North Dakota State Water Commission

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August 22, 2017

Mr. Ron Beyer, P.E., Chief Hydrology Section
US Army Corps of Engineers
Omaha District Hydrologic Engineering Branch
1616 Capitol Avenue
Omaha, NE 68102-4901

RE: Emmons County Section 22 Hydrology Report Erratum

Dear Mr. Beyer,

An error was found in the Beaver Creek Hydrology Report dated August 2016. On page 26, within Table 11, under the 20 percent chance of annual occurrence event, the initial storage deficit should state "Initial peak subbasins set to 2.5 in, all others set to 2.0 in" rather than the "All subbasins set to 2.0 or 2.1 in". The corrected page is attached.

Although, the results of the hydrology model remain unchanged from those published, the hydrology model was updated to separate the 20 percent and 50 percent annual occurrence synthetic basins for clarity. An updated hydrology model has been sent to you and Jennifer Davis via the Corps' Safesite. Please feel free to contact me with any questions.

Sincerely,

Mitch Weier P.E.
Water Resource Engineer
MW:ph/558

cc: Jennifer Davis, P.E., Hydrologic Engineer, US Army Corps of Engineers
Glenn Geffre, Chairman, Emmons County Resource District

Beaver Creek Hydrology Report

Emmons, Logan, and McIntosh Counties, North Dakota

SWC Project #558
August 2016

North Dakota
State Water Commission

Cover photograph: Beaver Creek near Linton, ND. (photograph by Mitch Weier, North Dakota State Water Commission, 2011)

Beaver Creek Hydrology Report

Emmons, Logan, and McIntosh Counties, North Dakota

SWC Project #558
North Dakota State Water Commission
900 East Boulevard
Bismarck, ND 58505-0850

For Acceptance by:
United States Army Corps of Engineers - Omaha District

August 2016

Prepared by:

REGISTERED PROFESSIONAL ENGINEER
MITCHELL
WEIER
PE-6984
DATE 8/5/16
NORTH DAKOTA

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Water Resource Engineer

Submitted by:

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State Engineer

North Dakota
State Water Commission

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Introduction

Beaver Creek is a tributary to the Missouri River that flows through Logan, McIntosh, and Emmons Counties in North Dakota (**Figure 1**). The City of Linton, located within Emmons County, has experienced numerous floods from Beaver Creek and local tributaries. Following the 2009 flood of record at Linton, the Emmons County Water Resource District (District) entered a Planning Assistance to States (Section 22) agreement with the United States Army Corps of Engineers (USACE) to conduct a study identifying measures that may mitigate flood damages at Linton. To aid in this study, the District entered an agreement with the North Dakota State Water Commission (SWC) to model existing hydrologic and hydraulic conditions. This report documents the hydrologic model development for the Beaver Creek watershed and storage area screening completed by the SWC as part of this study.

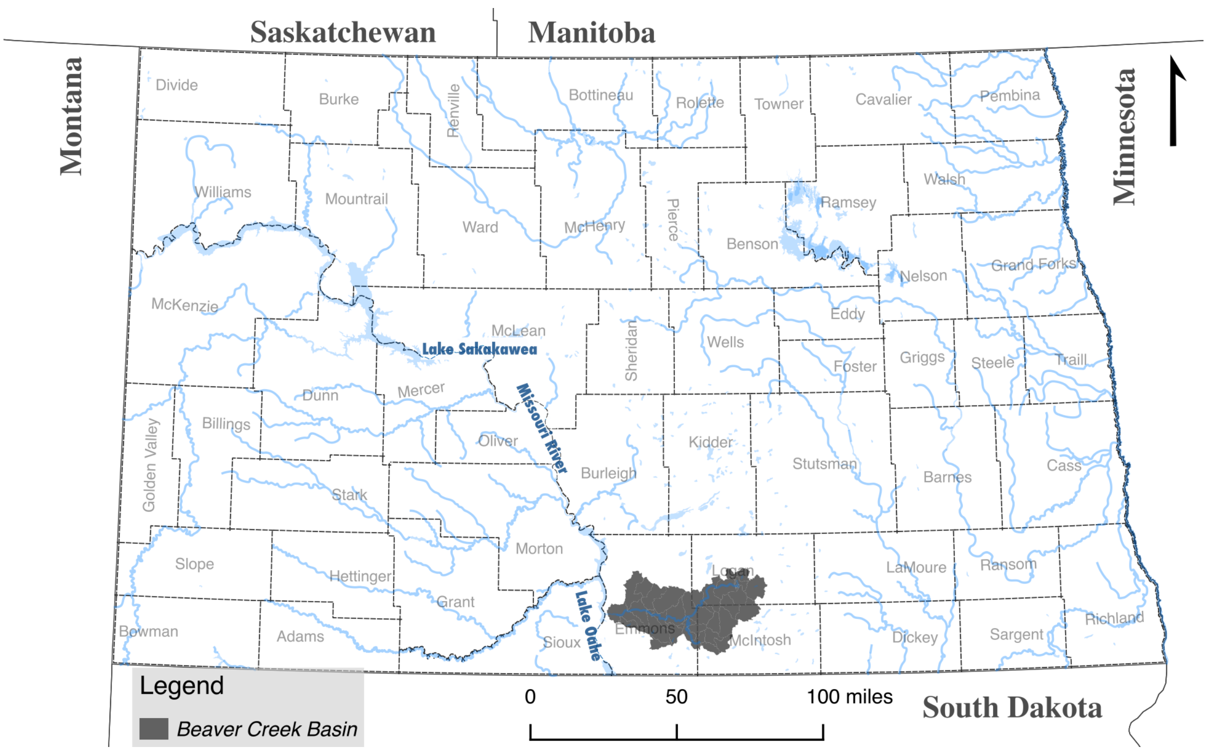

Figure 1: Project location.

A model was developed using HEC-HMS Version 4.0 software (Hydrologic Engineering Center, 2013). The model was used to determine the response of the Beaver Creek basin for several synthetic storm events. Infiltration losses and the runoff transformation were based on the deficit and constant loss method and the Clark transformation method, respectively. Other inputs include the watershed area, soil porosity and vertical hydraulic conductivity, land use, time of concentration, storage and elevation relationship for Beaver Lake, potential evapotranspiration (ET), and snowmelt and precipitation distributions and rates. The model was calibrated using four historical rainfall events and one historical snowmelt and rainfall event with available precipitation and stream gage data. Based on the calibration results, adjusted parameters were used to model synthetic events and these results were compared to statistically derived synthetic events from observed stream gage data. The model and associated geographical information system (GIS) files are included as an electronic appendix within **Appendix A**.

Study Location

The Beaver Creek watershed is located within south central North Dakota (**Figure 1**). The meandering creek flows west from Beaver Lake to the Missouri River. The northern and eastern portions of the watershed are characterized by steep, rolling hills and hummocky areas with non-integrated drainage existing near the southern and eastern edges of the basin.

Gage Locations

Currently there are three United States Geological Survey (USGS) streamflow gages within the basin (**Figure 2**). USGS gage 06354480 near Zeeland, ND is located on the South Branch Beaver Creek and was installed in 2009. USGS gage 06354490 near Strasburg, ND is located south of the confluence of Beaver Creek and South Branch Beaver Creek only provides stage data and also was installed in 2009. USGS gage 06354500 at Linton was operated from 1950 through September 1989. USGS gage 06354580 below Linton is located below Spring Creek and has operated since October 1989.

Calculated Watershed Parameters

Drainage Area

The size of the Beaver Creek drainage basin was estimated as 944 square miles (sq. mi.) with about 133 sq. mi. that are likely non-contributing (**Figure 2**). The watershed boundaries were estimated by processing the 1/3 arc second scaled Digital Elevation Map (DEM) from the National Elevation Dataset (NED) (Gesch et. al, 2002; Gesch, 2007) using the r.stream.extract algorithm within GRASS GIS (Jasiewicz and Metz, 2011; GRASS Development Team, 2012). The NED version used for this analysis was based on the USGS topographic map data collected in 1966. The boundaries were checked by aerial photos, USGS 1:24,000 scale quadrangle topographic maps of the area, hydrologic unit maps (USGS et. al., 2012), and limited field observations. **Figure 2** and **Table 1** contain the 27 subasins created in the watershed based on drainage characteristics, USGS stream gage locations, and potential storage sites. Beaver Lake was modeled as a subbasin to allow for a more realistic response to rainfall (i.e. no lag time).

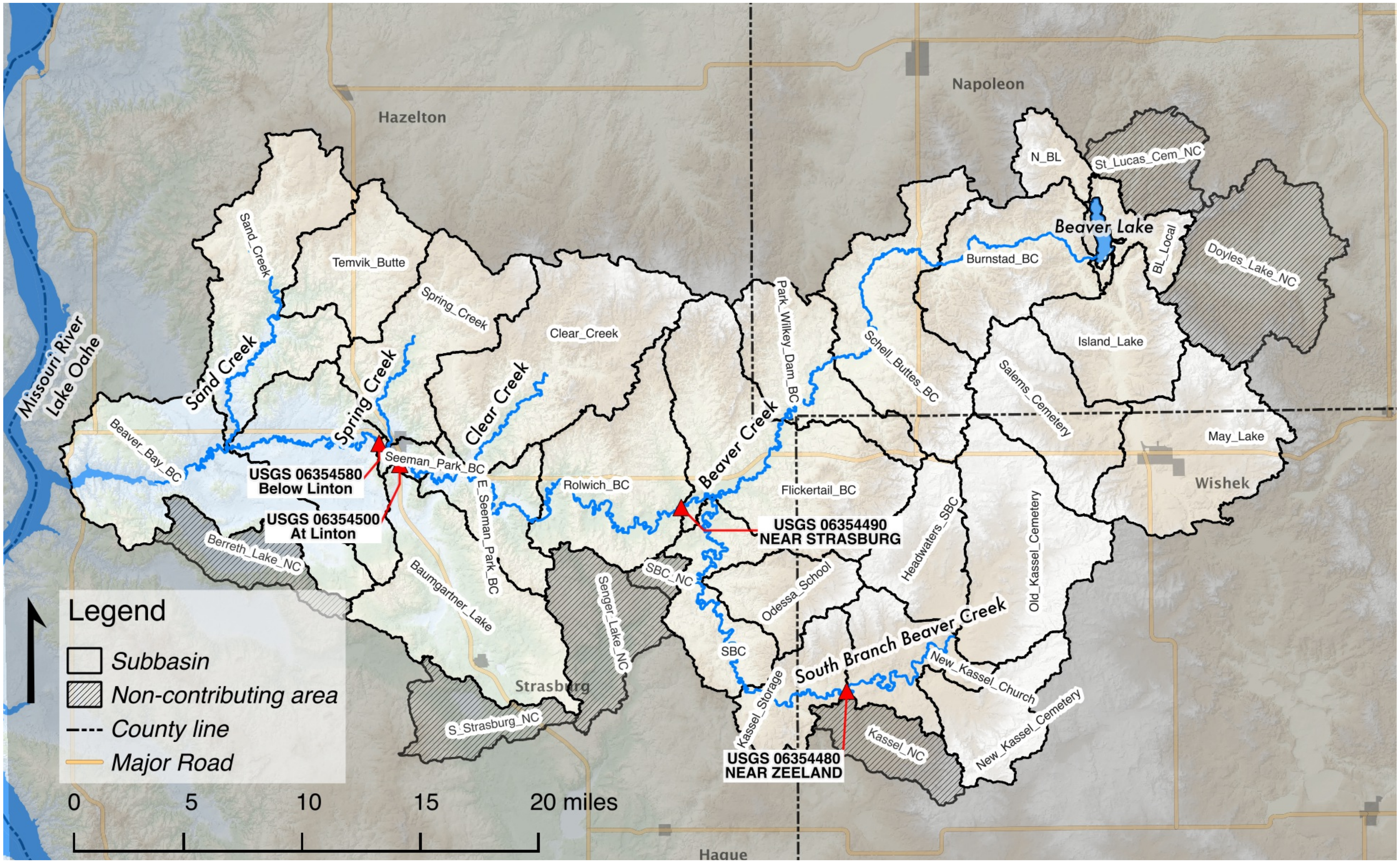

Figure 2: Beaver Creek subbasins and stream gages.

Table 1: Estimated subbasin parameters.

		Canopy		Deficit and Constant Loss				Clark Unit Hydrograph			Baseflow		
Subbasin	**Area, mi^2**	**Max Storage, in**	**Crop Coefficient**	**Initial Storage Deficit, in**	**Maximum Storage, in**	**Constant Rate, in/hr**	**Impervious, %**	**Travel Time (T_c), hrs**	**Storage Coefficient (R), hrs**	**$R/(R+T_c)$**	**Initial Baseflow**	**Recession Constant**	**Ratio to Peak**
May_Lake	41.6	0.02	1	Varies	4.949	0.171	1.01	13.92	9.28	0.4	0.04	0.85	0.15
Salems_Cemetery	29.4	0.02	1	Varies	5.323	0.130	0.28	12.73	8.49	0.4	0.04	0.85	0.15
Island_Lake	26	0.02	1	Varies	5.133	0.137	0.16	12.55	8.37	0.4	0.04	0.85	0.15
BL_Local	11	0.02	1	Varies	5.212	0.132	0.28	7.8	5.20	0.4	0.04	0.85	0.15
N_BL	8.5	0.02	1	Varies	5.014	0.163	0.13	9.95	6.63	0.4	0.04	0.85	0.15
Beaver_Lake	1.7	0.02	1	Varies	0.010	0.000	0.18	2.81	1.87	0.4	-	-	-
Burnstad_BC	35.5	0.02	1	Varies	5.330	0.153	0.29	10.89	7.26	0.4	0.04	0.85	0.15
Schell_Buttes_BC	44.2	0.02	1	Varies	5.319	0.160	0.39	15.09	10.06	0.4	0.04	0.85	0.15
Park_Wilkey_Dam_BC	27.5	0.02	1	Varies	5.224	0.231	0.36	15.86	10.57	0.4	0.04	0.85	0.15
Old_Kassel_Cemetery	43.7	0.02	1	Varies	5.231	0.143	0.29	13.59	9.06	0.4	0.04	0.85	0.15
Headwaters_SBC	21.9	0.02	1	Varies	5.258	0.135	0.34	13.12	8.75	0.4	0.04	0.85	0.15
New_Kassel_Cemetery	20.9	0.02	1	Varies	5.159	0.129	0.23	14.8	9.87	0.4	0.04	0.85	0.15
New_Kassel_Church	20.7	0.02	1	Varies	5.270	0.118	0.33	20.43	13.62	0.4	0.04	0.85	0.15
Kassel_Storage	17.6	0.02	1	Varies	5.216	0.148	0.32	14.77	9.85	0.4	0.04	0.85	0.15
Odessa_School	16.9	0.02	1	Varies	5.375	0.126	0.29	15.23	10.15	0.4	0.04	0.85	0.15
SBC	22.6	0.02	1	Varies	5.451	0.120	0.39	30.89	20.59	0.4	0.04	0.85	0.15
Flickertail_BC	60.8	0.02	1	Varies	5.353	0.175	0.38	25.09	16.73	0.4	0.04	0.85	0.15
Rolwich_BC	40.8	0.02	1	Varies	5.507	0.110	0.4	27.91	18.61	0.4	0.04	0.85	0.15
Clear_Creek	57.6	0.02	1	Varies	5.636	0.096	0.26	25.92	17.28	0.4	0.04	0.85	0.15
E_Seeman_Park_BC	17.7	0.02	1	Varies	5.480	0.109	0.39	15.9	10.60	0.4	0.04	0.85	0.15
Baumgartner_Lake	48.5	0.02	1	Varies	5.198	0.199	0.83	19.69	13.13	0.4	0.04	0.85	0.15
Spring_Creek	35.7	0.02	1	Varies	5.676	0.087	0.55	22.16	14.77	0.4	0.04	0.85	0.15
Seeman_Park_BC	3.6	0.02	1	Varies	5.493	0.133	7.88	7.55	5.03	0.4	0.04	0.85	0.15
Temvik_Butte	24.4	0.02	1	Varies	5.802	0.077	0.32	19.89	13.26	0.4	0.04	0.85	0.15
Sand_Creek	48.5	0.02	1	Varies	5.702	0.112	0.1	35.8	23.87	0.4	0.04	0.85	0.15
Maier_Lake_BC	33.3	0.02	1	Varies	5.149	0.218	0.21	21.87	14.58	0.4	0.04	0.85	0.15
Beaver_Bay_BC	50.3	0.02	1	Varies	5.128	0.250	0.25	15.8	10.53	0.4	0.04	0.85	0.15

Non-contributing drainage areas were determined by calculating the storage available within large depressions using the NED and with a runoff volume calculated by multiplying the depression's drainage area by 4.5 inches, which is approximately the 10-day 1-percent annual chance runoff event found in TR-60 for the Beaver Creek basin (U.S. Department of Agriculture, 2005). Detailed calculations are shown in **Appendix B**.

Loss Method

The deficit and constant loss method was used to better account for drying of the soil over multiple rain events. A simple canopy method was also used to allow for ET accounting. Initial loss parameters estimates are summarized in **Table 1**.

Soils parameters such as porosity and saturated vertical hydraulic conductivity within the basin were estimated from the Soil Survey Geographic (SSURGO) Database maintained by the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) National Geospatial Management Center (NGMC) for Emmons, Logan, and McIntosh Counties (Soil Survey Staff, 2013). The SSURGO representative vertical hydraulic conductivity overestimated the constant rate suggested in the HMS Technical Reference Manual (Hydrologic Engineering Center, 2000), so the conductivity was reduced by a factor of 16. The methods used to estimate these parameters are explained in **Appendix C**. The distribution of the estimated constant rate for the upper 18 inches of soil depth is shown in **Figure 3**. Impervious areas for the basin were obtained from the 2006 National Land Cover Dataset (NLCD) from the USGS for Emmons, Logan, and McIntosh County (Fry et al., 2011).

An initial constant rate was estimated from the saturated vertical hydraulic conductivity. Since it was assumed that the top 18 inches of soil largely controls infiltration, the maximum storage was estimated by multiplying the saturated water content (which is a surrogate for porosity) minus the water content at the wilting point (assumed to be 0.15 for all soils) by 18 inches.

