28.7

[1]Represents the percentage of the total rainfall amount in this bin that fell over the entire period of record.

The average rain magnitude for each bin was then used to determine the storm water runoff that would be produced during each 'typical' event. Because only hourly rainfall data was available for the period of record, the total volume was distributed into 15-minute increments using comparable storm durations and appropriate quartile distributions for Columbia from "*Bulletin 71: Rainfall frequency Atlas of the Midwest*" by Huff and Angel. The quartiles and storm durations used to approximate each bin for the period of record simulation are summarized below in Table 2.5.

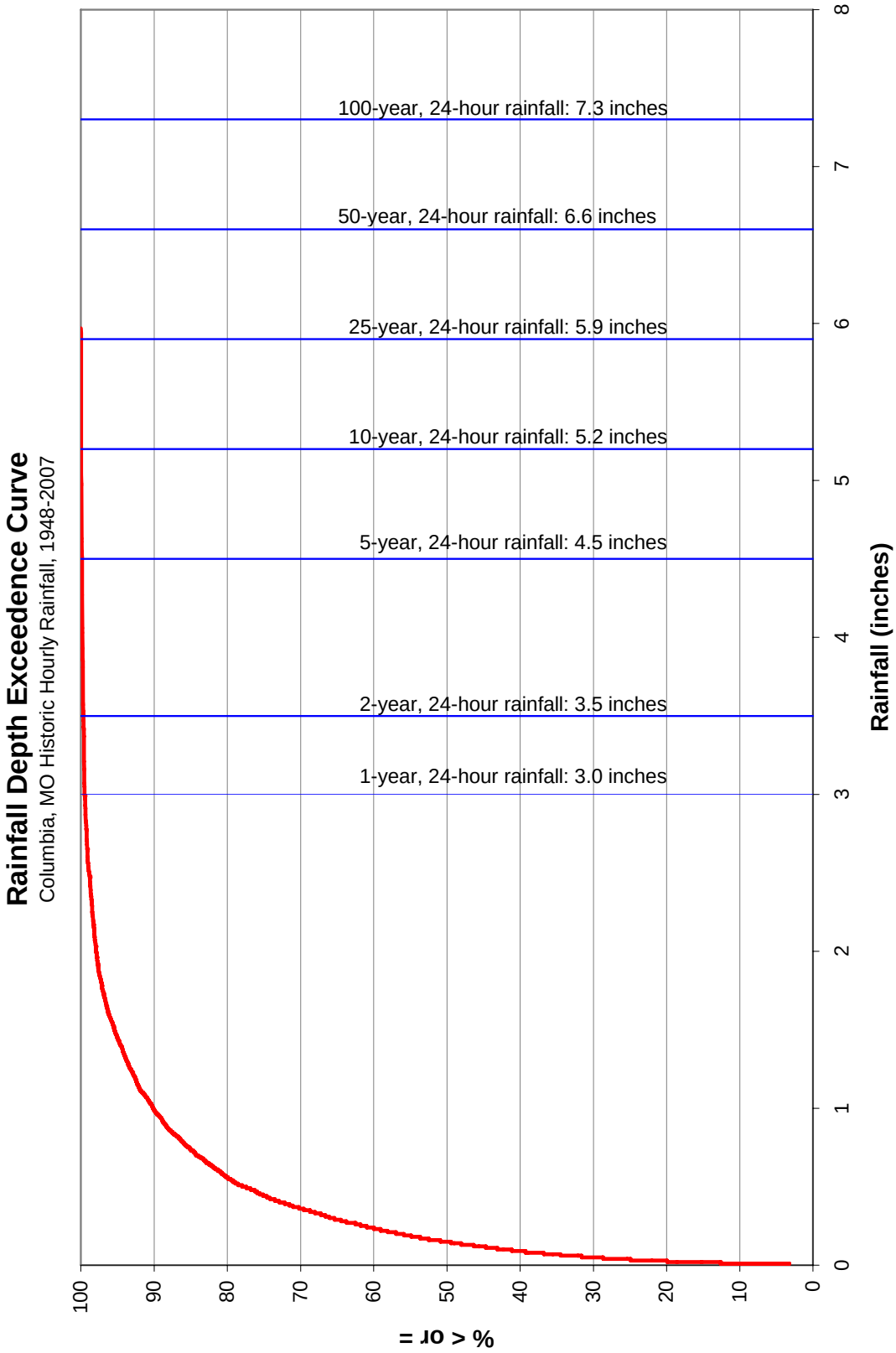
TABLE 2.5
HUFF Distribution Assumptions for Rainfall Bins

Bin	Modeled Storm Duration (hours)	Quartile Distribution
1	3	1st
2	6	1st
3	12	2nd
4	12	2nd
5	12	2nd
6	12	2nd
7	18	2nd
8	18	2nd
9	18	2nd
10	18	2nd
11	18	2nd
12	24	2nd
13	24	2nd

2.3.2 Storm Water Runoff Calculation

A model was created using the HEC-HMS version 3.1.0 modeling software. This software is a hydrologic modeling tool that derives stormwater runoff from precipitation using the runoff curve number methodology. The model incorporated the average annual rainfall series discussed in Section 2.3.1 as well as several design storm events to calculate runoff from the watershed. The 1-, 2-, 5-, 10-, 25-, 50-, and 100-year design storm events were modeled using the SCS Type II distribution. Figure 2.1 shows the rainfall exceedence curve for the historical rainfall data against the rainfall amounts for the various design storm events. The design storm events are much larger than the smaller rain events that occur most often in a typical year.

FIGURE 2.1
Rainfall Exceedence Curve and Design Storm Events



Four separate scenarios were developed to analyze the effect of these average and design storm events. In addition to the pre- and post-development conditions, two additional scenarios evaluate the post-development conditions including the effect of two different detention ponds: the first designed according to the Manual, and the second designed based only on management of the water quality volume and for channel protection.

The pre-development and post-development scenarios have the stormwater runoff flow into the trapezoidal channel described at the beginning of this section. The trapezoidal channel is included downstream of the detention pond.

2.3.3 Shear Stress Calculations

The maximum shear stress acting on the bottom of a channel is given by

$$\tau_b = \gamma S_e R_h$$

where γ is the specific weight of water, S_e the energy slope, and R_h the hydraulic radius. For a trapezoidal channel, the maximum shear stress acting on the side slopes is approximately 80 percent of the maximum on the bottom.

The flows in the trapezoidal channel calculated with the HEC-HMS model were used to determine the normal depth of flow in the channel. The results of the model simulations were compiled and the shear stress was calculated for each scenario. Figures showing the shear stress generated by the 1-, 10-, and 100-year storm events are shown in Figures 2.2 to 2.4.

To understand the long-term effects of excess shear stress, it is necessary to examine behavior of all storms. Therefore, the shear stress was calculated for each of the bin storm events in Table 2.4 and an average annual shear stress exceedence curve was developed based upon the average number of storm events occurring for each bin per year. A graph comparing the shear stress and the percent of events that produce a shear stress less than or equal to that shear stress was generated, and is displayed in Figure 2.5. It should be noted that this approach is only an approximation to the actual rainfall that the system would experience in a year. To simplify the computations in this analysis, the continuous record has been approximated by the discrete set of events listed in Table 2.4, each associated with a number of occurrences. The steps seen in the figure are the result of this approximation. Had a continuous simulation been carried out, the exceedence curves would appear smoother.

Several critical shear stresses are shown in Figures 2.2 to 2.5 and are listed below in Table 2.5. The categories shown represent typical channel conditions that may be encountered for a headwaters development in the City of Columbia. Bed material is typically silt loam, but incised channels typically expose stiff clay material. Typical channel critical shear stress in most cases will be between 0.048 psf and 2.16 psf

TABLE 2.5
Critical Shear Stress

Description	Critical Shear Stress (psf)
Silt Loam, Noncolloidal (ML), clear water	0.048 psf
Stiff Clay, very colloidal, CL, clear water	0.260 psf
Well-established dense vegetation to the normal low water	2.16 psf

2.3.4 Results

From Figure 2.5, it can be seen that the post-development curve resulting from the current design standard only reduces the shear stress to pre-development levels 50 percent of the time. During the other 50 percent, the shear stress is virtually equal to the post-development condition with no pond. The current design standard results in a 1.35-acre pond with a maximum storage of 3.6 acre-feet. The area between the pre- and post-development curves and above the critical shear stress, indicates the additional erosional work that the streambed experiences cumulatively in a given year as a result of unmitigated development.

If the pond were designed for water quality volume and channel protection as described in Section 2.2.2, the figure shows that the frequency of critical shear stress occurrences is significantly reduced, even below the pre-development conditions. The area of this pond is 1.04 acres with a maximum storage of 2.6 acre-feet, smaller than the pond resulting from the current standard.

It should be noted that even under the pre-development conditions, the critical shear stress is exceeded some of the time, which is consistent with the natural dynamic geomorphic processes taking place in the stream. This is observable throughout the City where bare soil and exposed roots can be seen in channel bottoms. The important criterion to consider is how different the post-development conditions are from the pre-development state. When higher shear stresses are experienced over time in a given channel, sediment is lost and erosion begins to occur. If the shear stresses are not mitigated and continue at higher levels over time or are allowed to increase, more sediment is lost in the channel bed and erosion worsens. Eventually, the channel becomes bare of vegetation and the erosion problem continues to move upstream and worsen.

The threshold shear stress values shown in Figure 2.5 assume that there is no vegetation or armoring of the stream bed material. This explains why channel erosion is such a large problem in Columbia (where bare channels and exposed tree roots already exist throughout the system) and shows the need for citywide stream assessment and restoration. All scenarios modeled produced annual shear stresses well below the critical shear stress for well-established, densely vegetated channels.

Although the shear stress curve for the channel protection criterion is well below the pre-development conditions, it should be pointed out that a lower target should be selected to mitigate current rates of erosion and channel degradation. The 1-year design storm event was selected for this analysis because it is commonly used for channel protection design. Most notably, this is the nearby criteria for MSD in the St. Louis metropolitan area and the State of Maryland. Additionally, due to the lack of 15-minute rainfall data, the annual period of record was approximated using Huff rainfall distribution and assumptions were made to represent a typical residential development. While these assumptions produce valuable results and verify that channel protection technology is a valuable tool for the City, thee true channel protection target should be closer to the critical shear stress frequency regime that existed during the original conditions, which do not necessarily coincide with the pre-development state. In practice, it is virtually impossible to return stream channels in urban or urbanizing watersheds to a pristine state; therefore, a sensible target is probably somewhere between the original and pre-development conditions.

A detailed analysis encompassing a more detailed approximation of the rainfall record and multiple land use scenarios is necessary to pinpoint the design event criteria most appropriate

to replicate pre-development shear stress conditions. Most jurisdictions in the United States have not performed this detailed analysis, which requires development of allowable shear stress curves for a variety of development scenarios and possible customization for different watersheds. Some jurisdictions in the state of California are moving toward developing these curves, and Western Washington State has completed such an analysis. Western Washington State has developed a stand-alone software application that designers can use to meet shear stress criteria for a wide range of conditions.

