STORMWATER MODELING REPORT

JULY 2006

South Washington Watershed District




HDR

STORMWATER MODELING REPORT

Prepared for

SOUTH WASHINGTON WATERSHED DISTRICT

JULY 2006

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

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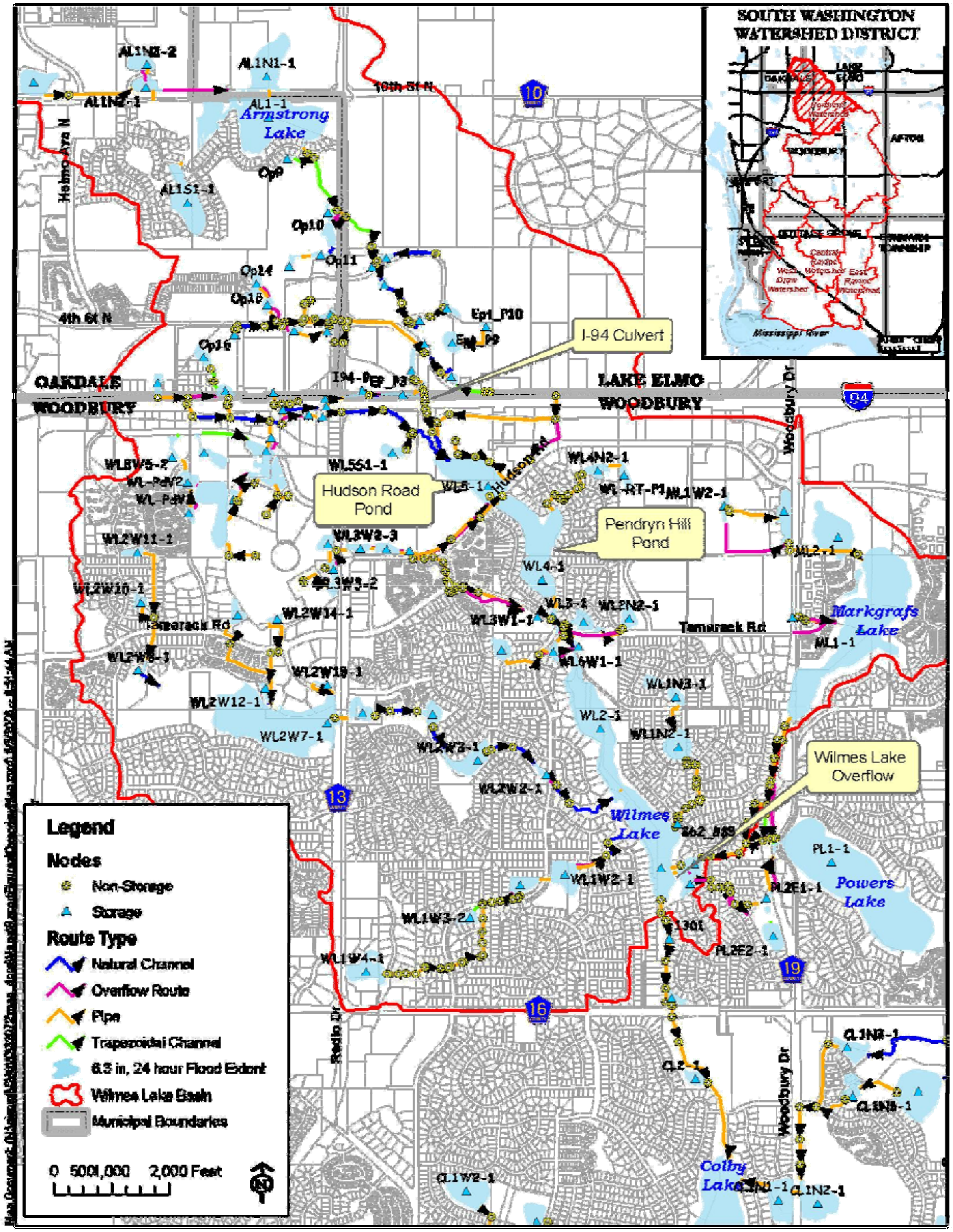
1.0 INTRODUCTION

The Wilmes Lake Watershed and subwatersheds comprise the Northern Watershed of the South Washington Watershed District (SWWD). This watershed includes those areas that are tributary to Wilmes Lake, and ultimately, Bailey Lake in the City of Woodbury. During October 4-5, 2005 (October storm), a large storm over this watershed caused high water levels throughout the northern SWWD watershed, including Wilmes Lake. The storm's intensity and overall volume exceeded the traditional design storm for the existing drainage system. The standard design storm adopted by the SWWD is the 6.3-inch, 24-hour event within a Type II distribution. Figure 1 shows several pictures of the localized flooding around Wilmes Lake that occurred during this storm. Figure 2 shows the Wilmes Lake Watershed with significant flow and stage locations highlighted.

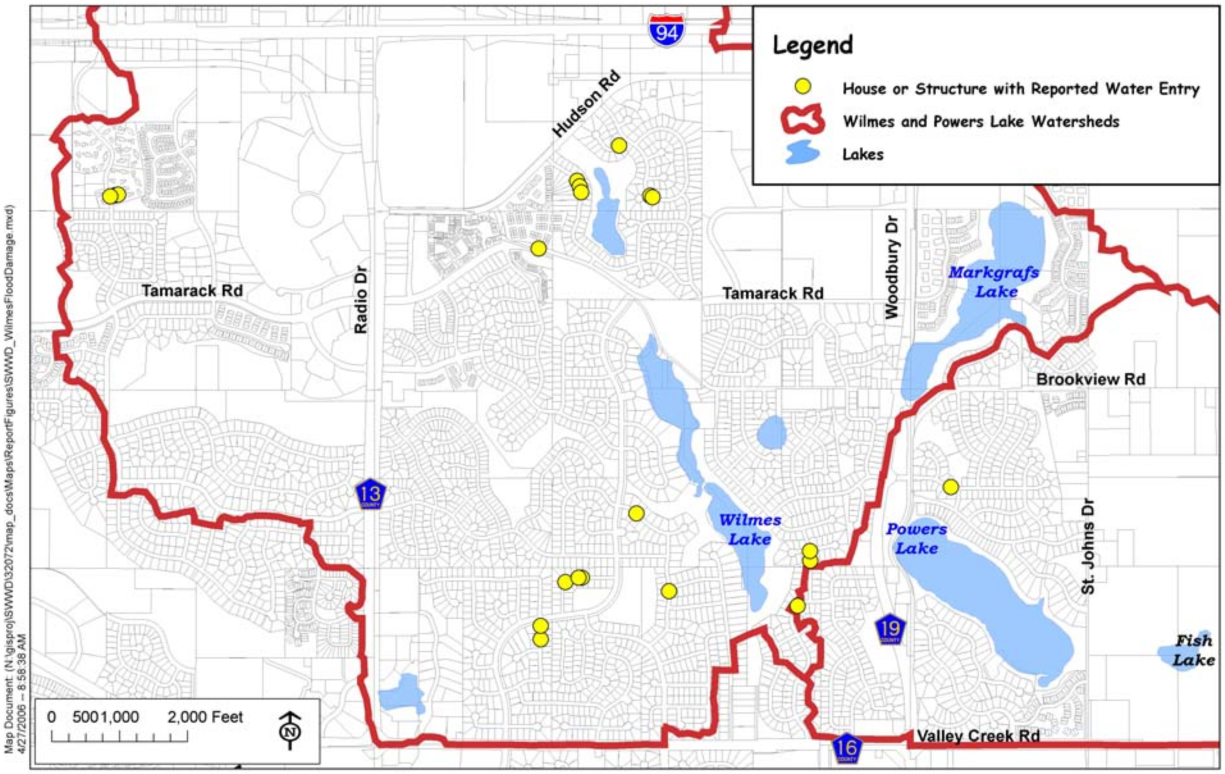
Figure 1
Wilmes Lake Localized Flooding
October 4 and 5, 2005

Figure 2
Wilmes Lake Watershed Map



This flooding spurred several, documented reports to the City of Woodbury of houses or structures with various degrees of water entry. Figure 3 shows the locations of the flooding complaints that were received during the October storm in the vicinity of Wilmes Lake.

Figure 3
Water Entry Reports during the October Storm



This storm, and the associated flooding, prompted the need to expedite the ultimate land use planning and study of the watershed system. This includes an update to the current drainage model maintained by SWWD to reflect current watershed conditions so that it can be used to predict watershed drainage characteristics in future conditions. The affects of this storm also highlighted that the operational water surface elevations for several water bodies, particularly for Wilmes Lake, are unknown or have changed from those expected or predicted in previous analyses. The update to the stormwater model will allow the SWWD to evaluate the expected water surface elevations for the watershed impoundments based on the Standard Design Storm, and other design storms, for both current and future conditions.

This report documents a hydrologic analysis and numerical model update for the Wilmes Lake Watershed and the contributing subwatersheds. The objectives of the hydrologic analysis and numerical model update are to:

- Update the SWWD's current SWMM numerical drainage model to reflect current land use patterns and drainage infrastructure for the Wilmes Lake Watershed.
- Utilize the rainfall data from the October Storm within the updated SWMM model to verify the model performance for use as a planning and evaluation tool and to characterize the probable lake or pond water levels during the October Storm.
- Quantify expected water levels in selected storage ponds and in Wilmes Lake for current and future (ultimate) conditions for the Standard Design Storm.

Section 2.0 of the report describes the refinement of and update to the XP-SWMM to current conditions. Section 3.0 provides a detailed description of the October storm and describes the model parameter adjustments and changes based on the actual storm data. Section 4.0 details the modifications to the model to reflect future or ultimate conditions and describes the results from this effort.

The updated SWMM model, configured to accurately model the current and ultimate drainage conditions within the Wilmes Lake Watershed, can be considered a good tool to analyze "what if" scenarios. The model can be used to explore the effectiveness of proposed flood control concepts that may reduce the high water concerns in Wilmes Lake or other watershed areas. To that end, subsequent sections of this report explore several conceptual options that have been proposed to reduce high water elevations in Wilmes Lake during specific flood events. The updated drainage model is utilized to explore the relative benefits of several conceptual, planning level options that might reduce the flood event high water levels in Wilmes Lake. These options include:

- Storage options in the upper Wilmes Lake Watershed north of Hwy. 94
- Storage options in the lower Wilmes Lake Watershed south of Hwy. 94
- Wilmes Lake outlet upgrades
- Wilmes Lake emergency overflow upgrades

Section 5.0 of this report provides a narrative description of each of the above options, describes how they were evaluated using the SWMM model, and quantifies their anticipated benefits. Table 1 provides the modeling conditions examined for each modeling scenario. Section 6.0 of the report compares and contrasts the relative effectiveness of each option and provides recommendations for further implementation activities for viable options.

Table 1
Modeling Scenario Definitions

Model Condition	Storm	Definition
Current Condition	Standard Design Storm	Current land use as of January 2006 with the 6.3-inch, 24-hour SCS Type II Distribution Standard Design Storm
Current Condition	October Storm Gridded Rainfall	Current land use as of January 2006 with the October 4-5, 2005 gridded rainfall
Ultimate Development	Standard Design Storm	Ultimate land use as of 2025 with 6.3-inch, 24-hour SCS Type II Distribution Standard Design Storm
Ultimate Development	October Storm Gridded Rainfall	Ultimate land use as of 2025 with the October 4-5, 2005 gridded rainfall

2.0 CURRENT CONDITIONS MODEL UPDATES

The last significant updates to the SWWD Northern Watershed model prior to this report occurred in 2002. New developments, infrastructure changes, recent surveys, software upgrades, and model refinements necessitated an update to the model and modeling process. Land use updates were obtained through field reconnaissance, engineering plans, and 2004 one-foot resolution color aerial imagery. Plans sets for new developments within the Wilmes subwatersheds were obtained for determining the stormwater infrastructure and grading plans.

For the purposes of this report, model updates were only completed for areas that ultimately drain to Wilmes Lake. Figure 4 provides an overview of major areas within the Wilmes Lake Watershed that have been developed or experienced land use changes since the last model update.

Figure 4
New Developments and Infrastructure Additions to the
Northern Watershed Model for the Wilmes Subwatersheds

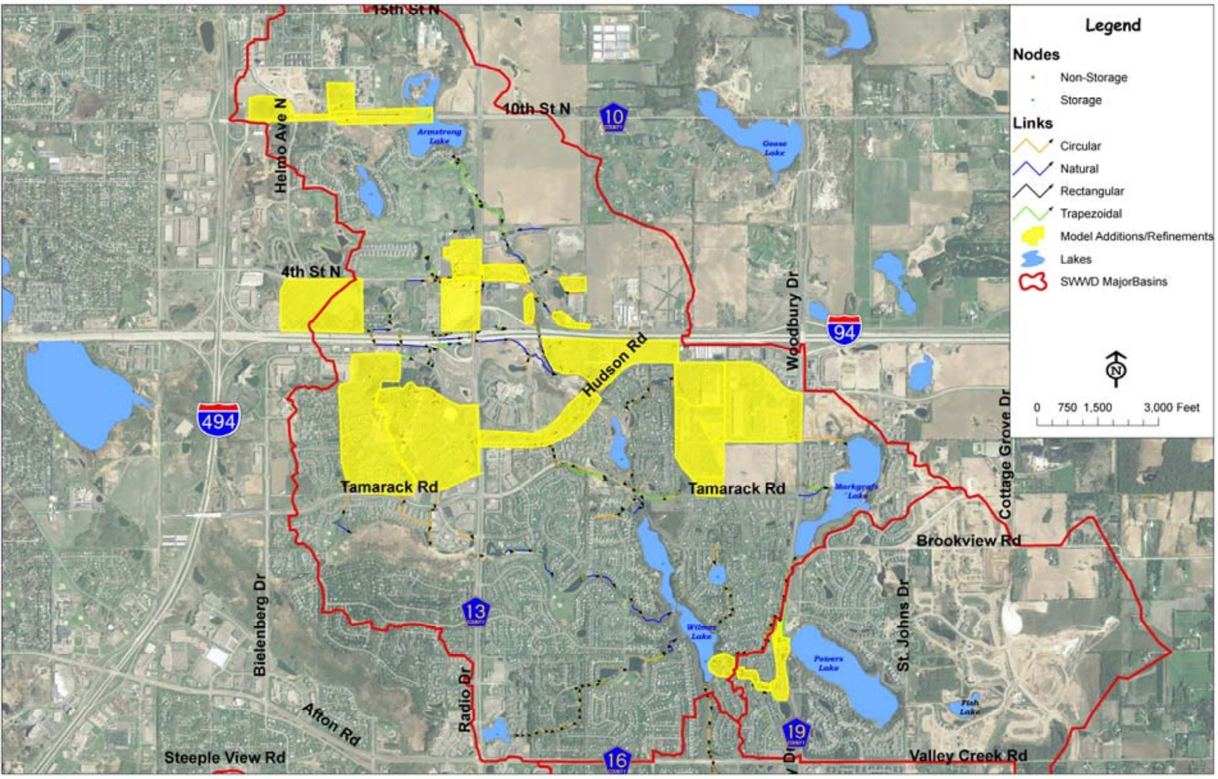


Figure 4 shows that several significant land use changes have occurred in the upper regions of the Wilmes Lake Watershed along the I-94 corridor.

2.1 NEW DEVELOPMENT UPDATES

The Wilmes Lake Major Watershed is under continuous development, resulting in changing land use, land grading, and stormwater infrastructure. Several new developments in the Wilmes Lake Major Watershed added to the current modeling effort include:

- Woodbury Market Place including the Rivertown Trading company, Sam’s Club, Commerce Drive, Commerce Center, and Signorelli Addition
- Hudson Road improvements from Hwy 13 to Hwy 19 (south of State Farm)
- Hudson Road weir
- Woodbury Lakes development and culvert passing under I-94
- Refinements to Tamarack Village
- Additions to the west of Tamarack Village, including the Pondview, Heritage Glen, and Clubhomes developments
- Pond and wetland areas to the north of Tamarack Village
- Refinements to the Eagle Point area, including the addition of a pond along Hudson Blvd., a pond in the office condominiums, drainage areas to the east of Eagle Point, and another pond to the south of Eagle Point
- New developments along 4th Street in Oakdale, including the Muir Site, Carlson Business Center, Oak Marsh, and Prom Center developments
- The 6th Street and Imperial improvements in Oakdale
- Refinements to the area draining into Armstrong Lake (added additional pond, broke up drainage basins, and added culverts connecting ponds)
- CSAH 19 (Woodbury Drive) road improvement in the vicinity of Powers Lake

2.2 INFRASTRUCTURE UPDATES

The model updates include several infrastructure additions derived from a survey conducted in late 2005 and early 2006, conversations with the SWWD, and drainage system performance observations documented during the October Storm. These updates include:

- Overflow patterns at Wilmes Lake and adjacent ponds (updates made with assistance from BRA January 2006 survey); an overflow route was added along the street towards Powers Lake.
- Flow splitter from Markgrafs Lake to Wilmes Lake and Powers Lake
- Drainage into Powers Lake corresponding to the flow slitter

- Powers Lake pump station (although for modeling purposes it is turned off)
- Changes to the drainage into Armstrong Lake

2.3 MODEL REFINEMENT AND ENHANCEMENTS

Field observations and a review of the actual conditions of the October Storm also necessitated the integration of several model refinements and enhancements into this modeling effort. These refinements and enhancements include:

- A review and update of all storage curves for the ponds within the study areas. This included the addition of bathymetry to all the new ponds and used existing DNR bathymetry to modify the storage curves of Wilmes, Markgrafs, Colby, Powers, and Bailey Lakes.
- Modification of storage curves to more accurately reflect the area at the storage node outlet and to correct issues where previous storage curves were inconsistently calculated from pond to pond.
- The addition of overflow routes across the Wilmes subwatersheds to accommodate the additional flow generated by the October Storm.
- The addition of entrance and exit losses to the pipes within the existing drainage system, with a general value of 0.5 across manholes and 1.0 at outfalls.
- The incorporation of modified pipe losses from Wilmes Lake, with entrance and exit losses increased to more accurately reflect the bends and inflow seen in those pipes.
- Lowered pipe roughness (Manning's n) from 0.015 to 0.013.
- Reduction of the effective weir length at Wilmes to account for the hydraulic contraction affect of the side walls.
- Reduction of the weir discharge coefficient from 3.0 to 2.7 at Wilmes.
- Increased conduit losses in the Wilmes outlet pipe to more accurately reflect pipe bends and inflows from other storage areas.
- Addition of gridded rainfall data for the October Storm to the model to accurately reflect the actual rainfall patterns that were observed during this storm.
- Decreasing impervious depressional storage from 0.2 to 0.1 inches and increasing pervious depressional storage from 0.1 to 0.2 inches, based on the finding of the model parameter verification study (report dated October 2005).

