Nash Spring Creek Hydrologic Analysis - Bozeman Creek and Tributaries Digital Flood Insurance Rate Map Restudy Project

prepared for

Montana Department of Natural Resources and Conservation

1424 9th Avenue

Helena, Montana 59620-1601

March 2014

RESPEC CONSULTING & SERVICES

3810 Valley Commons Drive, Suite 4

Bozeman, Montana 59718

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1.0 INTRODUCTION

1.1 Background

As part of the Mapping Activity Statement (MAS) contract for Bozeman Creek and tributaries, Gallatin County, Montana (**Reference 5**), RESPEC is completing a detailed floodplain study for approximately 2.4 miles of Nash Spring Creek within Gallatin County, Montana. The Nash Spring Creek study limits extend from the confluence with Bozeman Creek just south of Kagy Blvd at the downstream limit to the upstream limit of approximately 3,200 feet upstream of Goldenstein Ln. The project area is displayed in **Figure 1-1**.

A Flood Insurance Study (FIS) has been completed for Gallatin County (**Reference 6**). Flood hazards are currently mapped as detailed Zone AE for the entire study area of Nash Spring Creek. The effective flooding for Nash Spring Creek is shown in **Figure 1-2**.

The hydrologic analysis for Nash Spring Creek is summarized in this report. The flood study will include the 10-, 4-, 2-, 1- and 0.2-percent-annual-chance (%AC) flood events.

1.2 Basin Description

The Nash Spring Creek watershed is located within the Bozeman Creek watershed (HUC 12 100200080905) with Nash Spring Creek being a left bank tributary to Bozeman Creek. Nash Spring Creek flows in a northern direction from its source spring located just south of Nash Road (approximately two miles upstream of the study limit). Nash Spring Creek encompasses an area of 4.3 mi^2 with the main tributary of Leverich Creek located within the Gallatin National Forest of the Gallatin Mountain Range. Upstream of the confluence with Leverich Creek noted by the USGS Quadrangle Maps to be at Red Tail Ranch Road, Nash Spring Creek proper has a drainage area less than 0.2 mi^2 while Leverich Creek has an approximate drainage area of 3.6 mi^2. The topography of the watershed ranges from mild and steep mountain slopes in the upper reaches of the watershed to a low sloping valley. The watershed is largely comprised of forested areas in the upper reaches with a valley floor largely composed of residential developments mixed with agricultural lands such as farms and grazing pastures.