FIGURE 2.2.
1-year Design Storm Event Shear Stress Curve

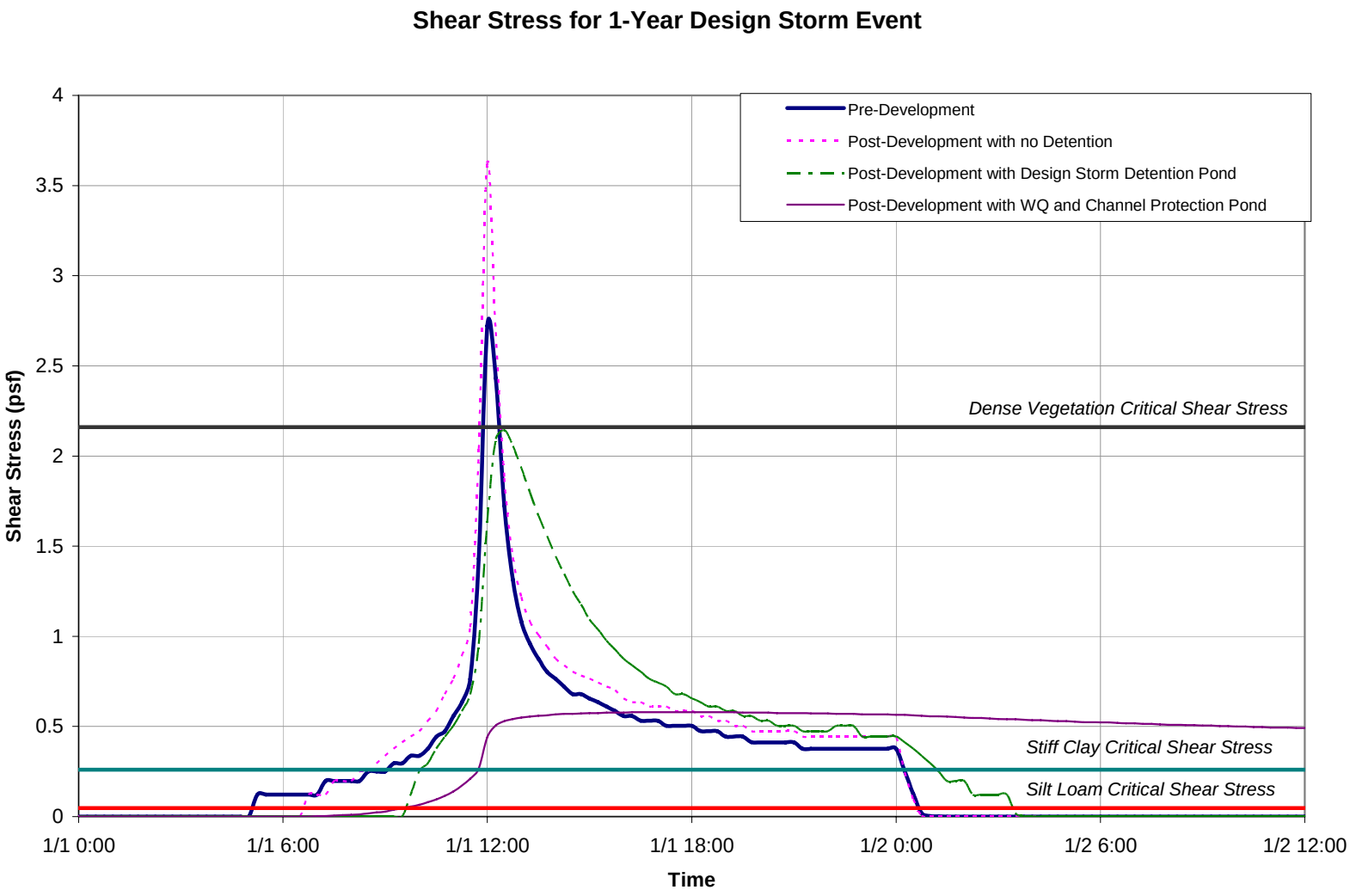


FIGURE 2.3.
10-year Design Storm Event Shear Stress Curve

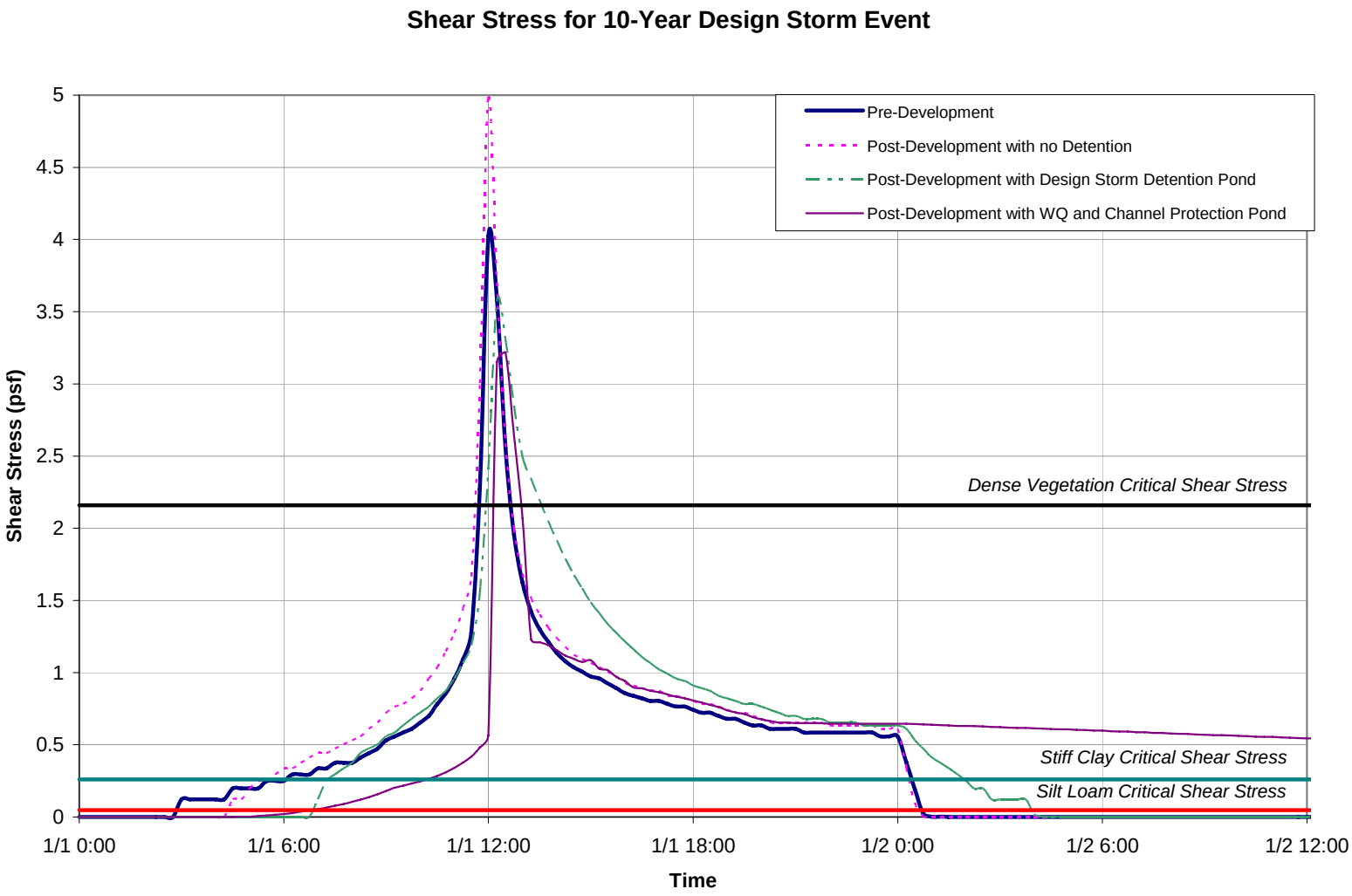


FIGURE 2.4.
100-year Design Storm Event Shear Stress Curve

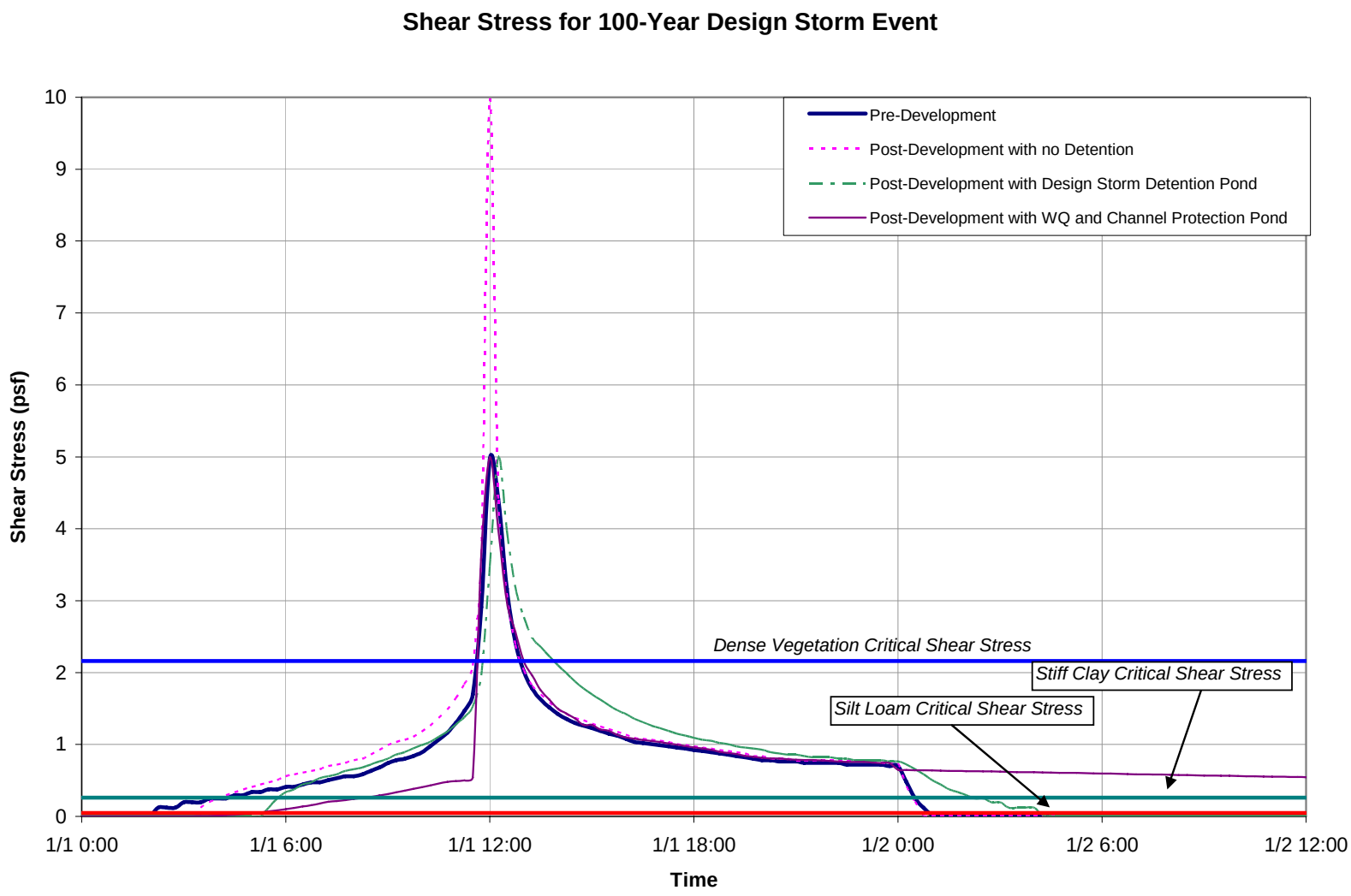
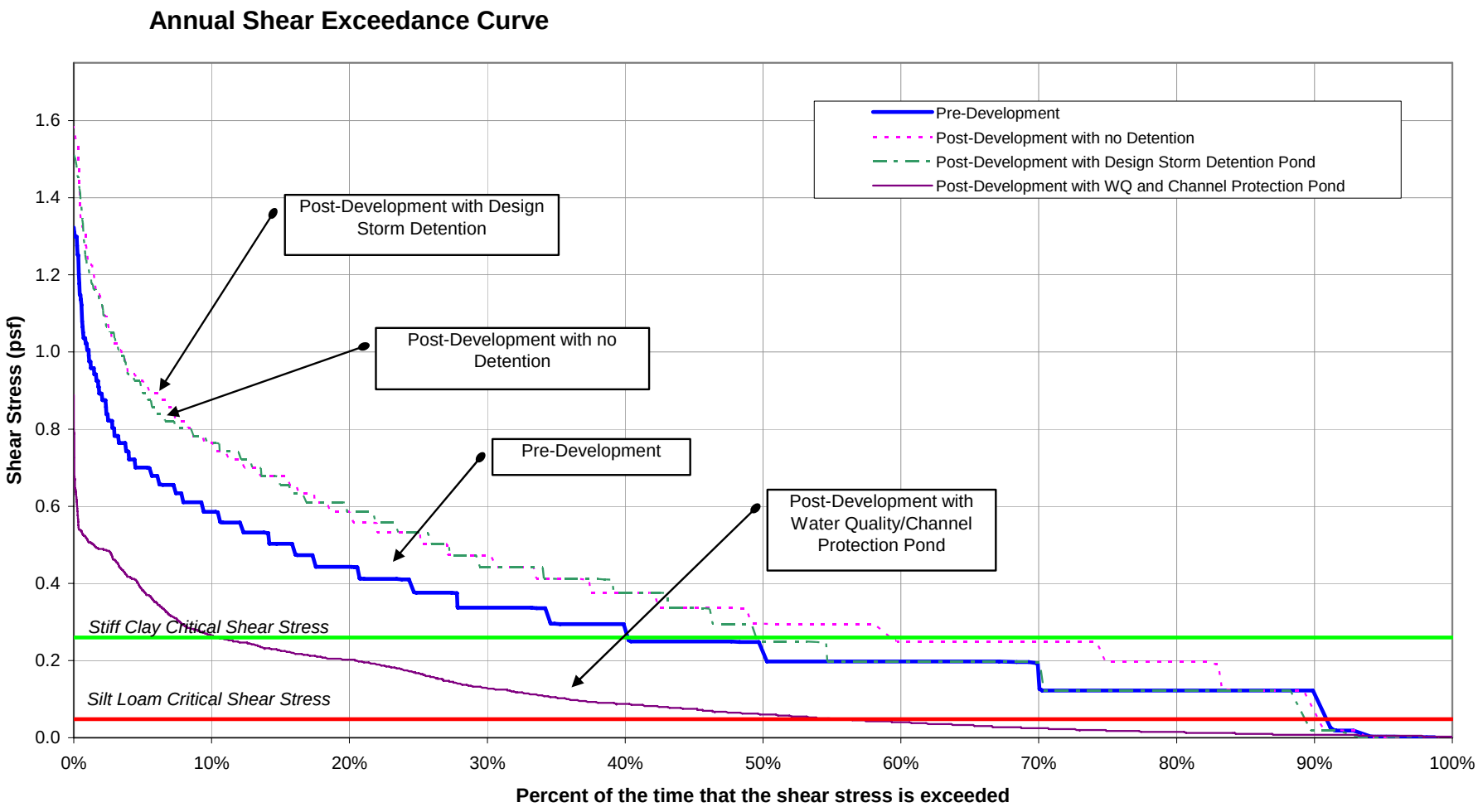