The model results and vertical information contained in this report are based on the NAVD 88 vertical survey datum.

2.4 MODEL DATABASE UPGRADE

For this modeling effort, the existing GIS modeling database was upgraded from ESRI shapefiles to a current technology called a “Personal Geodatabase”. This upgrade was required to modify and manage the model within the current versions of ArcMap 9.0 and above. ArcMap 9.0 is a software platform that is used for the SWWD to manage, via a database and a graphical interface, the drainage model input and output information. ArcMap 9.0 increases the ability to create and display the model output, and has been used to create several of the figures in this report.

Listed below are further enhancements resulting from this conversion:

- The model is supported in the most current ESRI GIS framework. This allows for greater data management and editing. All tools and functions of the latest ESRI technology can be supported, including incorporation and management of development drawings, incorporation of data contained in different spatial coordinates, editing tools, networking tools, etc.
- All related modeling files are contained within one geodatabase. Each modeling scenario has its own geodatabase, resulting in better model management.
- The transfer and maintenance of GIS metadata is greatly facilitated. Metadata is embedded directly within the geodatabase and documents the data sources and types of data used in the model.
- A linkage from GIS to XP-SWMM is fully supported. All modeling data is transferred back and forth seamlessly between GIS and XP-SWMM. This allows for quicker transfer of information between the two programs and allows for quicker and more accurate floodplain mapping.
- Topology rules are set for features within the geodatabase. This eliminates the possibility of overlap or gaps in spatial features. For example, subwatersheds cannot have gaps nor can they overlap one another.
- A geometric network is set up that allows for quicker and easier model calculation and editing. This decreases the time needed to perform model maintenance and the time to create new “what if” scenarios such as those used to explore the effectiveness of conceptual flood damage reduction projects.
- Rules and domains are established as to how modeling data can be entered into the geodatabase, with real-time enforcement of those rules. This promotes model data input consistency.
- Relationships between modeling components are established, creating faster and more powerful data management in a user-friendly framework. For example, storage curves are directly related to the “Nodes” features and are readily accessible.

3.0 OCTOBER STORM – OCTOBER 4-5, 2005

To establish that the Wilmes Lake Watershed SWMM model accurately, or to the greatest extent practical, reflects the behavior of the watershed, it is beneficial to enter an actual storm event into the model and measure calculated response to real world observations documented during that storm. If a model accurately recreates a known storm event, then the engineering team and the SWWD can have an increased level of confidence that the model is a reliable tool to analyze and evaluate the drainage system and develop options to solve problems.

The October Storm was well documented and data is available that can be entered into the model. The October Storm precipitation information was entered into the model and the model response was compared to the actual flood information. Areas where the model was deficient or incorrectly calculated the flood response were identified and the model was corrected, where possible, to more accurately represent the field conditions. The following sections describe the October Storm in detail and document the model verification procedure.

3.1 THE OCTOBER STORM

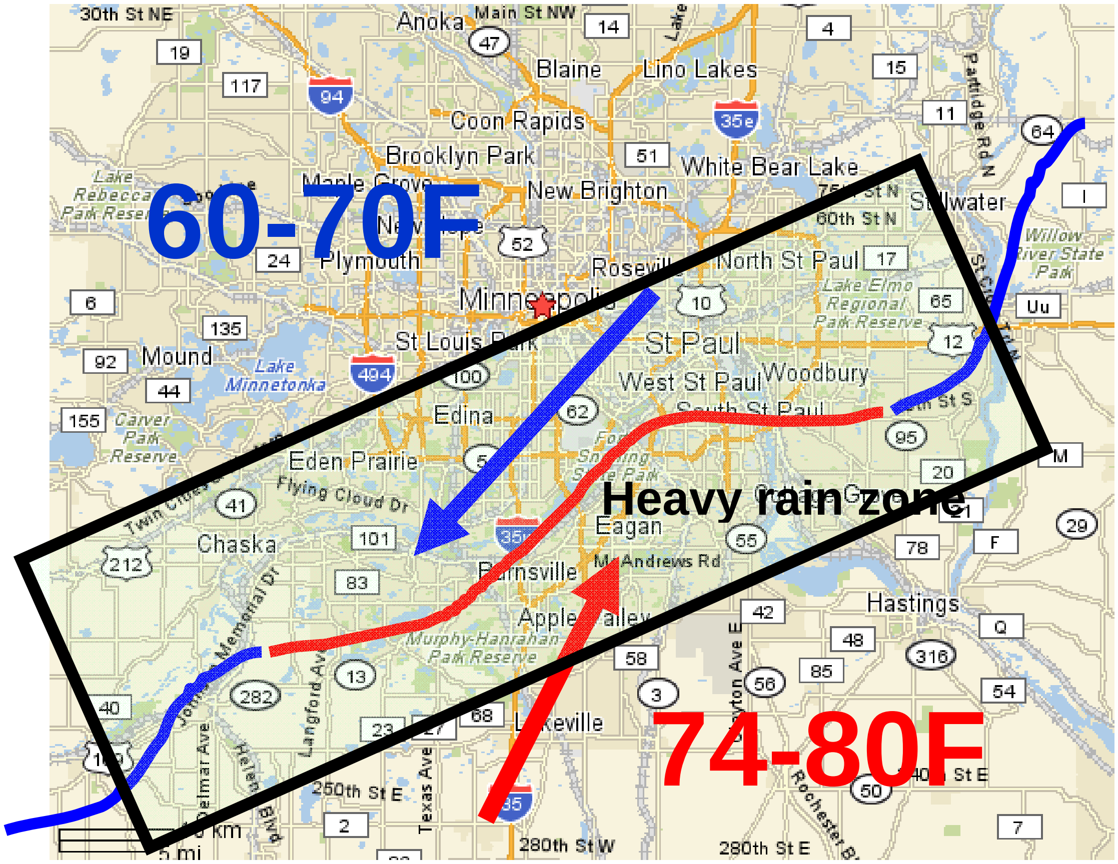
On October 4-5, 2005, a rain event occurred in the metro area causing record rainfall over many parts of the Twin Cities and flooding in the SWWD. The flooding rains of this storm were caused by the interaction of a stalled subtropical air mass holding almost 2 inches of water, a 40-50 mph low-level jet stream that lifted the wet air mass into thunderstorms, and a passing upper-level disturbance that organized them into a storm train. The training interaction caused thunderstorms to form and move repeatedly over the SWWD basin from the southwest to northeast from 6:00 PM until almost midnight.

The year 2005 had one of the wettest Octobers on record in the Minneapolis metropolitan area as humid warm air from the Gulf of Mexico settled into the Mid-West the first week. The Minnesota State Climatologist noted that observed dew points at local area airports were 70 degrees Fahrenheit on October 4, 2005, equal to highest observed daily records. Additionally, the overnight low the night before the flooding rains was 72 degrees Fahrenheit, the warmest overnight low in October in local weather history. The same weather patterns responsible for Hurricanes Katrina, Rita, and Wilma produced this warm muggy air mass.

The morning of October 4, 2005 found a stationary front draped across the Minneapolis metro area (Figure 5). To the south of this front was a very humid and warm sub-tropical air mass. The air mass held about 1.97 inches of water, which is more typical of late July than early October. Afternoon temperatures in this air mass reached 75 to 80 degrees Fahrenheit as skies became partly cloudy. A warm south wind (red arrow) gusted at 10-20 mph most of the day, keeping a ready supply of moist air to feed storm development.

Figure 5

Locations of the Warm Sub-tropical and Cool Air Masses and the Heavy Rain Zone

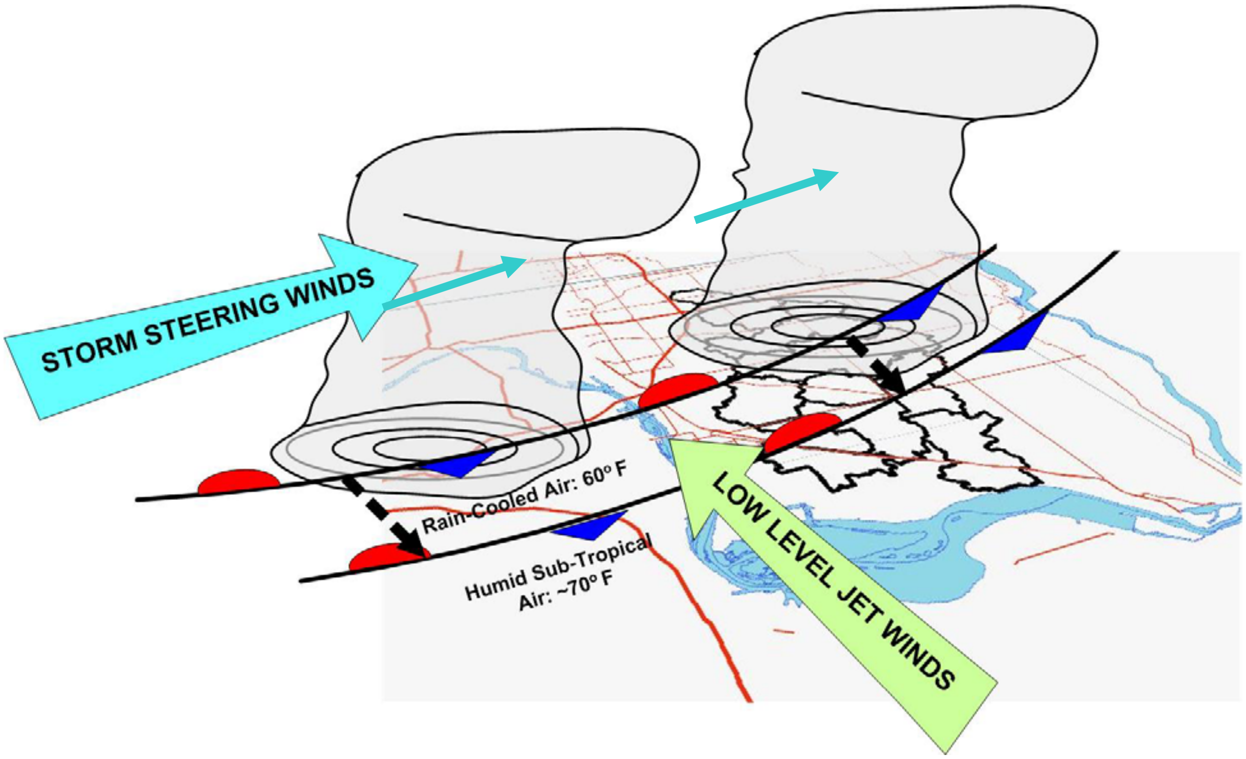


North of the stationary front a cloudy, rain-cooled air mass held afternoon highs in the sixties, and skies remained cloudy most of the day across much of the Minneapolis metro area. This cool air mass was quite stable as chilly, northeast breezes (blue arrow) held temperatures near seasonal normal. However, this air mass was 10-15 degrees cooler than the warmer air mass to the south. The boundary between these two air masses was poised to become the site of the heavy rain zone that developed that evening.

Around 6:00 PM, an upper level disturbance moved into southwestern Minnesota, triggering storm formation. As can be seen from Figure 5, the Wilmes Lake Watershed area was located right along this front. The thunderstorm formation was aided by the development of a strong 40-50 mph low-level jet stream just 1,500 ft above the ground. Aircraft arriving and departing from Minneapolis/St. Paul International Airport observed the strong low-level winds between 6:30 PM and 8:45 PM. This low-level jet stream lifted the warm, sub-tropical air into the updrafts of the developing thunderstorms, transforming them into efficient rainmaking machines. Rain rates in the thunderstorms approached 3 to 4 inches per hour for periods of 20-30 minutes.

Another factor produced by the low-level jet stream was a preferred location about 10-20 miles southwest of the Wilmes Lake basin where thunderstorms repeatedly formed into "trains of rain" moving to the northeast along the stalled stationary front. The thunderstorm steering winds at jet stream levels were parallel to the stalled surface front. As a result, the storms followed the same path for a three- to six-hour period (Figure 6).

Figure 6
Storm "Training" Process Caused by Interaction of Low-level Jet Stream, Thunderstorms, and Moist Sub-tropical Air



The Wilmes Lake Watershed received its heaviest rain bursts from approximately 7:30 PM until 10:00 PM, when an estimated 85 percent of the October Storm's rain fell. The thunderstorms and rain were accompanied by a nearly continuous lightning display.

3.2 RADAR TRACE RAINFALL DATA

Radar data was used to generate rainfall estimates in the area. The radar information came from NEXRAD (Next Generation Radar) towers in the area. NEXRAD does not measure rainfall directly, but measures reflected signals in the atmosphere. Spatial distribution and variation of these signals are generated and calibrated to rain gages. Errors in NEXRAD information include:

- Storm updrafts producing big radar returns but no rain (radar sees updrafts and downdrafts equally)
- National Weather Service (NWS) equations associate with NEXRAD under-estimating ‘warm rain’ events that are sub-tropical (surface dew points less than 70 degrees Fahrenheit)
- Winds reducing the rain catchment of gages by approximately 10 percent for every 10 miles per hour of wind
- Hail producing a false radar return

The Climatological Observatory on the University of Minnesota’s St. Paul Campus showed high winds during the peak period of the storm, suggesting a reduced catchment of rainfall of 5 to 10 percent at the gage locations. The SWWD was also located in the heavy rain track indicated by the NWS rainfall estimates for that storm, resulting in a 40 to 60 percent underestimation of observed rainfall. Accounting for these factors, radar-estimated rainfall of 3.5 to almost 7 inches fell over the SWWD basin from 4:30 AM, October 4, to 10:00 PM, October 5, 2005. The heaviest rainfall fell in two waves between 7:00 PM and 10:00 PM and accumulated 4 to 5 inches of rain, exceeding the 3-hour, 100-year value of 4 inches. Most of this rain fell in a two-hour period when the low-level jet stream enhanced thunderstorm rain rates. Figure 7 shows the radar-estimated cumulative rainfall in 0.5-mile-by-0.5-mile grids for the event. Note that the band of heaviest basin rain fell in the northern and central SWWD basin. Peak grid values reached 6 inches to almost 7 inches in this area.

Figure 7

HDR WSR-88D Radar-estimated Cumulative Rainfall for 0.5-mile by 0.5-mile Grids, 4:30 AM October 4 to 1:00 PM October 5, 2005

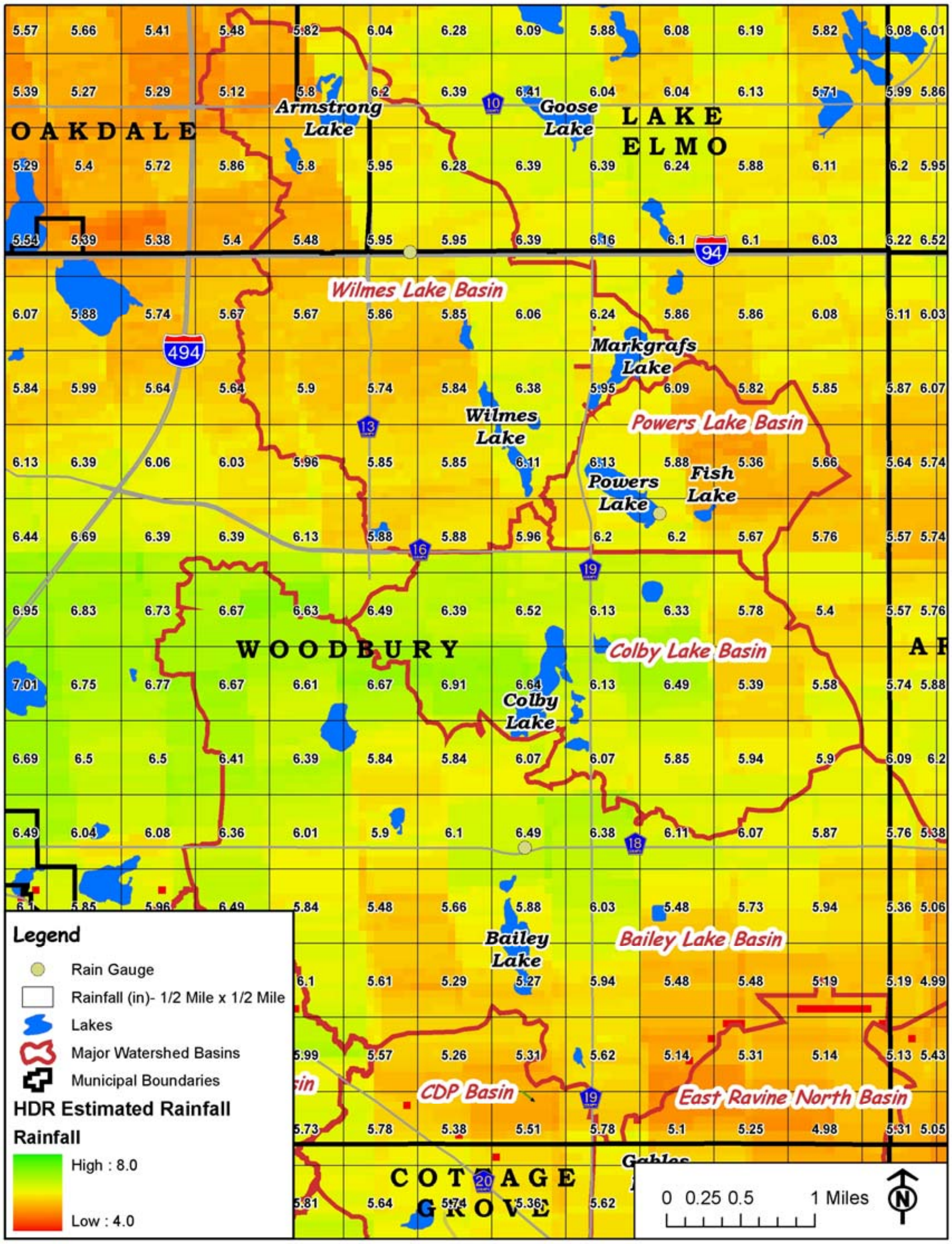
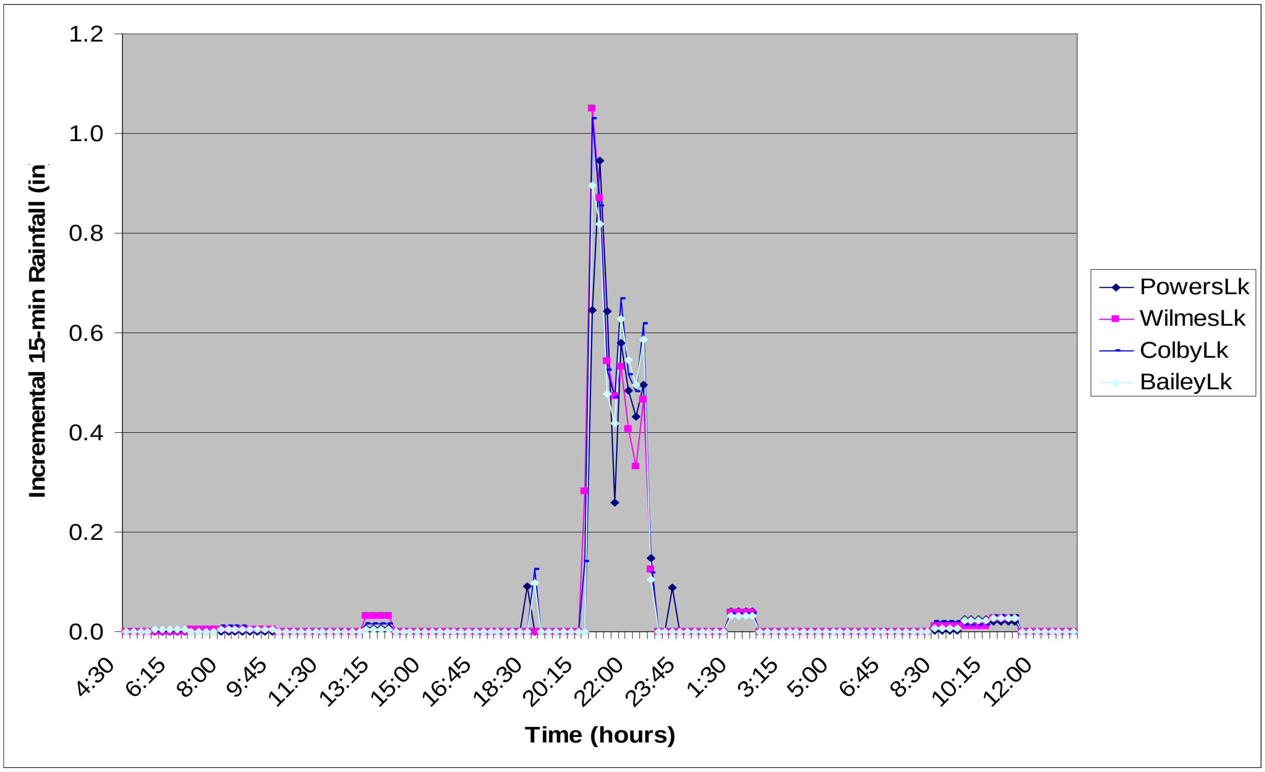