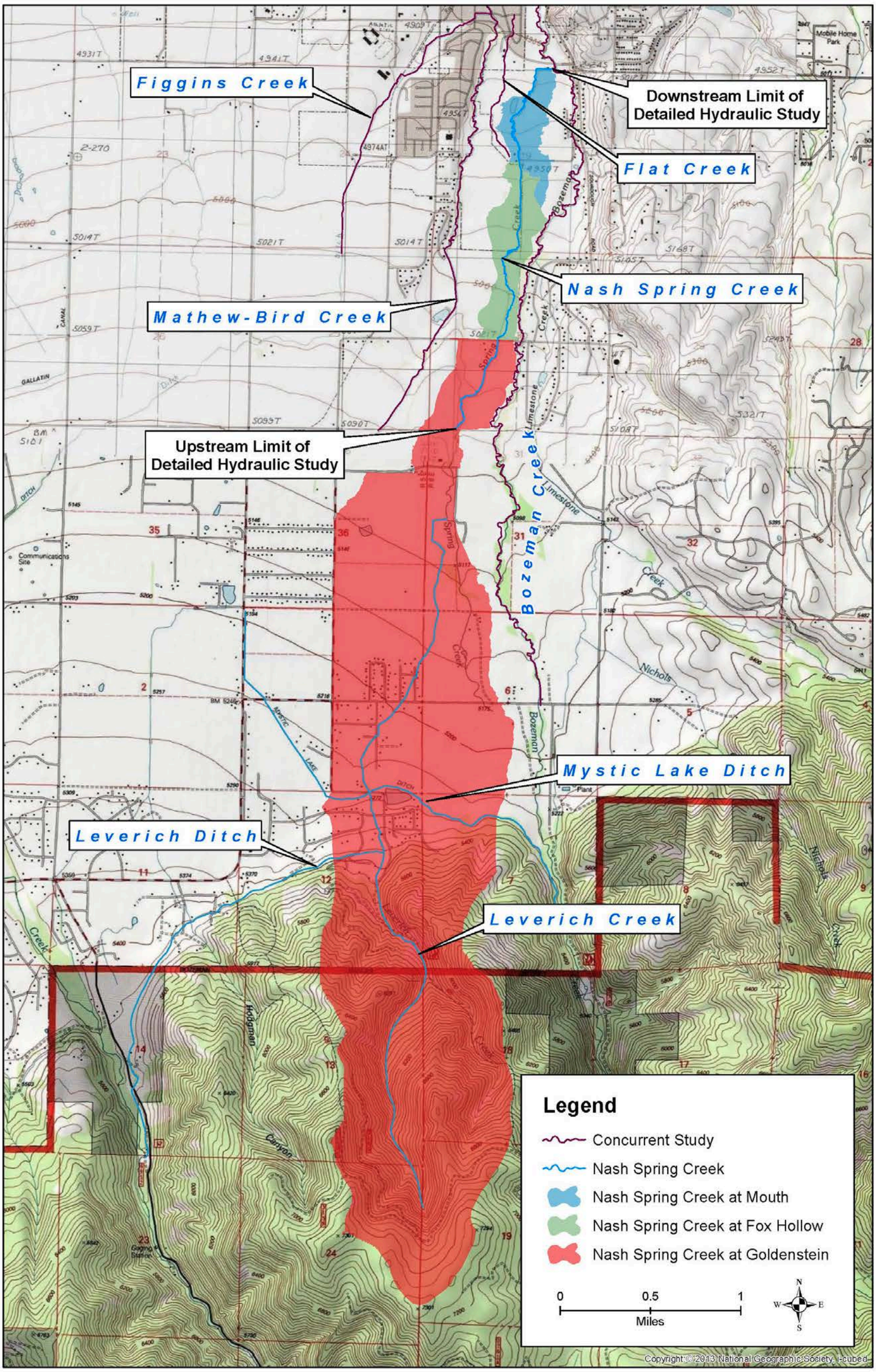

Figure 1-1. Nash Spring Creek watershed

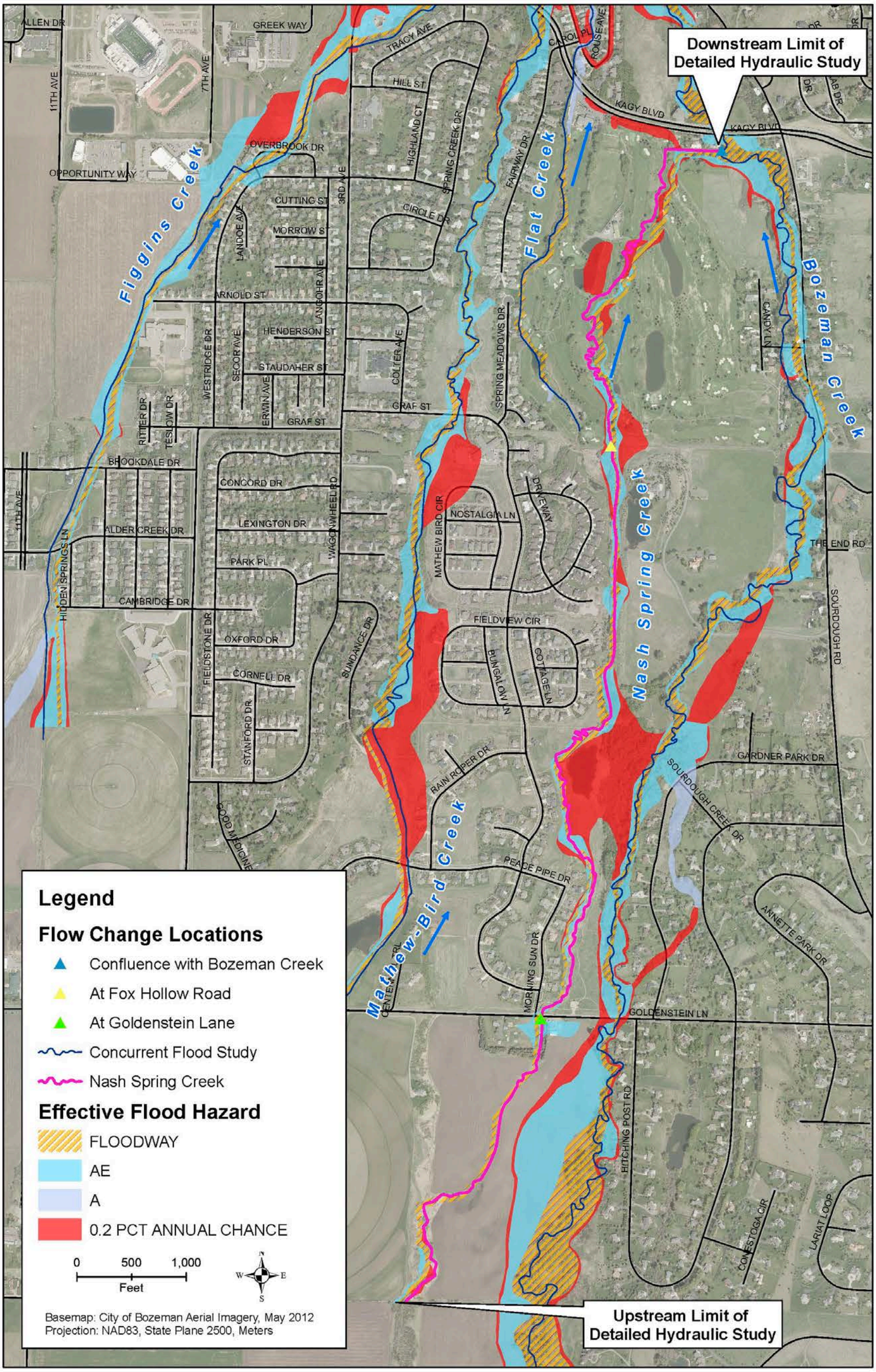

Figure 1-2. Effective flood hazard areas for Nash Spring Creek

1.3 Effective Hydrologic Analysis

As previously mentioned, flood hazards are currently mapped as detailed Zone AE for the entire study area of Nash Spring Creek. As detailed in the Gallatin County FIS which went effective in 2011, an original hydrologic analysis of Nash Spring Creek was completed in June 1979 by the U.S. Department of Agriculture, Natural Resources Conservation Service. A revised hydrologic analysis of Nash Spring Creek was completed by Morrison Maierle, Inc. in January 1985. The effective FIS states that peak discharges for Nash Spring Creek were computed using regression equations developed from 10 gages near the study area. It should be noted that the Summary of Discharges table located in the effective FIS notes that the tabulated peak discharges are "larger than computed by Regression Equations due to the transfer of flow to each basin by uncontrolled irrigation and road ditches." It is assumed that the discharges listed within the FIS are a result of split flows analyzed during the hydraulic analysis rather than the hydrologic analysis. Given that the flow locations listed for Nash Spring Creek in the effective FIS have a much lesser drainage area than the present analysis; it is possible that the effective study accounted for discharge leaving the Nash Spring Creek watershed through the irrigation canals, notably the Mystic Lake Ditch. However, the effective FIS and FEMA library provide no reference to support the assumption.

1.4 Flooding History

Notable flooding within the Bozeman Creek watershed has been recorded in April 1893, April 1948, April 1977, and most recently in May of 2011. All of these events were produced from either high rate snowmelt or rain on snow events. The FIS states that the 1948 event was the largest event with flood waters entering Bozeman (the City) causing considerable damage. There is no reference as to the history of flooding along Nash Spring Creek within the FIS and limited information available as to flooding along the spring creeks. Local administrators and citizens state that the higher discharges associated with the spring creeks south of Bozeman are largely attributed to receiving overflowing flood discharges diverted from Bozeman Creek. Citizen accounts of the 2011 event state that floodwaters overflowing the banks of Bozeman Creek accessed Nash Spring Creek upstream of Valley View Golf Club and Kagy Boulevard.

1.5 Other Studies

The City was consulted for previous study information for Figgins Creek. Unfortunately, the City didn't have any hydrologic data concerning the 100-yr event for the watershed outside of the effective analysis. For development purposes the City requires that storm sewer facilities be sized for the 25-yr event and retention facilities be sized for the 10-yr 2-hr event. Since the focus of the present project is the 100-yr 24-hr event, these studies were considered negligible.

2.0 HYDROLOGIC ANALYSES

Because no gage data is available for Nash Spring Creek, regional regression equations along with an HEC-HMS model were used to calculate the peak discharges. Discharges were calculated at major road crossings and locations of significant drainage area increases. By dividing the basin at structures and locations of significant inflows, the discharges applied to upstream reaches during the hydraulic analysis are not overly conservative. For the present study, flow change locations are located at Goldenstein Lane, Fox Hollow Road, and the confluence with Bozeman Creek just south of Kagy Boulevard. Coincidentally, the effective FIS states that the effective discharges were also calculated at Goldenstein Lane and at the mouth.

The analyzed basin has undergone alterations to its natural drainage patterns primarily for irrigation purposes but also for roads and development. Several irrigation ditches are located in the upstream extents of the basin along the foothills of the Gallatin Mountain Range. Nash Spring Creek also appears to have been realigned from its natural drainage. To some extent, the irrigation ditches have been incorporated into the analysis in the form of longest flow paths and routing parameters assessed in the creation of the HEC-HMS model. However, the presence of Leverich Ditch and Mystic Lake Ditch (noted in **Figure 1-1**) along with their potential to transfer flow to and from neighboring watersheds was largely neglected. These ditches require manual operation to divert flow from its sources of Hyalite Creek and Bozeman Creek, respectively. Additionally, it is suspected that many manually operated controls regulate that flow before reaching the basin. For this analysis, it is assumed that all ditch controls are closed and flow from adjacent watersheds does not enter the basin. It was also conservatively estimated that these ditches were closed and incapable of transferring discharge from the Nash Spring Creek watershed.

2.1 Regional Regression Equation Analysis

Regional regression equations were used to compute the annual peak discharge values for the Nash Spring Creek drainage area. These equations are presented in *Methods for Estimating Flood Frequency in Montana Based on Data through Water Year 1998: U.S. Geological Survey (USGS) Water-Resources Investigations Report (WRIR) 03-4308* (**Reference 11**). USGS WRIR 03-4308 separates Montana into eight different regions based on topography and climatic conditions. The entire drainage area for Nash Spring Creek is located in the Upper Yellowstone-Central Mountain Region

USGS WRIR 03-4308 provides regression equations based on basin characteristics, active-channel width, bankfull width, and various weighted combinations of the methods. It also provides the Standard Error of Prediction (SEP) for all the methods. Smaller SEP percentages point to greater reliability of the regression equations used.

Prior to using the equations, the variables for the regression equations were estimated. All estimated variables for Nash Spring Creek were within the acceptable range of values used to generate the regression equations. It should be noted that the applicability of the channel characteristics regression estimates for Nash Spring Creek is considered to be less reliable. The active-channel and bankfull widths measured for Nash Spring Creek during field reconnaissance are likely inapplicable due to man-made alterations of the natural channel in the form of road crossings, development, bank protection and grade control structures. The upper extents of the stream are more natural with the channel becoming more incised as it moves through the presence of urban development. This is proven in the fact that although the active-channel increases, the bankfull width measurement actually decreases from the upper extents (Goldenstein Lane) to the middle portion of the reach (Fox Hollow Rd). Because of this, the discharges for Nash Spring Creek derived from the regression equations based on channel characteristics should be used with caution. The range of values applied for the regression analyses are presented in **Table 2-1**.

ArcGIS 10.1 was used to estimate all variables for the basin characteristics equations in a manner consistent with the methods used by the USGS to formulate the regression equations. The drainage areas (A) were delineated using 2 ft LiDAR contours and USGS Topographic Quadrangle Maps. Drainage area delineations utilized for the regression analysis are shown in **Figure 1-1** and the values are shown in **Table 2-1**. As noted by the watershed delineation shown in **Figure 1-1,** the western boundary follows South 3rd Avenue until meeting the Mathew-Bird Creek watershed at approximately Red Tail Road. During research of digital data and field visits it was discovered that there was a lack of any hydraulic crossing allowing the drainage area west of South 3rd Avenue to access the delineated Nash Spring Creek watershed. Prior to overtopping South 3rd Avenue, all runoff on the west side of the roadway is directed along roadside ditches to the Mathew-Bird Creek watershed.

The percentage of drainage area above elevation of 6000' (E_{6000}) was estimated by delineating the 6000' contour from the USGS Topographic Quadrangle maps. The delineated area above 6000' totals 1.4 mi^2 and is shown on **Figure 2-1**. The resulting percentages of drainage area above elevation of 6000' are summarized in **Table 2-1** and calculations are included in **Appendix A**.