FIGURE 2.5.
Annual Shear Exceedence Curve



2.4 Downstream Flood Protection

Historically, the City has required detention where there are known downstream flooding problems. Problem locations identified after 2003 are currently mapped in the City's GIS system, while other locations are documented in a non-electronic format. Additionally, the city has mapping of floodplains on major channels throughout the City. All City areas for which Flood Insurance Rate Maps (FIRMs) exist are currently being remodeled in HEC-RAS, except for Meredith Creek. Hydrologic modeling, originally performed in HEC-1, is being redone in HEC-HMS and calibrated with stream gauge data where possible. Adequate historical data, mapping information, and modeling resources exist to identify areas where downstream flood protection is necessary. Additionally, if a stormwater master plan (as outlined in TM#1) is completed, a comprehensive listing of stormwater problem locations will be readily available.

A pond designed for water quality control and channel protection needs to undergo additional evaluation for flood control in situations where flooding is a known problem. In such cases, the potential benefit of adding a flood control design criterion to the pond needs to be compared with the effect of other flooding sources. For example, there is little benefit in providing flood peak attenuation for local flows caused by an extreme event at a site where the source of flooding is of a regional nature and due to upstream causes. In such cases, the pond should be designed to allow safe passage of local excess flows without damage to the facility.

2.5 Detention Requirements in Other Locations

Table 2.6 summarizes detention requirements for Midwestern municipalities with populations close to Columbia's and for the two cities in Missouri, Saint Louis and Kansas City. Requirements from several progressive statewide manuals are also included for comparison.

Independence and Lee's Summit, Missouri, with populations very close to Columbia's, do not require detention unless there is a risk of flooding problems. Kansas City, Missouri has the same requirement and the State of Maryland does not require detention beyond channel protection, but allows municipalities to require it if downstream flooding is a concern. Peoria, Illinois and Olathe, Kansas, which also have populations similar to Columbia, require detention only to the 25-year level as does nearby Rolla, Missouri and the State of Georgia. The remaining four similarly sized Midwestern municipalities and the Metropolitan St. Louis Sewer District do have a 100-year detention requirement.

TABLE 2.6
Detention Requirement Summary

Municipality	Storm Events	Requirements	Approximate Population (thousands)
Columbia, MO	1-, 2-, 10-, and 100-yr	Post-development must not exceed pre-development. Requires 1-foot of freeboard above 100-yr storm.	94
Independence, MO	1-, 10-, and 100-year	Section 5600 of the Kansas City Metropolitan Chapter of APWA Design Criteria. Level required depends on decision matrix. Required only if	110

TABLE 2.6
Detention Requirement Summary

Municipality	Storm Events	Requirements	Approximate Population (thousands)
		flooding problems occur as defined for existing or future peak flows. Not required if peak runoff is not increased.	
Lee's Summit, MO	1-, 10-, and 100-year	Section 5600 of the Kansas City Metropolitan Chapter of APWA Design Criteria. Level required depends on decision matrix. Required only if flooding problems occur as defined for existing or future peak flows. Not required if peak runoff is not increased.	82
Olathe, KS	10-year (residential), 25-year (commercial and industrial)	Post-development must not exceed pre-development. Requires 1-foot of freeboard above design elevations with emergency spillway being used. Emergency overflow must be designed to provide the safe passage of runoff generated from a 100-yr storm. All basins must be designed with the capability of passing a 100-yr hydrograph from a fully developed watershed through the outlet (without failure).	115
Peoria, IL	2- and 25-year	Post-development must not exceed pre-development.	113
Kansas City, MO	1-, 10-, and 100-year	Section 5600 of the Kansas City Metropolitan Chapter of APWA Design Criteria. Level required depends on decision matrix; Required only if flooding problems occur as defined for existing or future peak flows. Also, not required if peak runoff is not increased.	447
Metropolitan St. Louis Sewer District (MSD)	2- and 100-year	At a minimum, post-development runoff must not exceed pre-development. Stricter release rates apply to some watersheds on a case-by-case basis and are based on modeling.	1,370
Rolla, MO	2-, 10-, and 25-year	Post-development must not exceed pre-development. Also must safely pass the 100-year storm.	18
Springfield, MO	1-, 10-, and 100-yr	Draft regulations; Post-development peaks must not exceed pre-development. Also must safely pass the fully developed 100-year storm.	151
Champaign, IL	100-year	The peak 100-year discharge shall not be greater than 0.18 cfs per acre of property drained	74
Davenport, IA	100-year	Required volume must handle the runoff of a 100-year event, less the volume discharged during the same duration at the approved release rate.	100
Broken Arrow, OK	5- and 100-year	Storage must accommodate excess runoff from all storms from 5-year up to 100-year event. Peak release rates shall not exceed existing runoff pre-development for all storm frequencies up to and including the 100-year event. 5-, 10-, 50, and 100-yr events shall all be investigated at a minimum.	88

TABLE 2.6
Detention Requirement Summary

Municipality	Storm Events	Requirements	Approximate Population (thousands)
Western Washington State (General Area)	One-half the 2-year event through the 50-year event	Continuous event model used; Pre-project condition is defined as native forest rather than actual conditions at the time of the proposed project.	Varies by municipality
Georgia (Statewide)	25-year	Post-development runoff must not exceed pre-development to reduce overbank flooding	Varies by municipality
Maryland (Statewide)	No requirement	Controlling the peak discharge rate from the 10-year storm event to the pre development rate is optional and subject to local municipalities. For Eastern Shore of the state, control for the 2-year event is required. 100-year detention is noted as not usually necessary if development is excluded from 100-year floodplain and downstream conveyance is adequate. 2-yr requirement for Eastern Shore only.	Varies by municipality

2.6 Recommendation

2.6.1 Cost Implications

The above analysis shows that some level of detention is necessary. When the cost per acre required for detention remains constant, implementation of a water quality and channel protection standard and removing the 2-, 10-, and 100-year detention requirement generates a cost savings of approximately 26 percent. This estimate is based on a reduction in required land from 1.35 acres to 1.04 acres.

In addition, erosive shear stresses in the channels would be decreased as explained above and would generate a cost savings to the community by reducing the loss of land to erosion and the expenses of stream restoration. The analysis of how much these factors amount in term of savings requires additional citywide field data collection and is beyond the scope of this study. However, an idea of the benefits can be gleaned considering that the average value of an undeveloped acre of land in the City is $22,000 and that the cost to restore a 1000-foot reach of stream is around $500,000. The cost of a developed (but not built) 1-acre lot of land can range from $50,000 to $350,000 with an average of $125,000.

2.6.2 Channel Protection

Erosion control is one of the most serious stormwater management issues currently facing the City. As shown in Section 2.3.4, the current stormwater detention requirements do not reduce shear stress in the channels. A water quality and channel protection volume requirement would require less acreage and cost than the current requirements in the Manual, and would introduce a significant reduction in receiving channel shear stress. While water quality volume requirements are becoming more common in the Midwest,

MSD is the only entity in Missouri that currently has a channel protection volume requirement as a result of open channel erosion.

MSD's channel protection requirement is based on the 1-year design storm event. It is recommended that this be the initial criteria adopted by the City, although in the hypothetical case it proved to be conservative and produced shear stresses below the pre-development conditions. Customized shear duration criteria as described in Section 2.3.4 is complex to develop for a comprehensive range of scenarios and it has not yet been widely done by other jurisdictions. However, the City should allow the development community to develop customized criteria for a given development as long as it can be shown that the post-development shear stress does not exceed the pre-development shear stress over the duration curve time period.

The concept of duration curves and how a stormwater control affects them will be necessary to address the impending hydrology TMDL in Hinkson Creek. Therefore, design standards for this watershed may need to be modified to meet the TMDL conditions.

The City should keep the water quality volume requirements and implement a 1-year channel protection volume requirement in lieu of the current 100-year detention requirement for all developments. Developers should have the option to develop customized channel protection volume requirements for a specific development as long as a shear duration curve is produced that shows the post-development shear stress curve does not exceed the pre-development shear stress curve over the available rainfall period of record.

2.6.3 Flood Protection

Water quality and channel protection controls and LID site design principles similar to the BMPs in the Manual are capable of controlling design storm runoff through its primary strategy of restoring the developed area's natural rainfall-runoff relationship. However, where there are known problems, a hybrid approach may be needed to reduce liability and increase safety. ***The manual should require that new developments provide flood protection by affording an appropriate level of detention where increased flow would either create a flooding problem or worsen an existing problem. Otherwise, meeting water quality volume and channel protection volume requirements is adequate.*** Section 5600 of the Kansas City Metropolitan Chapter of APWA Design Criteria contains a decision science flowchart (Figure 5601-1) that can be used as a guide for evaluating the need for flood control when downstream flooding problems are a concern.

As shown in Section 2.5, it is not unusual for 100-year detention not to be a requirement both in similar sized municipalities in Missouri and in progressive stormwater management states such as Maryland and Georgia. Hybrid systems are recommended by the LID National Design manual where flooding problems exist. The City should create GIS mapping of flooding problems identified prior to 2003 and develop drainage area mapping for all problems, so that the drainage area contributing to a problem area can easily be identified. All developments should use the available hydrologic and hydraulic models to show that increased flows do not worsen flood risk or endanger properties. If no potential damage results from the new development, meeting water quality volume and channel protection volume requirements alone is adequate.

3. Level of Service Method (Section 6.8.1)

The value ratings found in Table 6.8.2.1 do not seem to reflect the most current information on BMP performance available. For example, parking lot detention receives water quality treatment credit, while it does not rely on pervious surface at all and provides very little, if any, water quality benefit.