A nominal canopy storage of 0.02 inches was assumed for all areas. A crop coefficient of 1.0 was assumed because potential ET was calculated outside the HMS model using a 'short' crop reference equation (American Society of Civil Engineers, 2005) and the overall effect of ET is not typically significant for a single flood event.

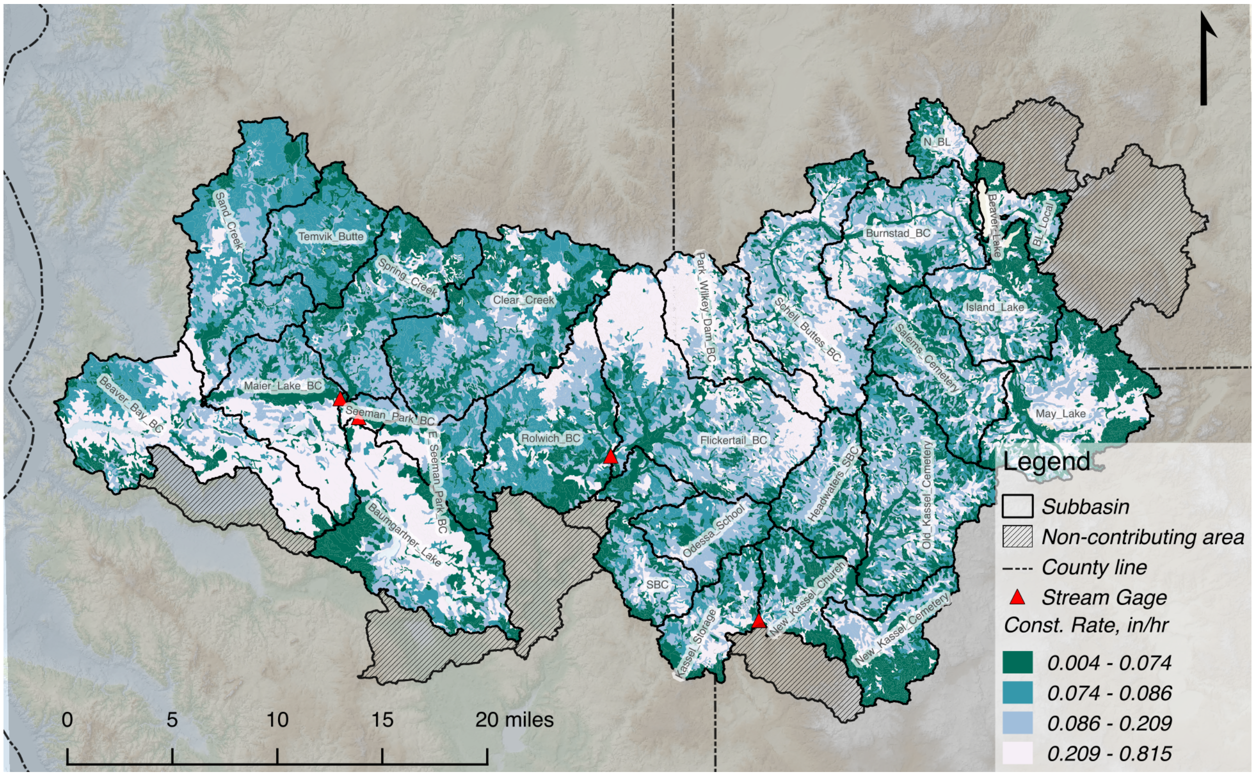

Figure 3: Constant infiltration rate distribution.

Hydrograph Development

The Clark unit hydrograph was used as a runoff transform. This method requires two parameters: the time of concentration (Tc), or the maximum travel time in each subbasin, and a storage parameter. Original travel time and storage parameter estimates are summarized in **Table 1**.

Time of concentration was calculated by using a gridded GIS travel time tool developed by the Minnesota Department of Natural Resources and revised by the SWC. A detailed explanation of the tool can be found in **Appendix D**.

The USACE has identified calibrated storage parameter values (R) throughout the Red River of the North Hydrologic Modeling – Phase 2 (USACE, 2012). From these calibrated values, initial estimates of R were obtained by applying a value of 0.4 for the R/(R+Tc) parameter over the watershed. These estimates are shown in **Table 1**.

Baseflow Method

The recession baseflow method was selected to model baseflow. Initial parameters were assumed to be 0.04 cubic feet per second per square mile (cfs/ sq. mi.), 0.8 for the recession constant, and 0.15 for the ratio to peak (**Table 1**); however, these are typically variable depending on the event conditions.

Routing Method

The Muskingum-Cunge routing method was used to route flow from junctions and selected reaches of subbasins. A representative cross-section and the channel slope for each reach were obtained from the NED, and channel geometry was estimated from aerial photos. Reach lengths and slopes were calculated using GIS. A minimum slope of 0.0004 was used in reaches that had a slope of less than 0.0004. A Manning's roughness of 0.035 was assumed and was adjusted as needed during calibration. **Figure 4** shows the modeled routing reaches. **Table 2** summarizes the estimated routing reach parameters.

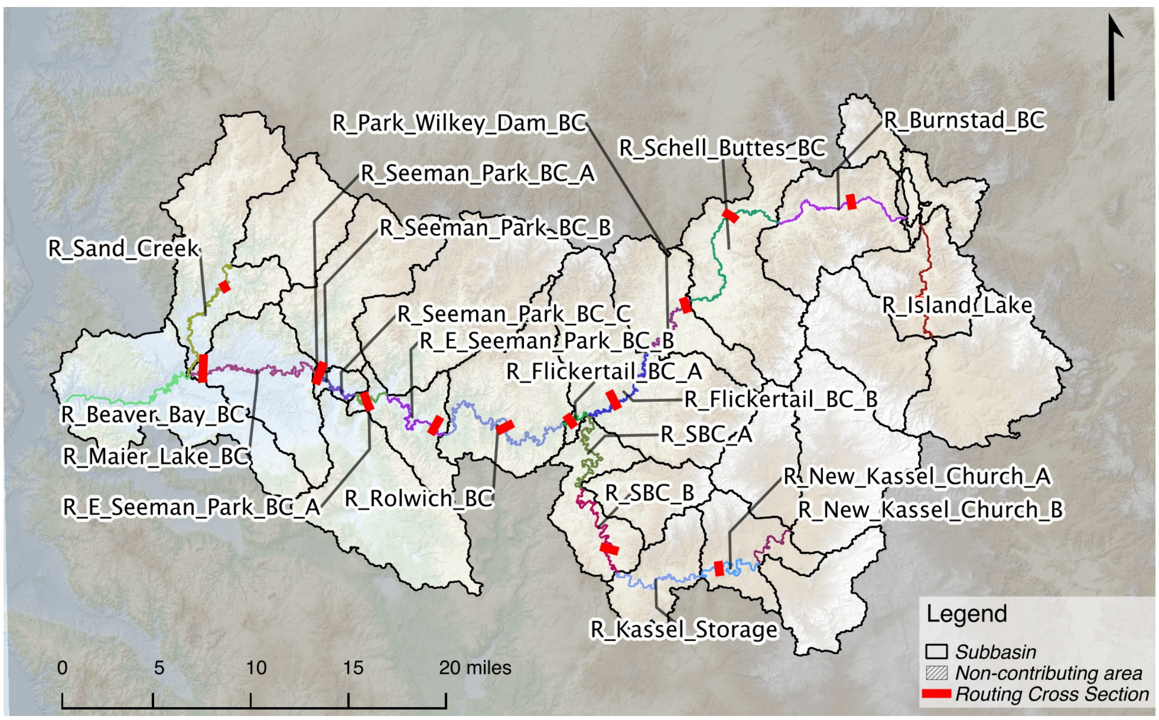

Figure 4: Routing reaches.

Table 2: Estimated routing reach parameters.

Reach	Length, ft	Slope	Left Bank Manning's n	Manning's n	Right Bank Manning's n	Invert, ft	Representative Cross Section
R_Island_Lake	51,297	0.0006	0.06	0.035	0.06	1977	R_Island_Lake
R_Burnstad_BC	59,873	0.0005	0.06	0.035	0.06	1949	R_Burnstad_BC
R_Schell_Buttes_BC	81,987	0.0006	0.06	0.035	0.06	1909	R_Schell_Buttes_BC
R_Park_Wilkey_Dam_BC	44,857	0.0004	0.06	0.035	0.06	1877	R_Park_Wilkey_Dam_BC
R_Flickertail_BC_B	58,676	0.0006	0.06	0.035	0.06	1854	R_Flickertail_BC_B
R_New_Kassel_Church_B	27,693	0.0005	0.06	0.035	0.06	2017	R_Flickertail_BC_A
R_New_Kassel_Church_A	46,347	0.0005	0.06	0.035	0.06	1996	R_New_Kassel_Church_A
R_Kassel_Storage	54,957	0.0008	0.06	0.035	0.06	1965	R_New_Kassel_Church_A
R_SBC_B	70,291	0.0009	0.06	0.035	0.06	1912	R_SBC_B
R_SBC_A	76,226	0.0006	0.06	0.035	0.06	1862	R_SBC_B
R_Flickertail_BC_A	15,625	0.0004	0.06	0.035	0.06	1835	R_SBC_B
R_Rolwich_BC	114,662	0.0005	0.06	0.035	0.06	1814	R_Flickertail_BC_A
R_E_Seeman_Park_BC_B	51,337	0.0005	0.06	0.035	0.06	1755	R_E_Seeman_Park_BC_B
R_E_Seeman_Park_BC_A	26,547	0.0005	0.06	0.035	0.06	1723	R_E_Seeman_Park_BC_A
R_Seeman_Park_BC_C	20,300	0.0005	0.06	0.035	0.06	1707	R_SeemanPark_BC_A
R_Seeman_Park_BC_B	9,740	0.0005	0.06	0.035	0.06	1699	R_SeemanPark_BC_A
R_Seeman_Park_BC_A	4,065	0.0005	0.06	0.035	0.06	1695	R_SeemanPark_BC_A
R_Maier_Lake_BC	93,448	0.0005	0.06	0.035	0.06	1661	R_MaierLake
R_Sand_Creek	88,062	0.0014	0.06	0.035	0.06	1698	R_Sand_Creek
R_Beaver_Bay_BC	76,464	0.0005	0.06	0.035	0.06	1624	R_MaierLake

Beaver Lake Storage and Elevation Relationship

Level pool routing was used to model the storage effect of Beaver Lake. A relationship between water storage and elevation for Beaver Lake is shown in **Table 3**. The area and capacity of Beaver Lake at an elevation of 1962.5 ft North American Datum of 1988 (NAVD88) was obtained from SWC's structures database. Areas above elevation 1962.5 ft were calculated from the NED. The initial lake elevation was set at 1963.68 ft in the HEC-HMS model. The spillway and dam top were modeled within HEC-HMS as broad crested weirs using a weir coefficient of 3.1.

Table 3: Beaver Lake storage elevation relationship.

Elevation, ft NAVD88	Storage, ac-ft
1955	0
1962.5	5,319
1963.7	5,447
1965.3	7,247
1967	9,140
1968.6	12,267
1970.2	15,291
1971.9	18,439
1973.5	21,860
1975.2	25,460

Model Calibration

Hydrographs from USGS stream gages 06354500 at Linton and 06354580 below Linton were reviewed to select the calibration events. Based on these data, it is apparent that the majority of the annual peak flows occurred during the spring melt. Four rainfall events were selected, June 2005, July 2011, June 2013, and June 2014, because of the distinct hydrograph peak that resulted and the availability of gridded rainfall data. The 2009 snowmelt event was also modeled.

The rain event models were run at an hourly time step, and output was compared to stream gage data with 15-minute resolution. The 2009 snowmelt event model also was run at an hourly time step; however, it only had a partial gage record available at a 15-minute resolution, so the daily average values were used for this calibration.

Meteorological Model Development

Rainfall

Rainfall was estimated by using hourly Quantitative Precipitation Estimate (QPE) rasters developed by the National Oceanic and Atmospheric Administration (NOAA) River Forecast Centers (RFC) and National Centers for Environmental Prediction - Environmental Modeling Center (Lin and Mitchell, 2005; National Center for Atmospheric Research, 2002). The QPE rasters contain hourly total rainfall estimates derived from radar data with approximately 4-km resolution that has been corrected to gage data and undergone a manual quality check by the responsible RFC.

An average value was obtained from each rainfall raster and a hyetograph was specified for each subbasin.

Snowmelt

Snowmelt was estimated by using daily snowmelt and liquid precipitation rasters obtained from NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) SNOw Data Assimilation System (SNODAS) model (NOHRSC, 2004). The sum of the snowmelt and liquid precipitation rasters were used as an estimate of total runoff. The raster data has 1-km spatial resolution and provides a consistent framework that integrates snow data from a variety of sources including remote sensing and ground surveys.

An average value was obtained from each liquid precipitation and snowmelt raster and a hyetograph was specified for each subbasin.

Evapotranspiration

ET was estimated by using data obtained from the North Dakota Agricultural Weather Network's (NDAWN) Linton station and calculating potential ET (PET) using the Penman-Monteith standard reference ET equation referencing 'short' vegetation as outlined in American Society of Civil Engineers, 2005.

An ET gage was created in the model and was applied to each subbasin for each calibration event.

Watershed Parameter Adjustment

The model was calibrated by adjusting loss, transform, and baseflow parameters. Generally, adjustments to parameters were made that produced a modeled hydrograph which reasonably fit the observed hydrographs at the gage below Linton (USGS 06354580) for all events and at the gage near Zeeland (USGS 06354480) when applicable.

Most parameters were adjusted from the initial estimates and held constant across all rainfall events. The parameters that varied between rainfall events include initial soil moisture deficit, initial baseflow, and ratio to peak constant. **Tables 4** and **5** summarize the calibrated watershed and routing parameters, respectively.

Saturated hydraulic conductivity values obtained from the SSURGO database were reduced by a factor of 16 to obtain constant infiltration rates. These constant infiltration rates remained were unchanged across the rainfall events. Generally, initial travel time estimates were unchanged for the rainfall events; however, Clark storage coefficients were adjusted by the $R/(R+T_c)$ parameter to better fit the model and observed hydrographs.

Constant rate and ET parameters were adjusted during the 2009 snowmelt event. The constant rate was reduced by a factor of 7, and ET was not considered.

Table 4: Calibrated subbasin parameters.

Subbasin	Area, mi^2	Canopy		Deficit and Constant Loss				Clark Unit Hydrograph			Baseflow		
		Max Storage, in [a]	Crop Coefficient [a]	Initial Storage Deficit, in	Maximum Storage, in	Constant Rate, in/hr [b]	Impervious, %	Travel Time (T_c), hrs	Storage Coefficient (R), hrs [c]	$R/(R+T_c)$	Initial Baseflow	Recession Constant	Ratio to Peak
May_Lake	41.6	0.02	1	***2.50 - 1.10***	4.949	0.171	1.01	13.92	***32.48***	***0.70***	***0.2 - 0.04***	0.85	***0.15 - 0.05***
Salems_Cemetery	29.4	0.02	1	***2.50 - 1.10***	5.323	0.130	0.28	12.73	***29.70***	***0.70***	***0.2 - 0.04***	0.85	***0.15 - 0.05***
Island_Lake	26	0.02	1	***2.50 - 1.10***	5.133	0.137	0.16	12.55	***29.28***	***0.70***	***0.2 - 0.04***	0.85	***0.15 - 0.05***
BL_Local	11	0.02	1	***2.50 - 1.50***	5.212	0.132	0.28	7.80	***18.20***	***0.70***	***0.2 - 0.04***	0.85	***0.15 - 0.05***
N_BL	8.5	0.02	1	***2.50 - 1.50***	5.014	0.163	0.13	9.95	***23.22***	***0.70***	***0.2 - 0.04***	0.85	***0.15 - 0.05***
Beaver_Lake	1.7	0.02	1	0.00	0.010	0.000	0.18	2.81	***0.10***	***0.03***	-	-	-
Burnstad_BC	35.5	0.02	1	***2.50 - 1.50***	5.330	0.153	0.29	10.89	***10.89***	***0.50***	***0.2 - 0.04***	0.85	***0.15 - 0.05***
Schell_Buttes_BC	44.2	0.02	1	***2.40 - 1.50***	5.319	0.160	0.39	15.09	10.06	0.40	***0.2 - 0.04***	0.85	***0.15 - 0.05***
Park_Wilkey_Dam_BC	27.5	0.02	1	***2.40 - 1.50***	5.224	0.231	0.36	15.86	***10.57***	***0.40***	***0.2 - 0.04***	0.85	***0.15 - 0.05***
Old_Kassel_Cemetery	43.7	0.02	1	***2.60 - 0.90***	5.231	0.143	0.29	***24.10***	***56.23***	***0.70***	***0.04 - 0.04***	0.85	***0.05 - 0.02***
Headwaters_SBC	21.9	0.02	1	***2.60 - 0.90***	5.258	0.135	0.34	***24.00***	***24.00***	***0.50***	***0.04 - 0.04***	0.85	***0.05 - 0.02***
New_Kassel_Cemetery	20.9	0.02	1	***2.60 - 1.30***	5.159	0.129	0.23	***34.00***	***34.53***	***0.50***	***0.04 - 0.04***	0.85	***0.05 - 0.02***
New_Kassel_Church	20.7	0.02	1	***2.60 - 1.30***	5.270	0.118	0.33	20.43	***47.67***	***0.70***	***0.04 - 0.04***	0.85	***0.05 - 0.02***
Kassel_Storage	17.6	0.02	1	***2.20 - 1.50***	5.216	0.148	0.32	***15.00***	***10.00***	0.40	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Odessa_School	16.9	0.02	1	***2.20 - 1.50***	5.375	0.126	0.29	15.23	***10.15***	***0.40***	***0.20 - 0.04***	0.85	***0.15 - 0.05***
SBC	22.6	0.02	1	***2.20 - 1.50***	5.451	0.120	0.39	***15.00***	***15.00***	***0.50***	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Flickertail_BC	60.8	0.02	1	***2.30 - 1.50***	5.353	0.175	0.38	25.09	***16.73***	***0.40***	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Rolwich_BC	40.8	0.02	1	***2.20 - 1.80***	5.507	0.110	0.4	27.91	***18.61***	***0.40***	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Clear_Creek	57.6	0.02	1	***2.50 - 1.80***	5.636	0.096	0.26	***8.00***	***4.00***	***0.33***	***0.20 - 0.04***	0.85	***0.15 - 0.05***
E_Seeman_Park_BC	17.7	0.02	1	***2.60 - 1.80***	5.480	0.109	0.39	15.90	***15.90***	***0.50***	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Baumgartner_Lake	48.5	0.02	1	***2.60 - 1.80***	5.198	0.199	0.83	***10.60***	***7.07***	***0.40***	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Spring_Creek	35.7	0.02	1	***2.40 - 1.80***	5.676	0.087	0.55	***13.80***	***9.20***	0.40	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Seeman_Park_BC	3.6	0.02	1	***2.40 - 1.80***	5.493	0.133	7.88	7.55	***17.62***	***0.70***	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Temvik_Butte	24.4	0.02	1	***2.40 - 1.50***	5.802	0.077	0.32	19.89	13.26	0.40	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Sand_Creek	48.5	0.02	1	***2.40 - 1.50***	5.702	0.112	0.1	35.80	***23.87***	***0.40***	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Maier_Lake_BC	33.3	0.02	1	***2.40 - 1.50***	5.149	0.218	0.21	21.87	14.58	0.40	***0.20 - 0.04***	0.85	***0.15 - 0.05***
Beaver_Bay_BC	50.3	0.02	1	***2.40 - 1.50***	5.128	0.250	0.25	15.80	***10.53***	***0.40***	***0.20 - 0.04***	0.85	***0.15 - 0.05***

Notes:

Bold and italic font indicates parameter has been adjusted from initial estimate

[a] - canopy was not modeled for 2009 snowmelt event

[b] - constant rate was decreased by a factor of 7 for the 2009 snowmelt event

Table 5: Calibrated routing reach parameters.