The active-channel width and bankfull width for all basins were measured during field reconnaissance based on guidelines presented in USGS WRIR 03-4308. These values are presented in **Table 2-1**.

Table 2-1. Regression parameters

Description	Drainage Area, A (mi^2)	Percentage of basin above 6,000 feet in elevation, E_{6000} (%)	Active Channel Width W_{ac} (ft)	Bankfull Channel Width W_{bf} (ft)
Upper Yellowstone-Central Mountain Region Range of Values Used to Develop Regression Equations	0.47 - 2,032	0 - 100	1.0 - 150	2.5 - 170
Confluence with Bozeman Creek	4.31	32.46	10.0	14.0
Fox Hollow Rd - Valley View Golf Course	4.19	33.41	6.0	8.5
At Goldenstein Lane	3.99	35.07	3.5	9.5

Regression equations for basin characteristics, active-channel width, and bankfull width were calculated for Nash Spring Creek at Goldenstein Lane, just east of Fox Hollow Rd at Valley View Golf Course, and at the confluence with Bozeman Creek independently. A weighted combination of the three methods was also computed for the three locations. All calculations were performed using the web-based USGS Flood Discharge at Ungaged Sites in Montana program. The program utilizes the equations presented in WRIR 03-4308. Results of the regression analyses are included below in **Section 3** of this report and the output data from the USGS web-based program is included in **Appendix B**.

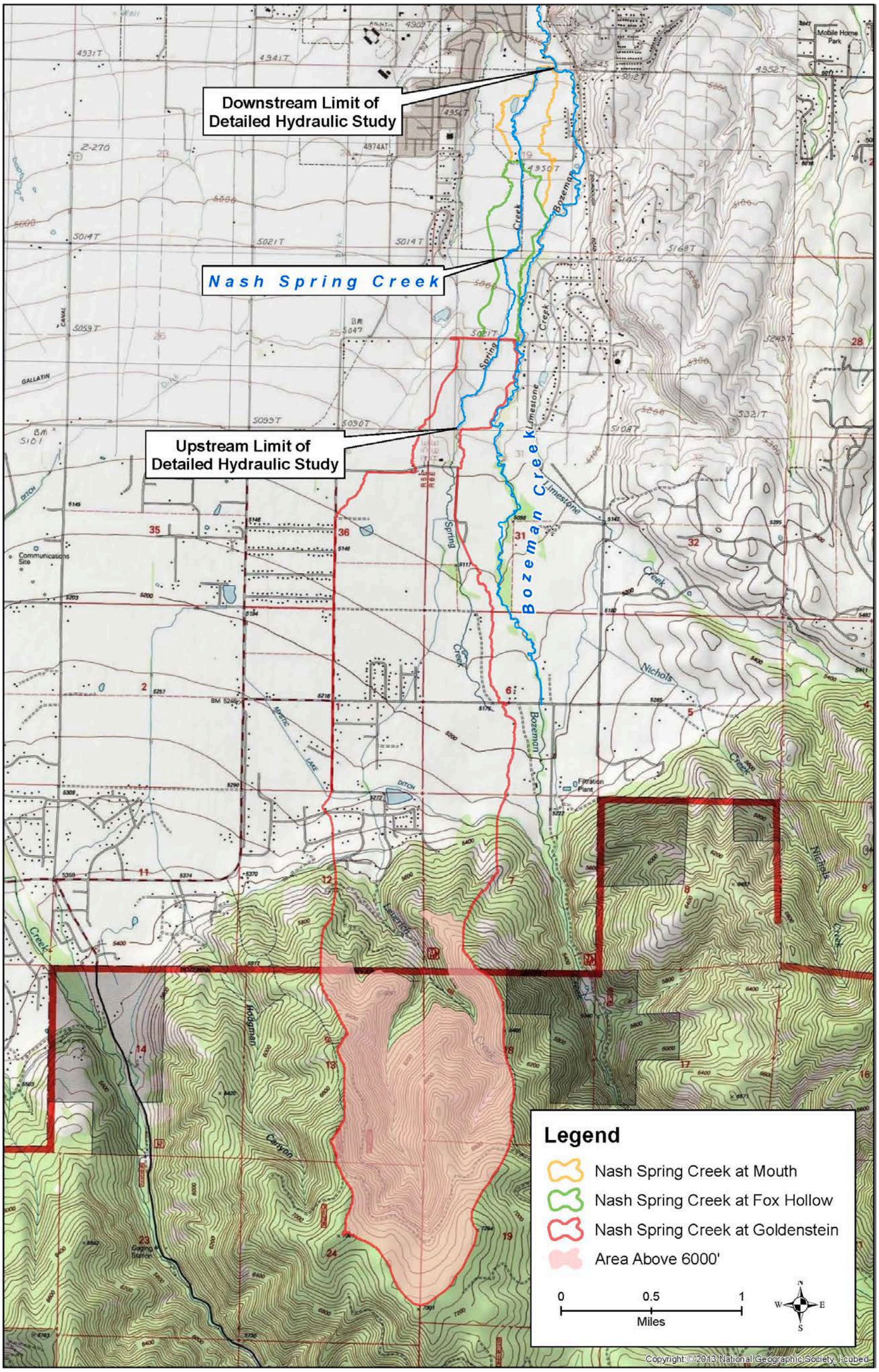

Figure 2-1. Nash Spring Creek watershed area above elevation of 6,000'

2.2 Rainfall-Runoff Analysis

The Nash Spring Creek watershed was also analyzed using the rainfall-runoff method. This was done utilizing the U.S. Army Corps of Engineers' (USACE) HEC-HMS modeling program Version 3.5. The HEC-HMS modeling program is a graphical user interface designed to simulate a precipitation-runoff response in urban or natural watersheds. The model takes into account a user specified meteorological model, loss and transform method, and reach routing method for each individual subbasin entered into the program.

The meteorological model for Nash Spring Creek utilized a 24-hour design storm to simulate the rainfall over the watershed. The SCS Runoff Curve Number Method was used to model potential losses. The transform method used is the Curve Number Method described in National Engineering Handbook (**Reference 9**). The Muskingum-Cunge routing method was used to route the hydrograph through the watershed. Results of the HEC-HMS model are provided in **Section 3**.

2.2.1 Precipitation

Design storms used in the hydrologic analysis of Nash Spring Creek consisted of a 24-hour design storm distribution. Point precipitation depths for the 10-, 4-, 2-, and 1-percent-annual-chance storm events were taken from the isohyetal maps found in *NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume I – Montana* (**Reference 5)** for durations of 6 and 24 hours. All precipitation durations less than six hours were obtained using equations, figures and tables presented in *NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume I – Montana* and *Short Duration Rainfall Relations for the Western United States* (**Reference 6**). The 0.2-percent-annual-chance storm event precipitation values were extrapolated from a log-probability curve of the 10-, 4-, 2-, and 1-percent annual chance storm events. All point precipitation depths are displayed in **Table 2-2**. All pertinent data used to determine the depths are included in **Appendix C**.

Table 2-2. Design storm rainfall depths

Duration	50-Percent-Annual-Chance Depth (in)	20-Percent-Annual-Chance Depth (in)	10-Percent-Annual-Chance Depth (in)	4-Percent-Annual-Chance Depth (in)	2-Percent-Annual-Chance Depth (in)	1-Percent-Annual-Chance Depth (in)	0.2-Percent-Annual-Chance Depth (in)*
5 min	0.17	0.26	0.33	0.42	0.49	0.57	0.72
15 min	0.31	0.49	0.61	0.77	0.92	1.06	1.35
1 hr	0.45	0.72	0.91	1.13	1.34	1.54	1.94
2 hr	0.52	0.79	0.98	1.22	1.42	1.60	2.04
3 hr	0.59	0.85	1.05	1.30	1.48	1.66	2.08
6 hr	0.75	1.00	1.20	1.50	1.65	1.80	2.25
12 hr	0.94	1.26	1.53	1.88	2.09	2.25	2.81
24 hr	1.20	1.60	1.90	2.30	2.60	2.80	3.37

**0.2-percent-annual-chance precipitation depths were extrapolated from 50- to 1-percent-annual-chance depths.*

It should be noted that the utilized rainfall values were compared with the values referenced in the City of Bozeman's (the City) *Design Standards and Specifications Policy* (**Reference 3).** Comparison of the City's rainfall depths shows close correlation with the isohyetal maps found in *NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume I – Montana*. However, the short duration values taken from *NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume I – Montana* and *Short Duration Rainfall Relations for the Western United States* were more conservative (larger) than those estimated utilizing the City's values.