Figure 8 below shows the SWWD subwatershed rainfall in 15-minute time steps from 4:30 AM on October 4 to 1:30 PM on October 5, 2005. It is easy to see the key rainfall period during the evening of October 4, 2005.

Figure 8

Subwatershed 15-min Rainfall for the October Storm Flooding Event in the SWWD



3.3 OCTOBER STORM VERSUS THE STANDARD DESIGN STORM

The impacts of the October Storm necessitated the comparison of this event to the 6.3-inch, 24-hour Type II Distribution event (Standard Design Storm) that is used for stormwater design within the SWWD. Although the average cumulative rainfall amounts across the Wilmes Lake Major Watershed for the October Storm were slightly less than 6.3 inches, the flooding and high water impacts exceeded previous modeling efforts based on the Standard Design Storm. The reasons for this are threefold and include:

- Timing and duration of the event
- Antecedent lake levels and moisture conditions
- Average /sustained intensity

Compared to the Standard Design Storm, the October Storm accumulated more rain over a shorter period of time with a peak rainfall intensity achieved much earlier from the start of rainfall (Figure 9 and Figure 10). The peak intensity of the October Storm, although less than that of the Standard Design Storm, was achieved at a much more rapid rate and sustained for a longer duration of time, causing the Wilmes Lake Watershed drainage system to become overwhelmed. The initial abstraction (interception, depressional storage, infiltration capacity) was achieved swiftly, causing a quicker runoff response that besieged the drainage system. Much of the initial rainfall that occurs during the Standard Design Storm is absorbed through abstractions, whereas most of the rain during the October Storm contributed to runoff. The Wilmes Lake Major Watershed also sustained a rainfall intensity of over 1 inch per hour for 2.25 hours during the October Storm, as opposed to 0.75 hours during the Standard Design Storm (Figure 9), meaning that the duration of high intensity rainfall for the October Storm exceeded the SCS Type II curve. Figure 10 is a mass curve of rainfall totals for a 6.3-inch Type II 24-hour storm and the observed rain event generated from gage and radar data for the major watershed in the SWWD. The Type II distributions start out with approximately 11 hours of steady rain (totaling approximately 1.5 inches), then have a period of intense rainfall (approximately 3.4 inches), followed by a period of steady rainfall (approximately 1.1 inches), to complete the 24-hour event. As Figure 10 indicates, the October Storm generates most of its total volume in a very intense manner. In addition, when looking at cumulative rainfall totals within the 0.5-mile-by-0.5-mile grids, there are areas directly contributing to Wilmes that achieved over 6.3 inches of water (Figure 7).

When compared to the storm return periods, based on the actual duration of the October Storm, which is close to 3 hours, the October Storm exceeded the return of the 3-hour, 100-year storm. The October Storm produced 5 inches of rainfall in 2.5 hours. This rainfall is in excess of the Huff and Angel mapped 3-hour, 100-year event of 4.15 inches and far in excess of the Huff and Angel tabulated 3-hour, 100-year event of 3.49 inches.

Figure 9
Hourly Graphs of Basin Average Radar Estimated Rainfall October Storm in the Wilmes Lake Basin vs. Standard Design Storm

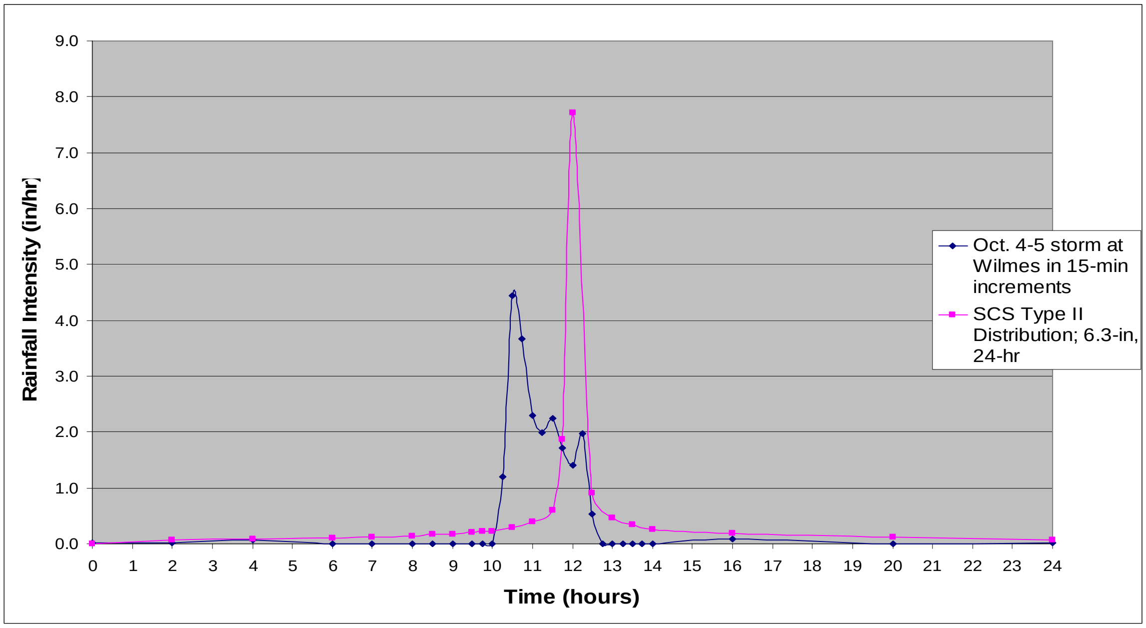


Figure 10
Hourly Graphs of Basin Average Radar Estimated Rainfall October Storm vs. Standard Design Storm

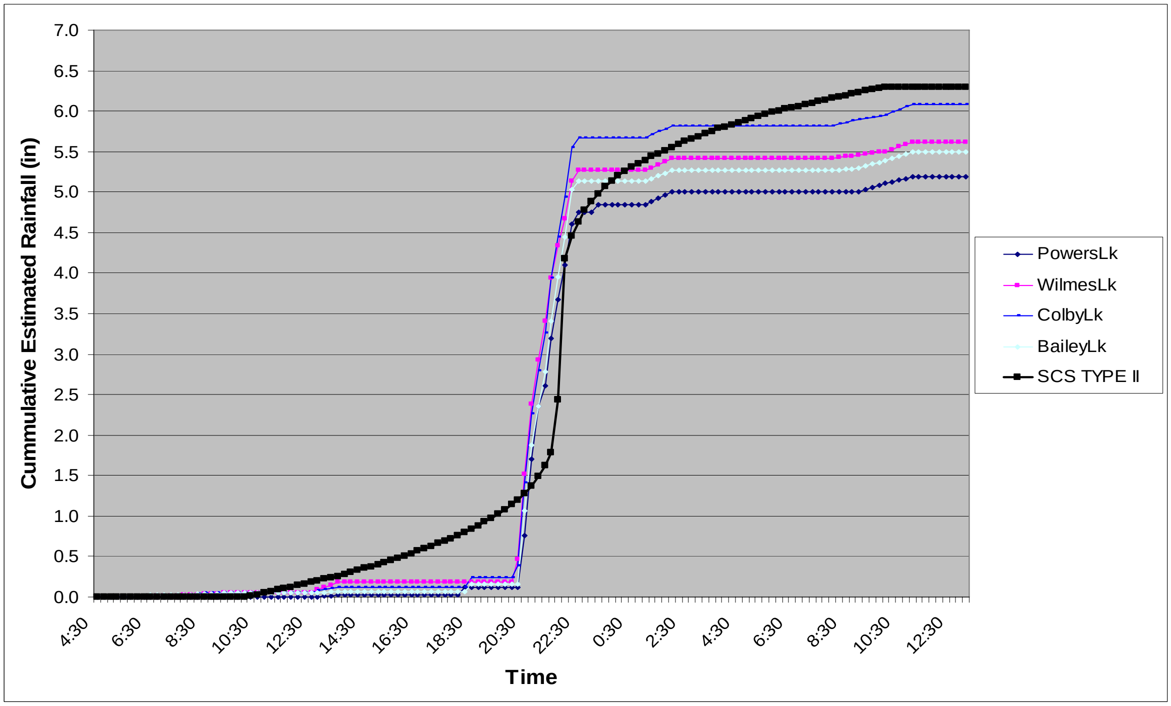


Table 2 presents the 1- to 4-hour storm intensities within the design and observed storms and the 100-year rainfall totals for storms of 1- to 4-hours in duration. It is noted that the TP-40 design intensity and total storm volume data is the standard applied for pond design throughout the SWWD. Table 2 illustrates that the observed storm intensity and volume during particular portions of the October Storm exceeded the SWWD's drainage system's design capacity by 14 to 40 percent.

Table 2
Imbedded Total Rainfall for Various 100-Year 24-Hour Storms

Imbedded Storm Duration	Standard Design Storm	October Storm	TP-40 Event	Huff Event	Percent October Storm Exceeded Standard Design Storm
1-hour	2.55 inch	2.9 inch	2.95 inch	3.0 inch	14 percent
2-hour	3.40 inch	4.7 inch	3.5 inch	3.65 inch	38 percent
3-hour	3.84 inch	5.37 inch	3.75 inch	4.1 inch	40 percent
4-hour	4.13 inch	5.37 inch	3.97 inch*	4.23 inch*	30 percent

** Interpolated*

Another influence to the October Storm's impact on the SWWD (watershed levels) is antecedent moisture conditions. All gaged lakes within the Northern Watershed had stages above their outlet elevations (Table 3), meaning they were already discharging prior to the storm event. Higher antecedent stage levels also resulted in these lakes having reduced storage capacity for the runoff generated during the October Storm, making them predisposed to higher peak stages then they would otherwise see under normal water level conditions. According to the Minnesota Climatology Working Groups, the Washington County area experienced a total rainfall of 4.3 inches in August and 4.6 inches in September and reported 6.5 inches of rainfall October 4-5, 2006. In the 2 weeks leading up to October 5, Washington County experienced 2.6 inches of rain with a corresponding average maximum temperature of 72 degrees Fahrenheit and average minimum temperature of 52 degrees Fahrenheit. Vegetation during this time of year is also entering its dormant stage, reducing the rate of transpiration, and subsequently increasing the amount of water in the soil. Solar radiation is also reduced this time of year, decreasing the amount of evaporation. Reduced evapotranspiration coupled with a fair amount of rainfall caused increased initial soil moisture conditions and lake levels.

Table 3
Comparison of October Storm with Design Storm Values

Lake	Starting Water Level on Sept. 30, 2005	Outlet Elevation	Difference (ft)
Armstrong Lake	1019.33	1017.35	+ 1.98
Wilmes Lake	903.75	902.59	+ 1.16
Markgrafs Lake	925.43	924.94	+ 0.49
Powers Lake	885.74	880.00	+ 5.74
Colby Lake	891.05	889.61	+ 1.44

3.4 RECREATING THE OCTOBER STORM IN XP-SWMM

For planning and analysis purposes, it is necessary to simulate the October Storm in the updated Current Conditions Model described in Section 2.0. The model can then be used as a planning tool to examine watershed and drainage system response to the October Storm and provide a way of investigating mitigation options to the storm.

The first step in modeling the October Storm was recreating the rainfall event in XP-SWMM. In addition to the cumulative rainfall summaries in the 0.5-mile-by-0.5-mile grids (Figure 7), hyetographs were generated for each of the major basins within the SWWD. These hyetographs were normalized and then multiplied by the area-weighted average cumulative rainfall totals for each subwatershed using GIS. These hyetographs and area-weighted average cumulative rainfalls were added to the GIS modeling database and exported directly to XP-SWMM.

The second step in modeling the October Storm was recreating the antecedent conditions within the SWWD. Lake levels were raised to antecedent conditions where available. The Wilmes Lake outlet was also raised to the antecedent level to prevent drainage prior to the onset of the storm hydrographs. Initial infiltration capacity was also reduced from 4 inches per hour to 3 inches per hour. Applying these two conditions resulted in a model (Gridded Scenario 1) reflecting the high water marks at key locations surveyed after the storm event (Table 5).

As another modeling scenario (Gridded Scenario 2), literature values were applied to the gridded rainfall model. This involved reducing the antecedent infiltration rate reduced from 4 inches per hour to 2.5 inches per hour, reducing the minimum (asymptotic) infiltration rate from 0.35 to 0.25 inches hour, and increasing the decay rate of infiltration from 0.0008 to 0.0015 (Table 4). These results are also summarized in Table 5. Gridded Scenario 1 is used as the October Storm base model because it produced the best results with minimum adjustments to the Current Conditions Model. However, Gridded Scenario 2 provides insight to the sensitivity of the Wilmes subwatersheds to antecedent moisture conditions and

Table 4
Modeling Results of Gridded Rainfall Compared to High Water Level (HWL) Surveys Following the October Storm

	Armstrong Lake HWL	Upstream of Hudson Road HWL	Downstream of Hudson Road (Pendryn Hill Pond) HWL	Wilmes Lake HWL	Markgrafs Lake HWL	Colby Lake HWL
Survey						
BRA Survey		924.4	920.2	911.7	928.4	895.4
Washington County Conservation District Survey	1020.45	924.03			928.36	894.06
Modeling Results						
Gridded Scenario 1[1]	1020.98	924.83	919.96	910.97	926.72	893.38
Gridded Scenario 1[2]	1021.32	925.32	921.47	911.08	926.91	893.82
Difference (Except for Armstrong Lake, differences are calculated from BRA Survey)						
Gridded Scenario 1[1]	0.53	0.43	-0.24	-0.73	-1.68	-2.02
Gridded Scenario 1[2]	0.87	0.92	1.27	-0.62	-1.49	-1.58

[1] *Lake Levels set to pre-storm, Wilmes outlet elevation raised to pre-storm water level conditions; Antecedent Infiltration Rate reduced from 4 inches per hour to 3 inches per hour.*

[2] *Lake Levels set to pre-storm, Wilmes outlet elevation raised to pre-storm water level conditions; Antecedent Infiltration Rate reduced from 4 in/hr to 2.5 in/hr, min infiltration rate reduced from 0.35 to 0.25 in/hr, decay rate of infiltration increased from 0.0008 to 0.0015.*

Table 5
Literature Based Versus Currently Modeled Values for Infiltration Parameters

Variable	Current	Literature Based	Units	Comment
Impervious Area Depressional Storage	0.20	0.18	inch	Based on catchment slope
Pervious Area Depressional Storage	0.1	0.1	inch	Grassed urban surfaces, suggested value of 0.1
Impervious Area Manning's Roughness[1]	0.014	0.014		Asphalt
Pervious Area Manning's Roughness[1]	0.300	0.450		Suggested value for bluegrass sod is 0.45
Maximum Infiltration Rate	4	3	inch/hour	3 inches per hour is suggested for dry, loam soils[2] with no vegetation. For moist, partially dried soils, this value is divided by 1.5 to 2.5. This value is a key subject to modification for antecedent conditions.
Minimum Infiltration Rate	0.35	0.25	inch/hour	Modeled high (B soils, range: 0.15-0.3)
Decay rate of Infiltration	0.0008	0.00115	1/second	Modeling on the low end of recommended values (0.00083-0.00167). In the absence of field data, 0.00115 1/sec is recommended.

[1] *Akin to Manning's n for open channels but usually higher*

[2] *Predominant soils are silts*

infiltration values, demonstrating that alteration to these parameters resulting from construction or other watershed practices can influence flood response within the Wilmes Lake drainage system (lakes, ponds, pipes, and channel). Currently the accepted modeling values for the SWWD assume optimum conditions. If conditions are less than optimum, the Wilmes Lake drainage system will have a greater response to a given storm event.