The updated 2008 MARC manual contains updated value ratings in the corresponding table and parking lot detention has been removed from the value rating (VR) list and the guidance is generally more detailed. It also provides documentation for the developed ratings based on the median concentration of total suspended solids (TSS) in the effluent and other criteria. TSS references also focus more on effluent limits rather than percent removal than in the current manual. The updated manual introduces a level of documentation to the LS method that is lacking in the previous version of the manual. The City should consider adopting the updated MARC value ratings after carefully reviewing the provided documentation and discussing the basis of the updates with the MARC manual's authors.

TSS removal is a common parameter used to gauge effectiveness of BMPs. Columbia should review the effluent levels and associated VRs in the updated MARC manual to ensure they are consistent with the City's expectations. The City should also consider whether there are any pollutants of particular concern specifically for Columbia, other than TSS, that would alter the VR's that the City would like to see assigned to different BMP's.

The LOS method in the City's manual has stringent redevelopment requirements. The City's manual requires a minimum level of BMP implementation for the entire legal property, regardless of percent impervious reduction or the percentage of the site being redeveloped.

The 2008 updated MARC manual contains the stricter redevelopment LOS requirements that Columbia is using, but these are informational only and are not required in Kansas City. Kansas City only requires BMP implementation if the percent impervious increases. They present the more stringent requirements in case a municipality wants to adopt more stringent requirements, as Columbia has. Water quality and quantity requirements for St. Louis MSD generally are required for new development and redevelopment when over 1 acre is disturbed or the differential runoff is greater than 2 cfs. MSD does require detention for a runoff increase on redevelopment projects.

It is unusual both in Missouri and across the country to require mitigation for previously developed sites when redevelopment does not result in an increase in impervious cover. The City should adopt standards similar to those in the updated 2008 MARC manual for redevelopment. Additionally, the City's manual currently requires mitigation for the entire legal site. This is also an unusual requirement. The City should adopt standards that require water quality mitigation only for the portion of the site that is to be disturbed, regardless of the legal property boundary.

4. Stream Buffer Ordinance (Article X. of Section 12A)

Some of the concerns expressed by stakeholders related to the stream buffer ordinance address the considerable financial burden due to the loss of developable land, the seemingly excessive zone sizes, the perception that homeowners may not desire native plants in and adjacent to their lawns, the dislike of homeowners for trails through their property, and the inaccuracy of stream categories based on United States Geological Survey (USGS) Quadrangle map information.

4.1 Buffer Size

A review of regulations in other jurisdictions shows that the City's stream buffer widths are similar to other widths required by municipalities in Missouri, the Midwest, and throughout the United States. A summary of this review is shown in Table 4.1. MoDNR has indicated that future NPDES II permit renewals will focus heavily on post-construction control measures such as appropriate buffer widths. Despite the perceived economic ramifications of land lost to development due to the ordinance, buffer widths should remain in effect as written for environmental protection and permit compliance. A 1995 study of the economic benefits of runoff controls found that natural surroundings increase real residential property values by up to 28 percent while enhancing the quality of life (*"Economic Benefits of Runoff Controls"*, EPA 841-S-95-002, September 1995). Developers may be pleasantly surprised that streamside lots with a buffer may be able to command a higher premium that could offset the opportunity cost of less developable land.

TABLE 4.1.
Stream buffer ordinance summary

Municipality	Requirements	Approximate Population (in thousands)
Columbia, MO	Varies from 30 to 100 feet, based on USGS line types and drainage area over 50 ac; can be increased based on slope	94
St. Louis, MO (MSD)	Provides incentives for stream buffer preservation implementation, but is not required.	1,370
Kansas City, MO	Varies from 40 ft to 120 ft, based on drainage area from 40 ac to over 5,000 ac	447
Rolla, MO	Minimum of 50 ft, can be increased based on slope, 100-yr floodplain extent, and location of water pollution hazards (such as landfills, petroleum storage, etc)	18
Springfield, MO	Varies from 20 ft to 100 ft, based on drainage area from 40 ac to over 4 sq.mi. Additional buffer may be required in special cases.	151
Topeka, KS	Varies (30 ft to 100 ft each side) based on 100-year floodplain, wetlands and critical areas, and type of stream. Additional buffers required based on slope, hazardous substances, petroleum storage, sewage disposal, septic systems, junkyards, etc.	122
Independence, MO	Minimum average of 85 ft on each side. Required to expand the buffer depending on size and type of stream and the presence of slopes over 15 percent.	110
Lee's Summit, MO	Buffer width between 40 ft and 120 ft (less than 40 acres to greater	82

TABLE 4.1.
Stream buffer ordinance summary

Municipality	Requirements	Approximate Population (in thousands)
	than 5,000 acres). Buffers are larger for special conditions	
Peoria, IL	Buffer width between 30 and 50 feet (less than/greater than 1 sq mile total surface area of watershed). Must extend to 100-year floodway. Other restrictions may apply.	113
Davenport, IA	Buffer width for 100 year floodplain - no less than 20 feet.	100
Broken Arrow, OK	No development within regulatory floodplain	88
Lincoln, NE	Minimum Flood Corridor of 3 times the depth of channel +30feet on each side. (New growth areas)	241
Western Washington State (General Area)	Similar requirements to Columbia. Larger buffers may be based on documented fish use or if a stream has particular water quality or functional benefits. WA Dept of Ecology Stormwater Design Manual.	-----
Georgia (Statewide)	Included in BMPs as a better-site design practice. Individual municipalities may have ordinances.	-----
Chesapeake Bay (several states)	Designated Resource Protection Area (RPA) of 100 ft on each side for perennial streams and 50 ft for intermittent or ephemeral streams. Blue lines in USGS quads used to define the perennial boundary but several jurisdictions have stream assessment protocols to define the boundary using field observations.	-----

4.2 Trails and Greenways

Allowance of a trail or public greenway within the buffer was another stakeholder concern. Recent studies have actually shown that streamside lots, even with greenway trails, can increase lot value (*"Economic Benefits of Trails and Greenways"*, Rails to Trails Conservancy, 2006). Construction of greenways and trails along creeks is not unusual in Missouri. In August 2007, a state law was passed (Missouri Revised Statutes, Section 258.100) that limits the property owner liability for greenway trails. Also, an easement would have to be obtained prior to any trail construction. The City may want to reconsider how trails are allowed within the buffer zone, for example a fence could be constructed by the owner of the trail within the easement, therefore separating the trail from the private property. Developers can also create a trail along the creek as part of the common ground of the development and market it as an amenity.

4.3 Vegetation

The requirement for native vegetation in the streamside zone to protect the physical and ecological integrity of the stream ecosystem is not unusual and is necessary for the buffer to perform its intended function. Managed lawns are permissible in the outer zone of Type II and III waterways. However, to maximize the ecological benefits of buffers, lawns should not extend to the water's edge. Native vegetation is the most effective and minimalist way to maintain a functional buffer.

According to the Center for Watershed Protection ("The Architecture of Urban Stream Buffers," in *Watershed Protection Techniques*. 1(4): 155-163, Article 39), three functional zones should exist in an urban stream buffer, each with different width, vegetation, and uses. The streamside zone should ideally be a mature forest that produces shade and woody debris essential to aquatic habitat and biota. The middle zone is between 50 and 100 feet and should be a managed forest with some clearing allowed. The outer zone is about 25 feet and can include turf although forest is the preferred option. As it is done in many of the jurisdictions in Table 4.1, the width of this three-zone buffer should be increased to allow for protection of special areas such as wetlands and the floodplain.

The boundaries of buffers need to be clearly marked and enforced and, whenever possible, buffers should be connected to form continuous green corridors.

4.4 Technical Issues

Streams are divided into three types for stream buffer width definition. The stream types are determined by the line type shown on the USGS quad maps. This can be controversial, as the USGS quad maps are often over ten years old and do not contain detailed data. While USGS definitions are traditionally used for stream buffer width definition, as mentioned earlier, other jurisdictions are currently moving toward defining stream categories with a more accurate set of protocols. It is recommended that the City undertake a study to develop perennial stream determination protocols appropriate for this ecoregion. In the current technology to address this issue, the protocols use indirect measures of hydrology such as channel geomorphology (e.g., bankfull, and flood-prone shelves), hydrology characteristics (e.g., hydric soil types), and biology components (e.g., benthic macroinvertebrate community structure). Once established, the appropriate ordinance should be changed to allow challenging the USGS definition using these protocols.

Section 12A-236(b) requires that the buffer be measured from the ordinary high water mark of the channel during base flows. This may be difficult to define. The City should consider changing this to the normal depth of the 1-year storm event, which is easily calculated.

Section 12A-237(e)(1) includes "Roads and bridges" as permitted activities in the streamside zone of the buffer. This usage is likely included to allow road crossings in the stream buffer. This section should be reworded to allow only crossings and not roadways parallel to the stream.

Section 12A-237(f)(4) includes "Drainage by ditching, underdrains, or other systems" as a prohibited activity in the streamside zone. However, this could be interpreted to prohibit a crossing of the buffer for a storm drainage outfall. This should be reworded to allow stormwater outfalls.

5. Open Channels and Stream Assessments (Chapter 5)

The current Draft of Chapter 5 of the City of Columbia's Stormwater Management and Water Quality Manual provides a solid foundation for guiding development in and around creeks. However, some sections could be improved and made easier to follow and enforce with some relatively simple reorganization and minor modifications. This document suggests ways to condense, simplify, and clarify the current draft. General suggestions to improve the chapter include combining Section 5.1.3b with 5.1.3c and 5.1.4e, replacing the

"Channel Condition Scoring Matrix" process described in Section 5.1.4g with a more comprehensive process that ranks channel stability based on the analyses described in Sections 5.1.4a through f, and incorporating more explicit consideration of fluvial geomorphic processes and thresholds as an organizing theme throughout. These changes are described in more detail in the following sections, along with more specific changes to individual sections.

5.1 Stream Construction (Section 5.1.3)

5.1.1 Energy Management (Section 5.1.3B)

The section heading "Energy Management" is confusing. A more appropriate title would be "Hydraulic and Geomorphic Energy Management"

Use of the term "adequate" to describe required sediment transport and channel protection designs can be problematic. This section could be improved by suggesting specific flow frequency, shear strength, or other quantitative criteria to guide designs, which could be provided in a separate section or appendix.

The requirement to limit the zone of influence downstream through energy dissipation or grade control does not include clear guidance regarding the distance over which this should occur. This section indicates that within the zone of influence, the energy of flow will be evaluated for potential of excessive scour, deposition, initiation of headcuts, or other instability, and continues to give examples of possible treatments that could be applied to address such issues. The section could be improved by directing that the required evaluation be used to delineate the zone of influence showing both the upstream and downstream boundaries of impacts on hydraulic and geomorphic energy from a project, and identifying measures that could be applied to offset those impacts.

5.1.2 Sediment Transport Continuity (Section 5.1.3C)

Because sediment transport continuity is closely linked with hydraulic and geomorphic energy, this section could be consolidated into section 5.1.3 B, essentially making that section a "Hydraulics, Sediment Transport, and Channel Morphology Management" section.

In addition to combining this section with 5.1.3.B, it would be beneficial to revise the sediment transport continuity guidance to be more consistent with geomorphic processes and thresholds. Instead of requiring shear stress with ultimate condition storm flows to be 90% of minimum pre-project shear stress, it would probably be more appropriate to require that the frequency of bed mobilization be maintained at some percent of pre-project frequencies (this percent would likely vary from site to site). This change would be relatively easy to implement, as Section 5.1.4E already requires a critical shear stress analysis, and would likely lead to measures that better recognize geomorphic thresholds and processes and are therefore more sustainable.

5.1.3 Transitions (Section 5.1.3D)

This is a vague requirement subject to interpretation. In addition, transition requirements are different for downstream and upstream conditions. It would be helpful to develop recommended expansion and contraction criteria.

5.1.4 Professional Judgment (Section 5.1.3F)

Because fluvial geomorphology is largely an interdisciplinary science, it would be preferable to say that decisions should be guided by prudent engineering and fluvial geomorphic judgment.