2.2.2 Loss Rate

The SCS Curve Number Method was chosen to model potential runoff loss with respect to soil type and land use conditions. Because the SCS Curve Number Method is recommended for drainage areas of three (3) square miles or less, the Nash Spring Creek watershed was divided into 11 subbasins. The subbasins utilized in the hydrologic modeling of Nash Spring Creek are shown in **Figure 2-2**. Drainage areas for the various subbasins are presented in **Table 2-3**.
Soils coverage for the Nash Spring Creek watershed was obtained in Soil Survey Geographic (SSURGO) format from the Natural Resources Conservation Service (NRCS) Geospatial Data Gateway (**Reference 8**). The hydrologic soil groups present within the Nash Spring Creek watershed are displayed in **Figure 2-3**. Land use data was also obtained from the NRCS Geospatial Data Gateway as well as the City (**Reference 4**). The land use classifications present within the Nash Spring Creek watershed are displayed in **Figure 2-4**. Shapefiles containing the soils and land use data were intersected and clipped to the watershed boundary. This process resulted in a shapefile containing the land use associated to each soil type, along with the total area of each soil and land use combination within the watershed. The NRCS

Urban Hydrology for Small Watersheds Technical Release 55 (TR-55) (**Reference 10**) was used to assign a set of curve numbers to each of the subbasins. When assigning curve numbers all areas were considered to be in good hydrologic condition with an antecedent moisture condition of two (AMCII). An on-site evaluation of the watershed was conducted in addition to the examination of aerial imagery and land use coverage. This evaluation aided in assigning the most representative set of curve numbers to the different land use and vegetative cover types present in the watershed. The adopted land use curve numbers utilized for this study are shown in **Appendix D**.

Each subbasin's cumulative loss rate was determined by calculating an areal weighted-average curve number value. This final weighted-average curve numbers for the subbasins of Nash Spring Creek are shown in **Table 2-3** below. Calculations for the curve number method are included in **Appendix E**.