Reach	Length, ft	Slope	Left Bank Manning's n	Manning's n	Right Bank Manning's n	Invert, ft	Representative Cross Section
R_Island_Lake	51,297	0.0006	0.06	***0.038***	0.06	1977	R_Island_Lake
R_Burnstad_BC	59,873	0.0005	0.06	***0.038***	0.06	1949	R_Burnstad_BC
R_Schell_Buttes_BC	81,987	0.0006	0.06	***0.038***	0.06	1909	R_Schell_Buttes_BC
R_Park_Wilkey_Dam_BC	44,857	0.0004	0.06	***0.038***	0.06	1877	R_Park_Wilkey_Dam_BC
R_Flickertail_BC_B	58,676	0.0006	0.06	***0.038***	0.06	1854	R_Flickertail_BC_B
R_New_Kassel_Church_B	27,693	0.0005	***0.07***	***0.045***	***0.07***	2017	R_Flickertail_BC_A
R_New_Kassel_Church_A	46,347	***0.00045***	***0.07***	***0.045***	***0.07***	1996	R_New_Kassel_Church_A
R_Kassel_Storage	54,957	0.0008	0.06	***0.038***	0.06	1965	R_New_Kassel_Church_A
R_SBC_B	70,291	0.0009	0.06	***0.038***	0.06	1912	R_SBC_B
R_SBC_A	76,226	0.0006	0.06	***0.038***	0.06	1862	R_SBC_B
R_Flickertail_BC_A	15,625	0.0004	0.06	0.035	0.06	1835	R_SBC_B
R_Rolwich_BC	114,662	0.0005	0.06	0.035	0.06	1814	R_Flickertail_BC_A
R_E_Seeman_Park_BC_B	51,337	0.0005	0.06	0.035	0.06	1755	R_E_Seeman_Park_BC_B
R_E_Seeman_Park_BC_A	26,547	0.0005	0.06	0.035	0.06	1723	R_E_Seeman_Park_BC_A
R_Seeman_Park_BC_C	20,300	0.0005	0.06	0.035	0.06	1707	R_SeemanPark_BC_A
R_Seeman_Park_BC_B	9,740	0.0005	0.06	0.035	0.06	1699	R_SeemanPark_BC_A
R_Seeman_Park_BC_A	4,065	0.0005	0.06	0.035	0.06	1695	R_SeemanPark_BC_A
R_Maier_Lake_BC	93,448	0.0005	0.06	0.035	0.06	1661	R_MaierLake
R_Sand_Creek	88,062	0.0014	0.06	0.035	0.06	1698	R_Sand_Creek
R_Beaver_Bay_BC	76,464	0.0005	0.06	0.035	0.06	1624	R_MaierLake

Notes:

Bold and italic font indicates parameter has been adjusted from initial estimate

Calibration Results

Four rainfall events were chosen to calibrate the model: the June 2005 event, the July 2011 event, the June 2013 event, and the June 2014 event. The 1993 event modeled in an early version of the model (Weier, 2013) was not included because of lack of gridded rainfall data.

The 2009 snowmelt event was modeled because, in addition to being the flood of record, it provides some insight on how the basin reacts to snowmelt events, which make up the majority of peak flows.

The events calibrated reasonably well as shown in **Table 6**. The modeled peak outflow was within 11 percent of the observed peak for all events. The timing of the modeled peak outflow was within 5 hours of the observed peak with the exception of the 2009 snowmelt event which used daily snowmelt, precipitation, and gage data. The modeled volume was within 30 percent of the observed volume for all events.

Table 6: Summary of calibration results.

Gage	Observed Peak Outflow, cfs	Modeled Peak Outflow, cfs	Percent Difference	Observed Date/Time of Peak Discharge	Modeled Date/Time of Peak Discharge	Difference, hrs	Observed Outflow, ac-ft	Modeled Outflow, ac-ft	Percent Difference	Nash-Sutcliffe Coefficient
June 2005 Rainfall Event										
06354580 below Linton	719	747	3.89%	Jun 10, 2005 12:00 AM	Jun 10, 2005 2:00 AM	-2h	3628	3,836	5.73%	0.88
July 2011 Rainfall Event										
06354480 near Zeeland	453	433	-4.42%	Jul 12, 2011 3:00 AM	Jul 12, 2011 5:00 AM	-2h	1,946	2,383	22.46%	0.94
06354580 below Linton	830	879	5.90%	Jul 14, 2011 6:00 AM	Jul 14, 2011 10:00 AM	-4h	9,863	9,473	-3.95%	0.94
June 2013 Rainfall Event										
06354480 near Zeeland	Event did not impact flow at gage. Observed flows remained at baseflow (5 cfs or less).									
06354580 below Linton	1,610	1,550	-3.73%	Jul 21, 2013 6:00 AM	Jul 21, 2013 8:00 AM	-2h	2419	3,149	30.18%	0.43
June 2014 Rainfall Event										
06354480 near Zeeland	163	180	10.43%	Jul 20, 2014 2:00 PM	Jul 20, 2014 2:00 PM	0ms	925	861	-6.92%	0.77
06354580 below Linton	1,120	1,161	3.66%	Jul 19, 2014 7:00 AM	Jul 19, 2014 7:00 AM	0ms	2,581	3,210	24.37%	0.92
March 2009 Rain/Snowmelt Event										
06354580 below Linton	14,000a	14,215	1.54%	Mar 24, 2009 6:00 AM	Mar 24, 2009 7:00 PM	-13h	106,277	127,258	19.74%	0.53

Notes:

[a] - Instantaneous value

2005 Rainfall Event

Figure 5 shows the modeled subbasin precipitation totals for the 2005 rainfall event. The upper subbasins received the majority of the rainfall. **Figure 6** shows the observed and modeled discharges at USGS gage 06354580 below Linton.

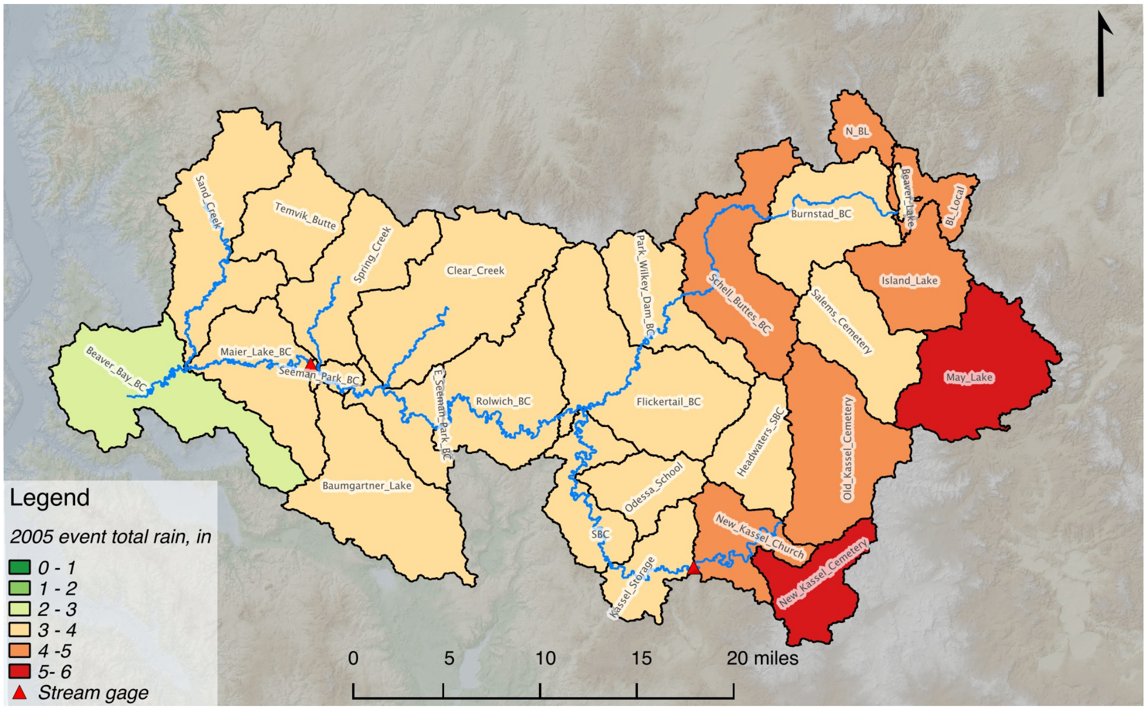

Figure 5: 2005 rainfall event total rainfall distribution.

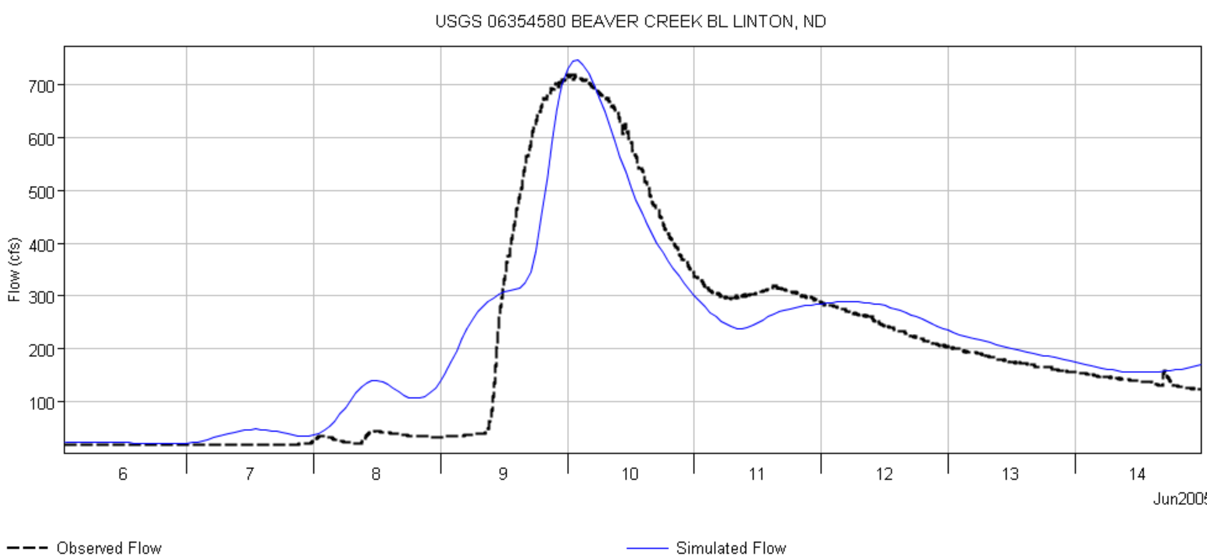

Figure 6: Observed and modeled discharges at USGS gage 06354580 below Linton for the 2005 rainfall event.

2011 Rainfall Event

Figure 7 shows the modeled subbasin precipitation totals for the 2011 rainfall event. The South Beaver Creek drainage received the majority of the rainfall. **Figures 8** and **9** show the observed and modeled discharges at USGS gages 06354480 near Zeeland and 06354580 below Linton, respectively. Note the larger, secondary peak in **Figure 9** caused by flows from South Beaver Creek.

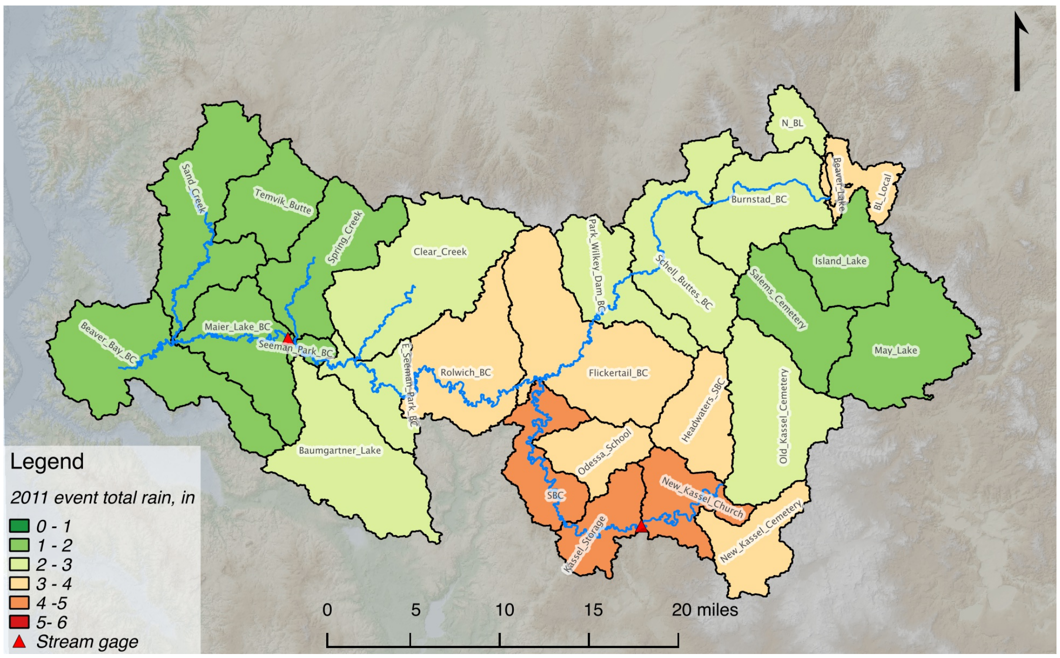

Figure 7: 2011 rainfall event total rainfall distribution.

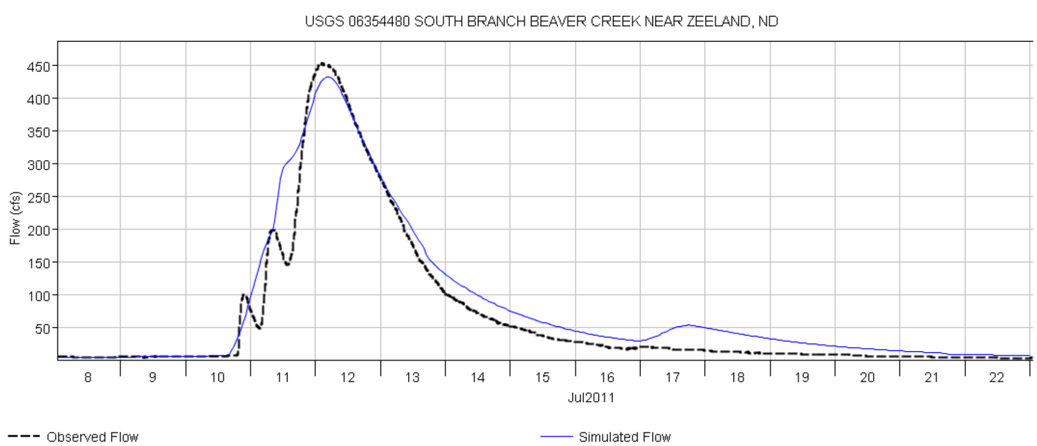

Figure 8: Observed and modeled discharges at USGS gage 06354480 near Zeeland for the 2011 rainfall event.

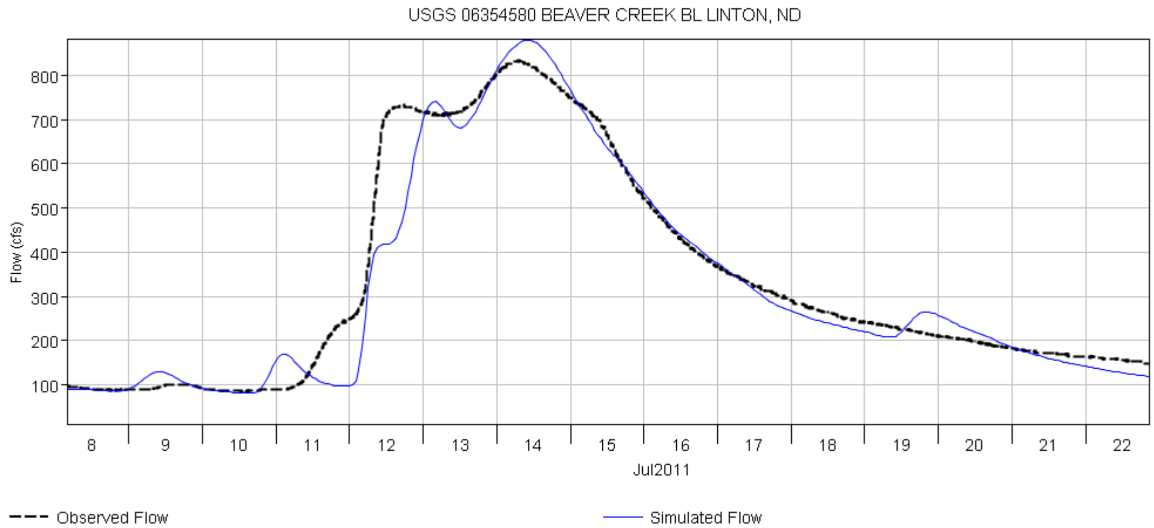

Figure 9: Observed and modeled discharges at USGS gage 06354580 below Linton for the 2011 rainfall event.