5.2 Stream Assessment (Section 5.1.4)

Requiring the assessment to span a minimum of one wavelength could prove difficult to apply, especially in urban settings. It would be better to use a more specific description of the limits, such as 7 to 10 channel widths, a distance that will typically capture at least one meander wavelength.

5.2.1 Plan Form Analyses and Inventory (Section 5.1.4A)

The manual should direct that the required plan form measurements be shown on a series of four site maps:

1) Basic Data (to include measurements 1, 2, 3, & 4)
2) Geomorphic Data (to include measurements 5, 6, 7, 9 & 10)
3) Vegetation Data (to include measurements 8)
4) Field photo location map

5.2.2 Bank-full Width, Depth, and Discharge (Section 5.1.4B)

It is likely that bankfull width will be difficult to identify in the field because many of the streams covered by this guidance are already impacted. Therefore, it would be helpful to provide some clarification as to how the elevation for the 100% storm flow should be estimated (e.g., with a hydraulic model of the reach, using Manning's equation for a representative cross section, etc.).

5.2.3 Longitudinal Profile and Sections (Section 5.1.4C)

Field surveys should require 0.01-foot accuracy rather than 0.1 foot.

Requiring a cross section survey at each pool and riffle could be problematic, especially in watersheds where most of the channels are composed of fine-grain sediment. This section could be improved by including guidance for cross sections surveys in channels without clear pool-riffle morphology (e.g., one cross section every 7 to 10 channel widths).

Requiring that cross sections be annotated with the 1% storm floodplain water surface elevation could also be problematic if a detailed flood insurance study (FIS) has not been performed, if such a study is outdated, or if only a FEMA approximate study exists. Unless a recent detailed flood study exists, estimating this elevation could be time consuming and complex.

5.2.4 Bed and Bank Materials Analysis/Critical Shear Stress Analysis (Sections 5.1.4D/E)

Section 5.1.4D requires that shear stress ratios be calculated for each riffle based on the applied shear stress at bankfull flow. Again, clear guidance for channels without clear pool-riffle morphology will eliminate confusion.

Taken together, these two sections describe analyses required to characterize the sediment composition of the channel and critical shear stress for the channel. Organizing these sections around the bankfull flow could be problematic, because of the reason mentioned above that bankfull flow is often difficult to identify in urban and urbanizing watersheds. These sections could be improved by organizing them around a range of flows (i.e. calculate applied shear stresses for the 1, 2, 5, 10, etc.- year flows and use these to calculate a range of applied critical shear stress ratios. This approach facilitates a more standardized evaluation of project impacts.

The term "effective flow" is introduced at the end of Section 5.1.4.E and calculation methods are provided. However, it is unclear what is expected with respect to effective flow. This material could probably be eliminated.

These two sections could also logically be combined with section 5.1.3B as they also consider hydraulic and geomorphic energy management. If this change were to be made, these two sections (primarily 5.1.4E should form the foundation of the energy management approach.

5.2.5 Plan-Form Ratios (Section 5.1.4F)

The first entry in the table in this section describes sinuosity as the meander length divided by the wavelength. In fluvial geomorphology, sinuosity is considered to be the channel length divided by the valley length.

5.2.6 Channel Condition Scoring Matrix/Using the Stream Assessment Data and the Channel Condition Scoring Matrix (Sections 5.1.4G/H)

While channel scoring schemes are used in many stream assessment programs, they can be difficult to use as they tend to be subjective and are not always strongly tied to geomorphic processes and thresholds. Because this chapter already requires a significant amount of basic geomorphology data collection, this section might not be absolutely necessary.

Assuming the channel condition scoring matrix remains in this chapter, it would be better to structure the use of the scoring matrix around fluvial geomorphic processes and thresholds. This approach would replace the scoring ranges (which could be subjective) with a more qualitative assessment of the primary impacted processes at each site that is guided or informed by the scoring process. Then, the stream assessment data can be used to validate and refine understanding of those processes and to guide design of measures that will effectively deal with these processes.

6. BMP Guidance (Appendix B)

6.1 Infiltration Basin (Appendix B, Page B15)

The manual states that "*conservative estimates of soil infiltration rates are in county soil surveys published by the U.S. Department of Agriculture or are obtainable by field testing methods.*" However, Section 12A-88 of the ordinance requires that "*When a stormwater management facility relies on the hydrologic properties of the soils (such as an infiltration basin) the developer shall submit a soils report. The soils report shall be based on onsite boring logs or pit profiles.*" These two statements conflict with each other. The City should change Appendix B of the Manual to state that field testing methods are the only acceptable source of soil infiltration rate information. In addition, the design should take into account the ultimate infiltration rate of

the facility close to the end of its useful life. A value typically used in design is that the long-term infiltration rate is 20 percent of the initial rate.

The manual also requires an emergency spillway capable of passing runoff from the 25-year, 24-hour storm without damage to the impounding structure. However, the City also requires safe conveyance of the 100-year storm event. The spillway requirement should be consistent with the City's expectations for safe conveyance, which is at present the 100-year storm event.

6.2 Wetlands (Appendix B, Page B45)

The manual states that "*The design should include a buffer to separate the wetland from surrounding land. A buffer of 25 feet is required as the minimum, plus an additional 25 feet if wildlife is a concern*". Acceptable uses within the buffer and recommended land cover are not defined, and "buffer" is not included in the definitions section of the manual. The City should clarify what constitutes a buffer around a wetland, what exceptions can be allowed, and possibly relate it to one of the buffer categories in the stream buffer ordinance.

6.3 Vegetated Swales (Appendix B, Page B2) and Channels (Appendix B, Page B7)

The Manual requires vegetated swales and channels to provide adequate conveyance for the 10-year storm event. However, the Manual also requires engineered open channels to have a 16-foot easement or wide enough to convey the 100-year design storm (Manual, Section 5.2.2(A). Appendix A guidance should be changed to be consistent with the requirements for engineered open channels.

The Level of Service method does not give partial credit for BMP's that cannot meet all the sizing requirements of Appendix B due to space constraints. The updated 2008 MARC manual includes different swale types that may be more adaptable to smaller sites.

6.4 Ponds and Lakes (Appendix B, Section B.12)

Very limited information for ponds and lakes is provided in Appendix B. Also, ponds and lakes are not given value ratings for the LOS method in Table 6.8.2.1. The City should either provide more substantial information on ponds and lakes as BMPs (either original material or reference to another source of information) and provide a value rating, or eliminate the ponds and lakes section from Appendix B. It should be noted that, in principle, natural or naturalized water bodies should not be utilized as stormwater management facilities. Euthrophication and other problems can arise from such practices.

7. Miscellaneous Review Recommendations

7.1 Culverts and Bridges (Section 5.1.6)

Section 5.1.6(E) states that "*culverts shall be designed so that there is no backwater effect at all flows up to the 50% storm discharge*". While this is not an unusual or overly stringent requirement for new culverts, it is usually accompanied with a disclaimer that flood elevations also cannot increase beyond a certain point downstream.

Existing culverts with high backwater sometimes act as mini-detention facilities and prevent flooding downstream. Therefore, increasing conveyance without checking downstream impacts can actually cause a flooding problem. The manual should be changed to include a

flood elevation change check both upstream and downstream and have an allowance for backwater if it does not cause upstream flooding problems and prevents problems downstream.

7.2 Rainfall/Intensity Duration Frequency Curve Documentation

Figure 2.2.1.1 (Appendix F, Page F13) does not include the source of the rainfall information. This should be included.

7.3 Detention Ponds for Water Quality Volume Control

Chapter 6 of the manual does not currently point out that a typical detention pond can also be used to detain and release the water quality volume. Appendix B contains information on the outlet structure for a bioretention facility (Section B.9.7) that could also be applied to a detention pond. Dry detention ponds do receive water quality credit for the LOS method in Table 6.8.2.1, but due to the lack of documentation for the LOS method, it is unclear if the value rating assumes that a water quality control outlet structure has been incorporated. It is not unusual for detention ponds to also have water quality outlet structures, or to be combined with bioretention facilities, as this can generate cost savings. Clarifications to the manual should be made to allow such pond designs with adequate credits given by the LOS method.

The updated 2008 MARC manual contains information on an extended dry detention basin with a water quality outlet that is not in the previous version of the manual. The City should consider adopting this information.

7.4 Manufactured Filtering Devices

Section 12A-90 of the ordinance states that "*BMP's shall be used to control the peak flow rates of stormwater discharge associated with specified design storms and to reduce the generation of stormwater runoff. These practices must use pervious areas to treat stormwater…….*" This statement eliminates manufactured filtering devices from use for meeting the water quality requirements.

There may be special situations where space constraints make the use of pervious areas for BMP's difficult, particularly if the water quality requirements are enforced for redevelopment in the central business district. The City should give filter devices careful consideration in special situations.

The City should charter a BMP committee made up of City staff to develop an evaluation protocol for determination of specific situations where proprietary BMPs would be allowed with special approval and develop an application and approval procedure for developments wishing to use proprietary BMPs. These procedures should be incorporated into the Manual.

The committee should also develop a master list of approved BMPs. Manufacturers, developers, or builders would make a formal application to the BMP committee to have a specific BMP considered for approval. Applications could be made for both manufactured devices and pervious BMPs not included in the Manual. The committee should have a set approval process, which could consist of a presentation to the committee by the applicant along with technical data or even installation of a demonstration project with monitoring for

a pilot study. Upon approval of a particular BMP, the committee would have to establish an appropriate value rating for use in the LOS method. Note that the March 2008 update to the MARC manual does provide small VRs for some alternative BMPs that the City may want to consider adopting.

A similar committee is in place in Missouri at the Metropolitan St. Louis Sewer District (MSD). The committee has a rigorous application and approval process. John Grimm (telephone 314-768-2743) is a member of this committee and could provide insights into how the MSD committee handles applications and approvals. Alternately, the City could review MSD's approved alternative BMP list and adopt selected BMP's that MSD has approved. MSD's new regulations were adopted in February, 2006 and to date only a handful of BMP's have been granted approval.

7.5 Improved Guidance and Details

Many of the details and information found in Appendix B of the Manual are from the Center for Watershed Protection and dated 1996. BMP technology has advanced since 1996 and better details, information, and performance data are now available. These issues have been partially addressed in the updated MARC manual and APWA 5600. The updated MARC manual contains many updates and much more detailed information than the current manual. However, the City should carefully review all design guidance and details in the updated manual and determine if the details and information reflect the up-to-date technologies that the City needs in order to provide state-of-the-art stormwater management.

The City should also consider adding the following information to the manual with standards developed by City staff, or request that MARC consider adding it to a future version of its own manual:

- Guidance for green roof design, including standard details, recommended soils and plants, hydrologic and value rating information for design
- Guidance for time of concentration calculation through various BMPs and open graded friction courses
- Develop a standard detail and mix design for asphalt and portland cement porous pavements.
- Consider adoption of the four quartile rainfall distributions developed in "*Bulletin 71: Rainfall frequency Atlas of the Midwest*" by Huff and Angel. These distributions were developed for the Midwest and may be more appropriate to represent rainfall in Columbia. These storm distributions can be run in HEC-HMS and other software as customized distributions.
- The City could perform pilot studies with calibration information on performance of subdivisions designed with the new regulations.

7.6 Design Tools

Many municipalities have adopted standardized computer design and review tools (such as Denver's Urban Storm Drainage Criteria Manual) or have developed customized tools

specific to their own regulations. These tools are typically downloadable from the municipality's website. This provides an additional design aid to the developer, helps to standardize designs, and decreases plan review time by putting all reviews into a similar format.

In particular, the City should consider development of a user-friendly tool for the Level of Service Method. Design tools for BMP's would also be beneficial. A standardized form for reporting the Calculations required in Section 12A-88 of the Ordinance would also help streamline the review process. Also, some BMPs in the updated MARC manual have design worksheets that could be useful.