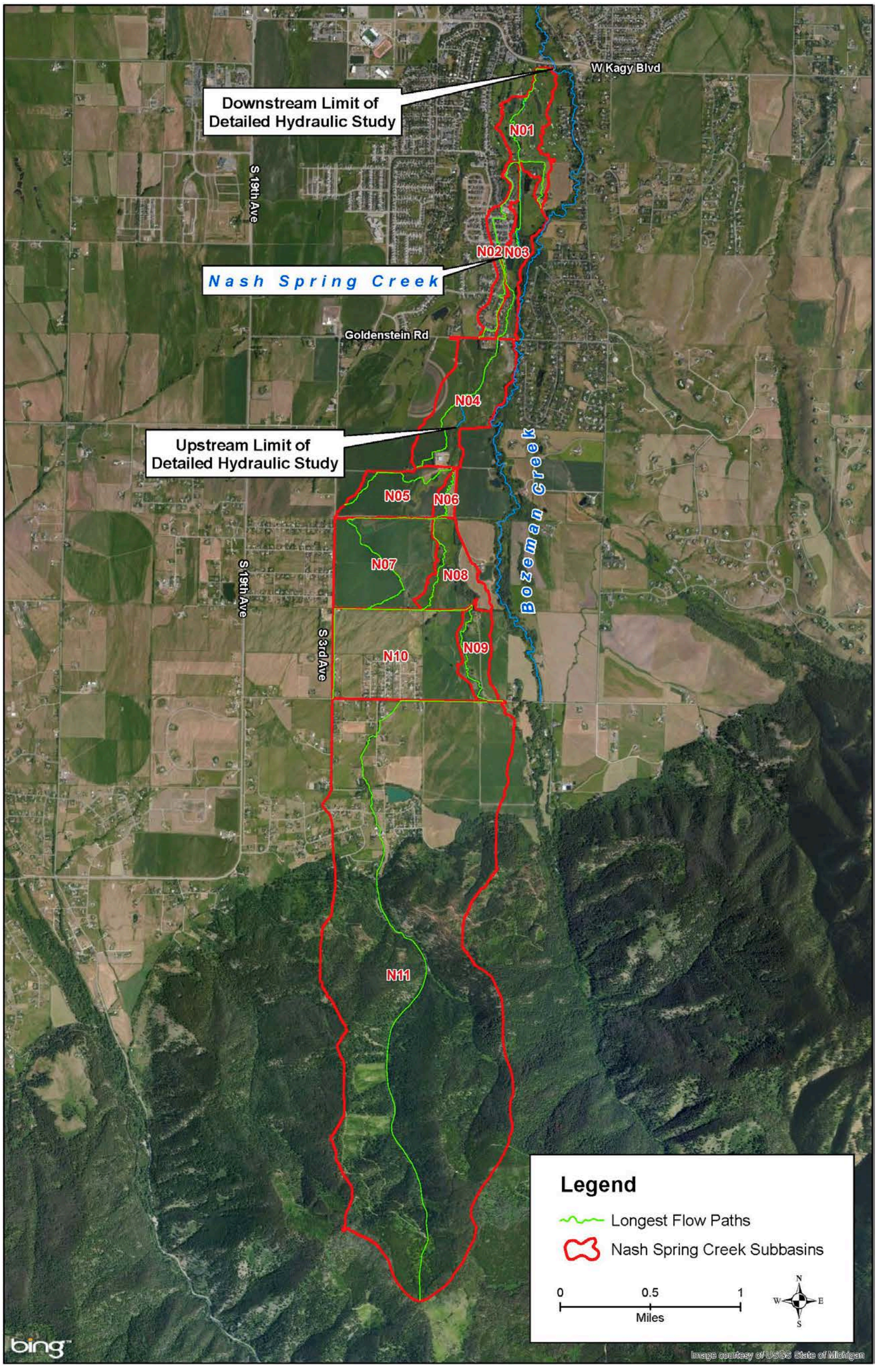

Figure 2-2. Subbasins and longest flow paths utilized for the hydrologic model

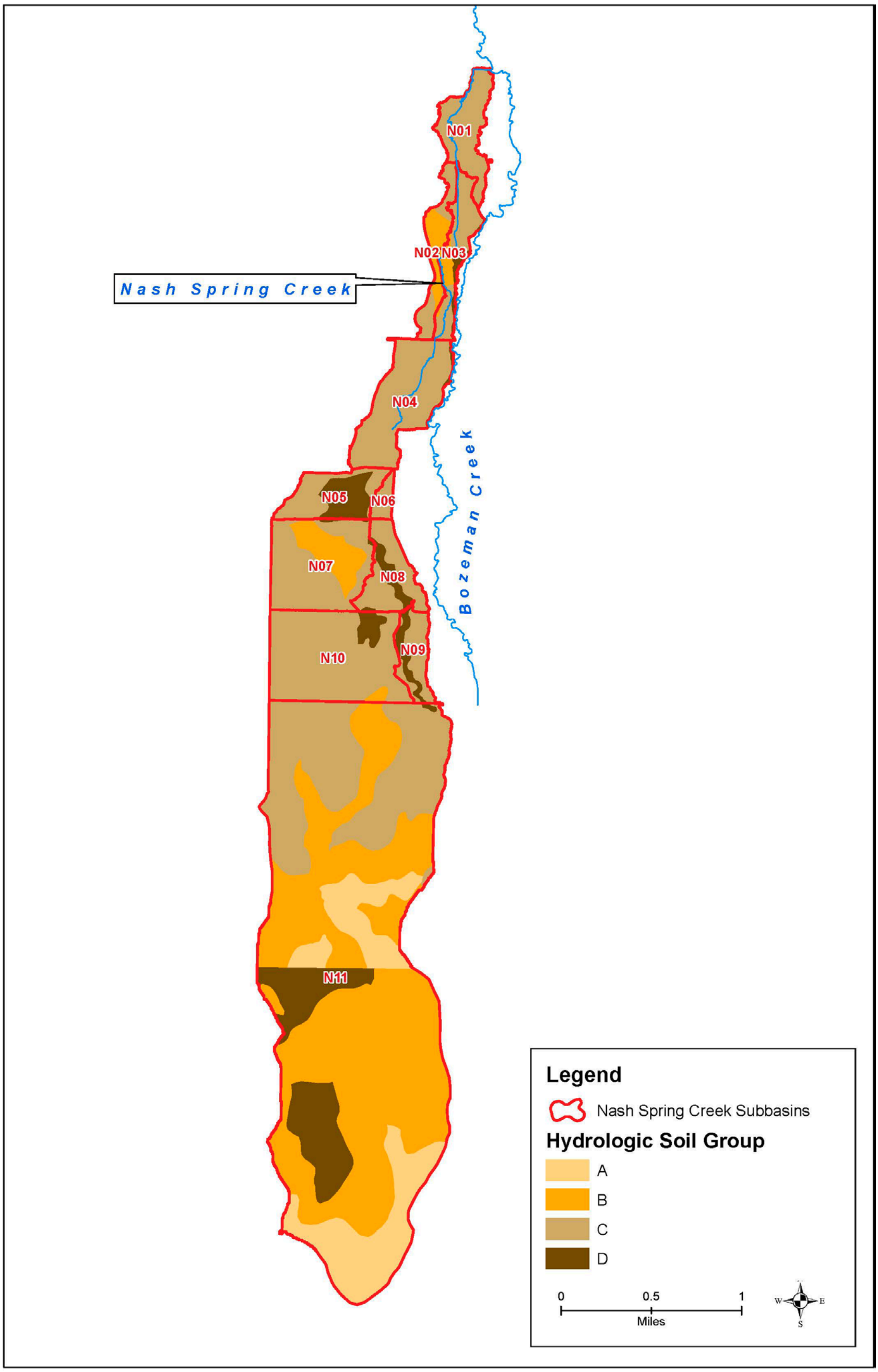

Figure 2-3. Hydrologic soil groups present within the Nash Spring Creek watershed

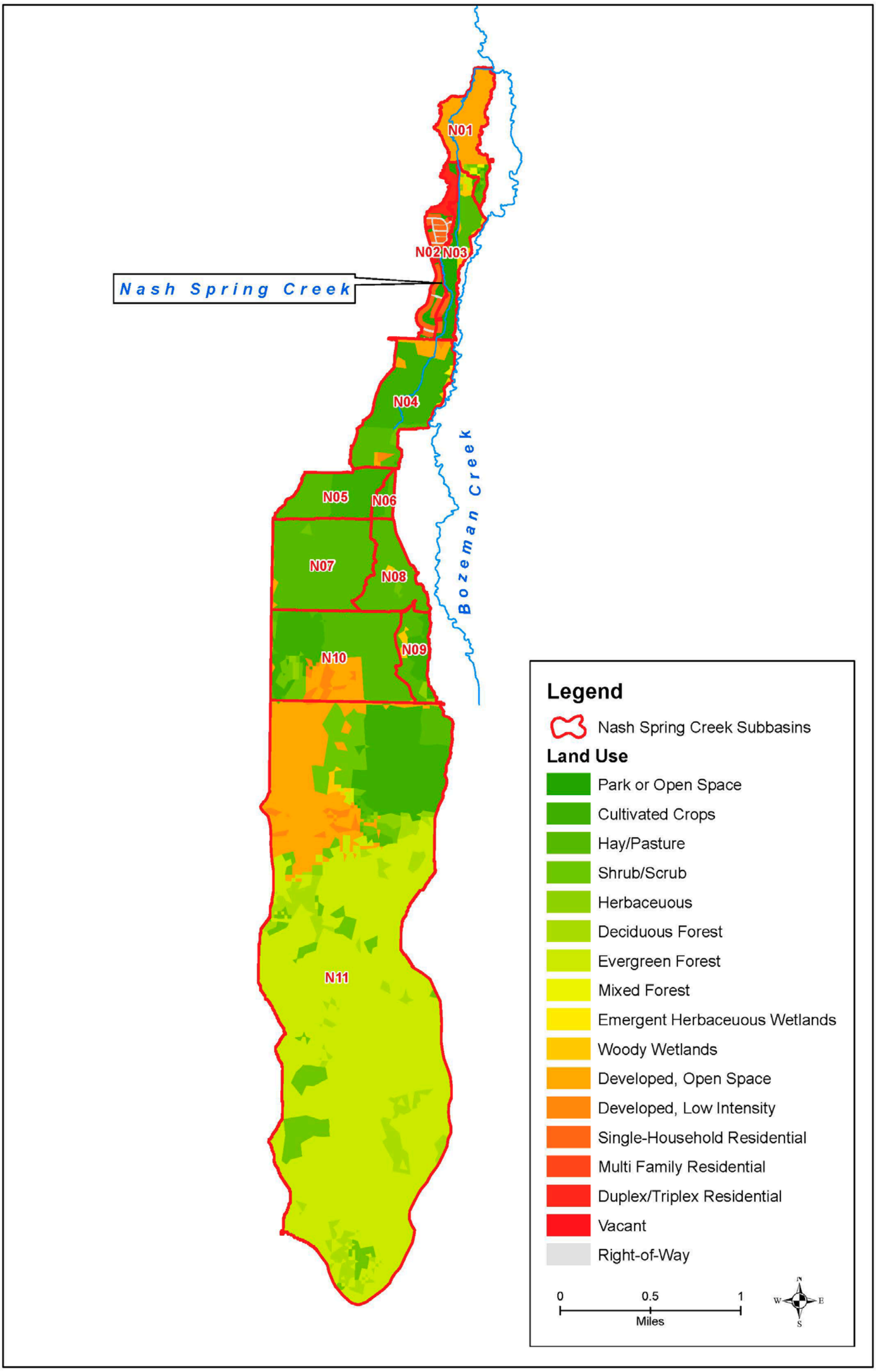

Figure 2-4. Descriptions of land uses present within the Nash Spring Creek watershed

2.2.3 Transform

In order to employ the SCS Dimensionless Unit Hydrograph method to distribute the runoff volume for the basin, the SCS lag time was required. The lag time for the basin was calculated using the Curve Number Lag Method described in the *National Engineering Handbook* (**Reference 8**). The lag time is calculated using the following equation:

$$L = (l^{0.8}(S+1)^{0.7}) / 1900Y^{0.5}$$

Where L equals the lag time in hours; l is defined as the hydraulic length of the catchment in feet; Y represents the average watershed land slope in percent; and

$$S = (1000 / CN) - 10$$

in which CN represents the dimensionless curve number described in **Section 2.2.2**.

Both the hydraulic length of the catchment and the average watershed land slope were calculated using ArcGIS 10.1 with the LiDAR and 10-m DEM datasets, respectively. The path of the hydraulic length for each subbasin is shown in **Figure 2-2**. Initial calculations of the watershed slope were performed with the LiDAR dataset, which includes many steep slopes along the channel and other small scale artificial topographic features such as building footprints. The method for calculating lag time and time of concentration was developed with topography from USGS quadrangle maps utilizing the length of contour lines and contour interval within the basin. The topography shown on those maps is the same dataset as the USGS 10-m DEM. Therefore, the USGS 10-m DEM dataset was used for the average basin slope calculation to better align with how the method was developed.

HEC-HMS then uses the lag time parameter to internally calculate the time of concentration (t_c) for the watershed using the following equation:

$$t_c = L / 0.6$$

The results of the described calculations are provided in **Table 2-3**. Supplemental information and calculations are provided in **Appendix F**.

Table 2-3. Summary of hydrologic parameters for each basin

HMS Basin	Area (mi^2)	Composite CN	Hydraulic Length (ft)	Average Watershed Land Slope (%)	Lag (min)	t_c (min)
N01	0.12	74.1	7,249	1.49	90.8	151.3
N02	0.08	82.1	8,214	1.43	80.4	134.0
N03	0.11	74.3	6,826	1.38	89.3	148.9
N04	0.23	78.5	6,260	1.98	61.6	102.6
N05	0.13	79.6	4,977	1.68	53.7	89.6
N06	0.02	78.2	2,719	1.52	36.3	60.5
N07	0.27	70.4	7,375	1.92	89.9	149.9
N08	0.12	74.9	3,754	1.73	48.6	81.0
N09	0.08	78.5	4,343	1.76	48.7	81.2
N10	0.36	75.6	6,815	2.06	70.5	117.4
N11	2.77	57.8	22,335	29.29	77.4	129.0

2.2.4 Routing

To computationally route the runoff hydrograph through the watershed, the Muskingum-Cunge routing method was chosen. This routing routine approximates the diffusion method, allowing the model to describe the physical nature of the basin and thus the attenuation potential. Within the HEC-HMS model the Muskingum-Cunge method allows the user to define an eight-point cross section to describe the channel and overbank geometries, roughness values, lengths and slopes for each reach. Routing reaches were delineated using ArcGIS 10.1. The eight-point channel cross sections, lengths and slopes were created for each reach of Nash Spring Creek using the best available topographic data for each subbasin. The Manning's *n* roughness values assigned within the HEC-HMS model were determined based on site visits, aerial photography, and engineering judgment. *Open Channel Hydraulics* by Ven Te Chow (**Reference 2**) provided tables of roughness coefficients for different surfaces. Assigned Manning's values throughout the simulated reaches varied from 0.045 – 0.050 for the channels to represent a meandering channel with stones and objects of variable form roughness. Manning's values of 0.045 – 0.12 were utilized in the overbanks to describe floodplains representing grasses to dense vegetation.