Other adjustments that could have been examined but were out the scope of this modeling effort include:

- Increased antecedent water levels in ponds across the basins. Most likely these water bodies were above their outlets as well.
- Refining infiltration parameters on a watershed by watershed basis based on soils. Currently, universal infiltration parameters are applied across the entire Northern Watershed.
- Updating the Colby and Bailey Lake portions of the model.
- Retiring the Markgrafs Lake portion of the model. At present, Markgrafs Lake is just producing an outflow.
- Refining the Powers Lake portion of the model. Currently, Powers Lake is modeled as one lumped watershed. However, the model is currently running with the assumption that the pump from Powers Lake is shut off, making it essentially landlocked.
- Further refining the Armstrong Lake subwatersheds.

3.5 MODELING IMPACTS OF THE OCTOBER STORM

The October Storm had a greater affect on the overall Northern Watershed of the SWWD than the Standard Design Storm primarily due to timing and volume issues. The timing and duration of the storm caused coincident peaks and overflows in the Wilmes Lake area drainage system.

As a rule, ponds in the SWWD have outlets smaller than their inlets, resulting in water inflow rates exceeding outflow rates. Subsequently, during storm events water builds up in the ponds as storage until either inflow equals outflow or the pond overflows to the next drainage system. All other variables remaining equal (i.e., the same drainage systems, land use, watershed areas, etc.), the rate of inflow to the pond is predicated upon the intensity of the storm and its duration.

The SWWD incorporates the U.S. Environmental Protection Agency (EPA) Runoff Method into their design models. The Runoff Method breaks a given subwatershed into two land surface types: impervious surface (pavement, water surfaces) and pervious surfaces (lawns, fields, parks, etc.). After the initial abstraction (pervious and impervious surfaces) caused by depressional storage, nearly 100 percent of the rainfall appears as runoff. When comparing the impervious runoff for the Standard Design Storm against what occurred in the October Storm, the results have similar volume generation but the delivery of water to the ponding sites occur over a much shorter period of time. The result is higher water levels in the ponds.

The pervious surfaces behave differently than the impervious surfaces. There is an initial abstraction and a process of water infiltrating into the subsurface during the course of the storm. The infiltration rate varies depending on the unique characteristics of the soil. Studies of water infiltration into soil indicate there is typically a high rate of initial infiltration, with a quick tail off to a much lower steady state rate of infiltration. For the Type II design storms, infiltration would play an important role in defining the total runoff volume from pervious surfaces because approximately 2.5 inches of the total 6.3-inch rainfall occur relatively gradually, allowing water to infiltrate into the soil. This type of infiltration does not occur when modeling the October Storm. With a sharp initial rainfall intensity and a larger volume of water falling over a shorter period of time (Figure 9) coupled with reduced initial infiltration capacity due to antecedent moisture, the modeled October Storm produced significantly more runoff then the Standard Design Storm. Hence, the modeled high water levels in the lakes are much higher than the Standard Design Storm base model (Table 6). The most notable difference is seen at Wilmes Lake, which increased 2.3 feet from 908.7 to 911.0.

The net result is that the October Storm produced more runoff for a given volume of rain than the Type II Standard Design Storm due to its sustained intensity. The ponds in the SWWD were not designed to handle that much volume over such a short time, resulting in numerous overflows of the ponds and the high water levels seen in the lakes.

Table 6

Results for the Current Conditions Model Comparing the 6.3-inch, 24-hour Standard Design Storm and the October Storm's Gridded Rainfall

Storm	Armstrong Lake HWL	Flow at I-94 at Eagle Pt	Upstream of Hudson Road HWL	Downstream of Hudson Road (Pendryn Hill Pond) HWL	Wilmes Lake HWL	Markgrafs Lake HWL	Colby Lake HWL
6.3-inch, 24-hour Type II Distribution	1019.74	494 cfs	923.60	918.43	908.67	926.17	892.49
October Storm Rainfall	1020.98	534 cfs	924.83	919.96	910.97	926.72	893.38
Difference	1.24	40 cfs	1.23	1.53	2.30	0.55	0.89

3.6 CRITICAL EVENT ANALYSIS

A critical event analysis was completed as an additional step to the recreation of the October Storm. Due to the impact and variation of the duration and intensity of the October Storm, various rainfall intensities and durations were modeled. Both the current conditions and Ultimate Development Model were used during this effort. A detailed account of this effort is included as Appendix B.

4.0 ULTIMATE DEVELOPMENT MODEL

Planning for future conditions within the district is necessary for the SWWD to formulate and optimize mitigation options and make decisions in stormwater management across political boundaries. In order to develop an "ultimate" development model from the updated Current Conditions Model, the model was modified to reflect the forecasted land use types from the Metropolitan Council 2020 Plan and the Lake Elmo Development Plan.

Sources for the Metropolitan Council's 2020 Plan came from communities' comprehensive plans and plan amendments and rights-of-way information from county parcel data. Each community (city or township) in the seven-county Twin Cities metropolitan area is required to complete a comprehensive plan for review by the Metropolitan Council. This comprehensive plan must detail what each community expects or plans their land use to be in the year 2020. When developing the 2020 Plan, the Council used a land use classification scheme endorsed by MetroGIS. For a complete description of the metadata associated with this dataset, see http://gis.metc.state.mn.us/metadata/landuse planned.htm.

Subwatershed ultimate development percent impervious values were calculated for both the Current Conditions Model and for each of the mitigation options. Table 7 compares the Current Conditions Model to the Ultimate Development Model conditions for both the 6.3-inch, 24-hour Standard Design Storm and the October Storm at key locations within the watershed.

The reader should note that the land use used in the ultimate conditions model represent predicted conversions of the watershed pervious areas to impervious areas at the end of the planning horizon without the beneficial affect of stormwater rate or volume controls – this is considered a conservative scenario for use as a planning tool. A comparison of the model results from the base conditions and the ultimate conditions model show that flood elevation increases of up to 1.5 feet (Pendryn Hill pond) will be realized if the ultimate development land use plans are implemented without appropriate stormwater rate or volume controls. It should also be noted that for Wilmes Lake, the ultimate development impacts (without additional stormwater controls) will be greater for the Standard Design Storm than what would happen if a storm identical to the October Storm were to occur. This analysis confirms the need for appropriate stormwater and flood mitigation planning for the watershed.

Table 7

Comparison of the Base Model to the Ultimate Development Model for the Standard Design Storm and the October Storm Gridded Rainfall

Model Condition	Storm	Armstrong Lake HWL	Flow at I-94 at Eagle Pt	Upstream of Hudson Road HWL	Downstream of Hudson Road (Pendryn Hill Pond) HWL	Wilmes Lake HWL	Markgrafs Lake HWL	Colby Lake HWL
Base Model: Ultimate Development	6.3-inch, 24-hour Type II Distribution Design Storm	1020.31	869 cfs	924.78	919.90	909.56	926.4	892.59
Base Model: Ultimate Development	October Storm Gridded Rainfall	1021.30	666 cfs	925.93	921.35	911.04	926.9	893.42
Departure from Base (Please see Table 6 for Base Model Conditions)								
Base Model: Ultimate Development	6.3-inch, 24-hour Type II Distribution Design Storm	+ 0.6 ft	+ 375 cfs	+ 1.2 ft	+ 1.5 ft	+ 0.9 ft	+ 0.2 ft	+ 0.1 ft
Base Model: Ultimate Development	October Storm Gridded Rainfall	+ 0.3 ft	+ 132 cfs	+ 1.1 ft	+ 1.4 ft	+ 0.1 ft	+ 0.2 ft	+ 0 ft

A comparison of the Wilmes Lake storage (south lobe) from 1979 Report to the updated Current Conditions Model shows that the amount of available storage is roughly consistent. The total amount of storage reported in the 1979 Storm Drainage Plan is 156 acre-ft at water level of 906.5. The updated storage curve shows 148 acre-ft of storage at the same water level of 906.5. The 1979 report also indicates that the normal water level in the south lobe of Wilmes Lake was 898.0. The current DNR permit for the south lobe sets the minimum operating level at 902.6, resulting in a rise in normal pool elevation of 4.6 feet (assuming equivalent vertical datums). The mandated increase in the normal pool level for the lake results in 64 acre-ft of storage having been converted from live storage to dead storage (storage unavailable for flood peak flow and volume/level attenuation).

Figure 11 shows the updated model's predicted stage-time series graph in Wilmes Lake for the four storms used in this analysis:

- The Standard Design Storm – 6.3-inch, 24-Hour SCS Type II storm, Current Land Use
- The Standard Design Storm – Future (Ultimate) Land Use
- The October Storm – Current Land Use
- The October Storm – Future (Ultimate) Land Use

Figure 12 graphs the stage-time series for Pendryn Hill Pond, another location that saw significant flooding during the October Storm.

Figure 11
Wilmes Lake Stage-Elevation Modeled under Current and Ultimate Conditions for the Standard Design Storm and October Storm

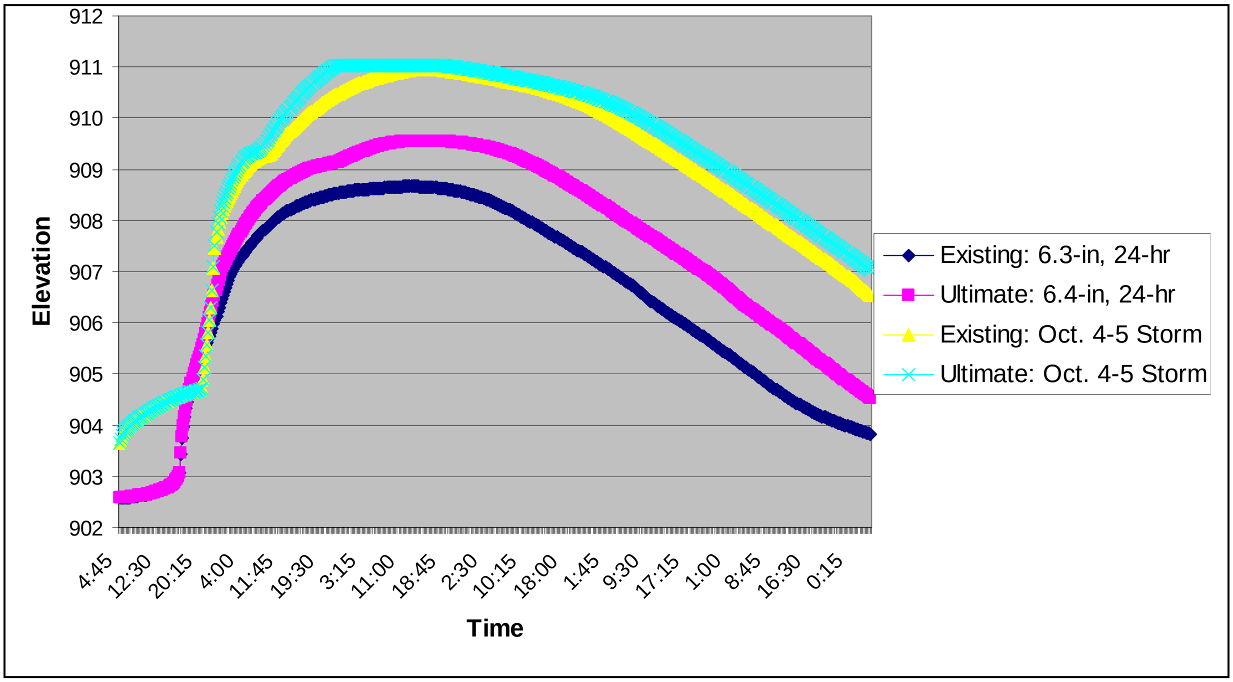
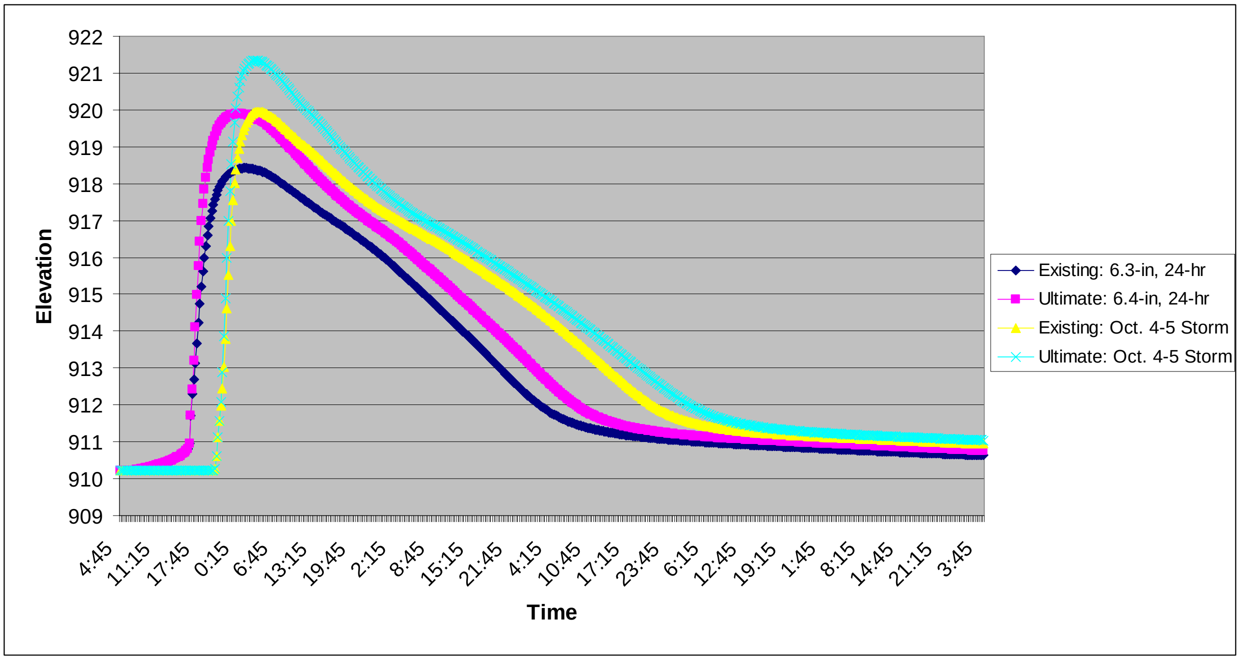


Figure 12

Pendryn Hill Pond Stage-Elevation Modeled Hydrograph under Current and Ultimate Conditions for the Standard Design Storm and October Storm



5.0 FLOOD MITIGATION ALTERNATIVES

5.1 REVIEW OF STORAGE POTENTIAL ON UNDEVELOPED PARCELS

Early in the study process, a preliminary review of the Wilmes Lake contributing subwatersheds was conducted to identify undeveloped parcels that were feasible locations for potential stormwater storage areas. An undeveloped parcel was defined as any parcel of land that was vacant at the time of the review and not considered residential, commercial, or suburban/urban land use. The purpose of the review was to estimate the total storage volume potential remaining on undeveloped parcels within the Wilmes Lake subwatersheds and to prioritize the most beneficial sites in regard to the reduction of high water levels in Wilmes Lake. The memorandum also provided suggestions for approaches that the SWWD could adopt to guide the decision-making process regarding the Wilmes watershed. The text of this memorandum is included in as Appendix A. The storage options identified for this review were then used as the basis for formulating the conceptual storage options evaluated in this study.

5.2 PURPOSE

As discussed in the introduction, the secondary goal of this analysis was to quantify the effectiveness of several conceptual flood mitigation options. The Current Conditions Model was used to analyze each individual option, or combinations of options, to determine probable flood control benefits in terms of reducing flood elevations in Wilmes Lake. Four options were identified as possible structural changes that can affect the high water level at Wilmes Lake:

- Option 1 – Additional storage south of I-94
- Option 2 – Additional storage north of I-94
- Option 3 – Outlet upgrade from Wilmes Lake to Colby Lake and then from Colby Lake to Bailey Lake
- Option 4 – Alternatives for an emergency overflow from Wilmes Lake to Powers Lake

Each of these options were modeled separately to adequately analyze the effectiveness of each of the mitigation measures under two storm conditions and two land use options – resulting in four modeling scenarios for each option:

- Current land use conditions with the Standard Design Storm (6.3-inch, 24-hour SCS Type II)
- Current land use conditions with the October Storm
- Ultimate land use conditions with the Standard Design Storm (6.3-inch, 24-hour SCS Type II)
- Ultimate land use conditions with the October Storm

5.3 OPINIONS OF PROBABLE COST ASSUMPTIONS

To compare the expected cost impacts of flood hazard mitigation options, opinions of probable costs are included in this report. The costs presented in this report are conceptual and represent planning level costs. Actual implementation and construction costs are likely to differ from the costs presented in this report depending on the final design configuration, construction conditions, seasonal groundwater and stream flow variations, environmental factors, and other influencing factors.

Planning level unit costs were developed for each flood improvement measure. These costs are detailed in Table 8.

Table 8
Conceptual Unit Costs

Flood Improvement Item	Unit	Unit Cost
Storage Volume	Acre-ft, in place	$ 35,000
Earth Work	Cubic-yards, in place	$ 15
Outlet Structures	Each, complete	$ 20,000
Pipe Upgrades	Lump sum (LS) allowance	Varies
Manholes	Each	$ 3,000
Misc. and Contingency Items (50 percent)	Lump sum, allowance based on a percentage of sum of other costs	50 percent

The calculated conceptual costs for each flood mitigation alternative are included in Appendix B. The summary costs for each alternative are presented in the section that describes that alternative.

5.4 OPTION 1: STORAGE OPTIONS SOUTH OF I-94

The first mitigation option examined storage options for the Wilmes Lake Watershed south of I-94. Six potential sites (Figure 13) were identified as potential locations where either new storage could be created (Sites 1, 2, 5, and 6) or where existing storage could be expanded (Sites 3 and 4). Table 9 provides a description of each pond and summarizes each of the potential storage locations for Option 1.