7.7 Use of other Standards

Section 12A-91(b) of the Ordinance states that "*The director is authorized to allow alternate and equivalent best management practices when using the level of service method outlined in the Water Quality Manual. The director shall consider alternate designs of best management practices when it is fully demonstrated that the alternate designs are equal to or better than designs contained in the Water Quality Manual*". Many of the designs in the water quality manual are based on older information, such as the Center for Watershed Protection and dated back to 1996. Better information is now available, but designers are unlikely to utilize it because the criteria for "fully demonstrating" the equivalence of the design is not well defined. Because of this, the City may be limiting the installation of innovative and highly functioning designs.

The City should provide better guidance for demonstrating equivalency, either by defining exactly what criterion must be proven and what level of calculations or literature review must be produced or by listing other manuals that contain equivalent designs. The list of resources in Section 1.12 of the Manual contains documents and resources that the City should consider for accepting as equivalent design guidance.

8. General Concerns Expressed by Stakeholders

8.1 General Effectiveness of BMPs in Local Soils

Many stakeholders have expressed a concern that because Columbia's soils have low permeability that infiltration BMPs will not be effective. One of the main purposes of the Manual, as stated in Section 12A-86 of the Ordinance, is as follows:

"*Minimize the total annual volume of surface water runoff which flows from any specific site during and following development to* ***not exceed the predevelopment hydrologic regime*** *to the maximum extent practicable*"

While it is true that Columbia's native soils are not high in permeability, it is important to remember that the purpose of the BMP is to mimic predevelopment hydrology. Therefore, if the native conditions have higher runoff rates than locations with native permeable soils, there is also less excess runoff after development to infiltrate than locations with native permeable soils because the soils are already less permeable. BMPs with soil amendments are effective in a wide range of soils because it is all relative to the native soil condition.

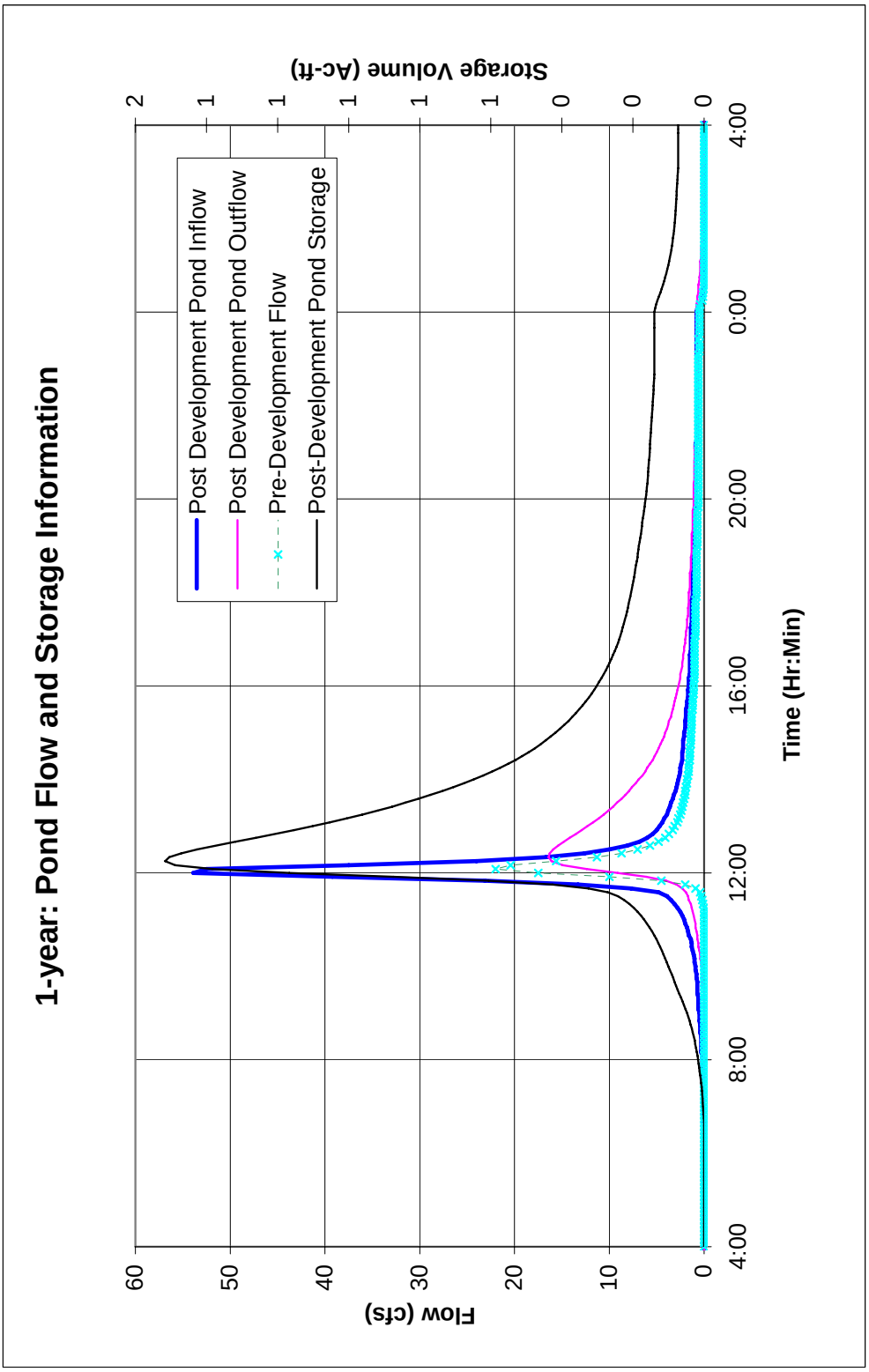
8.2 Central Business District

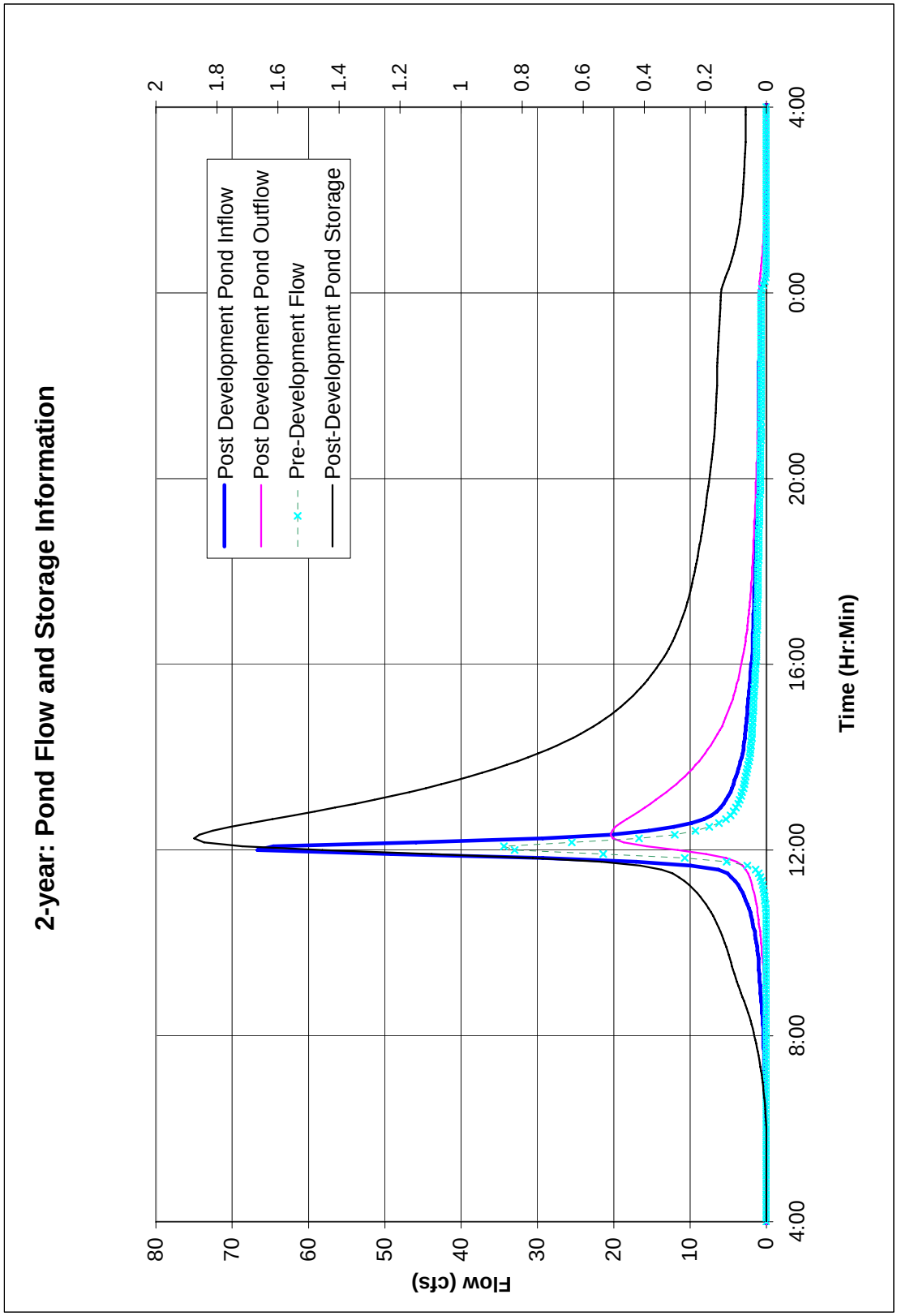
Section 12A-87-(a)(3)(b) of the ordinance states "*Stormwater detention is not required for redevelopment within the central business district.*" Section 6.4(D) of the Manual reiterates this statement. Water quality goal implementation is required for the Central Business District.

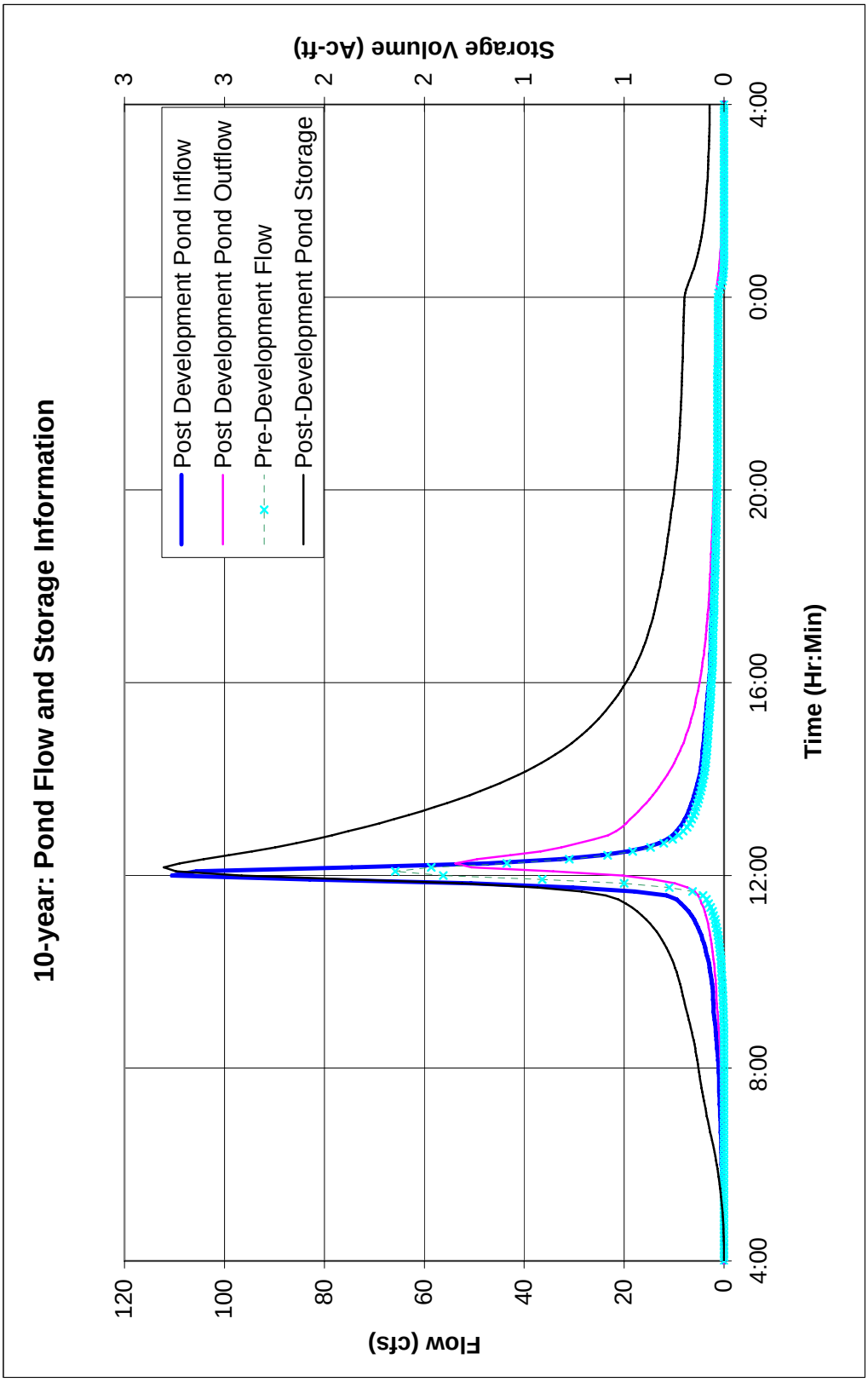
The central business district has been developed for over 80 years, and the downstream natural channels have absorbed the impacts caused by the development with flooding locations already known and accounted for. While redevelopment in the central business district is not likely to increase runoff or percent impervious, improvements in runoff quantity can be made with small-scale BMP's such as rain gardens or stormwater planters. The City should implement the techniques discussed in Technical Memorandum #1 as part of Goal #5.