3.HYDROLOGIC ANALYSES RESULTS

3.1 Summary of Discharges

The effective discharges used for Nash Spring Creek are shown in **Table 3-1**. Results of the various methods described in **Section 2** are summarized in **Table 3-2** through **Table 3-4**.

Table 3-1. Effective discharges for Nash Spring Creek

Location	Drainage Area (mi^2)	10-Percent-Annual-Chance Discharge (cfs)	4-Percent-Annual-Chance Discharge (cfs)	2-Percent-Annual-Chance Discharge (cfs)	1-Percent-Annual-Chance Discharge (cfs)	0.2-Percent-Annual-Chance Discharge (cfs)
Near Kagy Boulevard	1.9	47	*N/A*	92	135	250
At Goldenstein Lane	1.7	42	*N/A*	83	105	174
Approximately 0.6 miles upstream from Goldenstein Lane	1.5	40	*N/A*	79	101	167

Table 3-2. Resultant discharges for Nash Spring Creek at Goldenstein Lane

Method	Description	10%-Annual-Chance	4%-Annual-Chance	2%-Annual-Chance	1%-Annual-Chance	0.2%-Annual-Chance
2004 USGS Regional Regression Equations - Basin Characteristics	Discharge (cfs)	87	134	176	224	361
	SEP	63.6%	57.3%	56.1%	57.0%	65.5%
2004 USGS Regional Regression Equations - Active Channel Width	Discharge (cfs)	93	172	256	362	726
	SEP	71.1%	77.0%	83.5%	90.9%	112.4%
2004 USGS Regional Regression Equations - Bankfull Width	Discharge (cfs)	154	267	380	520	977
	SEP	73.7%	79.1%	85.4%	92.8%	114.5%
2004 USGS Regional Regression Equations - Weighted Basin, Active Channel & Bankfull Widths	Discharge (cfs)	100	155	199	238	361
	SEP	52.8%	54.0%	55.0%	56.8%	65.5%
HEC-HMS (HEC-HMS Element JN04)	Discharge (cfs)	62	104	153	207	420

Table 3-3. Resultant discharges for Nash Spring Creek at Fox Hollow Road

Method	Description	10%-Annual-Chance	4%-Annual-Chance	2%-Annual-Chance	1%-Annual-Chance	0.2%-Annual-Chance
2004 USGS Regional Regression Equations - Basin Characteristics	Discharge (cfs)	91	140	184	234	377
	SEP	63.5%	57.2%	56.0%	56.9%	65.4%
2004 USGS Regional Regression Equations - Active Channel Width	Discharge (cfs)	175	304	434	593	1110
	SEP	70.1%	75.8%	82.1%	89.3%	110.2%
2004 USGS Regional Regression Equations - Bankfull Width	Discharge (cfs)	132	232	334	461	879
	SEP	73.9%	79.3%	85.7%	93.2%	115.1%
2004 USGS Regional Regression Equations - Weighted Basin, Active Channel & Bankfull Widths	Discharge (cfs)	115	169	210	252	377
	SEP	51.8%	52.6%	54.4%	56.7%	65.4%
HEC-HMS (HEC-HMS Element JN02)	Discharge (cfs)	73	122	167	225	457

Table 3-4. Resultant discharges for Nash Spring Creek at mouth

Method	Description	10%-Annual-Chance	4%-Annual-Chance	2%-Annual-Chance	1%-Annual-Chance	0.2%-Annual-Chance
2004 USGS Regional Regression Equations - Basin Characteristics	Discharge (cfs)	93	144	189	241	388
	SEP	63.5%	57.2%	56.0%	56.9%	65.3%
2004 USGS Regional Regression Equations - Active Channel Width	Discharge (cfs)	319	522	715	945	1660
	SEP	69.3%	74.9%	81.1%	88.2%	108.7%
2004 USGS Regional Regression Equations - Bankfull Width	Discharge (cfs)	264	433	598	795	1410
	SEP	73.0%	78.2%	84.4%	91.7%	113.0%
2004 USGS Regional Regression Equations - Weighted Basin, Active Channel & Bankfull Widths	Discharge (cfs)	154	202	236	271	388
	SEP	51.5%	52.3%	54.1%	56.6%	65.3%
HEC-HMS (HEC-HMS Element Nash-Sink)	Discharge (cfs)	76	129	173	234	475

3.2 Recommended Discharges

In review of the discharges listed in **Table 3-2** through **Table 3-4**, one can see that there is a vast difference in calculated discharges of those methods dependent upon basin characteristics (basin characteristic regression and HEC-HMS) versus those produced from channel characteristics (active-channel and bankfull widths). As previously discussed the active-channel width and bankfull width regression equations were deemed less reliable due to the aforementioned man-made alterations to the natural channel. Due to this, the regression estimates utilizing the channel characteristics were deemed inapplicable. Although the weighted regression estimates provide a slightly lower SEP, it too is reliant on the channel characteristics and is therefore considered to be inapplicable. It should be noted that other weighted regression estimates based on channel characteristics were performed. However, due to the aforementioned lack of confidence in the channel variables, the results were not displayed in the above tables. The results of all performed regression analyses can be found in **Appendix B**.

Comparison of the basin characteristics regression estimates with the results of the hydrologic model shows a close resemblance. Although the results are similar, the basin characteristics regression is based off a regional data source while the hydrologic model describes the immediate conditions of the Nash Spring Creek watershed. Given that the HEC-HMS analysis better describes the hydrologic characteristics of the Nash Spring Creek watershed, the HEC-HMS model is considered the most appropriate method for determining peak flow estimates for Nash Spring Creek.

It should be noted that the recommended discharges are considerably higher than the effective discharges for Nash Spring Creek. This is likely due to the difference in methods as well as the increased drainage area for Nash Spring Creek attributed in the present study. While reviewing the difference in drainage areas for the present and effective studies it was noticed that the variance in drainage areas listed for Goldenstein Lane is about 2.2 mi^2. Coincidentally, this is the approximate drainage area delineated for Leverich Creek upstream of its confluence with the Mystic Lake Ditch. As previously discussed in **Section 2** of this report, it is possible that the effective study discounted the majority of the Leverich Creek drainage area with the idea that the Mystic Lake Ditch would intercept all runoff.

Recommended 10-, 4-, 2-, 1- and 0.2-percent annual chance discharges for all locations of Nash Spring Creek are presented below in **Table 3-5**. These discharges are proposed for use in the hydraulic analysis of Nash Spring Creek.

Table 3-5. Recommended discharges for Nash Spring Creek

Location	Drainage Area (mi2)	10%-Annual-Chance Discharge (cfs)	4%-Annual-Chance Discharge (cfs)	2%-Annual-Chance Discharge (cfs)	1%-Annual-Chance Discharge (cfs)	0.2%-Annual-Chance Discharge (cfs)
At Goldenstein Lane	3.99	62	104	153	207	420
Fox Hollow Rd - Valley View Golf Course	4.19	73	122	167	225	457
Confluence with Bozeman Creek	4.31	76	129	173	234	475

4.0 REFERENCES

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APPENDIX A

PERCENTAGE OF WATERSHED ABOVE ELEVATION 6000' CALCULATIONS

Location	Drainage Area (mi2)	Area above 6000' (mi^2)	E_{6000}
Confluence with Bozeman Creek	4.31	1.40	32.46
Fox Hollow Rd - Valley View Golf Course	4.18	1.40	33.49
At Goldenstein Rd	3.99	1.40	35.07