2013 Rainfall Event

Figure 10 shows the modeled subbasin precipitation totals for the 2013 rainfall event. Clear Creek received the majority of the rainfall. **Figure 11** shows the observed and modeled discharges at USGS gage 06354580 below Linton. The model predicts the peak quite well; however, additional rainfall that fell on the Clear Creek subbasin on June 22nd caused the model to erroneously predict a second peak flow around 1,000 cfs. The loss method did not allow for the soil moisture deficit to recover within the short time period.

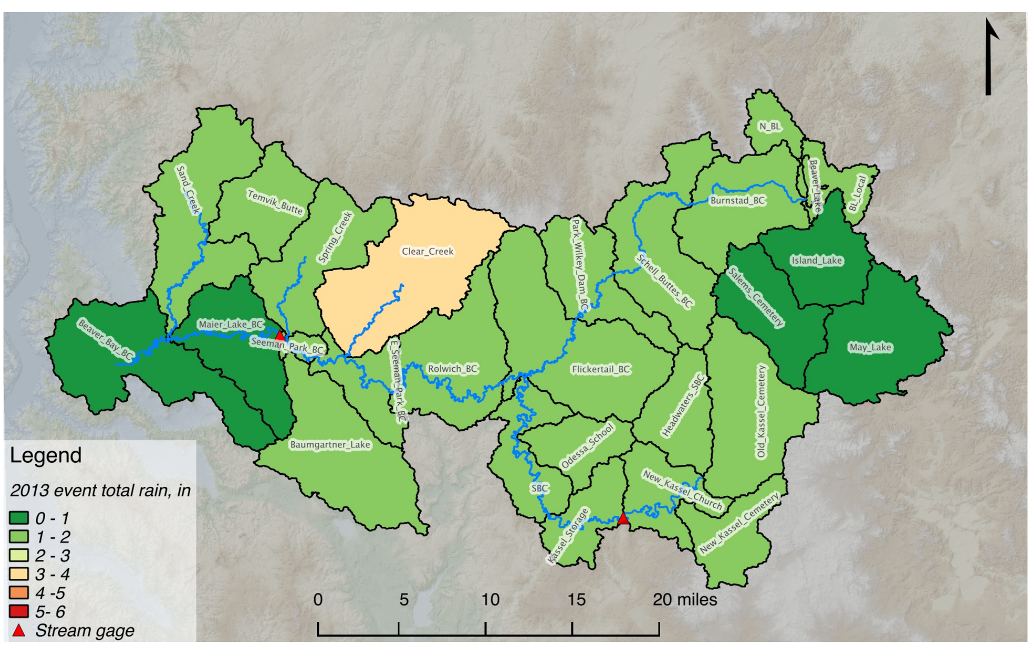

Figure 10: 2013 rainfall event total rainfall distribution.

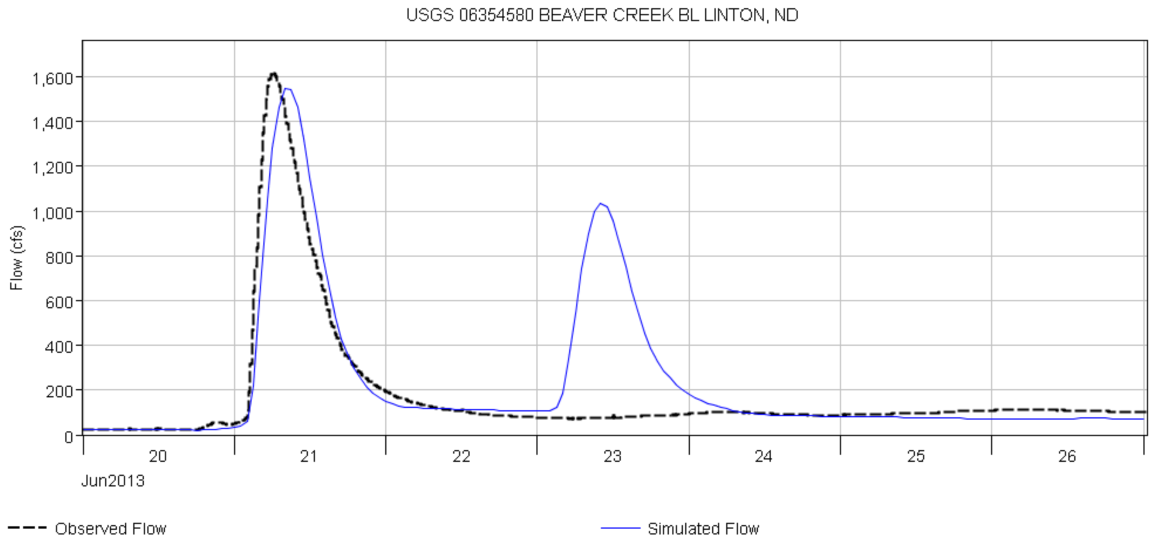

Figure 11: Observed and modeled discharges at USGS gage 06354580 below Linton for the 2013 rainfall event.

2014 Rainfall Event

Figure 12 shows the modeled subbasin precipitation totals for the 2014 rainfall event. Above the Linton stream gage, Baumgartner Lake subbasin received the majority of the rainfall. **Figures 13** and **14** show the observed and modeled discharges at USGS gages 06354480 near Zeeland and 06354580 below Linton, respectively. The simulated hydrograph at Linton is similar to the 2013 event.

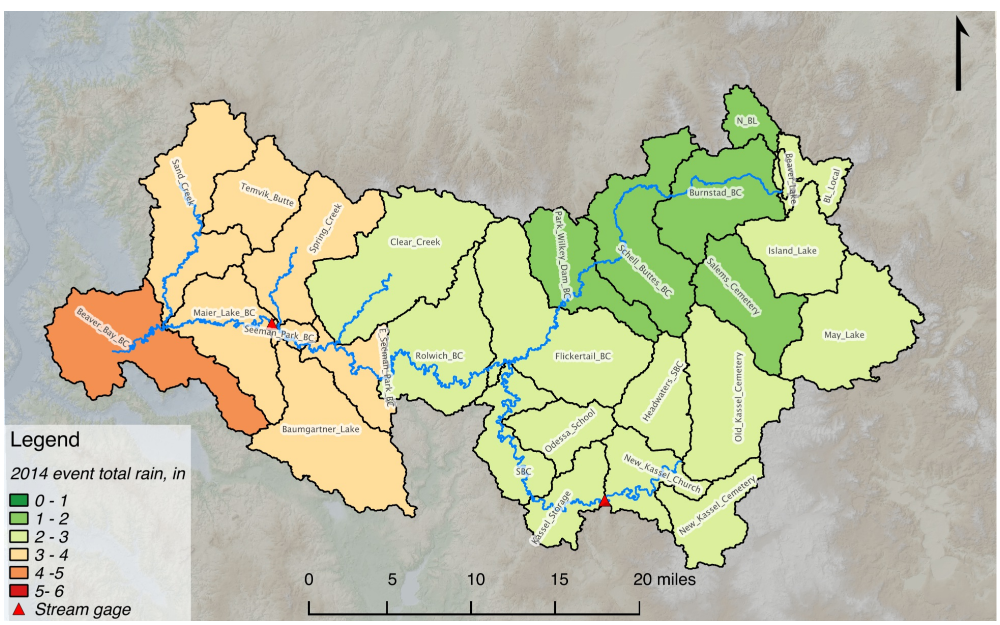

Figure 12: 2014 rainfall event total rainfall distribution.

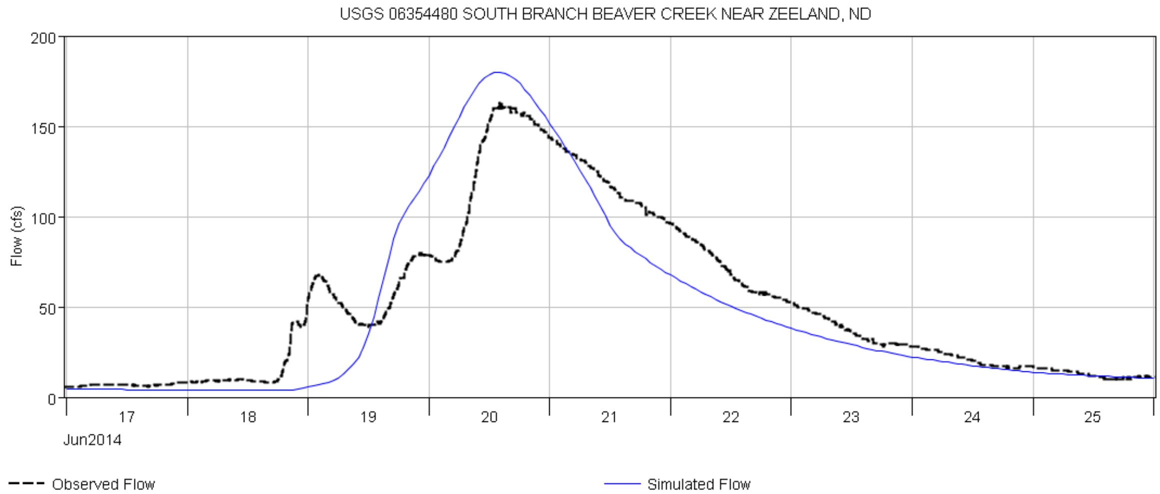

Figure 13: Observed and modeled discharges at USGS gage 06354480 near Zeeland for the 2014 rainfall event.

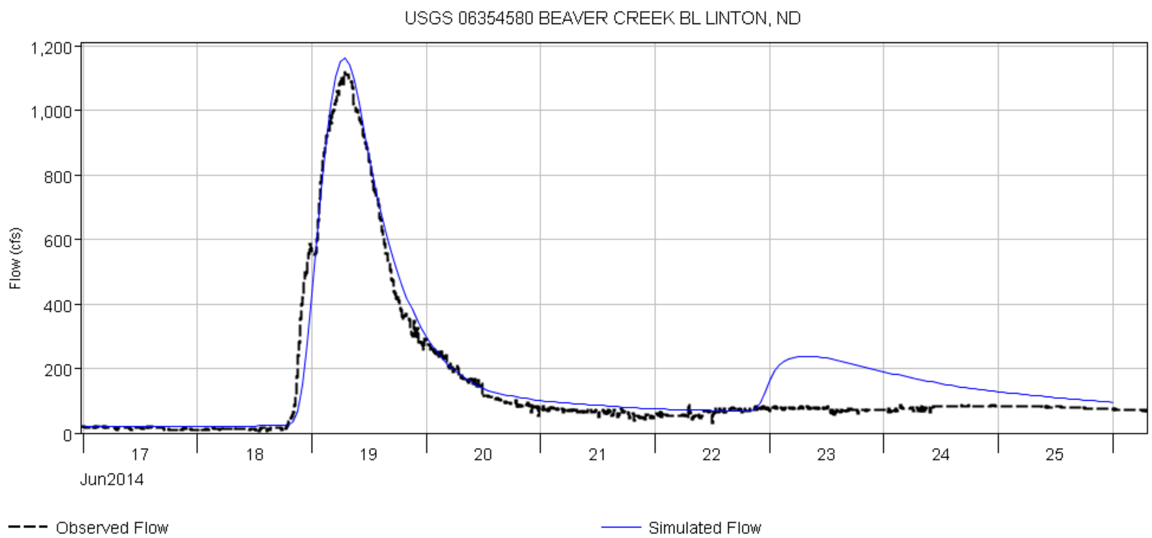

Figure 14: Observed and modeled discharges at USGS gage 06354580 below Linton for the 2014 rainfall event.

2009 Snowmelt Event

Figure 15 shows the modeled subbasin runoff and liquid precipitation totals for the 2009 snowmelt event. The basin was very wet especially in the upper subbasins. **Figure 16** shows the observed and modeled discharges at USGS gage 06354580 below Linton. The model matched the daily average hydrograph very well. The model matched the instantaneous peak fairly well considering the snowmelt and precipitation data was of daily resolution.

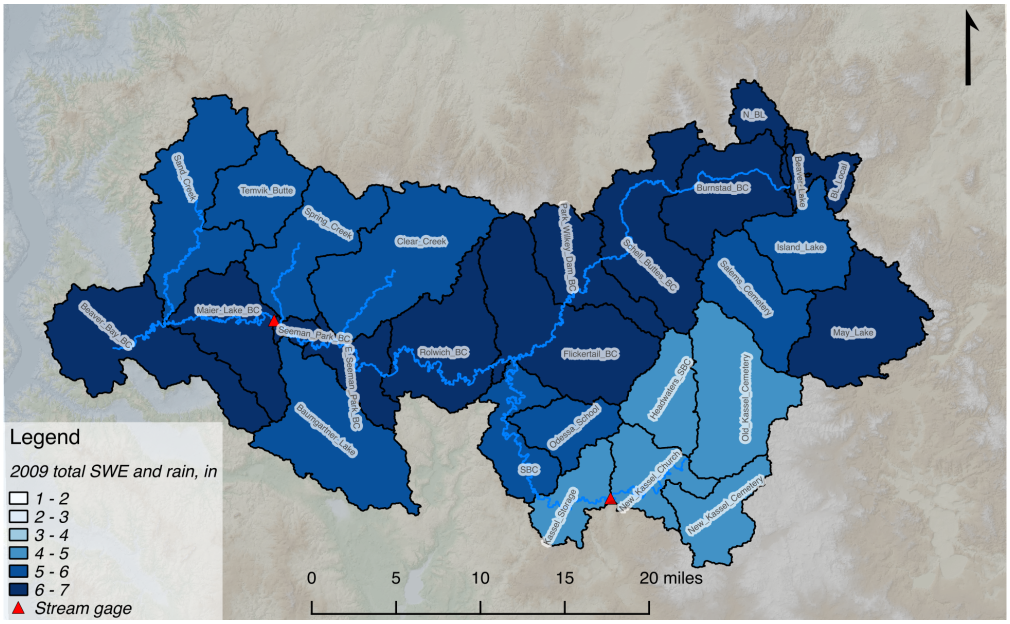

Figure 15: 2009 snowmelt event snow water equivalent (SWE) and rainfall total distribution.

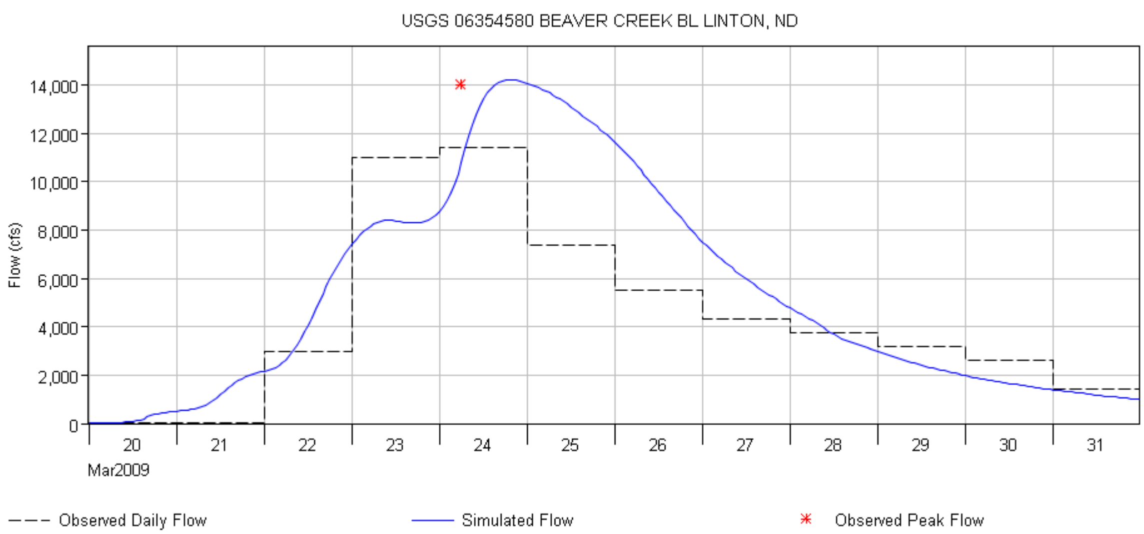

Figure 16: Observed and modeled discharges at USGS gage 06354580 below Linton for the 2009 snowmelt event.

Peak Discharge and Volume Frequency Analysis

Both peak discharge and volume frequency analysis were computed. Estimating the annual risk for both the peak flow and volume are important for the Beaver Creek basin because, as illustrated by the calibration events, the basin can behave differently depending on which subbasins receive precipitation. The subbasins near Linton are capable of generating flash flood type behavior with sharp hydrograph peaks (e.g. the 2013 and 2014 events), whereas the subbasins near the headwaters of Beaver Creek and South Branch Beaver Creek can be associated with flatter and wider hydrographs (e.g. the 2005, 2009, and 2011 events).

Peak Discharge Frequency Analysis

A peak discharge frequency analysis was performed using HEC-SSP. The discharge frequency analysis followed the Bulletin 17B guidelines of the Interagency Advisory Committee on Water Data (U.S. Interagency Advisory Committee on Water Data, 1982). Annual peak discharges including snowmelt recorded at USGS stream gages 06354580 below Linton, which has operated from October 1989 through 2013, and 06354500 at Linton, which has operated from 1950 to October 1989, were used in the analysis. The peak discharges were transferred from the gage at Linton (06354500) to the gage below Linton (06354580) using the drainage transfer equation developed by the USGS (Williams-Sether, 1992). Weibull plotting positions and the default station skew were used for the analysis. The computed probability curve is shown in **Figure 17**.

