

***Cedar River Watershed
Existing Conditions Model***

***Prepared for
Cedar River Watershed District***

September 23, 2013

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1.0 Introduction

1.1 Project Background

In 2009, the Cedar River Watershed District published their Cedar River Watershed District Watershed Management Plan (CRWD Plan). This plan sets the vision, guidelines, and proposed tasks for managing the water resources within the district. Within the plan, specific goals and objectives are defined in order for the district to protect and enhance safety, commerce, and natural resources of the watershed. The first set of goals for the district is in regard to flood control. The flood control goals of the district, as outlined by the CRWD Plan are as follows:

1. The protection of life, property, and surface water systems that could be damaged by flood events.
2. Correct/address existing flooding problems.
3. Prevent future flooding problems.

To achieve these goals, the district outlined a series of objectives which include regulation of runoff discharges to minimize flooding and reduce the overall flooding potential in the district. More specifically, the district would like to decrease the risk of flooding by at least 20% in the Cedar River through the City of Austin during the 100-year rainfall or snowmelt events. Meeting these objectives requires being able to quantify the existing runoff in the watershed before reductions in runoff can be evaluated.

A hydrologic and hydraulic model of the Upper Cedar River Watershed was prepared in 2007, prior to the creation of the watershed district and publication of the district's plan. This modeling effort was funded by the Upper Cedar River Ad Hoc committee and the main goal of this modeling effort was to determine if a 20% reduction in peak flow rate of the Cedar River through Austin, Minnesota was possible. The modeling effort included substantial data collection of bridge and culvert data across much of the watershed, delineation of over 400 subwatersheds, evaluation of the watershed's soils and land use data, and calibration of the final model.

The 2007 model calculated existing runoff from 435 subwatersheds (including subwatersheds in the Turtle Creek Watershed District (TCWD), which discharges to the Cedar River), and considered the effect of restricting the flow rate or establishing flow rate goals at 104 locations throughout the watershed (59 in the Dobbins Creek and Wolf Creek Watersheds, and 45 in the remainder of the watershed). The modeling effort showed that there could be a 17% reduction in peak flow rate

through Austin with the construction of 104 regional basins. It was estimated that the district's goal of a 20% reduction in peak flow rate through Austin, MN would be possible with the construction of additional basins upstream of the city.

1.2 Current Modeling Effort

The current modeling effort, which is the focus of this report, includes updating the original hydrologic and hydraulic model created for the Upper Cedar River Ad Hoc Committee to create the existing conditions model for both CRWD and TCWD that will help each district define existing runoff rates. This updated model used as much information as possible from the previous modeling effort including soils data, watershed outlet locations, and survey data of bridges and culverts. Additional survey data and more detailed topographic data were used to refine the 2007 model. A more robust hydrologic and hydraulic modeling program, XP-SWMM, was also used for the current effort. A detailed description of the modeling methodology is included in Section 2. Suggestions on the variety of ways the updated model can be used by the district are included in Section 4. Figure 1 shows the area of the two watershed districts modeled in 2007 and the total watershed area that was added in 2012.

2.0 Modeling Methodology

2.1 Hydrologic Inputs

The amount of runoff generated from a watershed depends on numerous factors, including the total watershed area, the soil types present in the watershed, the percent impervious area in the watershed, the runoff path through the watershed, and the slope of the land within the watershed. This section summarizes the watershed runoff characteristics used in the XP-SWMM model.

Watershed Delineation

The initial watershed delineation utilized subwatershed divides developed for the 2007 modeling effort. These divides were based on the USGS quadrangle maps, which was the only available topographic data at the time. Subwatersheds were delineated to locations of major flow restrictions such as culverts or bridges. For the 2012 modeling effort, a total of 645 separate subwatersheds were delineated using the more recently obtained county LiDAR data for Mower, Steele, Dodge, and Freeborn counties. The county LiDAR data has an approximate vertical accuracy of 1-foot. The watershed divides included in the XP-SWMM model are shown in Figure 2.

Land Use and Impervious Percentage

The published 2001 National Land Cover Dataset (NLCD) impervious percentage grid was used to determine the percent impervious area for each subwatershed within CRWD and TCWD. Figure 3 shows the land use distribution across the watershed as presented in the 2001 NLCD database. Land use types listed in the database were assigned a percent impervious to each category. Table 1 lists each land use category and its associated impervious percentage.