APPENDIX B

REGRESSION ANALYSES

USGS

Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Goldenstein**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Basin and Climatic Characteristics, Active-channel width, and Bankfull width**
Drainage area in square miles:	**3.99**
Percent basin above 6,000 feet:	**35.07**
Width of active channel in feet:	**3.5**
Width of bank full channel in feet:	**9.5**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on basin characteristics
 Flood frequency estimates for
 Nash Spring Creek at Goldenstein
Upper Yellowstone-Central Mountain Region: A =      3.99 E6 =    35.
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        26.        95.4              6.9              100.
     5        57.        73.0             19.4              170.
    10        87.        63.6             33.0              229.
    25       134.        57.3             55.4              325.
    50       176.        56.1             74.1              420.
   100       224.        57.0             93.0              541.
   200       278.        59.7            111.3              697.
   500       361.        65.5            133.9              973.
```

METHOD: Regression on active channel width
Flood frequency estimates for
Nash Spring Creek at Goldenstein
Upper Yellowstone-Central Mountain Region: WAC = 3.50

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	16.	72.7	5.6	49.
5	51.	69.1	18.1	146.
10	93.	71.1	31.9	271.
25	172.	77.0	55.1	538.
50	256.	83.5	76.0	863.
100	362.	90.9	99.1	1320.
200	497.	99.5	124.4	1990.
500	726.	112.4	160.4	3280.

METHOD: Regression on bank full channel width
Flood frequency estimates for
Nash Spring Creek at Goldenstein
Upper Yellowstone-Central Mountain Region: WBF = 9.50

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	39.	159.9	5.9	253.
5	91.	72.7	30.6	270.
10	154.	73.7	51.3	462.
25	267.	79.1	83.3	853.
50	380.	85.4	110.5	1310.
100	520.	92.8	139.4	1940.
200	693.	101.5	169.9	2820.
500	977.	114.5	211.8	4510.

METHOD: Combined methods 1, 2 and 3
Flood frequency estimates for
Nash Spring Creek at Goldenstein
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	19.	67.8	6.8	52.
5	62.	53.6	26.8	142.
10	100.	52.8	44.0	228.
25	155.	54.0	67.0	360.
50	199.	55.0	84.7	466.
100	238.	56.8	99.0	573.
200	279.	59.7	111.4	697.
500	361.	65.5	133.9	973.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Goldenstein**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Basin and Climatic Characteristics and Active-channel width**
Drainage area in square miles:	**3.99**
Percent basin above 6,000 feet:	**35.07**
Width of active channel in feet:	**3.5**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on basin characteristics
 Flood frequency estimates for
 Nash Spring Creek at Goldenstein
Upper Yellowstone-Central Mountain Region: A =      3.99 E6 =    35.
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        26.        95.4              6.9             100.
     5        57.        73.0             19.4             170.
    10        87.        63.6             33.0             229.
    25       134.        57.3             55.4             325.
    50       176.        56.1             74.1             420.
   100       224.        57.0             93.0             541.
   200       278.        59.7            111.3             697.
   500       361.        65.5            133.9             973.
```

```
 METHOD: Regression on active channel width
 Flood frequency estimates for
```

Nash Spring Creek at Goldenstein
Upper Yellowstone-Central Mountain Region: WAC = 3.50

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	16.	72.7	5.6	49.
5	51.	69.1	18.1	146.
10	93.	71.1	31.9	271.
25	172.	77.0	55.1	538.
50	256.	83.5	76.0	863.
100	362.	90.9	99.1	1320.
200	497.	99.5	124.4	1990.
500	726.	112.4	160.4	3280.

METHOD: Combined methods 1 and 2
Flood frequency estimates for
Nash Spring Creek at Goldenstein
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	19.	67.8	6.8	52.
5	54.	58.3	22.0	133.
10	89.	55.4	37.9	211.
25	143.	54.3	61.6	333.
50	187.	55.1	79.6	439.
100	232.	56.8	96.4	558.
200	278.	59.7	111.3	697.
500	361.	65.5	133.9	973.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Goldenstein**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Basin and Climatic Characteristics and Bankfull width**
Drainage area in square miles:	**3.99**
Percent basin above 6,000 feet:	**35.07**
Width of bank full channel in feet:	**9.5**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on basin characteristics
 Flood frequency estimates for
 Nash Spring Creek at Goldenstein
Upper Yellowstone-Central Mountain Region: A =      3.99 E6 =    35.
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        26.        95.4              6.9             100.
     5        57.        73.0             19.4             170.
    10        87.        63.6             33.0             229.
    25       134.        57.3             55.4             325.
    50       176.        56.1             74.1             420.
   100       224.        57.0             93.0             541.
   200       278.        59.7            111.3             697.
   500       361.        65.5            133.9             973.
```

```
 METHOD: Regression on bank full channel width
 Flood frequency estimates for
```

Nash Spring Creek at Goldenstein
Upper Yellowstone-Central Mountain Region: WBF = 9.50

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	39.	159.9	5.9	253.
5	91.	72.7	30.6	270.
10	154.	73.7	51.3	462.
25	267.	79.1	83.3	853.
50	380.	85.4	110.5	1310.
100	520.	92.8	139.4	1940.
200	693.	101.5	169.9	2820.
500	977.	114.5	211.8	4510.

METHOD: Combined methods 1 and 3
Flood frequency estimates for
Nash Spring Creek at Goldenstein
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	29.	89.5	8.0	102.
5	72.	58.6	29.4	178.
10	109.	55.3	46.3	257.
25	160.	54.1	68.9	371.
50	199.	55.0	84.7	466.
100	238.	56.8	99.0	573.
200	279.	59.7	111.4	697.
500	361.	65.5	133.9	973.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Goldenstein**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Active-channel width and Bankfull width**
Width of active channel in feet:	**3.5**
Width of bank full channel in feet:	**9.5**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on active channel width
 Flood frequency estimates for
 Nash Spring Creek at Goldenstein
Upper Yellowstone-Central Mountain Region: WAC =      3.50
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        16.        72.7              5.6              49.
     5        51.        69.1             18.1             146.
    10        93.        71.1             31.9             271.
    25       172.        77.0             55.1             538.
    50       256.        83.5             76.0             863.
   100       362.        90.9             99.1            1320.
   200       497.        99.5            124.4            1990.
   500       726.       112.4            160.4            3280.
```

```
 METHOD: Regression on bank full channel width
 Flood frequency estimates for
          Nash Spring Creek at Goldenstein
Upper Yellowstone-Central Mountain Region: WBF =      9.50
```

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	39.	159.9	5.9	253.
5	91.	72.7	30.6	270.
10	154.	73.7	51.3	462.
25	267.	79.1	83.3	853.
50	380.	85.4	110.5	1310.
100	520.	92.8	139.4	1940.
200	693.	101.5	169.9	2820.
500	977.	114.5	211.8	4510.

METHOD: Combined methods 2 and 3
Flood frequency estimates for
Nash Spring Creek at Goldenstein
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	16.	72.7	5.6	49.
5	61.	68.3	21.7	169.
10	108.	70.6	37.5	310.
25	193.	76.7	62.4	597.
50	280.	83.4	83.8	935.
100	384.	90.8	106.0	1390.
200	513.	99.5	129.3	2030.
500	726.	112.4	161.8	3250.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Fox Hollow**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Basin and Climatic Characteristics, Active-channel width, and Bankfull width**
Drainage area in square miles:	**4.18**
Percent basin above 6,000 feet:	**33.49**
Width of active channel in feet:	**6**
Width of bank full channel in feet:	**8.5**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on basin characteristics
 Flood frequency estimates for
 Nash Spring Creek at Fox Hollow
Upper Yellowstone-Central Mountain Region: A =      4.18 E6 =    33.
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        27.        95.3              7.2              103.
     5        60.        72.9             20.2              176.
    10        90.        63.5             34.4              238.
    25       140.        57.2             57.7              338.
    50       184.        56.0             77.3              438.
   100       234.        56.9             97.1              564.
   200       291.        59.6            116.3              726.
   500       377.        65.4            140.0             1010.
```

METHOD: Regression on active channel width
Flood frequency estimates for
Nash Spring Creek at Fox Hollow
Upper Yellowstone-Central Mountain Region: WAC = 6.00

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	37.	71.8	12.8	110.
5	103.	68.1	36.7	289.
10	175.	70.1	61.0	504.
25	304.	75.8	98.8	937.
50	434.	82.1	130.9	1440.
100	593.	89.3	165.1	2130.
200	788.	97.7	200.9	3090.
500	1110.	110.2	250.1	4920.

METHOD: Regression on bank full channel width
Flood frequency estimates for
Nash Spring Creek at Fox Hollow
Upper Yellowstone-Central Mountain Region: WBF = 8.50

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	32.	160.2	4.8	208.
5	77.	72.9	25.8	228.
10	132.	73.9	43.8	397.
25	232.	79.3	72.2	745.
50	334.	85.7	96.7	1150.
100	461.	93.2	123.0	1720.
200	618.	101.9	150.9	2530.
500	879.	115.1	189.6	4070.

METHOD: Combined methods 1, 2 and 3
Flood frequency estimates for
Nash Spring Creek at Fox Hollow
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	34.	67.2	12.4	94.
5	76.	53.0	33.4	174.
10	115.	51.8	51.1	258.
25	169.	52.6	74.2	383.
50	210.	54.4	90.3	490.
100	252.	56.7	104.9	605.
200	293.	59.6	117.4	733.
500	377.	65.4	140.0	1010.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Fox Hollow**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Basin and Climatic Characteristics and Active-channel width**
Drainage area in square miles:	**4.18**
Percent basin above 6,000 feet:	**33.49**
Width of active channel in feet:	**6.00**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on basin characteristics
 Flood frequency estimates for
 Nash Spring Creek at Fox Hollow
Upper Yellowstone-Central Mountain Region: A =      4.18 E6 =    33.
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        27.        95.3              7.2             103.
     5        60.        72.9             20.2             176.
    10        90.        63.5             34.4             238.
    25       140.        57.2             57.7             338.
    50       184.        56.0             77.3             438.
   100       234.        56.9             97.1             564.
   200       291.        59.6            116.3             726.
   500       377.        65.4            140.0            1010.
```

```
 METHOD: Regression on active channel width
 Flood frequency estimates for
```