Figure 13
Location of Conceptual Storage Options within Woodbury Modeled for Option 1

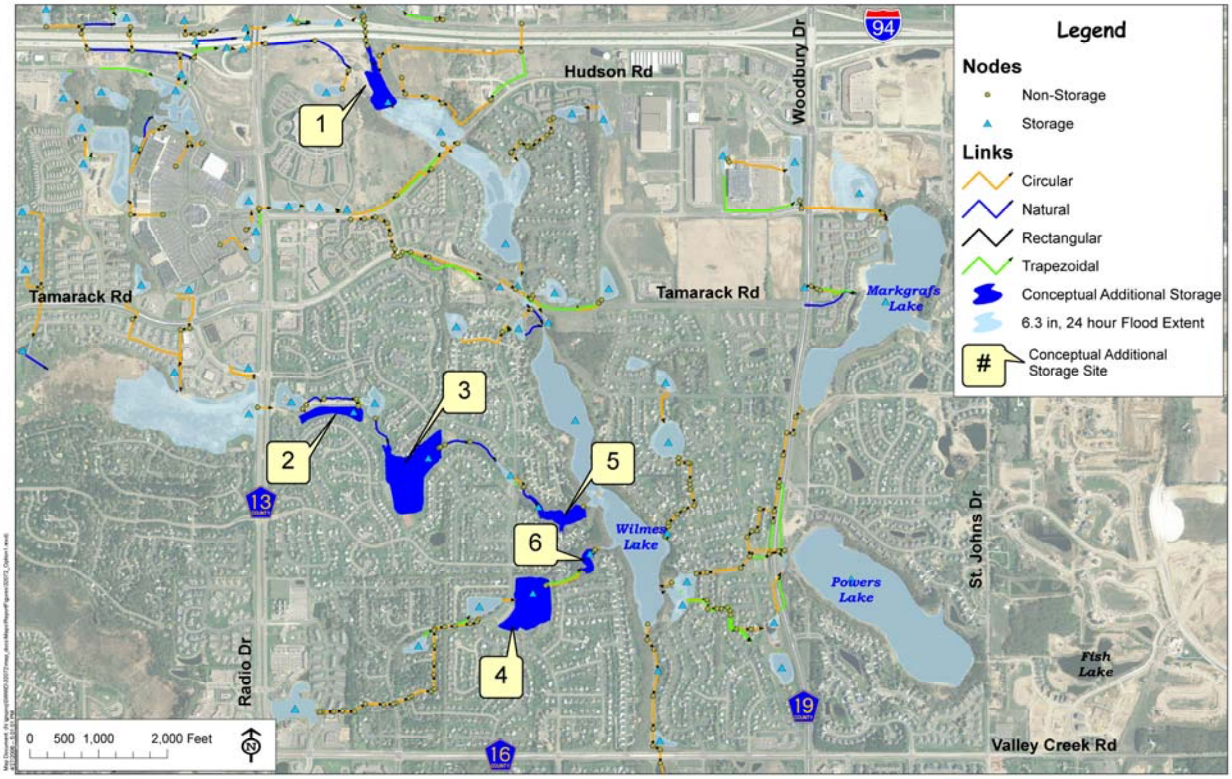


Table 9
Site Descriptions for Proposed Storage Locations

Site	Location	Description	Maximum Available Storage (acre-ft)	Added Storage to the Wilmes Subwatershed (acre-ft)
Site 1	Upstream of Hudson Road, downstream of Interstate 94, just east of State Farm office building and west of the Woodbury Lakes commercial development.	**New Proposed Pond** - potential storm storage modeled at this site is approximately 12 acre-ft. The potential storage amount was calculated by assuming the fill extents of the proposed frontage road and the amount of water a new six- foot impoundment constructed at the edge of the existing Hudson Road flood pool would be able to detain.	12	12
Site 2	Along bike path South of Seasons Parkway, north of Silverwood Road, east of Radio Drive	**New Proposed Pond - Existing Drainage Reroute** Construction of this pond involves rerouting water from the existing drainage system to create additional delay from this area. This option is downstream of the Evergreen Wetland and potentially creates a maximum storm storage volume of 11 acre-ft.	11	11
Site 3	Seasons Park off of Silverwood Road	**Existing Pond Expansion - Addition of an Outlet Structure**. Site 3 is downstream of Site 2 and involves the expansion of an existing pond at Seasons Park, located off Silverwood Road. This option involves adding berms and modifying the outlet structure, which would flood the park during a major storm. This option would conceptually produce 20 additional acre-ft of storage to create a total storm storage of 32 acre-ft.	32	20
Site 4	Summit Pointe Park off of Interlachen Parkway	**Existing pond expansion - Addition of an Outlet Structure**. Site 4 involves the expansion of a pond at Summit Pointe Park, located off Interlachen Parkway. This option involves adding berms and modifying the outlet structure, which would flood the park during a major storm. This option can potentially add 15 acre-ft of storage to 38 acre-ft under existing conditions.	54	15
Site 5	Ravine east of Interlachen Parkway, south of Scarborough Lane	**New Dam in Ravine**. Site 5 is located in a ravine immediately adjacent to Wilmes Lake east of Interlachen Parkway and South of Scarborough Lane. This site would put a 6-foot dam into the ravine, potentially creating 3.8 acre-ft of storage. Constructing this site would take out a bike path to Wilmes Lake.	3.8	3.8
Site 6	Ravine east of Thornhill Lane, south of Duckwood Trail	**New Dam in Ravine**. Site 6 is located in a ravine immediately adjacent to Wilmes Lake east of Thornhill Lane and South of Duckwood Trail. This site would put a 15-foot dam into the ravine, creating only 4.6 acre-feet of storage.	4.6	4.6

Option 1 was modeled under three different scenarios. The first scenario (Option 1a) included all six storage sites, with the results presented in Table 10. Sites 5 and 6 are less feasible, will require a high cost for construction, and will yield minimum benefits. Therefore, a second model (Option 1b) with only Sites 1, 2, 3 and 4 was completed and analyzed (Table 11). Site 1 has the potential to be an independent, stand-alone project; therefore, a third model (Option 1c) was completed for only this site (Table 12).

As expected, adding all three storage sites (Option 1a) had the greatest impact on Wilmes Lake, dropping the high water elevation 1.4 feet for the October Storm under current land use. Options 1b and 1c lowered Wilmes peak stage by the same amount of 0.7 feet during the October Storm under the current land use. These results illustrate that Sites 2, 3, and 4 have relatively little impact compared to Sites 1, 5, and 6. Site 1 also has an impact on the Pendryn Hill Pond, lowering its high water level (HWL) 0.4 feet for the October Storm under current land use.

In summary, for the October Storm under current land use, Site 1 on its own lowers Wilmes Lake 0.7 feet. Adding Sites 2, 3, and 4 has minimal impacts at Wilmes Lake. Adding Sites 5 and 6 lowers Wilmes Lake another 0.7 feet for a total of 1.4 feet. Table 13 summarizes the HWL at Wilmes Lake for all three model runs of Option 1 under the four different model conditions.

Table 10

Model Results for Option 1a, Additional Storage at Sites 1, 2, 3, 4, 5, and 6 in Woodbury

Model Condition	Storm	Armstrong Lake HWL	Flow at I-94 at Eagle Pt	Upstream of Hudson Road HWL	Downstream of Hudson Road (Pendryn Hill Pond) HWL	Wilmes Lake HWL	Colby Lake HWL
Option 1a: Current Condition	Standard Design Storm	1019.74	494 cfs	923.31	918.0	908.34	892.44
Option 1a: Current Condition	October Storm Gridded Rainfall	1019.84	531 cfs	924.37	919.21	909.6	893.25
Option 1a: Ultimate Development	Standard Design Storm	1020.24	860 cfs	924.3	919.44	908.7	892.57
Option 1a: Ultimate Development	October Storm Gridded Rainfall	1021.3	667 cfs	925.71	920.86	910.48	893.27
Departure from Base (Please see Table 6 and Table 7 for Base Model Conditions)							
Option 1a: Current Condition	Standard Design Storm	0	0 cfs	-0.29	-0.43	-0.54	-0.05
Option 1a: Current Condition	October Storm Gridded Rainfall	-1.14	- 3 cfs	-0.46	-0.75	-1.37	-0.13
Option 1a: Ultimate Development	Standard Design Storm	-0.07	- 9 cfs	-0.48	-0.46	-0.86	-0.02
Option 1a: Ultimate Development	October Storm Gridded Rainfall	0	1 cfs	-0.22	-0.49	-0.56	-0.15

Table 11

Model Results for Option 1b, Additional Storage at Sites 1, 2, 3, and 4 in Woodbury

Model Condition	Storm	Armstrong Lake HWL	Flow at I-94 at Eagle Pt	Upstream of Hudson Road HWL	Downstream of Hudson Road (Pendryn Hill Pond) HWL	Wilmes Lake HWL	Colby Lake HWL
Option 1b: Current Condition	Standard Design Storm	1019.74	494 cfs	923.31	918.0	908.26	892.44
Option 1b: Current Condition	October Storm Gridded Rainfall	1020.98	534 cfs	924.53	919.5	910.23	893.25
Option 1b: Ultimate Development	Standard Design Storm	1020.31	860 cfs	924.30	919.44	908.86	892.57
Option 1b: Ultimate Development	October Storm Gridded Rainfall	1021.3	666 cfs	925.67	920.85	910.53	893.27
Departure from Base (Please see Table 6 and Table 7 for Base Model Conditions)							
Option 1b: Current Condition	Standard Design Storm	0	0 cfs	-0.29	-0.43	-0.41	-0.05
Option 1b: Current Condition	October Storm Gridded Rainfall	0	0 cfs	-0.3	-0.46	-0.74	-0.13
Option 1b: Ultimate Development	Standard Design Storm	0	- 9 cfs	-0.48	-0.46	-0.7	-0.02
Option 1b: Ultimate Development	October Storm Gridded Rainfall	0	0 cfs	-0.26	-0.5	-0.51	-0.15

Table 12
Model Results for Option 1c, Additional Storage at Site 1 Only in Woodbury

Model Condition	Storm	Armstrong Lake HWL	Flow at I-94 at Eagle Pt	Upstream of Hudson Road HWL	Downstream of Hudson Road (Pendryn Hill Pond) HWL	Wilmes Lake HWL	Colby Lake HWL
Option 1c: Current Condition	Standard Design Storm	1019.74	504 cfs	923.319	918.0	908.5	892.45
Option 1c: Current Condition	October Storm Gridded Rainfall	1020.97	535 cfs	924.53	919.5	910.22	893.19
Option 1c: Ultimate Development	Standard Design Storm	1020.31	860 cfs	924.30	919.44	908.94	892.57
Option 1c: Ultimate Development	October Storm Gridded Rainfall	1021.29	667 cfs	925.67	920.85	910.45	893.22
Departure from Base (Please see Table 6 and Table 7 for Base Model Conditions)							
Option 1c: Current Condition	Standard Design Storm	0	10 cfs	-0.29	-0.43	-0.17	-0.04
Option 1c: Current Condition	October Storm Gridded Rainfall	-0.01	1 cfs	-0.3	-0.46	-0.75	-0.19
Option 1c: Ultimate Development	Standard Design Storm	0	- 9 cfs	-0.48	-0.46	-0.62	-0.02
Option 1c: Ultimate Development	October Storm Gridded Rainfall	-0.01	1 cfs	-0.26	-0.5	-0.59	-0.2

Table 13
Model Results at Wilmes Lake for All Options Under Option 1: Additional Storage at Site 1 Only in Woodbury

Model Condition	Storm	Base Model	Option 1a (Sites 1, 2, 3, 4, 5 and 6)	Option 1b (Sites 1, 2, 3, and 4)	Option 1c (Site 1 only)
Current Land use	Standard Design Storm	908.67	908.13	908.26	908.50
Current Land use	October Storm Gridded Rainfall	910.97	909.6	910.23	910.22
Ultimate Development Land use	Standard Design Storm	909.56	908.7	908.86	908.94
Ultimate Development Land use	October Storm Gridded Rainfall	911.04	910.48	910.53	910.45

Table 14 presents the conceptual costs for each of the three sub-options for Option 1.

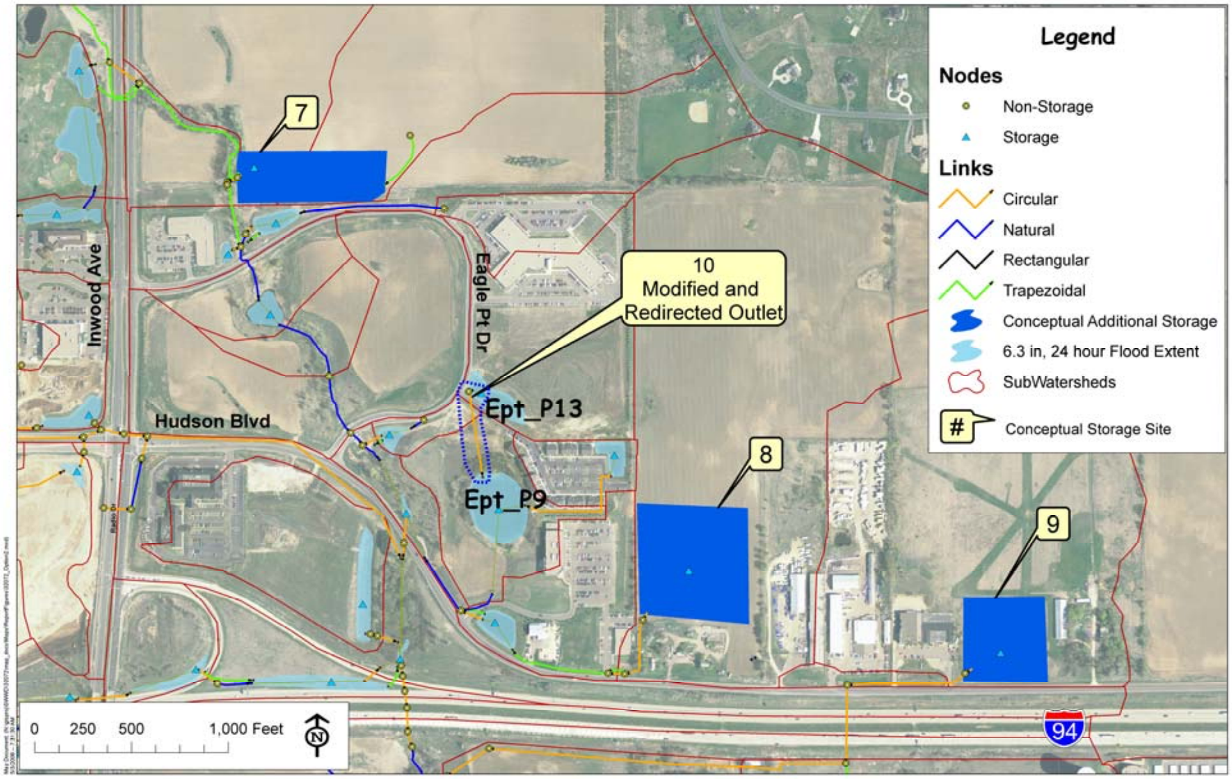
Table 14
Option 1 Probable Costs

Flood Mitigation Measure	Sites Included	Probable Cost	Cost per ft. of Wilmes Lake Level Reduction (Standard Design Storm)
Option 1a	1, 2, 3, 4, 5 and 6	$ 5,312,250	$ 7,589,000
Option 1b	1, 2, 3 and 4	$ 4,811,250	$ 8,441,000
Option 1c	1	$ 2,307,000	$ 4,614,000

5.5 OPTION 2: STORAGE OPTIONS NORTH OF I-94

Option 2 examines adding storage north of I-94 in the locations identified in the *Review of Storage Potential on Undeveloped Parcels*, Appendix A. Prior to exploring this option, however, the impact of flows crossing Interstate 94 was evaluated. The Current Conditions Model was run with all flows north of Interstate 94 (from Oakdale and Lake Elmo) removed from the model and essentially isolating Woodbury, resulting in the HWL at Wilmes Lake lowering 1.6 feet. The options for adding regional storage in Lake Elmo were then examined. Three sites for new ponds were identified (Sites 7, 8, and 9) and one reroute was investigated (Site 10) for this option (Figure 14). The locations of the additional ponds were envisioned for two reasons: 1) To control the runoff from a watershed that is currently uncontrolled, and 2) To plan for future land use. These sites are described below and summarized in Table 15.

Figure 14
Location of Conceptual Additional Storage within Lake Elmo Modeled for Option 2



Site 7 controls the runoff from two watersheds totaling 142 acres to the north of Eagle Point Business Park. The current land use is agricultural with uncontrolled runoff to the Eagle Point Business Park. This area is planned for future residential development, changing the percent imperviousness value significantly.

Site 8 controls the runoff from one 79-acre watershed to the west of Eagle Point Business Park. The current land use is predominantly agricultural with uncontrolled runoff. This area is planned for future commercial development, changing the percent pervious significantly.

Site 9 controls the runoff from one 67-acre watershed to the west of Eagle Point Business Park. The current land use is predominantly agricultural with uncontrolled runoff. This area is planned for future commercial and residential development, changing the percent imperviousness significantly.

Site 10 redirects the existing outlet from one pond (Ept-P13) to an existing storage area immediately to the south (Ept-P9).

Table 15
Site Descriptions for Option 2

Site	Location	Description	Maximum Available Storage (acre-ft)
Site 7	North of Eagle Point Business Park, East of Inwood Ave	New Proposed Pond	30.4
Site 8	West of Eagle Point Business Park, North of Hudson Blvd	New Proposed Pond	21.4
Site 9	West of Eagle Point Business Park, North of Hudson Blvd	New Proposed Pond	22.1
Site 10	Eagle Point Blvd.	Outlet Reconfiguration	N/A

Table 16 summarizes the modeling results of Option 2. A total of 74 acre-ft of storage was added within the City of Lake Elmo. The cumulative impact of Option 2 at Wilmes Lake is less than 0.5 feet. Similarly, the HWL at Pendryn Hill Pond reduces by approximately one foot if Option 2 is implemented.

Table 16
Model Results for Option 2, Additional Storage in Lake Elmo

Model Condition	Storm	Armstrong Lake HWL	Flow at I-94 at Eagle Pt	Upstream of Hudson Road HWL	Downstream of Hudson Road (Pendryn Hill Pond) HWL	Wilmes Lake HWL	Colby Lake HWL
Option 2: Current Condition	Standard Design Storm	1019.74	374 cfs	922.85	917.62	908.42	892.45
Option 2: Current Condition	October Storm Gridded Rainfall	1020.97	366 cfs	923.84	919.0	910.67	893.34
Option 2: Ultimate Development	Standard Design Storm	1020.31	573 cfs	923.47	919.04	909.11	892.58
Option 2: Ultimate Development	October Storm Gridded Rainfall	1021.29	448 cfs	924.46	919.97	911.04	893.35
Departure from Base (Please see Table 6 and Table 7 for Base Model Conditions)							
Option 2: Current Condition	Standard Design Storm	0	-120 cfs	-0.75	-0.81	-0.25	-0.04
Option 2: Current Condition	October Storm Gridded Rainfall	-0.01	-168 cfs	-0.99	-0.96	-0.3	-0.04
Option 2: Ultimate Development	Standard Design Storm Gridded Rainfall	0	-296 cfs	-1.31	-0.86	-0.45	-0.01
Option 2: Ultimate Development	October Storm	-0.01	-218 cfs	-1.47	-1.38	0	-0.07

Table 17 shows the unit cost elements and the probable cost calculation for Option 2.