Impervious area used in the XP-SWMM model is assumed to be hydraulically (or directly) connected to the drainage system being analyzed. This means that runoff from the portion of the impervious area that will not flow over a pervious area (such as agricultural land, open space, lawns, or other turfed areas) before reaching a storm sewer system is considered directly connected. This directly connected impervious area includes roads, driveways, rooftops, and parking areas that discharge directly to a storm sewer system. In comparison, runoff from the portion of a rooftop draining onto adjacent turfed areas would not be considered directly connected impervious areas. For modeling purposes, only directly connected impervious surfaces are considered as part of the impervious area. The majority of the impervious surfaces in the Cedar River watershed are not connected to a storm sewer; therefore, most areas have directly connected impervious percentages of zero.

Table 1 Percent Impervious by Land Use Classification Published in the NLCD Database

Land Use Classification	Directly Connected Percent Impervious Percentage
Barren Land (Rock/Sand/Clay)	0
Cultivated Crops	0
Deciduous Forest	0
Developed, High Intensity	30
Developed, Medium Intensity	16
Developed, Low Intensity	8
Developed, Open Space	0
Emergent Herbaceous Wetlands	0
Evergreen Forest	0
Grassland/Herbaceous	0
Mixed Forest	0
Open Water	0
Pasture/Hay	0
Woody Wetlands	0

Depression Storage

Depression storage, which includes the areas that must be filled with water prior to generating runoff from both pervious and impervious areas, was set within the general range of published values. It represents the initial precipitation loss caused by surface ponding, surface wetting, and interception. The model handles depression storage differently for pervious and impervious areas. The water stored as pervious depression storage is subject to both infiltration and evaporation. Alternatively, the impervious depression storage is subject to only evaporation. The depression storage was assumed to be 0.06 inches for impervious surfaces and 0.17 inches for pervious surfaces. These values are within the range of published values in the U.S. EPA SWMM Version 5.0 User's Manual. A sensitivity analysis was performed using varying depths of depression storage during the calibration process, however the analysis revealed the initially-assigned depths did not need to be changed.

Overland Roughness

Overland flow is surface runoff that occurs as sheet flow over land surfaces prior to concentrating into defined channels. In order to estimate the overland flow runoff rate, a modified version of Manning's equation is used by XP-SWMM. A key parameter in the Manning's equation is the roughness coefficient. The shallow flows typically associated with overland flow result in substantial

increases in surface friction. As a result, the roughness coefficients typically used in open channel flow calculations are not applicable to overland flow estimates. These differences can be accounted for by using an effective roughness parameter instead of the typical Manning's roughness parameter.

Typical values for the effective roughness parameter are published in the U.S. COE *HEC-1 User's Manual, June 1998*; and EPA *SWMM Version 5.0 Manual, October 2005*. After reviewing the above references, the pervious roughness coefficient for all pervious surfaces was assumed to be 0.2. The impervious roughness coefficient for all impervious surfaces was assumed to be 0.015. A sensitivity analysis was performed using varying overland roughness coefficients during the calibration process, however the analysis revealed the initially-assigned coefficients did not need to be changed.

Infiltration

Infiltration is the movement of water into the soil surface, and the rate of infiltration varies of the length of a storm event. At the beginning of the storm, the initial infiltration rate is the maximum infiltration that can occur because the soil surface is typically drier and full of air spaces. As the storm event continues, the infiltration rate will gradually decrease as the air space in the soil fills with water. For long storms, the infiltration rate will reach a nearly constant value, which is the minimum infiltration rate. The Horton infiltration equation was used to simulate this variation of infiltration rate with time. Horton infiltration variables include maximum infiltration rate (F_0), minimum infiltration rate (F_c), and a parameter known as a decay rate (K), which defines the speed the soil infiltration rate declines from its maximum rate to its minimum rate. The F_0 , F_c , and K values assigned to each watershed were based on the watershed's soils data, or more specifically, the hydrologic soil groups within the watershed.

The Natural Resource Conservation Service (NRCS) soil survey geographic (SSURGO) database released in July 2006 was used to determine the hydrologic soil group classifications of the soils within the study area. For areas where the hydrologic soil group was undefined, a hydrologic soil group was assigned based on the surrounding soils. Figure 4 depicts the hydrologic soil group classifications throughout the study area. The predominant hydrologic soil group in the study area is Type B, which indicates moderate infiltration rates.