Table 7 summarizes the computed curve values for the 0.2, 0.5, 1, 2, 4, 10, 20, and 50-percent annual chance flood events (project probability events). **Table 7** also illustrates the large range in the 95 percent confidence interval. This highlights that although, over 60 years of stream gage data were available, there is still a fair amount of uncertainty regarding the frequency of large flood events like those that occurred in 2009.

Table 7: Annual peak flows for the 0.2, 0.5, 1, 2, 4, 10 , 20, and 50 percent annual chance flood events (project probability events) for USGS gage 06354580 below Linton.

Chance of Annual Occurrence	Computed Curve Flow, cfs	95% Confidence Interval Lower Limit, cfs	95% Confidence Interval Upper Limit, cfs	95% Confidence Interval Range, cfs
0.2%	32,531	19,192	64,518	45,326
0.5%	23,265	14,236	43,835	29,599
1%	17,534	11,055	31,668	20,613
2%	12,792	8,329	22,063	13,734
4%	8,938	6,025	14,658	8,633
10%	5,047	3,574	7,682	4,107
20%	2,898	2,132	4,146	2,014
50%	953	719	1,267	549

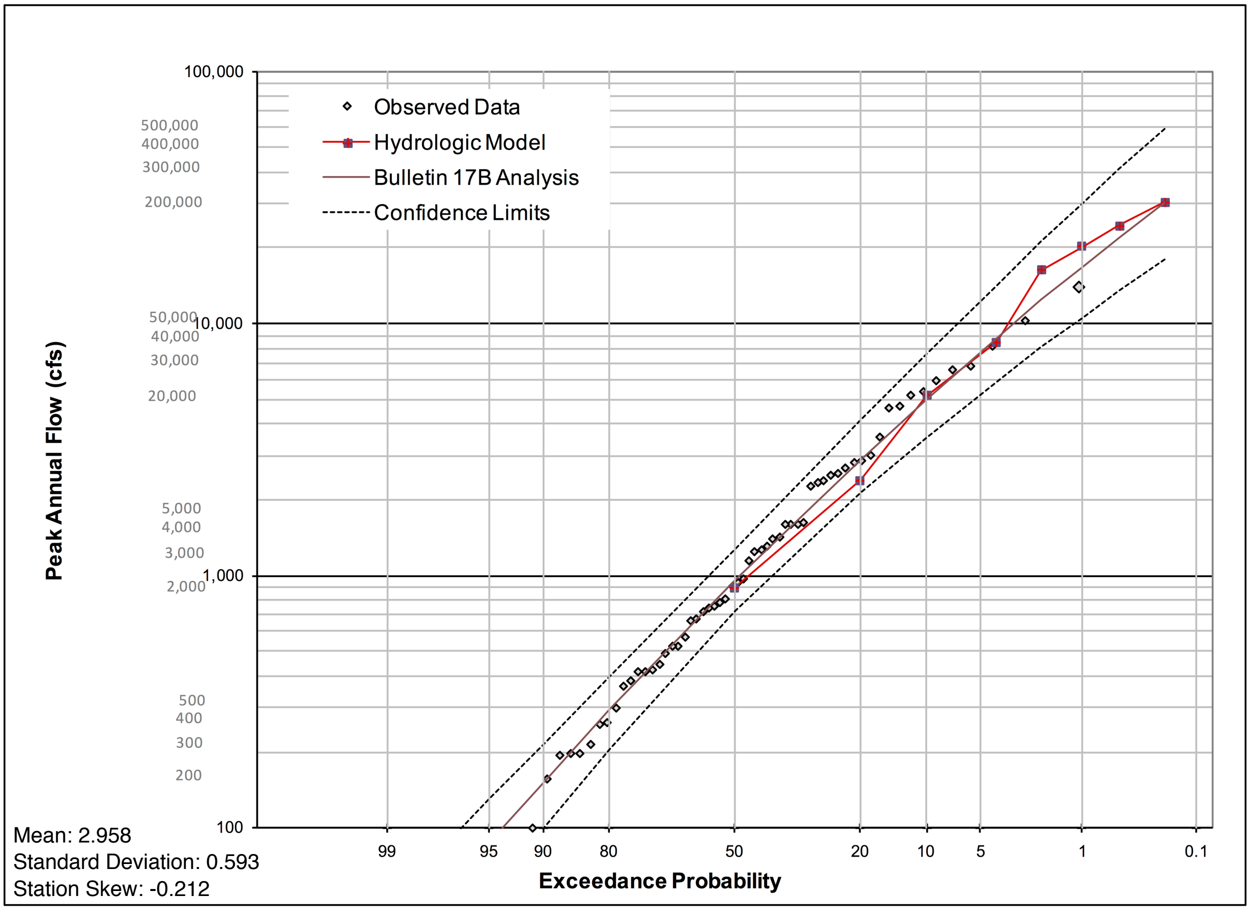

Figure 17: Annual peak flow frequency curve for USGS Gages 06354500 at Linton and 06354580 below Linton (1950 – 2013).

Table 8 shows the top ten annual flows recorded at the historic and current stream gages at or near Linton. Only two of the top ten flows did not occur in March or April, suggesting that the majority of floods on Beaver Creek are driven by snowmelt or rain-on-snow events. It is likely that the frequency flow analysis curve shown in **Figure 17** contains a mixed population (i.e. both snowmelt and rain event populations). However, it is the opinion of the author that the plotting positions in **Figure 17** generally fit the calculated curve well, and a more detailed Bulletin 17B analysis that addresses mixed populations is not necessary.

Table 8: Top ten annual peak flows recorded at USGS Gages 06354500 at Linton and 06354580 below Linton (1950 – 2013).

Date	Peak Discharge, cfs
Mar 24, 2009	14,000
Apr 8, 1952	10,235[1]
Mar 23, 1987	8,115[1]
Mar 31, 1997	6,780
Mar 29, 1978	6,580[1]
Jun 17, 1953	**5,901**[1]
Mar 14, 1995	5,200
Apr 9, 1969	5,389[1]
Apr 7, 1950	4,700[1]
Aug 28, 1989	**4,648**[1]

Notes:

Bold text indicates rain event

[1] Flow from gage 06354500 transformed to location of current gage 06354580

Volume Frequency Analysis

A volume frequency analysis was calculated also using HEC-SSP. Annual peak seven-day average daily discharges, which include snowmelt, from USGS stream gages 06354580 below Linton and 06354500 at Linton were used in the analysis and were assumed to have a log Pearson type III distribution. The difference in drainage areas between the two gages was assumed negligible, and normalizing adjustments were not made to flows from either of the gages for this analysis. Weibull plotting positions and the default station skew were used for the analysis. One, three, and seven day periods were analyzed, because the majority of flood waves from single events appear to pass at the Linton gage within seven days. The computed probability curve is shown in **Figure 18**. **Table 9** summarizes the computed volumes for the project probability events.

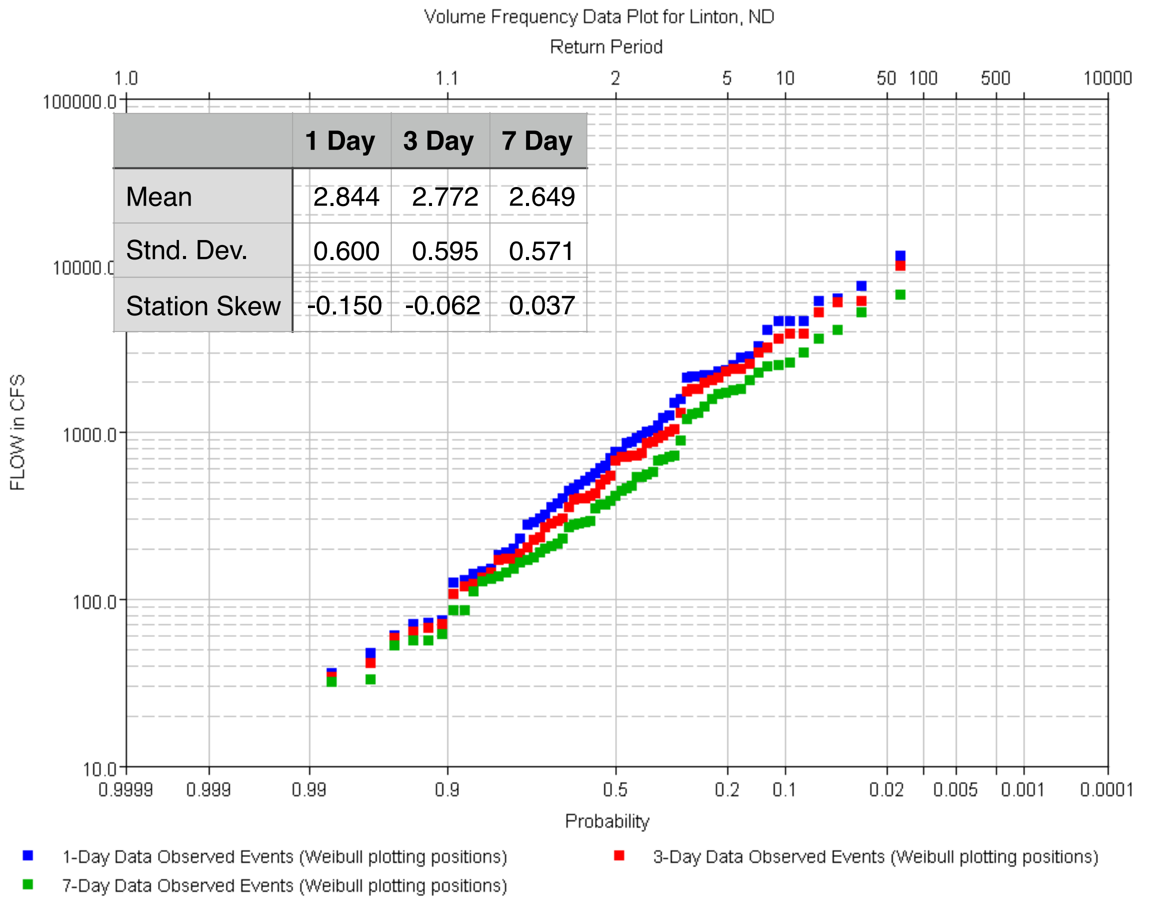

Figure 18: Annual maximum 1,3, and 7 day average daily flow frequency curve for USGS Gages 06354500 at Linton and 06354580 below Linton (1950 – 2013).

Table 9: Annual maximum one, three, and seven-day volume for the project probability events at USGS Gages 06354500 at Linton and 06354580 below Linton (1950 – 2013).

Chance of Annual Occurrence	1 day volume, average cfs/day	1 day volume, acre-ft	3 day volume, average cfs/day	3 day volume, acre-ft	7 day volume, average cfs/day	7 day volume, acre-ft
0.20%	28,984	57,490	27,600	164,234	20,870	289,768
0.50%	20,183	40,032	18,662	111,044	13,833	192,066
1.00%	14,905	29,563	13,486	80,246	9,864	136,953
2.00%	10,652	21,128	9,438	56,159	6,825	94,753
4.00%	7,290	14,460	6,332	37,675	4,538	63,006
10.00%	4,005	7,943	3,396	20,207	2,420	33,600
20.00%	2,253	4,468	1,883	11,203	1,347	18,695
50.00%	722	1,433	600	3,571	443	6,144

Synthetic Event Analysis

Development of synthetic events for the Beaver Creek basin presented some challenges, as both flash floods and floods with longer durations and larger volumes are possible at Linton. The flash floods are typically created by short duration, high intensity rainfall that occurs in the steeply sloped subbasins near Linton. The longer and larger floods are typically caused by snowmelt or rain during snowmelt.

Precipitation Frequency Estimate

Synthetic events were generated for rainfall events using point precipitation frequency estimates from data developed as part of NOAA's Atlas 14 study (Perica et. al., 2013). **Table 10** summarizes partial duration point precipitation obtained at the centroid of the portion of the basin that contributes to the stream gage below Linton for the 0.2, 0.5, 1, 2, 4, 10, 20, and 50-percent annual chance precipitation events for a 5-min, 15-min, 1-hr, 2-hr, 3-hr, 6-hr, 12-hr, 24-hr, 2 day, 4 day, 7 day, and 10 durations.

Table 10: Summary of point precipitation frequency estimates at the centroid of the contributing watershed that drains to USGS gage 06354580 below Linton.

Storm Duration	0.2% Annual Exceedance, in	0.5% Annual Exceedance, in	1% Annual Exceedance, in	2% Annual Exceedance, in	4% Annual Exceedance, in	10% Chance Annual Exceedance, in	20% Chance Annual Exceedance, in	50% Chance Annual Exceedance, in
5-min	1.24	1.05	0.92	0.80	0.69	0.55	0.45	0.35
15-min	2.21	1.88	1.65	1.43	1.23	0.98	0.81	0.63
60-min	3.88	3.28	2.86	2.48	2.11	1.68	1.40	1.08
2-hr	4.73	3.99	3.47	2.99	2.55	2.02	1.68	1.31
3-hr	5.21	4.38	3.80	3.27	2.78	2.21	1.83	1.43
6-hr	5.94	5.01	4.35	3.75	3.19	2.54	2.12	1.65
12-hr	6.50	5.53	4.85	4.21	3.62	2.90	2.43	1.90
24-hr	6.93	5.95	5.26	4.61	3.99	3.24	2.73	2.15
2-day:	7.33	6.33	5.62	4.95	4.32	3.54	3.02	2.42
4-day:	7.85	6.88	6.17	5.50	4.85	4.03	3.46	2.80
7-day:	8.48	7.52	6.81	6.12	5.45	4.60	3.99	3.27
10-day:	9.14	8.16	7.42	6.71	6.00	5.10	4.45	3.69

The rainfall events were modeled using the frequency storm method and assumed that the storm size is equal to the watershed size above the Linton gage, 655 sq. mi. HEC-HMS 4.0 automatically reduces the point precipitation value to an appropriate value using methods outlined in TP-40 (National Weather Service, 1961).

Synthetic Event Results

When these synthetic rainfall events were modeled with the calibrated watershed and channel routing parameters shown in **Tables 4** and **5** (assuming no soil moisture deficit), the peak discharge and volumes generated matched those predicted by the stream gage peak flow and volume frequency analysis for the one and two percent annual exceedance events. The model generally over-predicted peaks and volumes for higher frequency events (4%, 10%, 20%, and 50%) and underpredicted for the lower frequency events(0.2% and 0.5%). To better match the peak flows and volumes determined by the gage analysis, the synthetic event loss parameters were adjusted as shown in **Table 11**.

Table 11: Summary of synthetic event loss parameter adjustments.

	Adjustment From Rainfall Calibration Loss Parameters	
Chance of Annual Occurrence	**Initial Storage Deficit**	**Constant Rate**
0.2%	Reduced to 0 in	Reduced by 80%
0.5%	Reduced to 0 in	Reduced by 80%
1%	Reduced to 0 in	None
2%	Reduced to 0 in	None
4%	Initial peak subbasins[1] set to 2.5 in, all others set to 0 in	None
10%	Initial peak subbasins[1] set to 2.5 in, all others set to 0 in	None
20%	All subbasins set to 2.0 or 2.1 in	None
50%	All subbasins set to 2.0 or 2.1 in	None

[1] Initial peak subbasins include Clear Creek, E Seeman Park, Baumgartner Lake, and Spring Creek

The constant rate was reduced by 80% and the soils were set to saturation for the 0.2% and 0.5% events. This is a reasonable adjustment because very large flood events are typically snowmelt driven and the infiltration rate would be reduced because of frozen ground or extreme rainfall following a period of successive moderate events that saturate the ground. Soil moisture was set to saturation for the 1% and 2% events. For more frequent events, initial soil moisture content was increased.

Table 12 summarizes the modeled synthetic event results and how they compare with those obtained from regression analysis. **Figure 17** shows the peak flow regression analysis plotted along with the simulated peak flows for the synthetic events. The simulated peak, 1 day volumes, 3 day volumes, and 7 day volumes match reasonable well (within 33%) with those obtained from regression values.

Table 12: Summary of modeled synthetic results.

Chance of Annual Occurrence	0.2%	0.5%	1%	2%	4%	10%	20%	50%
Simulated Peak Flow, cfs	30,446	24,403	20,224	16,305	8,445	5,190	2,383	898
Regression Peak Flow, cfs	32,531	23,265	17,534	12,792	8,938	5,047	2,898	953
Percent Difference	-6%	5%	15%	27%	-6%	3%	-18%	-6%
Simulated 1 day volume, acre-ft	50,036	40,352	24,215	19,958	13,507	9,283	4,256	1,160
Regression Analysis 1 day volume, acre-ft	57,490	40,032	29,563	21,128	14,460	7,943	4,468	1,433
Percent Difference	-13%	1%	-18%	-6%	-7%	17%	-5%	-19%
Simulated 3 day volume, acre-ft	119,987	97,018	60,162	48,872	33,858	22,597	9,955	2,979
Regression Analysis 3 day volume, acre-ft	164,234	111,044	80,246	56,159	37,675	20,207	11,203	3,571
Percent Difference	-27%	-13%	-25%	-13%	-10%	12%	-11%	-17%
Simulated 7 day volume, acre-ft	196,905	163,735	105,289	86,280	61,937	40,502	17,757	5,338
Regression Analysis 7 day volume, acre-ft	289,768	192,066	136,953	94,753	63,006	33,600	18,695	6,144
Percent Difference	-32%	-15%	-23%	-9%	-2%	21%	-5%	-13%

Comparison of Observed Events to Synthetic Events

A comparison of observed events to roughly equivalent synthetic events was performed to further evaluate performance of the model. The flood of record, March 2009 snowmelt event, and the largest flood event caused by rainfall, June 1953 event, were compared to the synthetic 2% and 10% events, respectively. **Figures 19** and **20** show the simulated and observed hydrographs for the March 2009 and June 1953 events, respectively. **Table 13** shows a comparison of the observed and modeled peak flow and 1, 3, and 7 day volume for both events.