Table 17
Option 2 Probable Costs

Item Description	Unit	Unit Cost	Quantity	Total
Storage Volume	Acre-ft	$ 35,000	75	$ 2,625,000
Earth Work (addition to storage area)	Cubic-yards	$ 15		
Outlet Structures	Each	$ 20,000	3	$ 60,000
Pipe Upgrades	LS			
Manholes	Each	$ 3,000		
Misc. and Contingency Items (50 percent)	LS			$ 1,342,500
Total Conceptual Cost				$ 4,027,500
Cost per foot of Wilmes Lake Level Reduction (standard design storm)				$ 16,110,000

5.6 OPTION 3: OUTLET UPGRADE FROM WILMES LAKE TO BAILEY LAKE

Option 3 evaluated the impact at Wilmes Lake and Colby Lake if the outlet capacity at Wilmes Lake and the pipe capacity from Wilmes Lake to Bailey Lake were doubled. Two sets of models were completed for this effort. The first model looked at the impact if the flow capacity was doubled only to Colby Lake. The second model looked at the impact if the flow capacity was doubled all the way to Bailey Lake. The impact to Bailey Lake was not evaluated as the Bailey Lake watershed model is being revised.

The present outlet pipe consists of 3,587 feet of 48-inch pipe from Wilmes Lake, which increases to a 54-inch pipe for 1,435 feet before entering Colby Lake. Colby Lake is then connected to Bailey Lake through a series of pipes and ponds. The model was modified to double the existing conveyance capacity by adding another parallel pipe to the existing system south of Wilmes Lake.

When the capacity was increased just to Colby Lake, the Colby Lake HWL increased by approximately one foot with the Wilmes Lake HWL decreasing approximately 2.5 feet. The second model showed similar impacts at Wilmes Lake with minimal impact to Colby Lake; however, flow rates increased significantly south of Colby Lake to Bailey Lake.

Table 18
Pipe Sizes and Lengths Carrying Outflow from Wilmes Lake to Bailey Lake

	Pipe Size	Pipe Length
Wilmes to Colby	48 inch	3587
Wilmes to Colby	54 inch	1435
Colby to Bailey	24 inch	367
Colby to Bailey	36 inch	390
Colby to Bailey	48 inch	442
Colby to Bailey	60 inch	2883

Table 19 contains a summary of the model results for option 3.

Table 19
Model Results for Option 3, Outlet Upgrade from Wilmes to Bailey Lake

Model Condition	Storm	Upstream of Hudson Road HWL	Downstream of Hudson Road (Pendryn Hill Pond) HWL	Wilmes Lake HWL	Colby Lake HWL
Option 3: Current Conditions	Standard Design Storm	923.6	918.42	906.16	892.2
Option 3: Current Conditions	October Storm Gridded Rainfall	924.83	919.96	908.34	892.96
Option 3: Ultimate Development	Standard Design Storm	924.78	919.9	907.19	892.29
Option 3: Ultimate Development	October Storm Gridded Rainfall	925.93	921.35	908.74	892.97
Departure from Base (Please see Table 6 and Table 7 for Base Model Conditions)					
Option 3: Current Conditions	Standard Design Storm	0	-0.01	-2.51	-0.29
Option 3: Current Conditions	October Storm Gridded Rainfall	0	0	-2.63	-0.42
Option 3: Ultimate Development	Standard Design Storm	0	0	-2.37	-0.3
Option 3: Ultimate Development	October Storm Gridded Rainfall	0	0	-2.3	-0.45

Table 20 shows unit cost elements and the probable cost calculation for Option 2.

Table 20
Option 3 Probable Costs

Item Description	Unit	Unit Cost	Quantity	Total
Storage Volume	Acre-ft	$ 35,000		
Earth work (addition to storage area)	Cubic-yards	$ 15		
Outlet Structures	Each	$ 20,000		
Pipe Upgrades	LS	$ 2,500,000	1	$ 2,500,000
Manholes	Each	$ 3,000		
Misc. and Contingency Items (50 percent)	LS			$ 1,250,000
Total Conceptual Cost				$ 3,750,000
Cost Per Foot of Wilmes Lake Level Reduction (standard design storm)				$ 1,494,000

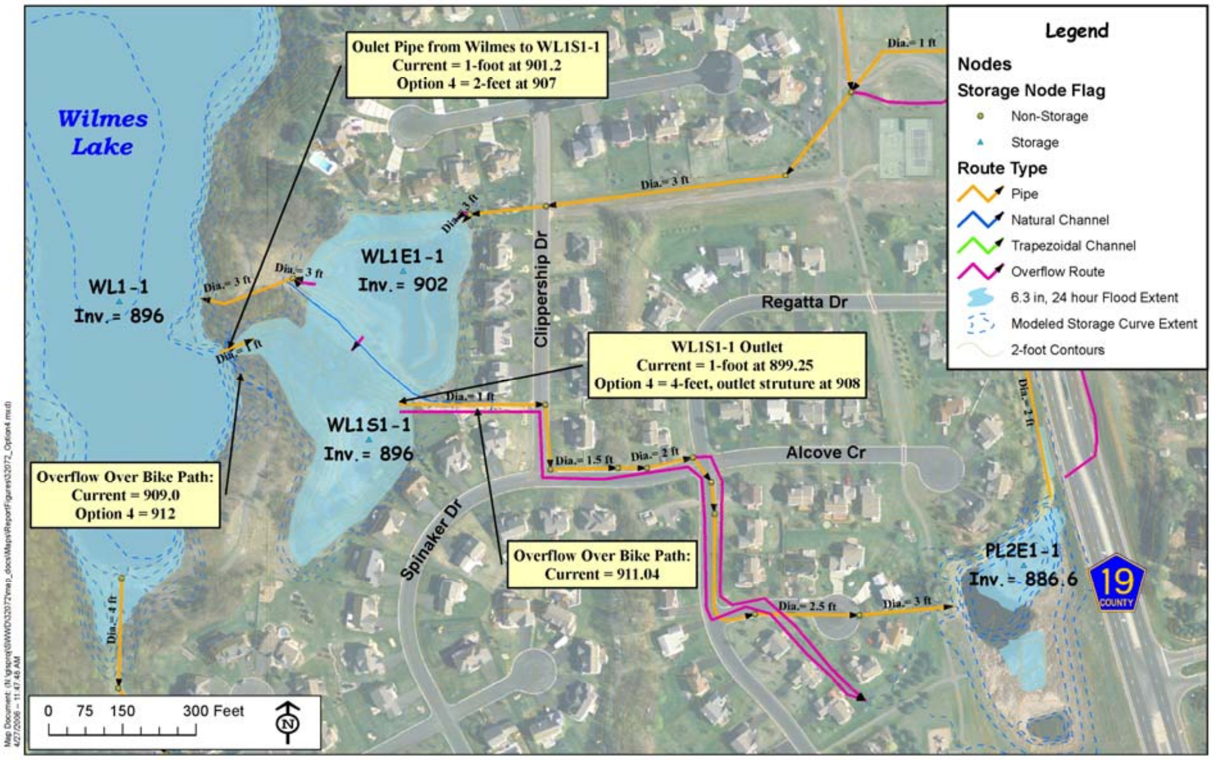
5.7 OPTION 4: EMERGENCY OVERFLOW FOR WILMES LAKE

Option 4 explores the creation of an emergency overflow from Wilmes Lake to Powers Lake. The current overflow sees Wilmes Lake spilling over an adjacent bike path at elevation 909 to wetland WL1S1-1 (Figure 15). A 1-foot pipe outlets wetland WL1S1-1 at 899.25. This pipe follows several residential streets and finally outlets to pond PL2E1-1, transitioning from a 1-foot to a 3-foot pipe along the way. Pond PL2E1-1 is adjacent to County Road 19 and outlets to Powers Lake through a 2-foot pipe. During the October Storm, Wilmes Lake and pond WL1S1-1 merged together and reached a measured elevation of 911.7, causing an overflow at 911.04 along another bike path leading from WL1S1-1 to Clippership Drive (Figure 15).

The intent of Option 4 was to modify this overflow and prevent flooding onto Clippership Drive. A series of modeling scenarios were examined for this effort. The final option used for discussion (Figure 15) increases the pipe leading from Wilmes Lake wetland to WL1S1-1 from 1-foot to 2-feet in diameter and raises it from 901.2 to 907. The bike path was also raised from 909 to 912, essentially controlling the amount of water that can pass from Wilmes Lake to wetland WL1S1-1. For this option, an outlet structure in wetland WL1S1-1 was also conceptualized at elevation 908, with the outlet pipe increased to 4-feet the entire distance to PL2E1-1.

Table 21 presents the modeling results for Option 4. Option 4 causes a 1.2-foot HWL drop at Wilmes for the October Storm under current conditions and a 0.8-foot drop under ultimate conditions. Table 22 presents an estimate of the probable costs for this effort.

Figure 15
Location of Wilmes Overflow modified for Option 4



Oulet Pipe from Wilmes to WL1S1-1
Current = 1-foot at 901.2
Option 4 = 2-feet at 907

WL1S1-1 Outlet
Current = 1-foot at 899.25
Option 4 = 4-feet, outlet struture at 908

Overflow Over Bike Path:
Current = 909.0
Option 4 = 912

Overflow Over Bike Path:
Current = 911.04

Table 21
Model Results for Option 4, Emergency Overflow for Wilmes Lake

Model Condition	Storm	Upstream of Hudson Road HWL	Downstream of Hudson Road (Pendryn Hill Pond) HWL	Wilmes Lake HWL	Colby Lake HWL	County Road 19 Pond (D/S of Wilmes)	Powers Lake HWL
Option 4: Current Conditions	October Storm Gridded Rainfall	924.87	920.07	909.73	893.28	899.84	892.01
Option 4: Ultimate Development	October Storm Gridded Rainfall	925.95	921.38	910.24	893.31	900.08	893.12
Departure from Base (Please see Table 6 and Table 7 for Base Model Conditions)							
Option 4: Current Conditions	October Storm Gridded Rainfall	0.04	0.11	-1.24	-0.1	4.18	1.44
Option 4: Ultimate Development	October Storm Gridded Rainfall	0.02	0.03	-0.8	-0.11	2.6	1.12

(See Table 6 and Table 7 for base model conditions.)

Table 22 shows the unit cost elements and the probable cost calculation for Option 2.

Table 22
Option 4 Probable Costs

Item Description	Unit	Unit Cost	Quantity	Total
Storage Volume	Acre-ft	$35,000		
Earth work (addition to storage area)	Cubic-yards	$15	10000	$150,000
Outlet Structures	Each	$20,000	2	$40,000
Pipe Upgrades	LS	$210,000	1	$210,000
Manholes	Each	$3,000	5	$15,000
Misc. and Contingency Items	LS			$207,500
Total Conceptual Cost				$622,500
Cost Per Foot of Wilmes Lake Level Reduction (October Storm, no benefit for std design storm)				$502,000

6.0 CONCLUSIONS AND RECOMMENDATIONS

All subwatersheds that ultimately drain to Wilmes Lake in the Northern Watershed model were updated to match current land use and infrastructure conditions. Following the land use update, the storm conditions that occurred in October 2005 were modeled to reflect the flooding that resulted at Wilmes Lake. The updated land use was further modified to develop the Ultimate Development Model using projected land use changes provided by the cities of Woodbury, Lake Elmo, and Oakdale. The Current Conditions Model and the Ultimate Development Model were then used to evaluate the effectiveness of potential structural modifications to the drainage system within the Wilmes Lake Watershed.

6.1 STRUCTURAL MODIFICATIONS

The structural modifications considered included storage and conveyance improvements. That is, structural improvements achieve flood damage reduction and increases in public safety by preventing flood waters from encroaching on or inundating damageable private and public property or endangering public safety within the floodplain. The results at Wilmes Lake were used to measure the impacts of each option. Overall, the conveyance improvements lowered the HWL at Wilmes Lake more than the storage improvements. A summary of the modeling results are as follows:

- For Option 1, Site 1 has the highest independent impact on the HWL at Wilmes Lake. Site 1 adds approximately 12 acre-ft of storage, but the dam required to contain the water makes this site a less probable option. Sites 2, 3, and 4 are more feasible since these sites are primarily outlet reconfigurations and simple grading; however, the cumulative impact of these three storage sites is less than 0.5 foot at Wilmes Lake.
- The modeling results from Option 2 indicate that storage north of I-94 will provide less than 0.5 feet of HWL stage reduction at Wilmes Lake. The proposed storage locations provide approximately 75 acre-ft of storage to attenuate runoff from 288 acres within Lake Elmo's city limits. The total reduction in flow rate and volume crossing I-94 is for the Standard Design Storm under current conditions is 120 cfs and for the Standard Design Storm under ultimate conditions is 296 cfs.
- Option 3 will require about one mile of pipe upgrade from Wilmes Lake to Colby Lake, and an additional 0.75-mile of pipe upgrade from Colby Lake to Bailey Lake. This option does have an adverse impact at Colby and Bailey Lakes with the increased rate and volume of flow from Wilmes Lake and violates downstream impact criteria of the SWWD and the City of Woodbury.
- Option 4, which is an emergency overflow from Wilmes Lake to Powers Lake, provides about one foot of relief during a major storm. This option includes a berm that will provide added protection to the houses threatened with flood damage during high water conditions at Wilmes Lake. Powers Lake is adversely impacted due to the added flow from Wilmes Lake, which violates downstream impact criteria of the SWWD and the City of Woodbury.

The relative impacts of each of the options indicate that none, independently, provide sufficient relief during a flood event. Cumulative storage within Woodbury and Lake Elmo, however, can add the effectiveness of storage and possibly justify the added costs. Combining selected storage locations with an emergency overflow will provide the optimum relief during a flood event at Wilmes Lake. Any option will require evaluation of downstream impacts.

Table 23
Wilmes Lake Relative HWL Reductions for the Standard Design Storm under Current Land Use Conditions

Option	Description	< 0.5 ft	0.5 ft to 1 ft	1.0 to 1.5	1.5 to 2.0	2 to 3	3.o and above
Option 1a	Storage south of I-94, all sites		X				
Option 1b	Storage south of I-94, sites 1, 2, 3 and 4	X					
Option 1c	Storage south of I-94, site 1 only	X					
Option 2	Storage north of I-94	X					
Option 3	Wilmes Lake Outlet Upgrade (Not reported due to negative impacts to downstream storage areas.)						
Option 4	Emergency Overflow from Wilmes Lake	X					

Table 24
Wilmes Lake Relative HWL Reductions for the October Storm under Current Land Use Conditions

Option	Description	< 0.5 ft	0.5 ft to 1 ft	1.0 to 1.5	1.5 to 2.0	2 to 3	3.0 and above
Option 1a	Storage south of I-94, all sites			X			
Option 1b	Storage south of I-94, sites 1,2,3, and 4		X				
Option 1c	Storage south of I-94, site 1 only		X				
Option 2	Storage north of I-94	X					
Option 3	Wilmes Lake Outlet Upgrade (Not reported due to negative impacts to downstream storage areas.)						
Option 4	Emergency Overflow from Wilmes Lake			X			

6.2 NON-STRUCTURAL IMPROVEMENTS

Non-structural improvements describe a class of improvements that are not related to physical drainage system, storage area modifications, or “structural” modifications to the drainage system. That is, structural improvements achieve flood damage reduction and increases in public safety by preventing flood waters from encroaching on or inundating damageable private and public property or endangering public safety within the floodplain. Conversely, non-structural improvements represent programs or actions that achieve flood mitigation, damage reduction and an increase in public safety by implementing policies, rules, or programs that educate the public, incorporate preventive measures (e.g. development regulation), and promote steps that deal with flood hazard mitigation before and after flood events.

The FEMA 480 NFIP guide describes five basic categories for non-structural flood mitigation measures:

1. Prevention – measures designed to keep the flooding problem from getting worse or occurring in the first place. Prevention includes programs to ensure that future development does not make the flood problem worse or increase flood damages. These types of measures are usually administered by the local municipality that governs development and include:

- Planning and zoning
- Open space preservation
- Floodplain development regulations
- Stormwater management
- Drainage system maintenance

2. Property Protection – measures used to modify buildings subject to flood damage rather than to keep flood waters away. These measures are often implemented by or cost-shared with property owners. These measures can include:

   - Property acquisition
   - Relocation
   - Raising elevator
   - Floodproofing
   - Sewer backup protection
   - Flood insurance or additional insurance

3. Natural Resource Protection – measures where flood losses may be reduced and natural habitats improved by restoring some natural areas or natural functions of a floodplain and/or a watershed area. These measures are usually implemented by a municipal or environmental agency. These measures can include:

   - Zoning or preserving open space to protect natural resources and promote infiltration.
   - Wetland protection
   - Erosion and sediment control
   - Best Management Practices (BMPs) for stormwater runoff

4. Emergency Services – measures that protect people during and after a flood event. Emergency services are most often provided by the local municipality, county, state, or federal agency. These entities may maintain an emergency management office to coordinate flood warnings and disaster response and recovery operations. These measures can include:

- Flood warning systems
- Flood response plans and strategies
- Critical facilities protection policies (e.g. stormwater pump stations)
- Health and safety maintenance

5. <u>Public Information</u> – measures and activities that advise property owners, potential property owners, and visitors about the hazards, ways to protect people and property from those hazards, and the natural and beneficial functions of the floodplains. These measures can include:

   - Map information for public consumption
   - Outreach projects
   - Real estate disclosures
   - Technical assistance
   - Environmental education

For the Wilmes Lake Watershed, several items in the non-structural mitigation categories may provide benefit to flood problems. While it is not within the scope of this report to explore the full breadth of the potential non-structural alternatives, several that might be considered or are already in place include:

- Promulgating community design and development standards that promote decreases in impervious surfaces and increases in drainage technologies that promote infiltration and reductions in peak stormwater flow rates and runoff volumes. This can include development standards for stormwater quantity, rate, and quality as well as public outreach and education programs that promote responsible land use and irrigation practices. The SWWD and the communities within the District already promote these types of standards in various forms and degrees – although there may be some inconsistencies in standards, implementation, and enforcement.
- Optimizing the available, unused storage in existing ponds, lakes, and detention basins so as to maximize the attenuation of flood peak in the system. This involves evaluation of current operations strategies, and changes to those strategies if required, for detention areas and other flood facilities or structures so that their overall flood mitigation effectiveness is maximized. Wilmes Lake may serve as an example of this type of strategy. As discussed in Section 4.0, the starting, normal high water level in Wilmes Lake is 902.6. If the lake elevation were annually lowered before the start of the flood season to 901.5 (the October Storm is out of season), then additional live storage volume could be recovered and used to mitigate flood impacts and high water elevations on Wilmes Lake.