No soils verification efforts were performed as part of the data gathering process. It should be noted that a review of the soils showed more uniformity than would be expected in some areas, while other areas showed abrupt changes in hydrologic soil group at county boundaries. These observations may reveal issues in the accuracy of the hydrologic classification.

Table 2 summarizes the hydrologic soil groups and their initially-assigned infiltration parameters and those arrived at after the calibration of the hydrologic model. These rates fall within guidelines established in the SWMM User’s Manual. Horton infiltration parameters were calculated for each subwatershed, so a composite infiltration rate was calculated by computing a weighted average based on the percentage of each soil type in the watershed.

Table 2 Horton Infiltration Parameters

Hydrologic Soil Group	Fo before calibration (in/hr)	Fo after calibration (in/hr)	Fc before calibration (in/hr)	Fc after calibration (in/hr)	K before calibration (in/hr)	K after calibration (in/hr)
A	5	4	0.38	0.3	0.00115	0.00115
B	3	2	0.23	0.15	0.00115	0.00115
C	2	1	0.1	0.05	0.00115	0.00115
A/D, B/D, C/D, D	1	0.7	0.03	0.01	0.00115	0.00115

Subwatershed Width

The SWMM Runoff Non-linear Reservoir Method was used as the hydrograph generation method for this modeling effort. This method computes outflow as the product of runoff velocity and depth, and a watershed width factor. For this analysis, the watershed “width” was calculated using Equation (1) below:

$$W = (2 - Sk) * L \quad (1)$$

where W = subcatchment width
L = length of main drainage channel
Sk = a skew factor calculated using Equation (2)

$$Sk = (A2 - A1)/A \quad (2)$$

where A1 = area to one side of the main drainage channel
A2 = area to the other side main drainage channel
A = total subcatchment area

During calibration of the model a sensitivity analysis was performed using varying width values, which revealed that the originally assigned values did not need to be changed to create a calibrated model that accurately represents the watershed.

2.2 Hydraulic Inputs

Drainage Network

The drainage network consists of established waterways, open ditches, culverts, and bridges used to convey stormwater downstream to the outlet of the Cedar River at the Minnesota state border. The flow control structure information necessary for the detailed modeling was acquired from: (a) various project record drawings and construction plans available from the 4 counties, 29 townships, and the Minnesota Department of Transportation's online database; and (b) surveys performed by the district staff, NRCS staff, and Jones, Haugh and Smith. Figure 5 shows the location of each of the flow control structures included in the existing conditions XP-SWMM model.

A total of 648 structures were surveyed for the 2007 modeling effort and this current modeling effort. Survey information collected on culverts included pipe size, shape, material, invert elevations both upstream and downstream, and the low overflow elevation of the road or berm they pass through. For surveyed bridges, elevations of the bridge deck, the bridge deck width and length, the number and size of piers, and elevation points along the river channel thalweg were surveyed or measured.

The Geneva Lake outlet within the Turtle Creek Watershed District was modeled based on construction plans provided by Ducks Unlimited. Plans provided by the Minnesota Department of Transportation were used to define the geometry at the I-90 crossing on Dobbins Creek and the CSAH 23 bridge on Turtle Creek.

The CRWD intends to update the computer model when projects are constructed to keep it current. For the 2012 modeling, the Rolfson wetland, located at the headwaters of Dobbins Creek, was included in the existing conditions model, and the project storage and control structures were based on engineering reports provided by the Minnesota Board of Soil and Water Resources.

Rainfall Information

Three storm events were evaluated as a part of the existing conditions XP-SWMM modeling: the 2-, 10-, and 100-year 24-hour rainfall events. Rainfall depths were taken from the *Minnesota Hydrology Guide* and are as follows: the 2-year 24-hour rainfall volume is 2.9 inches; 10-year 24-hour rainfall volume is 4.3 inches; the 100-year 24-hour rainfall volume is 6.2 inches. The SCS Type II distribution was used to create the hyetograph for these events.

3.0 Model Calibration

The XP-SWMM model was calibrated so it would produce results that were a good fit with flow data collected at monitoring stations located within the study area for sizeable storms that had recently occurred. Through the calibration process adjustments are made so that the model accurately represents the watershed dynamics as much as possible. The calibration process included modifications to numerous hydrologic variables to accurately represent observed runoff volumes, peak runoff rates, and runoff timing. The methodology and results of the calibration are described in further detail in the following sections.