Matching a synthetic hydrograph with an observed hydrograph caused by a real flooding event will result in considerable discrepancies for Beaver Creek watershed below Linton, because the watershed exhibits a dual peak behavior. Depending on the distribution of the snowmelt or rainfall the peak of the observed flood could coincide with either one of these peaks. However, the simulated peaks, volumes, and hydrograph recession limbs generally match the observed data. This further validates the model.

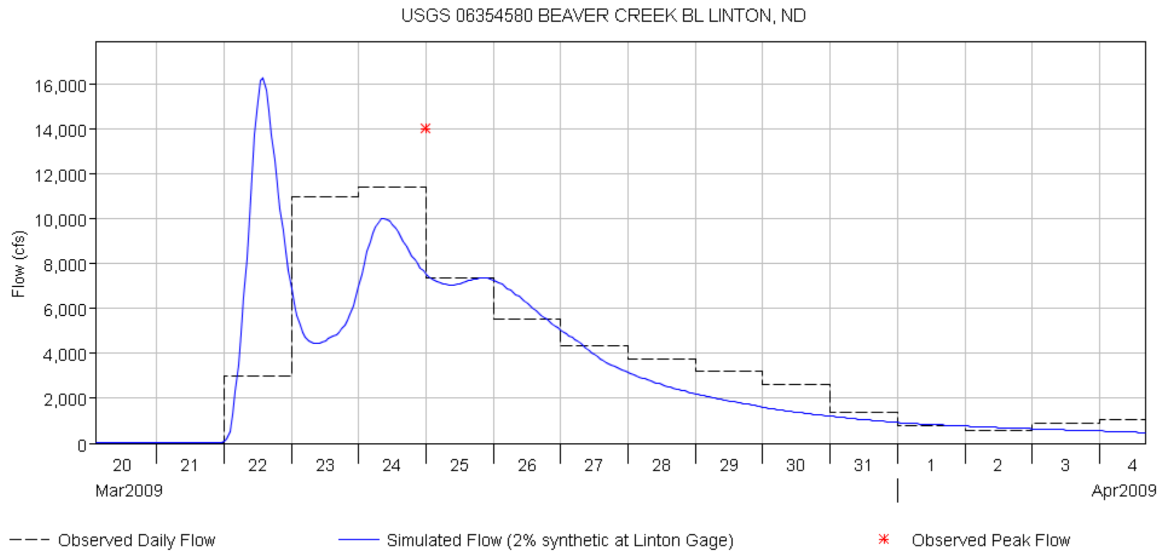

Figure 19: Observed March 2009 snowmelt event and simulated 2% synthetic event hydrographs.

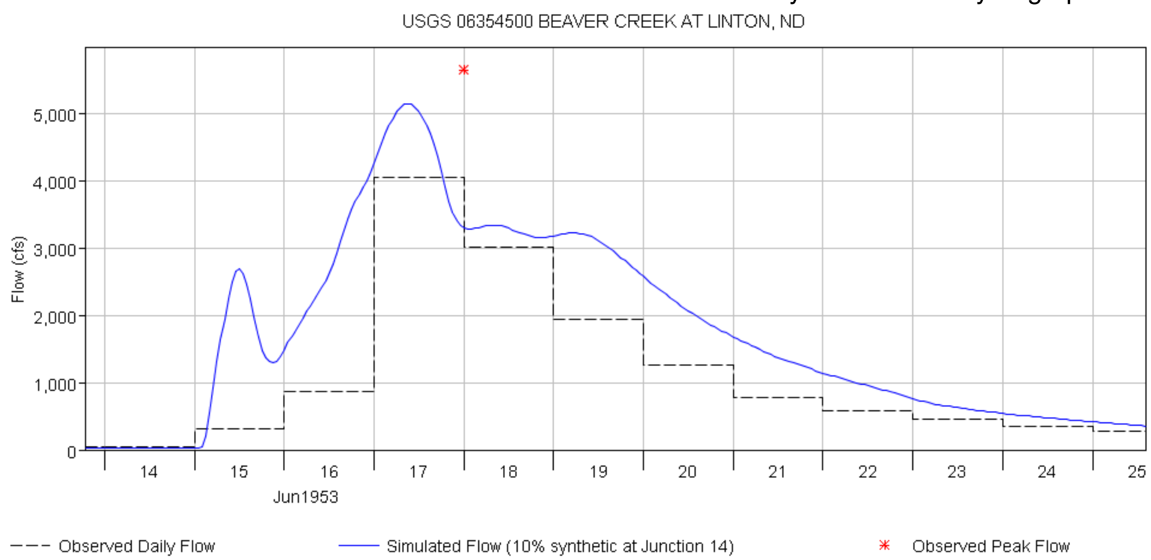

Figure 20: Observed June 1953 rainfall event and simulated 2% synthetic event hydrographs.

Table 13: Comparison of observed flood events to similar synthetic events.

Event	Peak Flow, cfs	1 day volume, acre-ft	3 day volume, acre-ft	7 day volume, acre-ft
	2009 Snowmelt Event			
Observed	14,000	22,612	59,008	92,311
2% Simulation	12,792	21,128	56,159	94,753
Difference	-9%	-7%	-5%	3%
	1953 Rainfall Event			
Observed	5,910	8,033	17,871	24,819
10% Simulation	5,047	7,943	20,207	33,600
Difference	-17%	-1%	12%	26%

Storage Area Screening

Storage areas were screened to evaluate their effectiveness at mitigating peak flows at Linton for a 1-percent annual chance, 10 day event (screening event). **Figure 21** shows storage sites where storage volumes were calculated. **Table 14** summarizes the maximum storage, maximum surface area, dam length, and dam height. These storage area sites were selected based on potential effectiveness and avoiding existing homes or ranching operations to the extent practicable. For the purposes of this screening, it assumed that these would be dry dams whose purpose would be solely to mitigate the flood peaks.

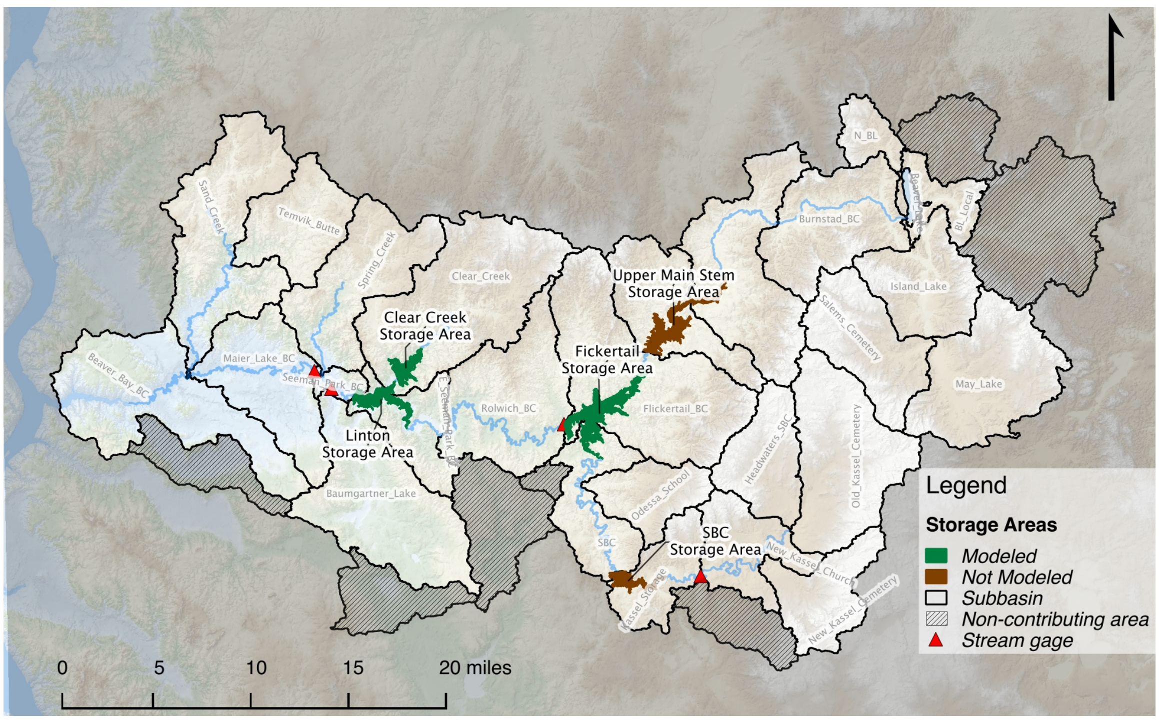

Figure 21: Maximum footprint of storage areas.

Table 14: Storage area characteristics.

Name	Maximum Storage, ac-ft	Maximum Surface Area, ac	Dam Height, ft	Dam Length, ft
Flickertail SA	20,171	2,301	32	1,100
Linton SA	17,095	1,075	40	3,100
Clear Creek SA	15,900	722	71	3,200
Upper Main Stem SA	13,905	1,687	23	2,800
SBC SA	5,723	626	33	5,000

The seven-day volume for the screening event is over 100,000 acre-ft (**Table 12**), and the largest evaluated storage area has a maximum storage volume of roughly 20,000 acre-ft (**Table 14**). It is obvious that the volume of the screening event is much greater than the storage areas. Increasing the size of the storage areas is probably not reasonable because of the impact to additional homes and infrastructure and high cost.

Figure 22 shows a hydrograph at the Linton gage produced by modeling the screening event. The initial peak shown in **Figure 22** is caused by the adjacent steeply sloped basins (i.e. Clear Creek, Spring Creek, Baumgartner Lake, etc.), and the later peak is caused by the upper basin runoff. Based on the current model, Clear Creek appears to be a major contributor to the initial peak (**Figure 22**). If the initial peak is flattened or delayed, the later peak can be exacerbated. Therefore, a modeled scenario that mitigates both the initial peak and later peak was tested.

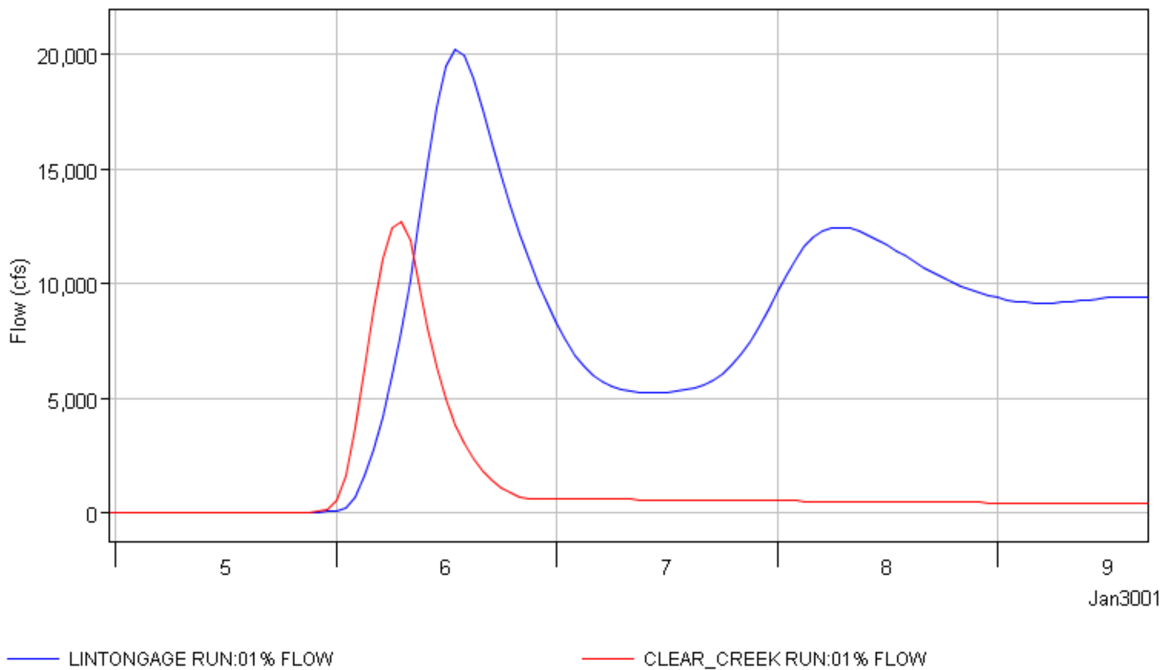

Figure 22: Modeled baseline hydrograph at Linton and Clear Creek subbasin for the 10-day, 1-percent annual chance event (screening event).

Modeled Storage Area Scenario

The Clear Creek, Linton, and Flickertail storage areas were modeled as a system of dry, flood control dams to mitigate the screening event. All three storage areas were modeled together to represent the best possible flood control scenario. The modeled storage areas assumed empty initial conditions with modeled outlets that restricted flow enough so the storage areas became full, but were large enough to prevent overtopping. Detailed information on the outlets and figures of the storage elevation relationships for the storage areas are provided in **Appendix E**. The SBC and Upper Main Stem storage areas were not included in the model because of their small size or distance from the City of Linton.

Figure 23 shows a plot of the modeled hydrographs at Linton for the baseline scenario and the storage scenario which includes the three storage areas. The storage areas appear effective in reducing the peak flow by nearly 50%; however, the peak is still over 10,000 cfs. This would result in a water surface elevation at Linton that is still well above major flood stage[1].

In order to be effective at mitigating flows at Linton, additional storage areas would have to be added within the Spring Creek and Baumgartner Lake watersheds to store the initial peak, and very large storage areas would need to be added within the upper basin. This would likely prove to be very costly.

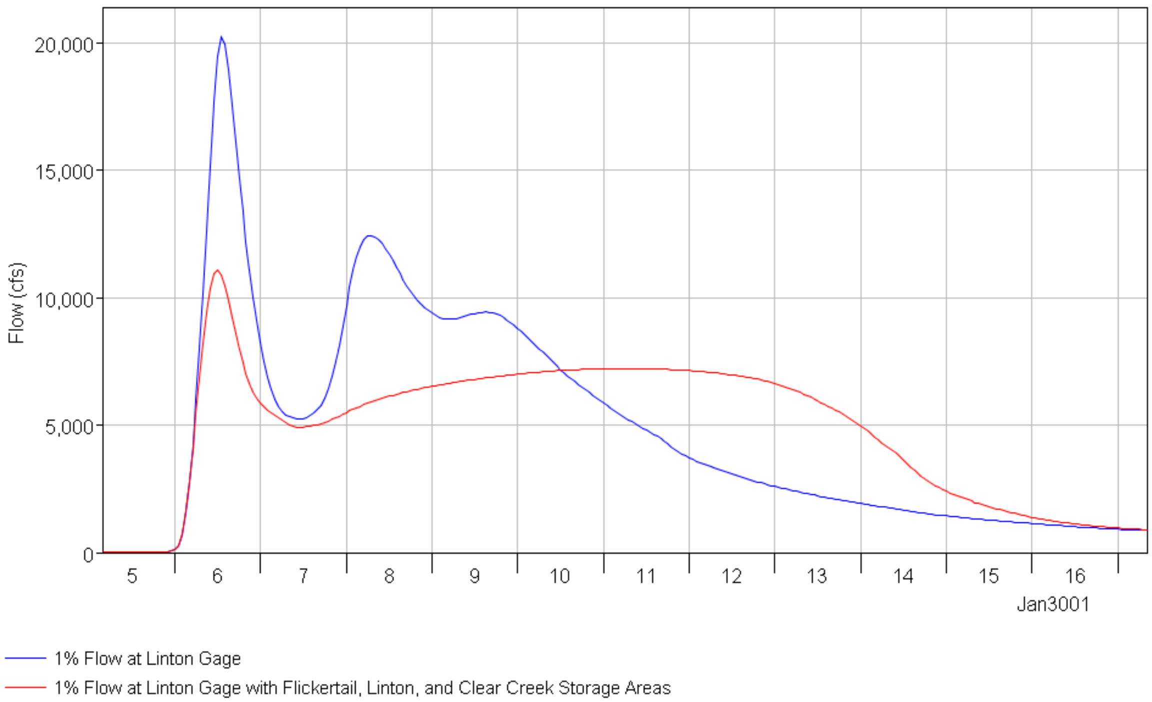

Figure 23: Modeled baseline and storage scenario hydrograph at Linton for the 10-day, 1-percent annual chance event (screening event).

Conclusion

The SWC created a hydrologic model with improvements in response to the comments provided by the USACE regarding previous models completed. The model was calibrated and reasonably reproduced recent flood events. Modeled synthetic events produced results consistent with those predicted by the stream gage peak flow and volume frequency analysis at USGS gages 06354580 below Linton and 06354500 at Linton.

[1] Major flood stage at Linton is reported by the National Weather Service as 13 ft which roughly corresponds to 2400 cfs.

The hydrologic analysis shows that flash flooding at Linton can be caused by runoff from local subbasins, and upper basin runoff can cause long sustained flood peaks at Linton. Many times these occur in tandem; however, if the initial rapid peak is delayed by storage, peak flows could be increased by amplifying the longer, sustained flood peak with the retained water.

Storage area options were screened, and three storage areas were selected to be evaluated against a screening event, the 10 day, 1-percent annual chance event. Three storage areas were modeled in series as dry dams to assess the mitigation of the initial rapid flood peak and the sustained secondary flood peak at Linton. The analysis showed that the storage area system was effective at reducing the initial peak flow, but the volume of the flood event quickly filled the modeled reservoirs and as a result did not provide substantial flood protection at Linton for a 1-percent annual chance event.

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Appendix A

Hydrologic model, associated GIS files, previous comment responses (electronic only – see attached DVD)

North Dakota State Water Commission

Project:	Beaver Creek non-contributing analysis	**Prepared By:**	Mitch Weier
Project No.:		**Date:**	2014-09-09
		Checked By:	

Appendix B

Non-contributing Analysis

Overview

The majority of the Beaver Creek watershed is characterized by steep to rolling hills; however, the east and south portions of the watershed encompass some lakes and depressions which typically do not contribute runoff to Beaver Creek on a regular basis. **Figure 1** shows the maximum depression or lake footprint for seven non-contributing subbasins identified within the basin.