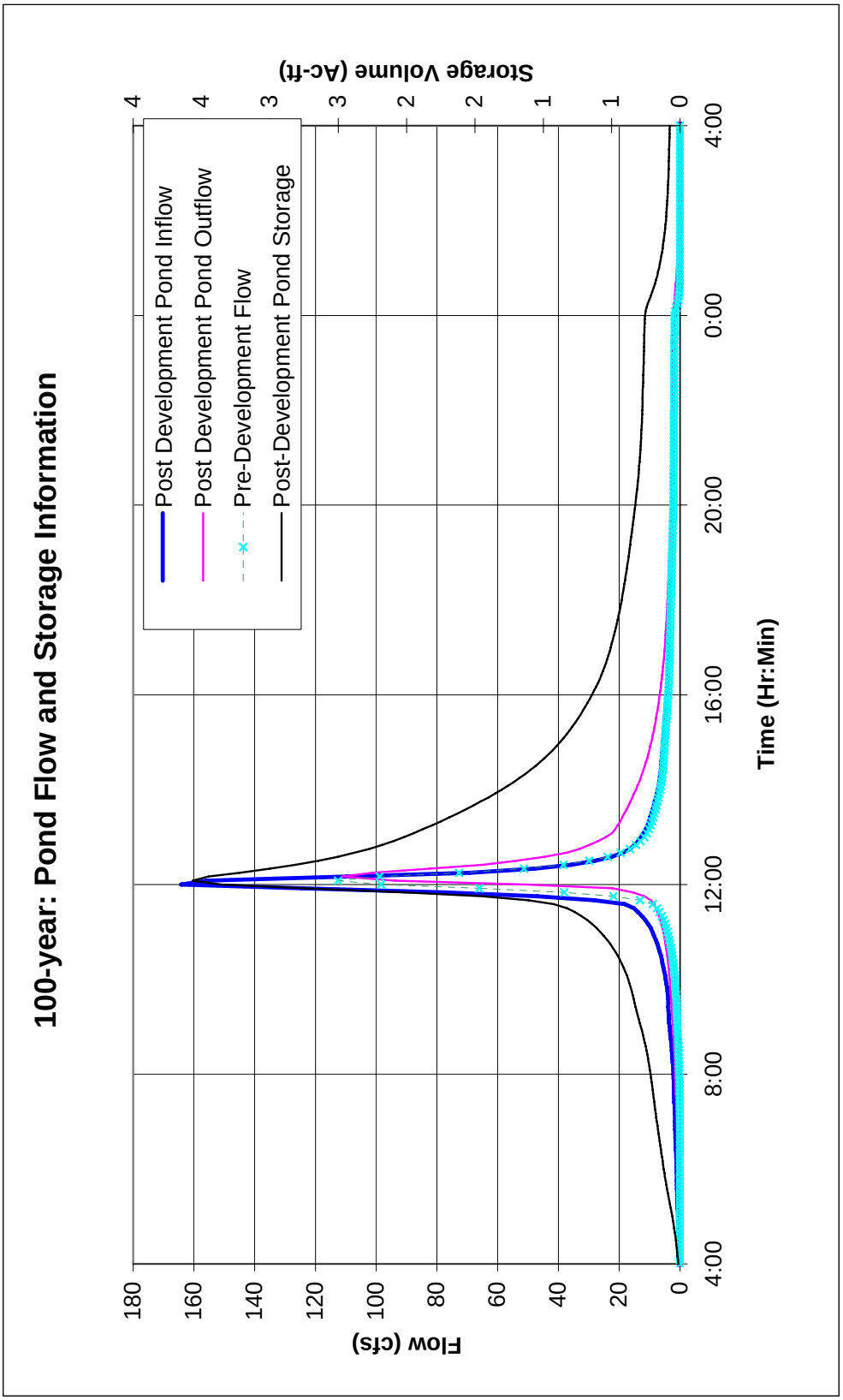
Appendix A

Design Storm Pond Results for Design Storm Events


1-year: Pond Flow and Storage Information
Flow (cfs)
60
50
40
30
20
10
0
Storage Volume (Ac-ft)
2
1
1
1
1
1
0
0
0
4:00
8:00
12:00
16:00
20:00
0:00
4:00
Time (Hr:Min)
Post Development Pond Inflow
Post Development Pond Outflow
Pre-Development Flow
Post-Development Pond Storage

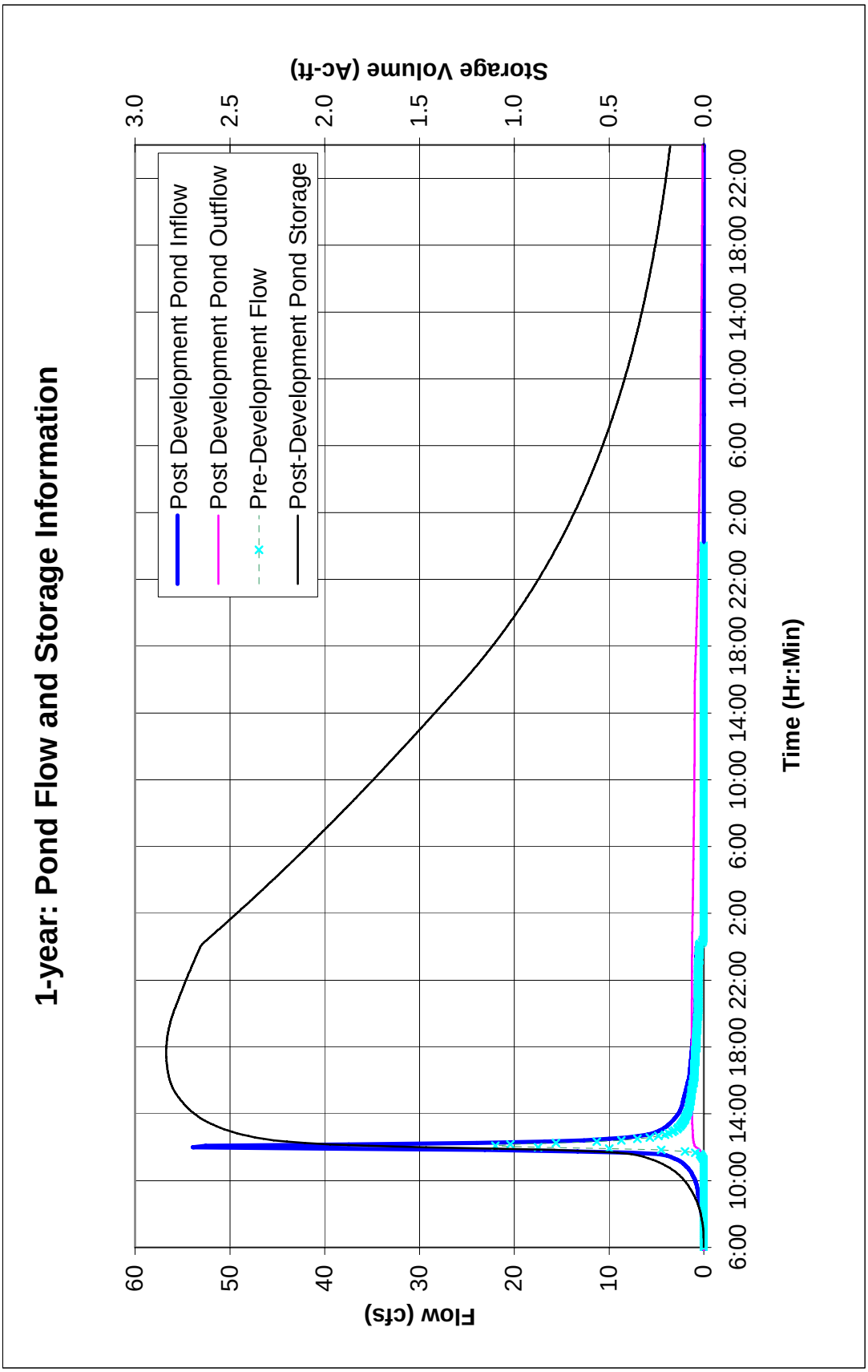

2-year: Pond Flow and Storage Information
Post Development Pond Inflow
Post Development Pond Outflow
Pre-Development Flow
Post-Development Pond Storage
Flow (cfs)
80
70
60
50
40
30
20
10
0
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
4:00
8:00
12:00
16:00
20:00
0:00
4:00
Time (Hr:Min)