- Developing Emergency Action Plans (EAPs) or Flood Response Plans (FRPs) that recognize the potential for the flood threat to public safety and act to remove people from the floodplain or mitigate flood damages in a proactive manner. They identify areas prone to flood emergencies during a particular flood situation and outline the best and highest use of emergency responder resources to mitigate the toll of flooding on life and property. The SWWD has previously formulated an FRP for the watershed and implementation of this plan, in conjunction with the local municipalities, would be a valuable flood hazard mitigation tool.

- Implementing flood warning systems or monitoring systems (e.g. rain gages, stream gages, or lake elevation gages) that allow the responsible agency to recognize when flood threats are more probable or beginning to occur so that EAPs or FRPs can be initiated. Flood warning systems increase the lead time within which people can leave flood prone areas or take mitigative actions to protect their own property (e.g. sand bagging). Presently, the SWWD and the City of Woodbury do not have the capability to perform real-time monitoring water surface levels of Wilmes Lake or other storage areas. The City of Woodbury does maintain a SCADA (Supervisory Control and Data Acquisition) system for managing and monitoring several of the municipality's assets (i.e., pump stations, wells, lift stations etc.). It is possible to install lake level monitoring stations at key locations that would communicate on a real-time basis with the SCADA system so that lake levels and their rate-of-rise could be monitored continuously. The SCADA system could then monitor the rate-of-rise and the absolute elevation of several key impoundments, such as Pendryn Hill Pond and Wilmes Lake, and issue alerts at key trigger points to activate Flood Response Plans and provide warnings to residents. As seen in Figure 11, shown previously in this report, the peak high water level in Wilmes Lake during a flood event is preceded by a significant period of time when the lake elevation rate-of-change increases – usually preceding the peak within a range from 18 to 48 hours. This flood response characteristic of Wilmes Lake may make this type of system a key component of a flood hazard mitigation plan for the SWWD and the City of Woodbury.

- Floodproofing structures and properties to prevent flood damage. During the October Storm, approximately 10 properties in the vicinity of Wilmes Lake and 6 properties in the vicinity of Pendryn Hill Pond reported flood impacts that were directly attributable to high water surface elevations in these water bodies. In each case, and based on the reported and calculated water depths, the flood depths in these areas were all less than approximately 2 feet. The relatively shallow depths of flooding in these areas may make them good candidates for floodproofing using such options as low floodwalls, floodproofing basements, or contour regrading protect them from the high water levels. Interior (local) drainage considerations as well as aesthetic impacts would have to be evaluated for this type of option.

- Removing damageable structures or private or public assets from an active floodplain through buy-out or relocation programs. Property buy-out or relocation programs are typically used in areas where there are relatively few structures or properties that are jeopardized by flooding.

- The City of Woodbury is also currently compiling and evaluating non-structural practices and alternatives in addition to or complementing those listed in this report.

6.3 RECOMMENDATIONS

There are no recommended structural improvements at this time. Structural flood improvement elements may be warranted in the future when combined with other local projects.

Table 25 provides an overall comparison to the conceptual, structural HWL reduction options explored for Wilmes Lake. This study did not perform an incremental benefit-to-cost analysis of the conceptual flood mitigation options as it was outside the scope of and budge of the authorized project. Given the cost (present value or yearly annuity) of all the projects analyzed, it is doubtful that a full incremental benefit-to-cost ratio analysis of the studied flood projects would yield a feasible, fiscally responsible project from the general, conceptual options studied. Figure 16 and Figure 17 indicate the level of freeboard available for homes around Wilmes Lake and Pendryn Hill Pond.

Table 25
Option Comparison for HWL Reductions at Wilmes Lake for the Standard Design Storm under Current Land Use Conditions

Option	Description	< 0.5 ft	0.5 ft to 1 ft	1.0 to 1.5	1.5 to 2.0	2 to 3	3.0 and above	Probable Cost	Cost per ft[1]
Option 1a	Storage south of I-94, all sites		X					$5,312,250	$7,589,000
Option 1b	Storage south of I-94, sites 1, 2, 3 and 4		X					$4,811,250	$8,441,000
Option 1c	Storage south of I-94, site 1 only		X					$2,307,000	$4,614,000
Option 2	Storage north of I-94	X						$4,027,500	$16,110,000
Option 3	Wilmes Lake Outlet Upgrade							$3,715,000	$1,494,000
Option 4	Emergency Overflow from Wilmes Lake	X						$622,500	$502,000[2]

1. Cost per foot of Wilmes Lake level reduction for the Standard Design Storm.

2. Cost per foot for the October Storm. Option has no effect on the Standard Design Storm.

Figure 16
Wilmes Lake Overflow – Parcel Base Slab Information

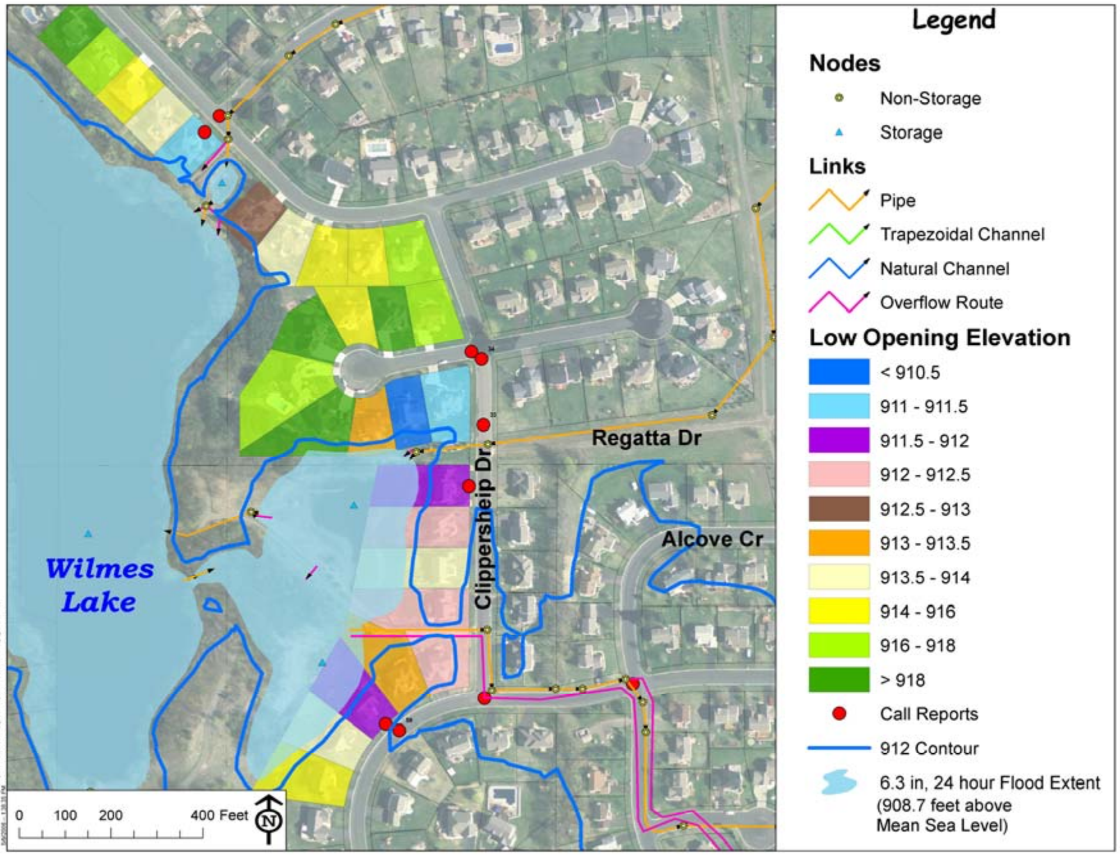
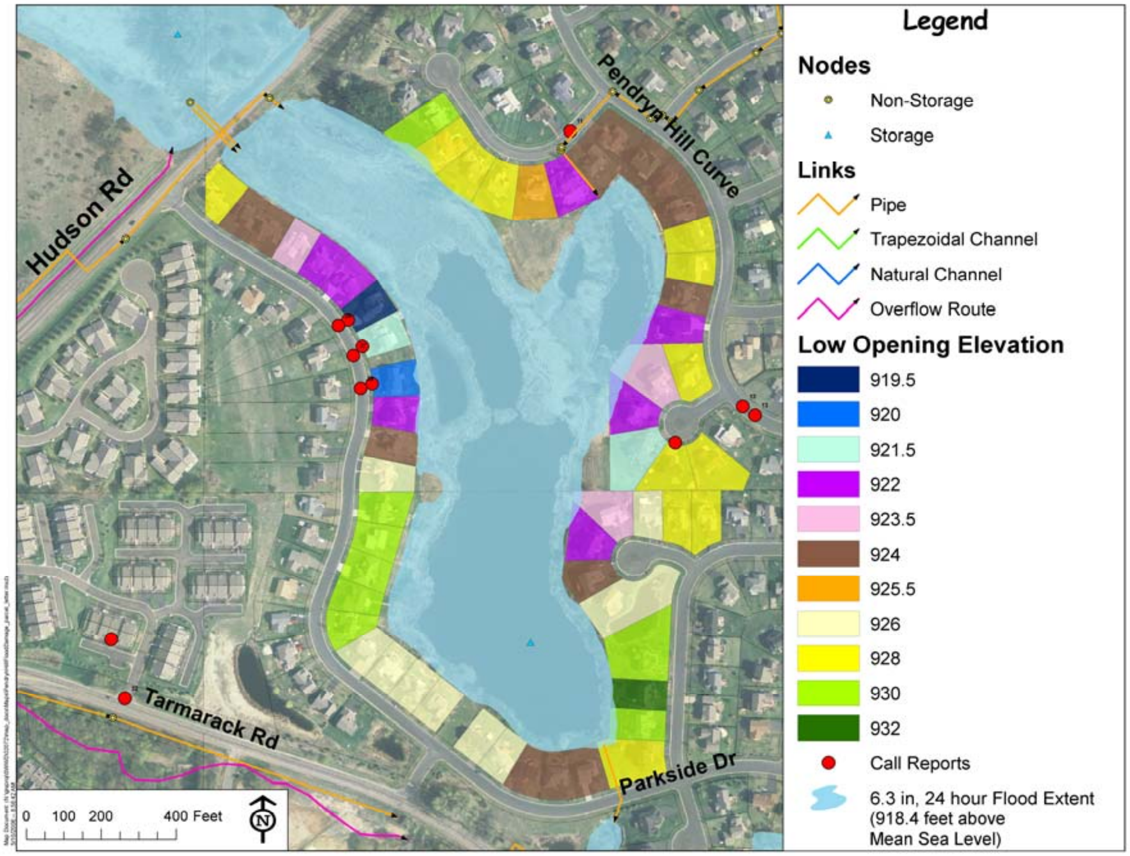


Figure 17

Pendryn Hill Pond – Parcel Base Slab Information



A reduction of HWL to increase flood freeboard and provide more protection for events that exceed the standard design event, such as the October Storm or for events up to the 95th percentile of the 100-year event (7.8-inch, 24-hour SCS Type II storm) may be achieved with Option 4. This option would provide more freeboard for events greater than the Standard Design Storm in Wilmes Lake and avoid the uncontrolled overflow situation that occurred in October 2005. If a decision is made to further explore this option, then preliminary design and detailed final design efforts will be required, including analysis of potential downstream effect.

In all cases, the non-structural solutions presented in Section 6.2 may also increase the level of hazard mitigation for the low-lying parcels around Wilmes Lake and Pendyrn Hill Pond. The non-structural solutions recommended for further consideration include:

1. Installation and coordination of real-time lake elevation and/or flow monitoring locations at key points on Wilmes Lake, Pendryn Hill Pond, or the Hudson Road weir.
2. A review and update, if necessary, of the existing ERP and FRP for Wilmes Lake or areas where optimized flood response may provide additional flood hazard mitigation.
3. Optimization, particularly for Wilmes Lake, of the lake operation practices to maximize the amount of live storage available during the flood season. This may require a modification of the DNR permit and coordination with this agency.
4. Continue review of community development plans and enforce design standards with and between the stakeholders in the SWWD, including the cities of Woodbury, Lake Elmo, Cottage Grove, and Oakdale. The SWWD has reviewed all development plans for abstraction, water quality, and rate control within the watershed. The specific design standards or guidance are:

    - 2002 Engineering Report
    - 2003 Flood Damage Reduction Report Wilmes Lake Subwatershed
    - 2005-2006 Watershed Plan
    - SWWD Rules (http://www.swwdmn.org/)
    - Rules specific to each Municipality (i.e., Woodbury, Lake Elmo, etc.)
    - NPDES Rules
    - DNR Rules relating to Public Waters

    With the ongoing modeling efforts, land use updates with development activity, and study efforts by the SWWD, rules and design standards will be continually modified to take into account the changing response patterns of the watershed.
5. Flood proofing at-risk structures and provide protection from damage due to flooding to a flood depth of as high as 2 feet.

6.4 SUMMARY

The Wilmes Lake Watershed within the Northern Watershed model of the SWWD was updated to represent the current land use and infrastructure. Subsequently, the Ultimate Development Model was constructed to represent full build-out conditions.

Both the Standard Design Storm and the October Storm were modeled for the watershed. Spatially distributed rainfall totals and hyetographs derived from the storm were used to model the October Storm. HWLs and key lakes within the watershed were calibrated to surveyed high water marks obtained after the October Storm. The models were then used to analyze four flood mitigation alternatives, including storage options and an emergency overflow.

There are no recommended structural improvements at this time. Structural flood improvement elements may be warranted in conjunction with other local projects.

It is recommended that the SWWD, along with the associated municipalities, continue with the ongoing and recommended non-structural solutions.

Appendix A

Memorandum of Possible Storage Locations

Technical Memo

To:	Mr. Matt Moore, Administrator SWWD 2301 Tower Drive Woodbury, MN 55125
From:	Bob Beduhn, PE – HDR Engineering, Inc. Mike Johnson – HDR Engineering, Inc.
Re:	Re: Review of Storage Potential on Undeveloped Parcels – Wilmes Lake Subwatershed
Date:	January 5, 2006

EXECUTIVE SUMMARY

The Wilmes Lake Watershed was reviewed and mapped relative to "undeveloped" parcels. An undeveloped parcel was defined as any parcel of land that is vacant and is not in a residential, commercial or suburban/urban land use. The purpose of the review is to estimate the total storage volume potential remaining on undeveloped parcels within the Wilmes Lake watershed. This first phase focused on the largest parcels with opportunity to provide regional storage in the Wilmes watershed. The following technical analysis was completed:

1) Overlay the parcel information with the subwatershed maps for the most recent 6.3-inch 24-hour Type II storm Wilmes Lake subwatershed model.
2) Utilize the existing model to estimate storage requirements on these parcels.
3) Prioritize the most beneficial storage relative to high water levels on the Wilmes Lake system.
4) Compare runoff volumes to the volume to Wilmes Lake storage and the volume of water which discharges over the Hudson Road Weir.

The results of the analysis indicate that 100 acre-ft of total storage over nine potential storage sites would be created. The storage will require 25-35 acres of land to achieve depending upon storage depth and site specific design. There are other smaller, more distributed opportunities in the watershed; however, these nine sites represent locations with sufficient available land to construct the storage. Of the 100 ac-ft, 63 ac-ft are on parcels that are currently in agricultural land use within Lake Elmo. There are 10 ac-ft identified in the Eagle Point Development and 20 ac-ft can potentially be achieved in the area between I-94 and the Hudson Road storage site. The remaining 7 ac-ft is achieved by expanding existing pond sites in Woodbury. Assuming this storage is managed in accordance with the Wilmes Lake Report, the effect would be 0.5 ft to 1.0 ft lower Wilmes Lake levels depending upon how the storage is utilized and managed. All the storage sites identified are upstream of Hudson Road.

There are some opportunities downstream of Hudson Road, which will be addressed in later phases of the study. However, they are smaller and the result of conversion of existing suburban land use into storage.

The model predicts 271 ac-ft overflows the Hudson Road structure. Therefore, if an additional 100-ac-ft of storage were constructed, it represents 37 percent of the total overflow of the Hudson Road weir for the design event evaluated.

Figure 1 illustrates the parcels evaluated within the Wilmes Lake Watershed. Watersheds EP4-1, EP3-2, EP2-4 and EP2-3 are in Lake Elmo and are largely undeveloped and in agricultural land use. It may be possible to combine storage in watersheds EP-4-1 and EP3-2 into storage site as well as to combine sites EP2-4 and EP2-3 into one site.

Watersheds Ept P13 and Ept NC2 are in the Eagle Point development. Storage in those locations is most likely to be achieved through the development review process unless the SWWD desires a more proactive approach in that development.

The 20 ac-ft between I-94 and Hudson Road (Hudson Road II) potential site would require construction of a dam structure across the drainage way/valley and would provide in-channel storage of regional intra-community flows.