Non-contributing drainage areas were determined by calculating the storage available within large depressions based on the National Elevation Dataset (NED) and comparing the storage volume with a runoff volume calculated by multiplying the depression's drainage area by 4.5 inches, which is approximately the 10-day 1-percent chance annual exceedance runoff event found in TR-60 for the Beaver Creek basin (Gesch, 2007; U.S. Department of Agriculture, 2005). The NED version used for this analysis was based on topographic map data dated 1966.

Table 1 summarizes spill point elevation at which each depression would become contributing, the available storage at that elevation, calculated runoff volume, and excess storage available after the runoff event.

North Dakota State Water Commission

Project:	Beaver Creek non-contributing analysis	**Prepared By:**	Mitch Weier
Project No.:		**Date:**	2014-09-09
		Checked By:	

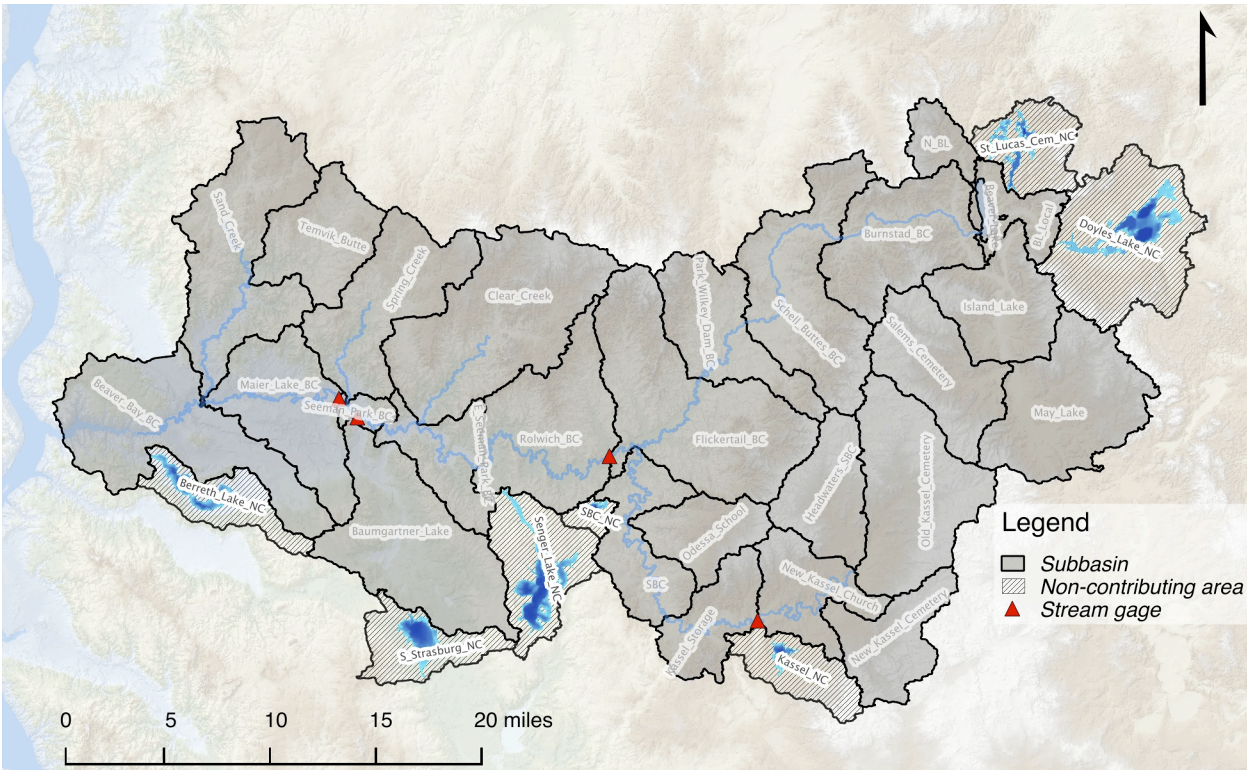

Figure 1: Non-contributing areas and associated depressions or lakes.

Table 1: Summary of non-contributing areas and associated depressions or lakes.

Depression or Lake Name	Maximum Elevation, ft NAVD88	Maximum Storage, acre-ft	Drainage Area, mi2	Runoff, in	Runoff Volume, acre-ft	Excess Storage, acre-ft
Senger Lake	1863.6	79,302	24.0	4.5	5,760	-73,542
S Strasburg	1819.13	40,074	16.0	4.5	3,840	-36,234
St Lucas Cemetary	2009.6	27,444	16.3	4.5	3,912	-23,532
Doyles Lake	1975.16	30,605	43.5	4.5	10,439	-20,166
Barreth Lake	1706.1	15,316	15.7	4.5	3,768	-11,548
SBC	1888.2	3,510	2.9	4.5	696	-2,814
Kassel	2011.3	4,231	14.7	4.5	3,528	-703

References

Gesch, D.B., 2007, The National Elevation Dataset, in Maune, D., ed., Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99-118.

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Appendix C - Description of soil parameter derivation

Using the SSURGO Database to Estimate Infiltration Loss Parameters

Overview

The North Dakota State Water Commission (SWC) has developed an algorithm that uses data from the Soil Survey Geographic (SSURGO) Database to estimate parameters for infiltration loss methods for use in hydrologic models. These parameters may include saturated hydraulic conductivity, satiated water content, wilting point, field capacity, etc. The algorithm produces subbasin parameters for input into various loss methods within the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) developed by the United States Army Corps of Engineers (USACE).

The SSURGO database is available from the Natural Resource Conservation Service (NRCS) and contains soils data collected over the past century. The database contains map outline areas or map units that correspond to typical soil types found in an area based on visual and laboratory testing. These map units typically contain multiple component soils that are made up of soil types within a number of soil horizons (**Figure 1**).

The SSURGO data used in Beaver Creek watershed analysis was dated 2013-12-22 for all three counties.

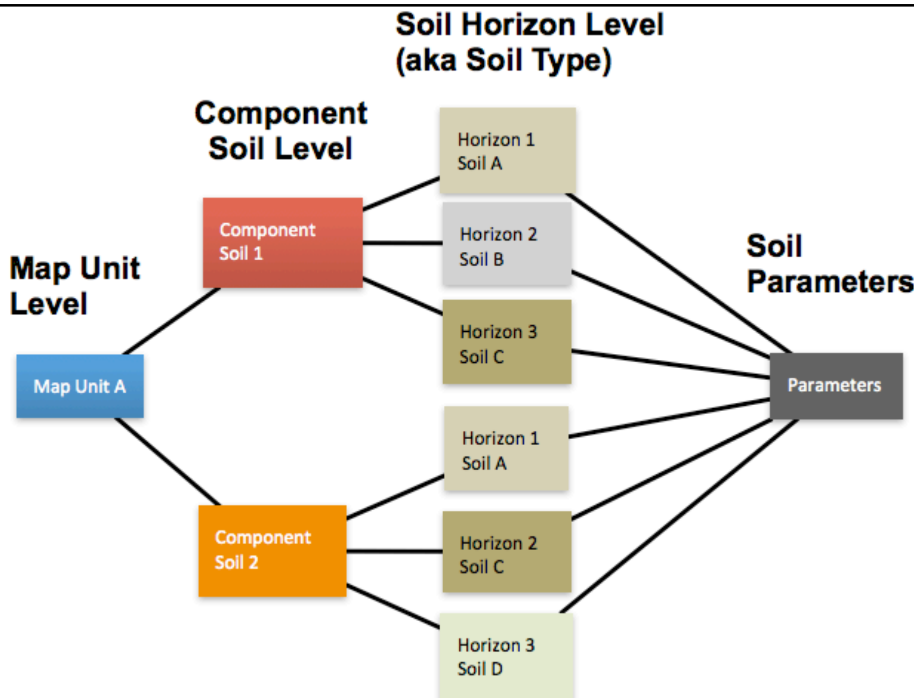

Figure 1: Generalized schematic of SURRGO database structure used within the algorithm.

Parameter Weighting:

Parameters such as hydraulic conductivity, percent sand, silt, and clay, and others are available for most if not all soil types at the soil horizon level, but are not readily available at the map unit level. To estimate a parameter at the map unit level the parameter is calculated by a weighted average based on the ratio of soil type contained within the soil horizons and component soil for a given depth.

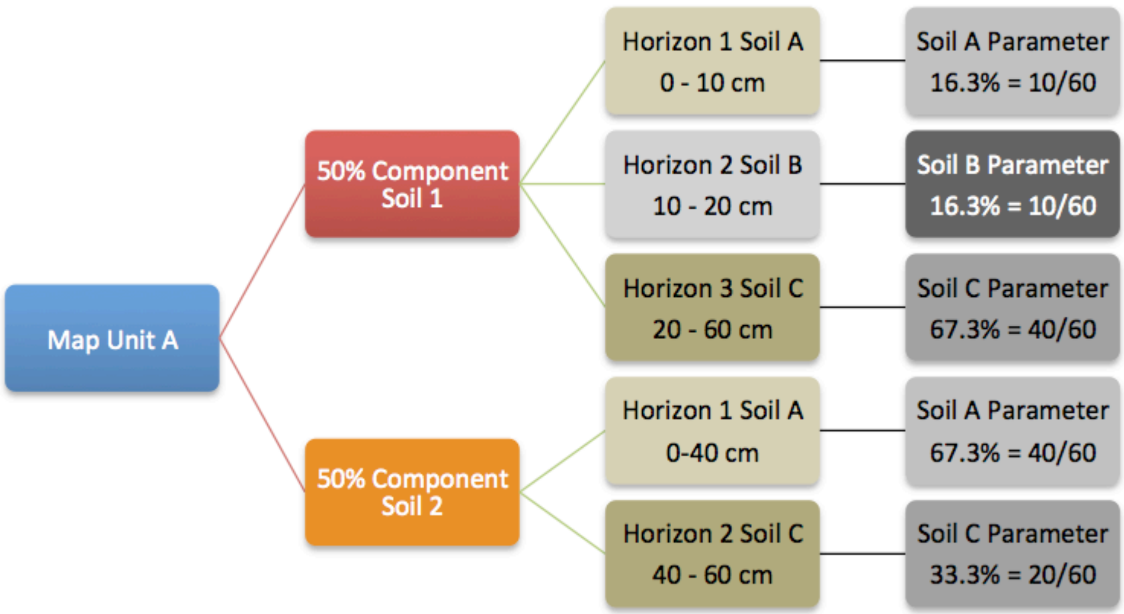

Figure 2: Example soil type distribution to a depth of 60 cm within a map unit.

In the example shown in **Figure 2**, an average arbitrary parameter for Map Unit A considering a depth of 60 cm would be obtained as follows:

$$MapUnitAparam = \frac{1}{2}[SoilComponent1param] + \frac{1}{2}[SoilComponent2param]$$

$$\begin{aligned} MapUnitAparam \\ &= \frac{1}{2}\left[\frac{10cm}{60cm}SoilAparam + \frac{10cm}{60cm}SoilBparam + \frac{40cm}{60cm}SoilCparam\right] \\ &+ \frac{1}{2}\left[\frac{40cm}{60cm}SoilAparam + \frac{20cm}{60cm}SoilCparam\right] \end{aligned}$$

$$\begin{aligned} MapUnitAparam \\ &= \left[\frac{1}{12}SoilAparam \times \frac{1}{12}SoilBparam \times \frac{1}{3}SoilCparam\right] \\ &+ \left[\frac{1}{3}SoilAparam + \frac{1}{6}SoilCparam\right] \end{aligned}$$

$$MapUnitAparam = \frac{5}{12}SoilAparam \times \frac{1}{12}SoilBparam \times \frac{1}{2}SoilCparam$$

The algorithm estimates parameters for each map unit by weighting the parameters' arithmetic average as shown in the above equations with the exception of saturated vertical hydraulic conductivity. Hydraulic conductivity is harmonically averaged for each soil column (a.k.a. component soil) to account for variations in conductivity with depth.

$$K_{soilcomponentAparam} = \frac{Depth\ of\ soil\ column}{\sum \frac{layer\ thickness}{K_{soilparam}}}$$

The algorithm creates an average parameter value for each subbasin by summing the weighted averages of the map unit parameter which are weighted by percent coverage area within the subbasin as shown in **Figure 3**.

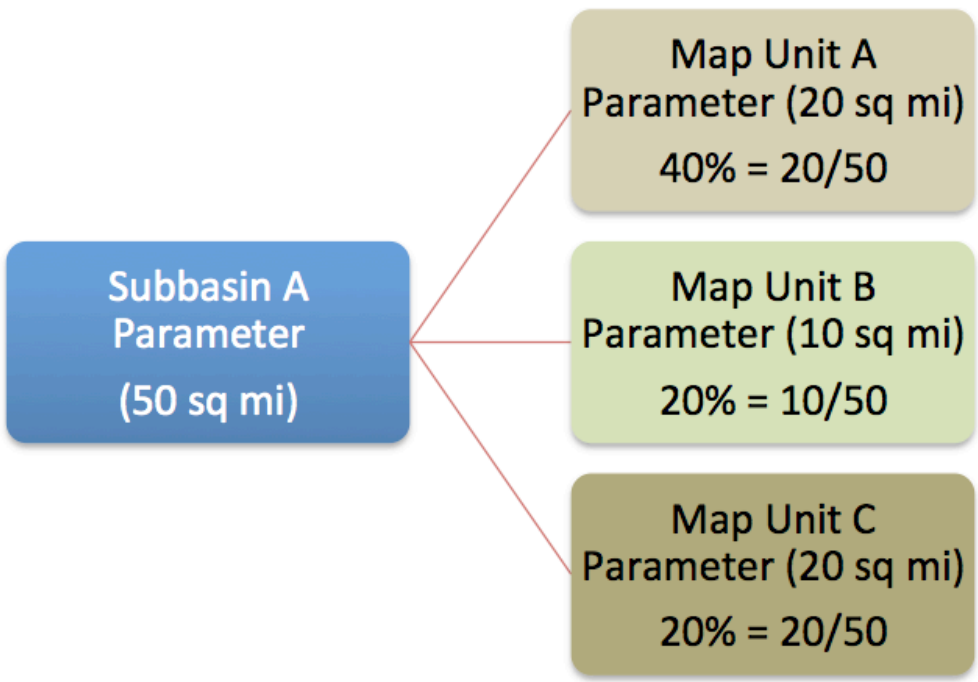

Figure 3: Example subbasin parameter weighting.

There are times when a map unit does not have a corresponding component soil (e.g. water, mining), a component soil does not have a corresponding soil horizon, the soil horizon data does not cover the specified depth or a soil type does not contain the desired parameter. These cases are rare, typically affecting less than 5% of a basin, so the algorithm handles this by ignoring them.

Derivation of Input Parameters:

The required inputs for the deficit and constant loss method within HEC-HMS are initial storage deficit, maximum storage, constant rate, and percent impervious. The soil parameters are obtained either directly from the SSURGO database or obtained by using readily available parameters described further below. Percent of impervious land cover is obtained by averaging the impervious land cover available from the National Land Cover Database 2006 over each subbasin (Fry et. al., 2011).

Saturated vertical hydraulic conductivity and satiated water content are available for nearly all soil types within the database. The database also contains a range of values (low, representative, and high) for some parameters such as hydraulic conductivity. Saturated vertical hydraulic conductivity was used as an estimate of the constant rate. Since saturated vertical hydraulic conductivity greatly overestimated the constant rate, the representative hydraulic conductivity values obtained from SSURGO were reduced by a factor of 16.

The top eighteen inches of soil were considered to be relevant during the modeled storm events. Since the database does not contain porosity, satiated water content is used as a surrogate for porosity. Therefore, the maximum storage was calculated as follows:

$$Max\ storage, in = 18in(\phi_{sat}\text{-}\phi_{wp})$$

where:

ϕ_{sat} = satiated water content

ϕ_{wp} = water content at wilting point (assumed to be 0.15 for this project)

References

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77(9):858-864.

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Appendix D

Description of travel time derivation

Overview

The North Dakota State Water Commission (SWC) has revised an algorithm developed by the Minnesota Department of Natural Resources (DNR) that estimates runoff travel time by using terrain, land use, and empirical data (Minnesota Department of Natural Resources, 2011). The original algorithm operates using an Esri™ GIS platform and has been rewritten for use with the free and open-source Grass GIS platform by the SWC (Grass Development Team, 2013). The rewritten algorithm did not change the logic of the original algorithm; however, it utilizes Grass GIS commands which typically are much faster than equivalent Esri™ GIS-based commands.

Calculation

The travel time tool calculates velocities using Manning's equation for each cell of a digital elevation map (DEM).

$$v = \frac{k}{n} R^{\frac{2}{3}} \sqrt{S}$$

where:

v is the flow velocity in ft/s or m/s
k is a conversion factor (1.49 for English units or 1.0 for metric)
R is the hydraulic radius in feet or meters
S is the bed slope in ft/ft or m/m
n is the Manning's roughness constant

The velocities are converted to time based on the cell resolution and direction of flow and a given starting cell (i.e. the outlet for the entire basin). An estimate of travel time for a given subbasin can be obtained by subtracting the maximum travel time value from the minimum travel time value within the subbasin. However, it was found that if the sum of the mean and variance was subtracted from the minimum travel time, a more realistic estimate may result. This gives less weight to outlier areas which may have travel times which don't represent the rest of the subbasin.

The tool classifies the DEM into three separate flow regimes based on thresholds set by contributing area: overland flow, shallow concentrated flow, and channel flow.

The 2006 National Land Cover Dataset (NLCD) was used for land classification (Fry et. al., 2011). The National Wetlands Inventory (NWI) dataset was used to determine wetland locations (U.S. Fish and Wildlife Service, 2013).

Manning's Roughness Constant

Manning's roughness was assigned based on land classification and flow regime. Manning's roughness values used for the overland and shallow, concentrated flows are summarized in **Table 1**.

Table 1: Manning's roughness values for specified land classification and flow regime.