3.1 Precipitation Data

Calibration for the XP-SWMM model was conducted for the two largest storms occurring in the watershed area since the year 2004 for which there was suitable rainfall information and resulting flow data recorded at the calibration gages. These events occurred on September 15 and 16, 2004 and September 22 and 23, 2010. Data was also collected for two days following the event, resulting in two four-day storm events. Precipitation data for these events was obtained from multiple sources including:

- NEXRAD Doppler precipitation data collected at the KMPX-Minneapolis, MN site; this data ranges from four-minute to twenty-minute intervals.
- Hourly precipitation GIS grids based on National Climatic Data Center (NCDC) multi-sensor data.
- Daily rainfall depths collected at numerous volunteer gages within the Cedar River watershed district and submitted to Minnesota Climatology Working Group's High Density Network (HDN).

Unit hyetographs for each subwatershed were created using rainfall intensities from the NEXRAD data. Total rainfall depth in each watershed was calculated using the hourly NCDC data for the 2004 storm, and the high density network for the 2010 storm. The NEXRAD unit hyetographs were then multiplied by the NCDC or HDN totals to obtain rainfall distributions for each subwatershed. Figures 6 and 7 show the total rainfall depths in each watershed for the two storm events.

3.2 Monitored Gage Data

The Minnesota Department of Natural Resources (MnDNR) has installed monitoring gages at three locations within the Cedar River watershed area. These monitor the flows in the Little Cedar River,

Dobbins Creek, and Turtle Creek near their respective confluence with the Cedar River. Additionally, the United States Geological Survey (USGS) has installed a monitoring gage on the Cedar River downstream of the city of Austin, Minnesota. Figure 8 shows the locations of these monitoring gages.

Two gages were selected to calibrate the XP-SWMM model:

- MnDNR gage 48023001, Cedar River near Lansing CR2
- MnDNR gage 48027001, Turtle Creek at Austin 43rd St

These gages were selected for calibration because they allowed for individual calibration of the Upper Cedar River Watershed and the Turtle Creek Watershed. Since the flow characteristics of these watersheds varied (overall watershed slope and the number of ditches in the Turtle Creek Watershed as opposed to the Upper Cedar River Watershed) individual calibration of each watershed allowed for more flexibility and a more accurate calibration. The USGS gage 05457000, Cedar River near Austin, MN, was selected to validate the calibrated models.

The Cedar River near Lansing gage contains a 164 square mile tributary of predominantly agricultural land use. This gage is located just downstream of the Cedar River and Roberts Creek confluence. The Turtle Creek gage includes drainage from Turtle, Mud and Deer Creeks, as well as Lake Geneva. This tributary area is approximately 147 square miles in size and is also predominantly agricultural land use. The USGS gage is located downstream of the city of Austin and just over a mile downstream of the Cedar River and Turtle Creek confluence. This gage also includes inputs from the Wolf, Murphy and Dobbins Creeks.

Stream gages recorded water depth and flow at 15-minute intervals. The exception is the USGS stream gage during the 2004 event, which only recorded daily flow totals. However, water depth was recorded at periodic intervals for that station. Using water-depth and a USGS published rating curve, flows were extrapolated for each water depth data point in order to check the flow calibration at that location.

3.3 Calibration Results

The XP-SWMM model was calibrated to two storm events at three monitoring stations. During calibration, hydrologic variables were modified to adjust the modeled hydrographs in effort to create a best match to the recorded data. Model calibration focused on matching the recorded stage, peak flow rate, and the general shape of the hydrographs for each storm event.

Comparisons of the observed and modeled stage hydrographs from the three calibration sites and two storm events are shown Figures 9 through 14. Overall, the modeled hydrographs reflect a good fit with the monitored runoff. The minor deviations between the modeled results and the gage station flow data are most likely due to the variability of tile across the watershed and the different crop types affecting the overland roughness. Inaccuracies in soils data can also affect the calibration results. The existing conditions model is not detailed enough to vary roughness based on crop type (or time of year) nor does it take into account where tile systems are located in the watershed.