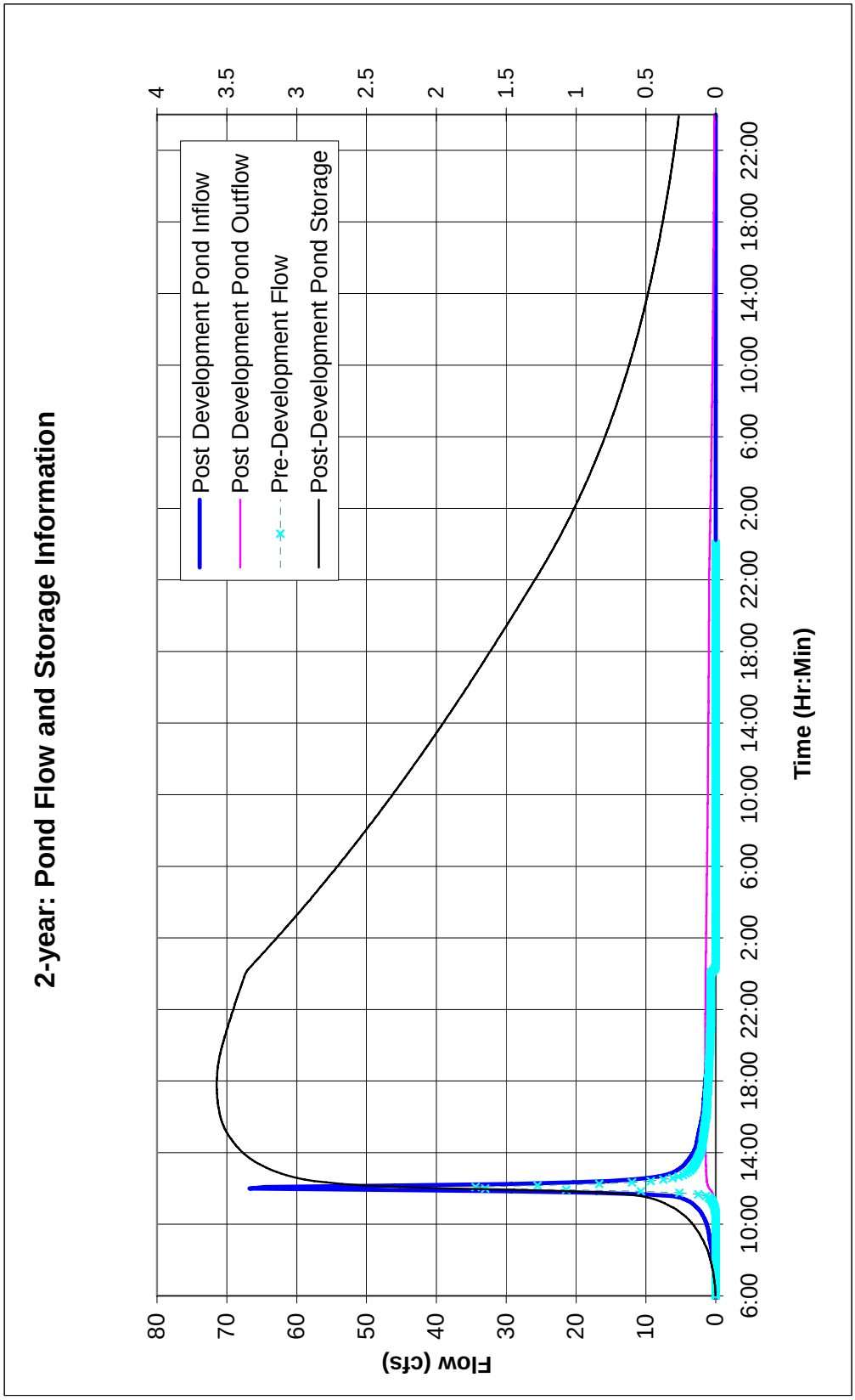

10-year: Pond Flow and Storage Information
Post Development Pond Inflow
Post Development Pond Outflow
Pre-Development Flow
Post-Development Pond Storage
Flow (cfs)
Storage Volume (Ac-ft)
Time (Hr:Min)
120
100
80
60
40
20
0
3
3
2
2
1
1
0
4:00
8:00
12:00
16:00
20:00
0:00
4:00

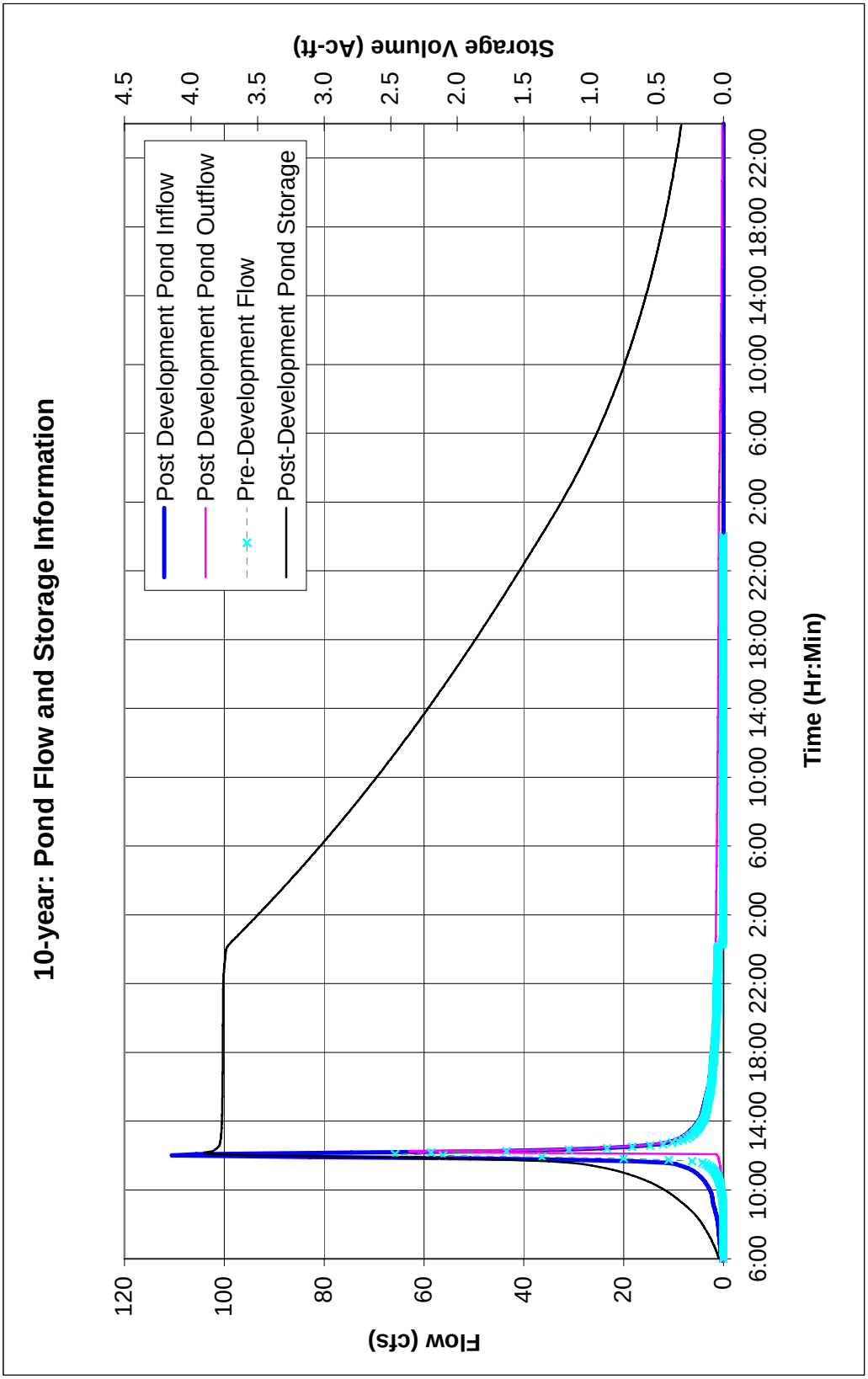

100-year: Pond Flow and Storage Information
Post Development Pond Inflow
Post Development Pond Outflow
Pre-Development Flow
Post-Development Pond Storage
Flow (cfs)
Storage Volume (Ac-ft)
Time (Hr:Min)
180
160
140
120
100
80
60
40
20
0
4
4
3
3
2
2
1
1
0
4:00
8:00
12:00
16:00
20:00
0:00
4:00

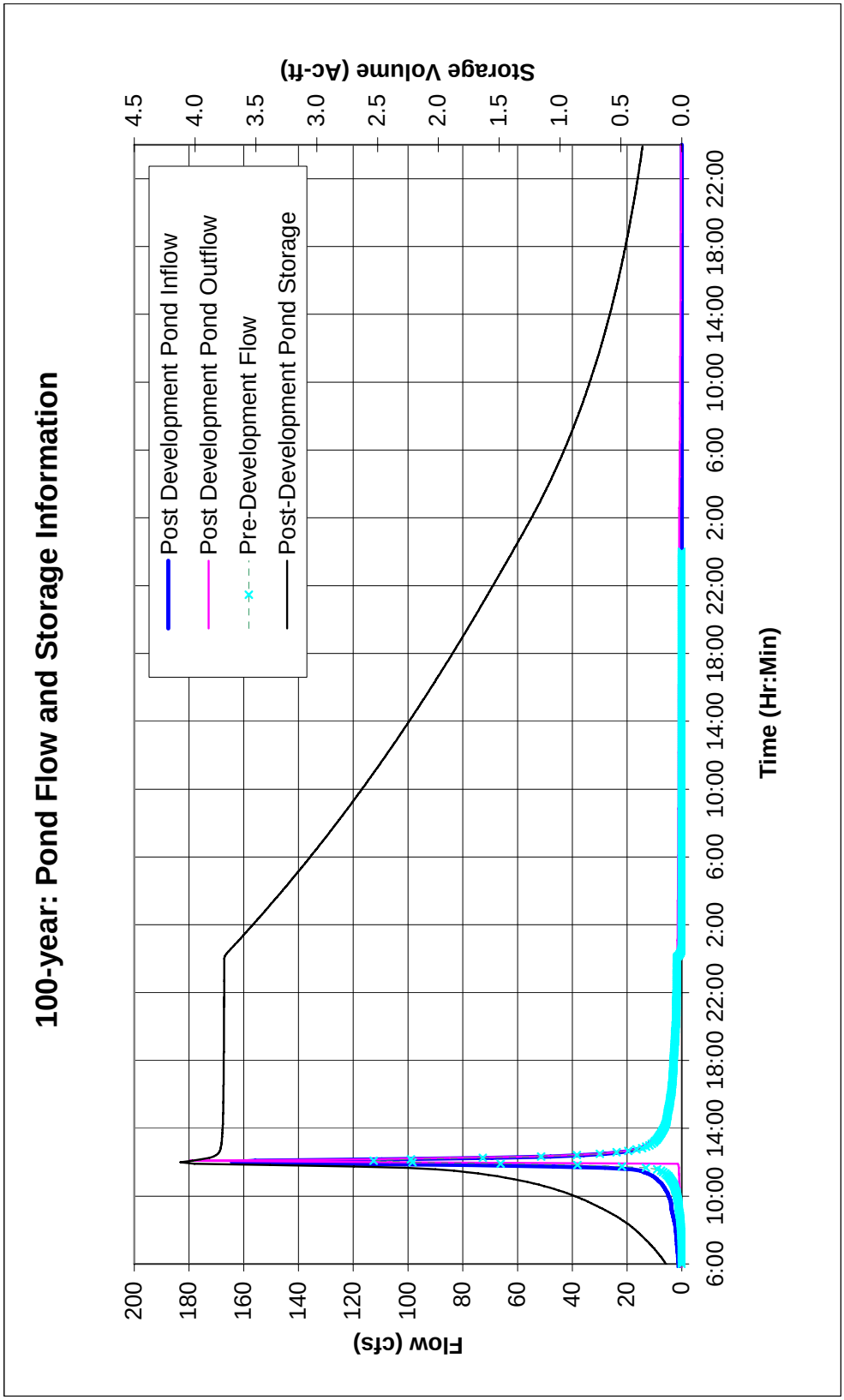
Appendix B

Channel Protection/Water Quality Volume Pond Results for Design Storm Events


1-year: Pond Flow and Storage Information
Post Development Pond Inflow
Post Development Pond Outflow
Pre-Development Flow
Post-Development Pond Storage
Flow (cfs)
Storage Volume (Ac-ft)
Time (Hr:Min)
0
10
20
30
40
50
60
0.0
0.5
1.0
1.5
2.0
2.5
3.0
6:00
10:00
14:00
18:00
22:00
2:00
6:00
10:00
14:00
18:00
22:00
2:00
6:00
10:00
14:00
18:00
22:00


2-year: Pond Flow and Storage Information
Post Development Pond Inflow
Post Development Pond Outflow
Pre-Development Flow
Post-Development Pond Storage
Flow (cfs)
80
70
60
50
40
30
20
10
0
4
3.5
3
2.5
2
1.5
1
0.5
0
6:00
10:00
14:00
18:00
22:00
2:00
6:00
10:00
14:00
18:00
22:00
2:00
6:00
10:00
14:00
18:00
22:00
Time (Hr:Min)


10-year: Pond Flow and Storage Information
Post Development Pond Inflow
Post Development Pond Outflow
Pre-Development Flow
Post-Development Pond Storage
Flow (cfs)
120
100
80
60
40
20
0
Storage Volume (Ac-ft)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
6:00
10:00
14:00
18:00
22:00
2:00
6:00
10:00
14:00
18:00
22:00
2:00
6:00
10:00
14:00
18:00
22:00
Time (Hr:Min)


100-year: Pond Flow and Storage Information
Post Development Pond Inflow
Post Development Pond Outflow
Pre-Development Flow
Post-Development Pond Storage
Flow (cfs)
Storage Volume (Ac-ft)
Time (Hr:Min)
0
20
40
60
80
100
120
140
160
180
200
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
6:00
10:00
14:00
18:00
22:00
2:00
6:00
10:00
14:00
18:00
22:00
2:00
6:00
10:00
14:00
18:00
22:00