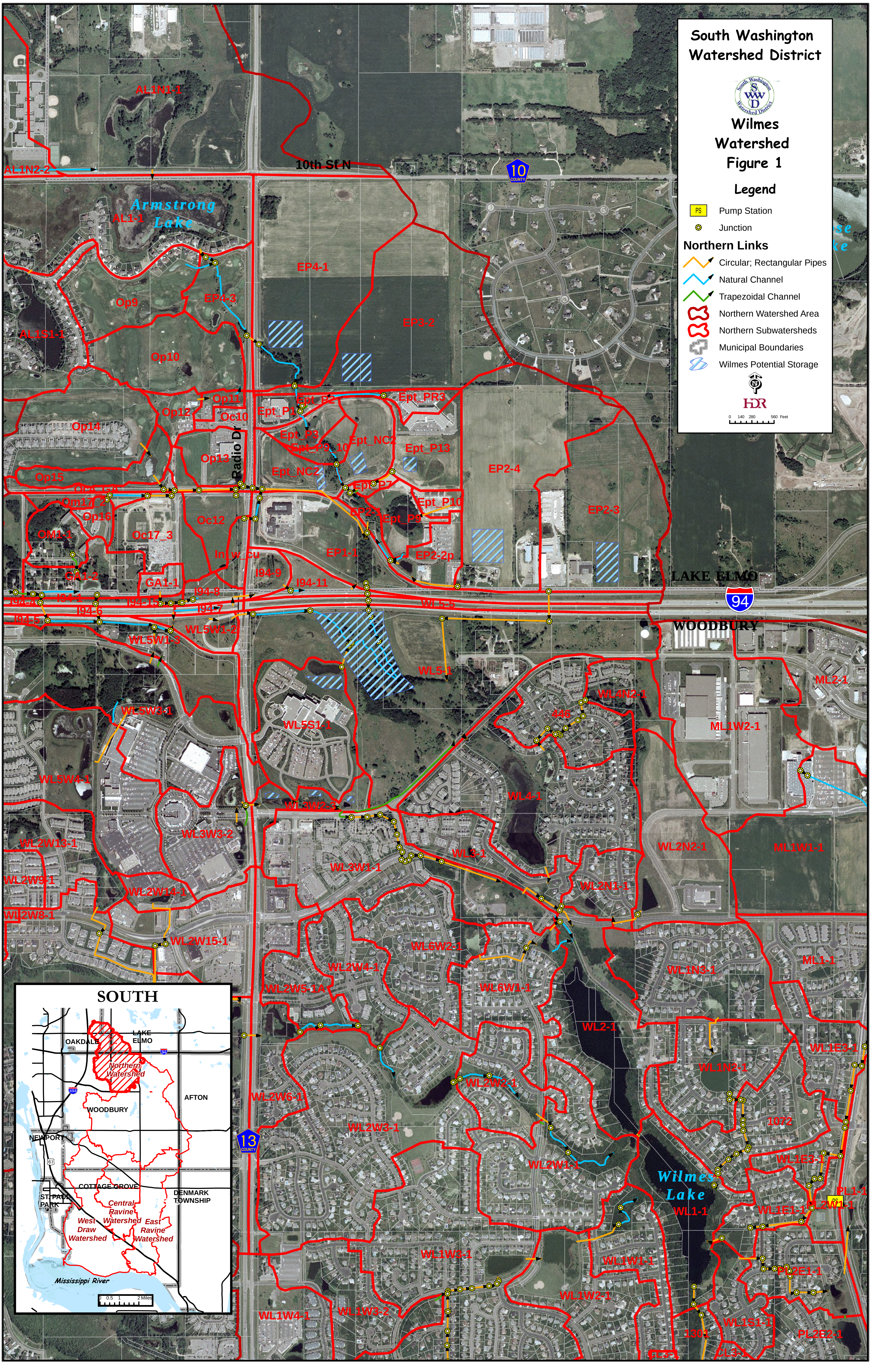
The mapping indicates that the storm water basin serving watershed WL5S1-1 could be expanded to provide additional storage and extended detention storage of approximately 5 ac-ft. In addition, there appear to be opportunities to expand basins serving watershed WL3W2-3 for 1-2 ac-ft of storage depending upon other constraints in the vicinity of the pond.

ENGINEER'S OPINION

Essentially, there are four approaches the SWWD can adopt to guide the decision-making process regarding the Wilmes watershed. These include:

- Adopt a 100-year high water at Wilmes Lake of 906.5 and then back into watershed-wide storage and capacity needs.
- Target an intra-community flow of 347 cfs between Lake Elmo and Oakdale with Woodbury to achieve consistency with Woodbury's 79 plan.
- Conduct a flood damage economic analysis of the watershed considering damage, economics, social and environmental costs. Use cost-to-benefit to guide decision-making process.
- Flood damage minimization – construct overflow for Wilmes, implement more strict development review or rules, enhance flood-proofing and flood fighting.

Based upon this review and HDR Engineering, Inc.'s (HDR's) previous experience in analyzing the Wilmes watershed, the 100 +/- ac-ft of storage identified in this brief review is likely the most accessible and feasible to implement. HDR is currently under scope to explore a range of other, smaller and more dispersed sites. That work includes existing storm water system retrofits and converting current uses to storm water storage sites. The work is scheduled to be completed in March of 2006. As the work progresses, the SWWD should consider what should be the decision criteria to guide application of the design and modeling methods.



South Washington Watershed District

Wilmes Watershed Figure 1

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Appendix B
Critical Event Analysis

CRITICAL EVENT ANALYSIS

To better understand the characteristics of a particular watershed, system of watersheds, and/or waterbody, it is necessary to isolate and determine its particular critical rainfall volume and intensity. For this effort, a couple of approaches were incorporated. First, rainfall volumes were taken, as in past modeling efforts, from the isopleth maps presented in Huff and Angel (1992). Second, an appropriate rainfall distribution with appropriate rainfall intensities was selected. Maintaining consistency with previous modeling efforts required the use of SCS synthetic rainfall distributions. However, due to reasons described in TR-55, the Type II distribution is available for a 24-hour duration. Therefore, the Type II distribution was scaled down to a 12-hour duration and up to both a 48-hour and 10-day duration. Scaling the Type II down to 3- and 6- hours, however, produced rainfall intensities of 40 and 20 inches per hour, respectively (Table B-1). Although for only very short periods, these rainfall intensities are unreasonable. Besides the 24-hour, Type II distribution, the Soil Conservation Service also developed a 6-hour distribution (Mays 2001). Therefore, the 6-hour distribution was used for the 6-hour rainfall event and a 6-hour distribution scaled down to 3 hours was used for the 3-hour rainfall event (Table B-2).

As a methods check, the process outlined by Huff and Angel (1992) for estimating synthetic storm mass curves were also incorporated into the modeling effort. A second quartile storm distribution at a point was used. Although the total rainfall volume for a given return period is the same, Huff and Angel produce rainfall intensities that are much less than the Type II distribution (Table B-1, Figure B-1). For a proper Huff and Angel analysis, the critical duration would need to be determined for each subwatershed that ultimately drains into Wilmes Lake, and then each of these critical durations would be run together to determine the maximum elevation at Wilmes. This type of analysis is beyond the scope of this modeling effort.

The critical event analysis was run for the Northern Watershed with ultimate land use conditions in place for both wet and dry conditions. Figure B-2 plots the results of these model runs. The 24-hour event was the critical event for the Type II distribution for both wet and dry conditions and for the Huff and Angel 2nd quartile distribution. The second greatest impact on Wilmes Lake came from the 10-day event followed by the 48-hour, 12-hour, 3-hour, and 6-hour events (Table B-1). The 3-hour event had a greater impact than the 6-hour event due to the 3-hour event having twice the peak intensity and not an equivalent difference in cumulative rainfall. The critical duration pattern produced from the Huff and Angel distribution were similar to the SCS distributions (Figure B-2). Another interesting note about Figure B-2 is that the differences in peak elevation at Wilmes between dry and wet antecedent soil moisture conditions decreases with increases in storm duration. This difference illustrates the role of abstraction within the watershed. For longer duration, less intense storms, abstraction plays a greater role in influencing hydrologic response.

The watersheds within the SWWD are very sensitive to rainfall intensity, which stands to reason for urbanized watersheds. These finding are also consistent with what was seen in the October Storm, where a sustained high intensity produced the same watershed response with less total rainfall volume. The October Storm produced 5 inches of rain in 2.5 hours. This rainfall volume is in excess of the Huff and Angel mapped 3-hour, 100-year event of 4.15 inches, and far in excess of the Huff and Angel tabulated 3-hour, 100-year event of 3.49 inches for the SWWD. Furthermore, the average rainfall intensity during this 2.5 hour period was 2.0 inches per hour, which is greater than the peak average intensity of 1.4 inches per hour for a 2.5 hour period yielded by the 24-hour, Type II distribution.

With the critical duration of 24-hours established, return periods of 2-, 5-, 10-, 25-, and 50-year for the 24-hour event were modeled under ultimate land use conditions (Table B-4). Peak elevations at Wilmes ranged from 904.3 for the 2-year event to 908.3 for the 50-year event.

Table B-1

Comparison of Peak Intensities for Different Rainfall Distributions

		Duration					
		3-hour (4.15 inches)	6-hour (4.4 inches)	12-hour (5.05 inches)	24-hour (6.3 inches)	48-hour (6.55 inches)	10-day (9.4 inches)
SCS Type II Distribution	Peak Intensity (in/hr)				7.71		
	Duration of Peak Intensity (min)				15		
SCS Type II Distribution Scaled	Peak Intensity (in/hr)	40.67	21.54	12.36	-	4.01	1.15
	Duration of Peak Intensity (min)	1.9	3.75	7.5	-	30	69
SCS 6-hour Distribution	Peak Intensity (in/hr)	-	3.33	-	-	-	-
	Duration of Peak Intensity (min)	-	7.2	-	-	-	-
SCS 6-hour Distribution Scaled	Peak Intensity (in/hr)	6.28	-	-	-	-	-
	Duration of Peak Intensity (min)	3.6	-	-	-	-	-
Huff and Angel Distribution, 2nd quartile, at a point.	Peak Intensity (in/hr)	3.32	1.76	1.01	0.63	0.33	0.09
	Duration of Peak Intensity (min)	9	18	36	72	144	720

Table B-2
Final Distributions used for the Critical Event Modeling Effort

		Duration					
		3-hour (4.15 inches)	6-hour (4.4 inches)	12-hour (5.05 inches)	24-hour (6.3 inches)	48-hour (6.55 inches)	10-day (9.4 inches)
SCS Type II Distribution	Peak Intensity (in/hr)	6.28	3.33	12.36	7.71	4.01	1.15
	Duration of Peak Intensity (min)	3.6	7.2	7.5	15	30	69
Huff and Angel Distribution, 2nd quartile, at a point.	Peak Intensity (in/hr)	3.32	1.76	1.01	0.63	0.33	0.09
	Duration of Peak Intensity (min)	9	18	36	72	144	720

Figure B-1
24-Hour Distribution Comparisons for the Type II and Huff and Angel Mass Curves

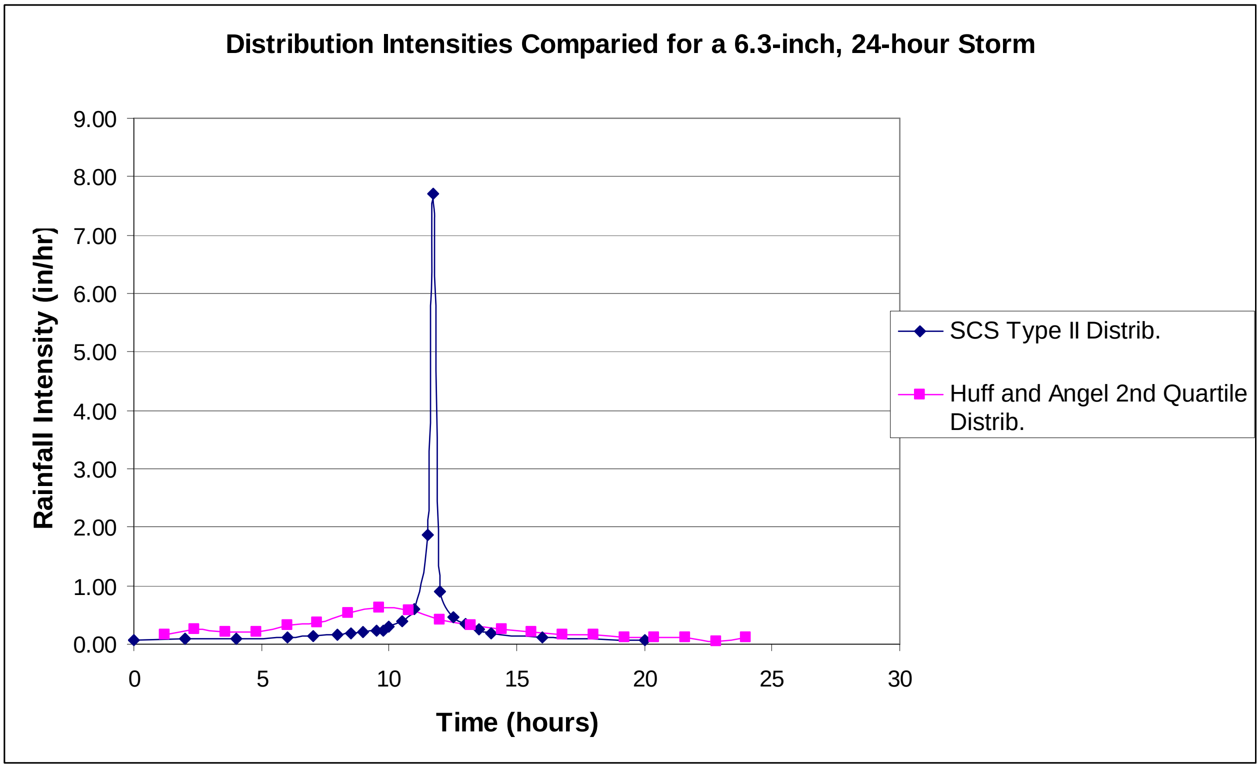


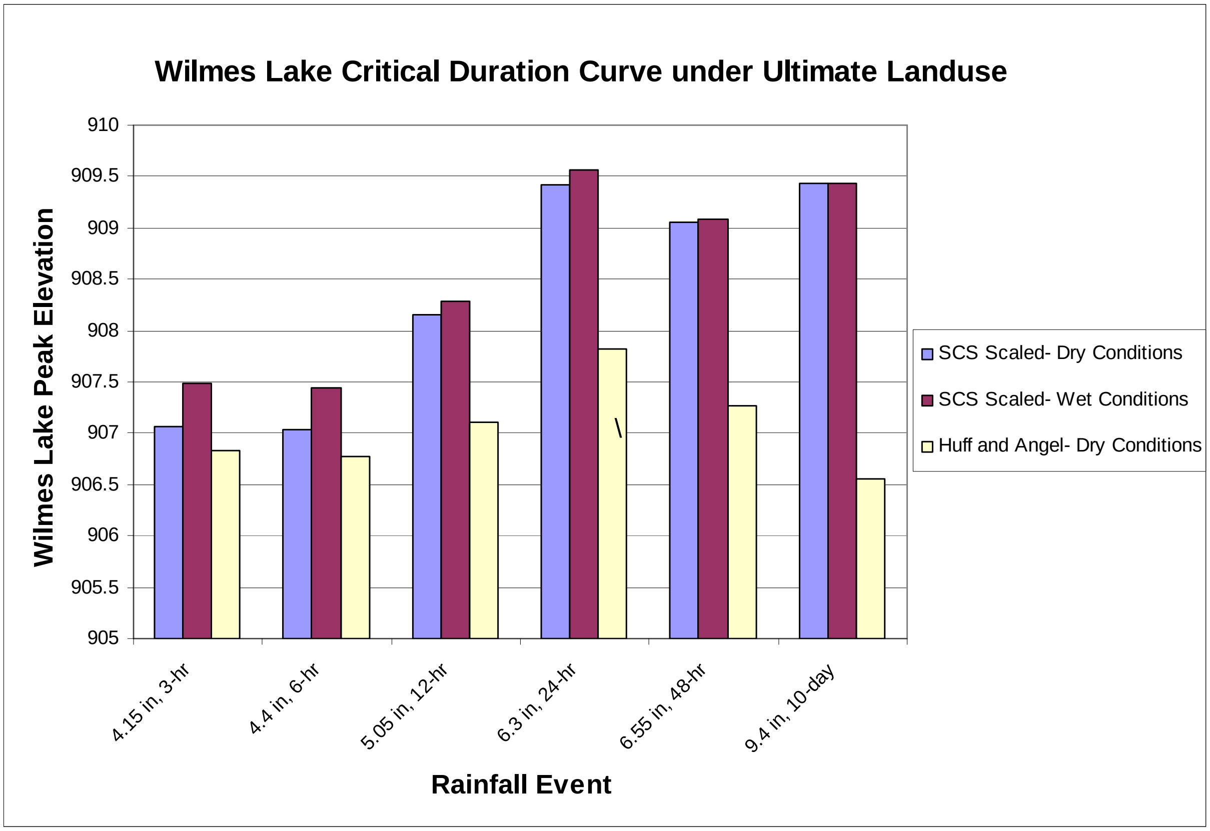
Table B-3
Results of the Critical Event Modeling Effort for Dry Antecedent Soil Moisture and Ultimate Land Use Conditions

Rainfall	Rainfall Distribution Type	Armstrong HWL (AL1-1)	I-94 at Eagle Pt Flow (WL5-7)	U/S Hudson Road HWL (WL5-1)	D/S Hudson Road HWL (WL4-1)	Wilmes HWL (WL1-1)	Colby HWL (CL1-1)	Summit Point Park (WL1W2-1)
4.15 in, 3-hr	SCS 6-hour Distribution Scaled	1019.25	548 cfs	923.3	917.27	907.06	892.2	943.82
4.4 in, 6-hr	SCS 6-hour Distribution	1019.27	453 cfs	922.75	917.25	907.04	892.19	943.68
5.05 in, 12-hr	SCS Type II Scaled	1019.69	675 cfs	923.34	918.51	908.16	892.37	944.47
6.3 in, 24-hr	SCS Type II	1020.29	702 cfs	923.9	919.92	909.42	892.58	945.31
6.55 in, 48-hr	SCS Type II Scaled	1020.07	580 cfs	923.57	919.12	909.06	892.55	944.66
9.4 in, 10-day	SCS Type II Scaled	1020.02	344 cfs	923.5	918.71	909.43	892.72	944.35

Table B-4
Results of the Duration Modeling for Dry Antecedent Soil Moisture and Ultimate Land Use Conditions

Rainfall	Rainfall Distribution Type	Armstrong HWL (AL1-1)	I-94 at Eagle Pt Flow (WL5-7)	U/S Hudson Road HWL (WL5-1)	D/S Hudson Road HWL (WL4-1)	Wilmes HWL (WL1-1)	Colby HWL (CL1-1)	Summit Point Park (WL1W2-1)
2.75 in, 24-hr	SCS Type II	1018.28	220 cfs	919.57	912.98	904.31	891.37	940.75
3.5 in, 24-hr	SCS Type II	1018.59	354 cfs	921.28	914.13	904.95	891.79	941.51
4.05 in, 24-hr	SCS Type II	1018.87	448 cfs	921.94	915.37	905.69	892.01	942.23
4.9 in, 24-hr	SCS Type II	1019.38	567 cfs	922.84	917.33	907.37	892.24	943.44
5.6 in, 24-hr	SCS Type II	1019.83	643 cfs	923.43	918.59	908.32	892.41	944.42
6.3 in, 24-hr	SCS Type II	1020.29	702 cfs	923.9	919.92	909.42	892.58	945.31

Figure B-2
Results of the Critical Event Modeling Effort at Wilmes Lake



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