The surface model alone did not result in a satisfactory match to actual measured flows. Through the calibration process, it was determined it was necessary to return some of the infiltrated runoff back into the system to simulate the effects of the drain tiles located in the agricultural land. The “groundwater” module in XP-SWMM allowed infiltrated runoff to be returned to each subwatershed at a delayed rate much like a drain tile would function in a field. A sensitivity analysis was conducted to determine which groundwater parameters affected the rate at which runoff was directed back into the subwatersheds. For calibration purposes, the input parameters that defined the saturated hydraulic conductivity of the soil were adjusted. Due to differences in soil types and drain tile simulations, saturated hydraulic conductivity was calculated separately for the Cedar River and Turtle Creek watersheds. Table 3 lists the variables within the groundwater module that were used for calibration for the two watersheds.

Table 3 Values Used in the Groundwater Module to Represent Drain Tile in Cedar River and Turtle Creek Watersheds

Parameter	Value used for the Cedar River Watershed	Value used for the Turtle Creek Watershed
Saturated Hydraulic Conductivity	0.1	0.23
Porosity Expressed as a Fraction	0.9	0.9
Curve Fitting Parameter	5	5
Initial Upper Zone Moisture (as fraction)	0.5	0.5
Coefficient for Unquantified Losses	0.0035	0.0035

Calibration also included evaluation of runoff volume, as represented by the runoff depth. Observed and modeled runoff depths were calculated for each storm event at each calibration site. The runoff depths were calculated from the measured and the modeled runoff using the equation:

$$\text{Runoff Depth} = \text{Measured (or Modeled) Runoff Volume} / \text{Drainage Area}$$

Table 4 summarizes the runoff depths for observed conditions and the calibrated model results..

Table 4 Runoff Depths based on Observed and Modeled Conditions

		Storm Event	
		September 14-14, 2004	September 22-25, 2010
MnDNR # 48023001	RO Depth Gage [in]	3.93	3.23
	RO Depth XP-SWMM [in]	3.67	3.46
	Percent Difference [%]	6.79	6.64
	RO Depth XP-SWMM with Groundwater module [in]	4.94	4.32
	Percent Difference [%]	22.78	28.77
MnDNR # 48027001	RO Depth Gage [in]	2.22	1.44
	RO Depth XP-SWMM [in]	3.96	3.28
	Percent Difference [%]	56.22	78.01
	RO Depth XP-SWMM with Groundwater module [in]	5.82	4.40
	Percent Difference [%]	89.40	101.25
USGS # 05457000	RO Depth Gage [in]	2.67	1.63
	RO Depth XP-SWMM [in]	3.39	3.05
	Percent Difference [%]	23.77	60.66
	RO Depth XP-SWMM with Groundwater module [in]	4.83	4.03
	Percent Difference [%]	57.48	84.78

4.0 Future Model Uses

This 2012 modeling effort is possibly the most important step in aiding the CRWD and TCWD achieve their goals for flood control, as it helps each understand the current flow dynamics for various storms throughout their respective watershed. It enables both watershed districts to understand all of the current flow control features in their respective watershed are a system and not individual autonomous structures.

The existing conditions model is a tool that will be used in the future to evaluate the hydraulic effects of any proposed flow control device or group of devices that either watershed district is considering constructing. Such devices might include, but are not limited to, new ponding basins with new outlet structures, flow diversions, modifications to existing culverts and roads, and wetland restorations. For example, additional proposed basins to those included in the existing conditions model, or modification to any current feature could be evaluated to determine its incremental impact on achieving the 20% peak flow rate reduction for 100-year flows passing through Austin. The model can also be used to define the flow rate goals across the district where there are no current flow rate goals set. This information would then be incorporated into the next version of the CRWD's and TCWD's Watershed Management Plan.

In addition to supporting each watershed district in achieving their respective flood control goals, the following are other potential uses of the existing conditions model:

1. Proposed land use changes in the watershed (such as new residential, commercial, or industrial developments) can be integrated into the model to define the changes in runoff rates from a subwatershed and determine their effect on flood flows, and what resources are needed to ensure they do not negatively impact land or the water resources.
2. The model can be used to support County or Township road construction, or culvert or bridge replacement. Changes in road elevation or culvert and bridge configurations can easily be modeled to determine how flow rates are affected and to help size such features.
3. The model can be easily updated as projects across the two districts are implemented so a current maintained model will always be available.
4. Model output can be used concurrently with water quality software to define water quality treatment across the district.

5. The XP-SWMM model software is accepted by FEMA for development of flood insurance rate maps (FIRMs). As such it can be used when needed to rectify issues with FEMA-developed FIRMs that are not perceived to accurately depict the 100-year flood plain.