NLCD Land Classification Code	NLCD Land Classification Description	Overland Flow Manning's Roughness	Shallow, Concentrated Flow Manning's Roughness
11	Open Water	0.002	0.002
12	Perennial Ice/Snow	0.01	0.01
21	Developed, Open Space	0.05	0.04
22	Developed, Low Intensity	0.05	0.04
23	Developed, Medium Intensity	0.03	0.01
24	Developed High Intensity	0.03	0.01
31	Barren Land (Rock/Sand/Clay)	0.05	0.04
41	Deciduous Forest	0.1	0.08
42	Evergreen Forest	0.1	0.08
43	Mixed Forest	0.1	0.08
51	Dwarf Scrub	0.2	0.13
52	Shrub/Scrub	0.2	0.13
71	Grassland/Herbaceous	0.2	0.1
81	Pasture/Hay	0.07	0.08
82	Cultivated Crops	0.07	0.08
90	Woody Wetlands	0.2	0.13
95	Emergent Herbaceous Wetlands	0.01	0.01

For channelized flow Manning's roughness was assigned as a function of flow accumulation as shown in **Table 2**. If the channel is classified as either a wetland or a lake by the NWI an overriding Manning's roughness is assigned.

Table 2: Manning's roughness values for channelized flow and wetland classification.

Channel Condition	Manning's roughness
Drainage area less than 5 square miles	0.045
Drainage area between 5 and 20 square miles	0.040
Flow within a wetland (overrides drainage area based n)	0.010
Flow within a lake (overrides drainage area based n)	0.002

Hydraulic Radius

Similarly, hydraulic radius values were also assigned based on land classification and flow regime. These values are based on documentation provided for the original DNR travel time tool (Minnesota Department of Natural Resources, 2011). Hydraulic radius values used for the overland and shallow, concentrated flows are summarized in **Table 3.**

Table 3: Hydraulic radius values for specified land classification and flow regime.

NLCD Land Classification Code	NLCD Land Classification Description	Overland Flow Hydraulic Radius, ft	Shallow, Concentrated Flow Hydraulic Radius, ft
11	Open Water	1	2
12	Perennial Ice/Snow	1	2
21	Developed, Open Space	0.1	0.6
22	Developed, Low Intensity	0.1	0.6
23	Developed, Medium Intensity	0.1	0.6
24	Developed High Intensity	0.1	0.6
31	Barren Land (Rock/Sand/Clay)	0.1	0.6
41	Deciduous Forest	0.1	0.6
42	Evergreen Forest	0.1	0.6
43	Mixed Forest	0.1	0.6
51	Dwarf Scrub	0.1	0.6
52	Shrub/Scrub	0.1	0.6
71	Grassland/Herbaceous	0.1	0.4
81	Pasture/Hay	0.1	0.4
82	Cultivated Crops	0.1	0.4
90	Woody Wetlands	0.1	0.4
95	Emergent Herbaceous Wetlands	0.1	0.4

For channelized flow hydraulic radii were calculated as a function of flow accumulation using the following equation.

$$R = aX + b$$

where:

R is the hydraulic radius in feet

a is a constant with a default setting of 0.0032

X is the accumulated drainage area in square miles

b is a constant with a default setting of 1.7255

Slope

A slope raster was calculated for the overland and shallow, concentrated flow by using the Grass GIS algorithm r.slope.aspect. A threshold for the minimum slope was set at 0.0002. Slopes within the channelized flow areas were calculated by only considering the slope along the channel path. Again, a minimum threshold of 0.0002 was used to handle low and negative slopes.

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North Dakota State Water Commission

Project:	Storage Area Parameters	**Prepared By:**	Mitch Weier
Project No.:		**Date:**	2015-01-31
		Checked By:	

Appendix E

Storage Area Parameters

Overview

Storage areas were screened to evaluate their effectiveness at mitigating peak flows at Linton for a 1-percent annual chance, 10-day event (screening event). **Figure 1** shows storage sites where storage volumes were calculated. **Table 1** summarizes the maximum storage, maximum surface area, dam length, and dam height. These storage area sites were selected based on potential effectiveness and avoiding existing homes or ranching operations to the extent practicable. For the purposes of this screening, it assumed that these would be dry dams whose purpose would be solely to mitigate the flood peaks.

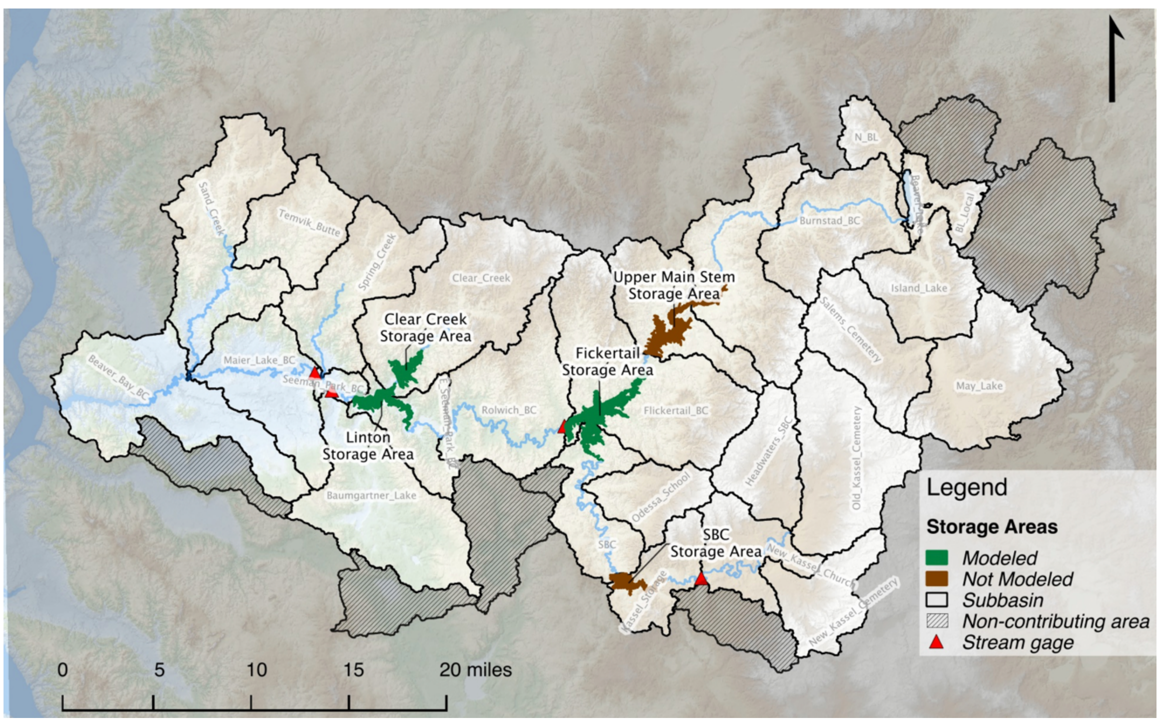

Figure 1: Maximum footprint of storage areas.

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Table 1: Storage area characteristics.

Name	Maximum Storage, ac-ft	Maximum Surface Area, ac	Dam Height, ft	Dam Length, ft
Flickertail SA	20,171	2,301	32	1,100
Linton SA	17,095	1,075	40	3,100
Clear Creek SA	15,900	722	71	3,200
Upper Main Stem SA	13,905	1,687	23	2,800
SBC SA	5,723	626	33	5,000

Physical characteristics of the storage areas (dam length, dam height, and storage volume, elevation, and area relationships) were determined by using GRASS GIS (GRASS Development Team, 2013) and the r.reservoir algorithm developed by the State Water Commission that is based on the r.lake algorithm. In general terms, the digital elevation model (DEM) is altered by setting the elevation within the footprint of the dam to the specified dam crest elevation, which calculates the dam length and height. Then the area behind the altered DEM is "flooded" from the lowest point up to the dam crest by a specified increment, which calculates the storage capacity curve.

The Clear Creek, Linton, and Flickertail storage areas were modeled as a system of dry, flood control dams to mitigate the screening event. Two of the storage areas, SBC and Upper Main Stem, were not modeled because of their small size or distance from the City of Linton.

Figures 2, **3**, and **4** show the elevation-storage relationship for the Flickertail, Linton, and Clear Creek storage areas, respectively.

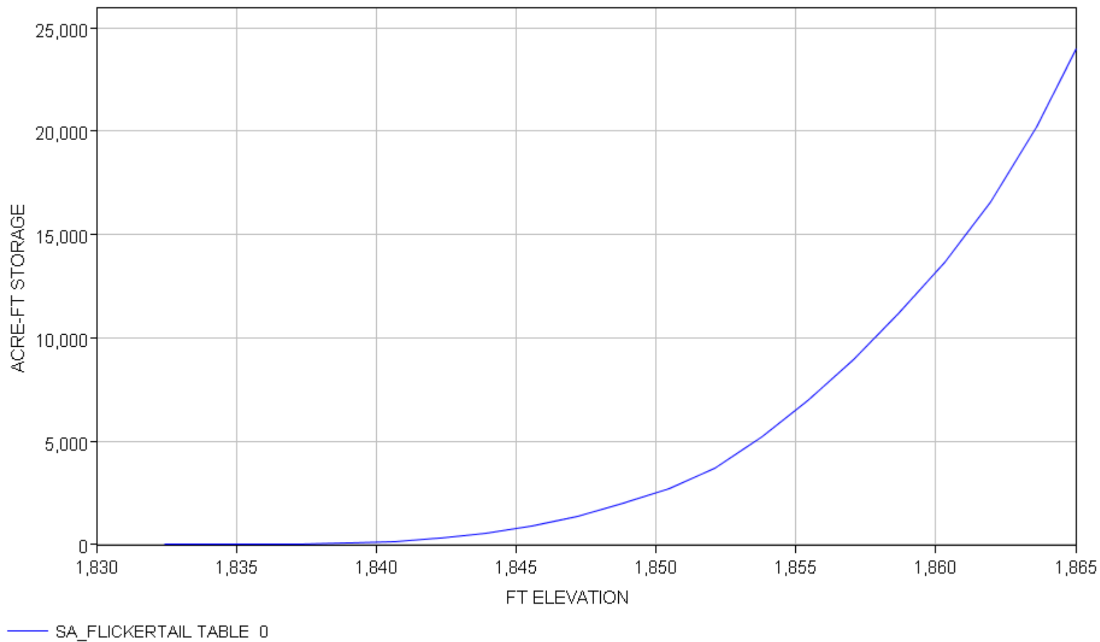

Figure 2: Elevation-storage relationship for the Flickertail storage area.

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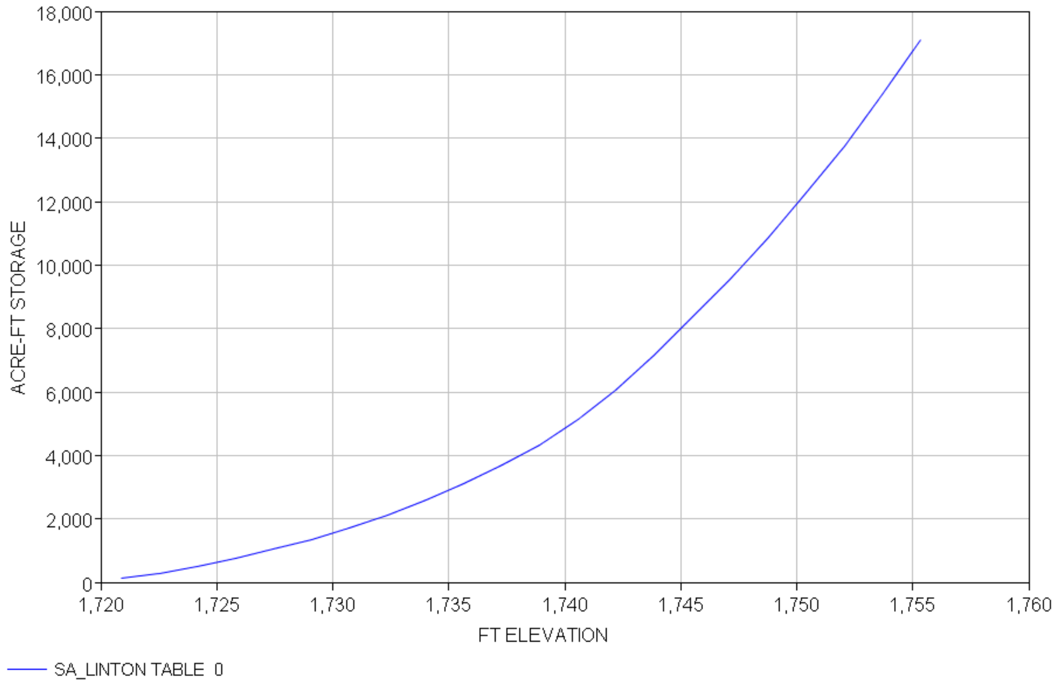

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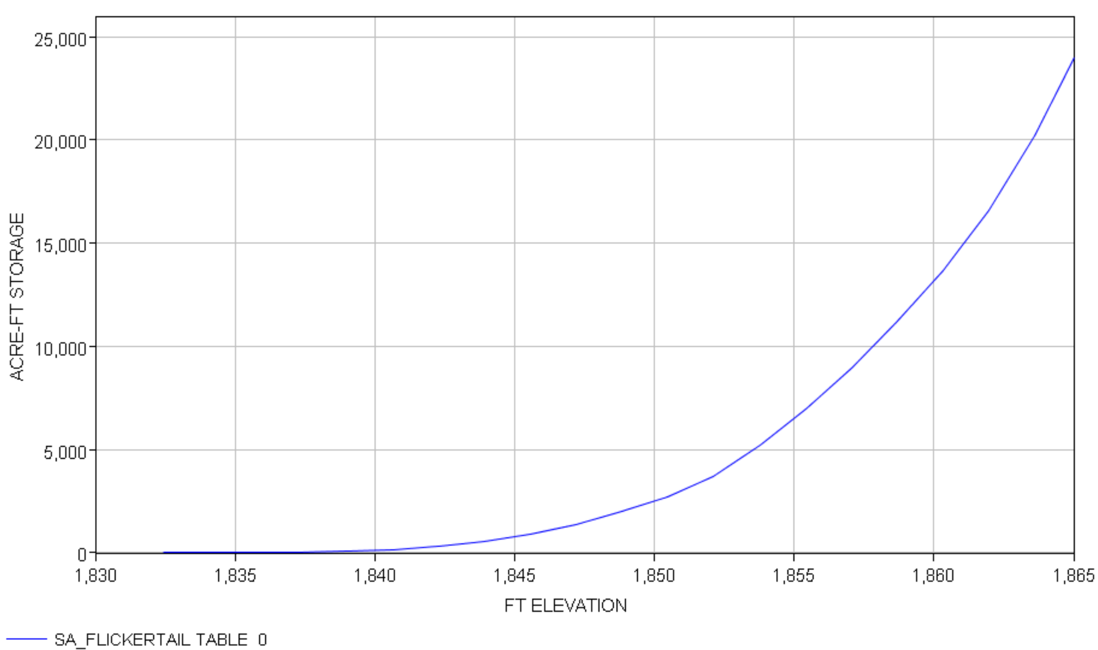

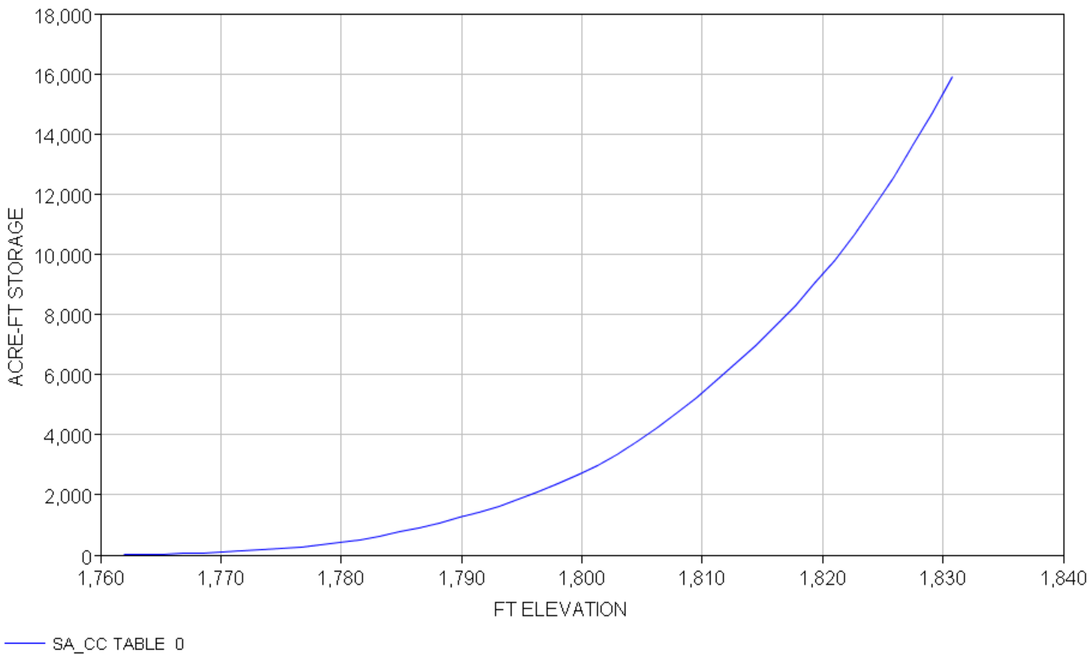

Figure 4: Elevation-storage relationship for the Clear Creek storage area.

The Flickertail, Linton, and Clear Creek storage areas were modeled as dry dams with box culverts sized to maximize storage for the 10-day, 1% chance annual exceedance event. Each box culvert or set of culverts had an assumed length of 100 feet, flared wingwalls, an entrance coefficient of 0.7, an exit coefficient of 1, and a mannings roughness coefficient of 0.013. The Flickertail and Linton storage area outlets were modeled as a pair of 12 ft x 12 ft box culverts. The Clear Creek storage area outlet was modeled as a single 5 ft x 5 ft box culvert.

References

GRASS Development Team, 2013. Geographic Resources Analysis Support System (GRASS) Software, Version 6.4.3. Open Source Geospatial Foundation. http://grass.osgeo.org