Nash Spring Creek at Fox Hollow
Upper Yellowstone-Central Mountain Region: WAC = 6.00

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	37.	71.8	12.8	110.
5	103.	68.1	36.7	289.
10	175.	70.1	61.0	504.
25	304.	75.8	98.8	937.
50	434.	82.1	130.9	1440.
100	593.	89.3	165.1	2130.
200	788.	97.7	200.9	3090.
500	1110.	110.2	250.1	4920.

METHOD: Combined methods 1 and 2
Flood frequency estimates for
Nash Spring Creek at Fox Hollow
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	34.	67.2	12.4	94.
5	81.	57.8	33.0	196.
10	120.	55.0	51.1	281.
25	173.	54.0	74.5	400.
50	212.	54.9	90.4	496.
100	252.	56.7	104.9	605.
200	293.	59.6	117.4	733.
500	377.	65.4	140.0	1010.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Fox Hollow**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Basin and Climatic Characteristics and Bankfull width**
Drainage area in square miles:	**4.18**
Percent basin above 6,000 feet:	**33.49**
Width of bank full channel in feet:	**8.5**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on basin characteristics
 Flood frequency estimates for
 Nash Spring Creek at Fox Hollow
Upper Yellowstone-Central Mountain Region: A =      4.18 E6 =    33.
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        27.        95.3              7.2             103.
     5        60.        72.9             20.2             176.
    10        90.        63.5             34.4             238.
    25       140.        57.2             57.7             338.
    50       184.        56.0             77.3             438.
   100       234.        56.9             97.1             564.
   200       291.        59.6            116.3             726.
   500       377.        65.4            140.0            1010.
```

```
 METHOD: Regression on bank full channel width
 Flood frequency estimates for
```

Nash Spring Creek at Fox Hollow
Upper Yellowstone-Central Mountain Region: WBF = 8.50

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	32.	160.2	4.8	208.
5	77.	72.9	25.8	228.
10	132.	73.9	43.8	397.
25	232.	79.3	72.2	745.
50	334.	85.7	96.7	1150.
100	461.	93.2	123.0	1720.
200	618.	101.9	150.9	2530.
500	879.	115.1	189.6	4070.

METHOD: Combined methods 1 and 3
Flood frequency estimates for
Nash Spring Creek at Fox Hollow
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	28.	89.4	7.9	100.
5	68.	58.6	27.5	167.
10	105.	55.3	44.6	247.
25	159.	54.1	68.4	368.
50	201.	54.9	85.9	472.
100	245.	56.7	101.9	588.
200	291.	59.6	116.3	726.
500	377.	65.4	140.0	1010.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Fox Hollow**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Active-channel width and Bankfull width**
Width of active channel in feet:	**6**
Width of bank full channel in feet:	**8.5**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on active channel width
 Flood frequency estimates for
 Nash Spring Creek at Fox Hollow
Upper Yellowstone-Central Mountain Region: WAC =      6.00
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        37.        71.8              12.8              110.
     5       103.        68.1              36.7              289.
    10       175.        70.1              61.0              504.
    25       304.        75.8              98.8              937.
    50       434.        82.1             130.9             1440.
   100       593.        89.3             165.1             2130.
   200       788.        97.7             200.9             3090.
   500      1110.       110.2             250.1             4920.
```

```
 METHOD: Regression on bank full channel width
 Flood frequency estimates for
          Nash Spring Creek at Fox Hollow
Upper Yellowstone-Central Mountain Region: WBF =      8.50
```

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	32.	160.2	4.8	208.
5	77.	72.9	25.8	228.
10	132.	73.9	43.8	397.
25	232.	79.3	72.2	745.
50	334.	85.7	96.7	1150.
100	461.	93.2	123.0	1720.
200	618.	101.9	150.9	2530.
500	879.	115.1	189.6	4070.

METHOD: Combined methods 2 and 3
Flood frequency estimates for
Nash Spring Creek at Fox Hollow
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	37.	71.8	12.8	109.
5	96.	67.7	34.8	267.
10	166.	69.9	58.4	474.
25	298.	75.7	97.4	911.
50	434.	82.1	131.8	1430.
100	593.	89.3	166.4	2110.
200	788.	97.7	202.6	3070.
500	1110.	110.2	252.4	4870.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Mouth**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Basin and Climatic Characteristics, Active-channel width, and Bankfull width**
Drainage area in square miles:	**4.31**
Percent basin above 6,000 feet:	**32.46**
Width of active channel in feet:	**10**
Width of bank full channel in feet:	**14**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on basin characteristics
 Flood frequency estimates for
 Nash Spring Creek at Mouth
Upper Yellowstone-Central Mountain Region: A =      4.31 E6 =    32.
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        28.        95.2              7.3              105.
     5        61.        72.8             20.7              181.
    10        93.        63.5             35.3              244.
    25       144.        57.2             59.3              347.
    50       189.        56.0             79.5              450.
   100       241.        56.9             99.9              579.
   200       299.        59.6            119.7              746.
   500       388.        65.3            144.2             1040.
```

METHOD: Regression on active channel width
Flood frequency estimates for
Nash Spring Creek at Mouth
Upper Yellowstone-Central Mountain Region: WAC = 10.00

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	82.	71.3	28.0	238.
5	200.	67.5	71.7	555.
10	319.	69.3	112.2	910.
25	522.	74.9	171.1	1590.
50	715.	81.1	218.2	2350.
100	945.	88.2	266.5	3350.
200	1220.	96.4	314.9	4720.
500	1660.	108.7	379.1	7240.

METHOD: Regression on bank full channel width
Flood frequency estimates for
Nash Spring Creek at Mouth
Upper Yellowstone-Central Mountain Region: WBF = 14.00

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	77.	159.3	11.7	502.
5	164.	72.1	55.5	482.
10	264.	73.0	88.5	785.
25	433.	78.2	136.7	1370.
50	598.	84.4	175.6	2040.
100	795.	91.7	215.6	2930.
200	1030.	100.2	256.2	4150.
500	1410.	113.0	310.1	6420.

METHOD: Combined methods 1, 2 and 3
Flood frequency estimates for
Nash Spring Creek at Mouth
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	60.	66.8	22.0	166.
5	114.	52.7	50.2	259.
10	154.	51.5	68.8	344.
25	202.	52.3	89.3	457.
50	236.	54.1	101.7	547.
100	271.	56.6	113.0	650.
200	306.	59.6	122.6	764.
500	388.	65.3	144.2	1040.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Mouth**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Basin and Climatic Characteristics and Active-channel width**
Drainage area in square miles:	**4.31**
Percent basin above 6,000 feet:	**32.46**
Width of active channel in feet:	**10**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on basin characteristics
 Flood frequency estimates for
 Nash Spring Creek at Mouth
Upper Yellowstone-Central Mountain Region: A =      4.31 E6 =    32.
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        28.        95.2              7.3             105.
     5        61.        72.8             20.7             181.
    10        93.        63.5             35.3             244.
    25       144.        57.2             59.3             347.
    50       189.        56.0             79.5             450.
   100       241.        56.9             99.9             579.
   200       299.        59.6            119.7             746.
   500       388.        65.3            144.2            1040.
```

```
 METHOD: Regression on active channel width
 Flood frequency estimates for
```

Nash Spring Creek at Mouth
Upper Yellowstone-Central Mountain Region: WAC = 10.00

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	82.	71.3	28.0	238.
5	200.	67.5	71.7	555.
10	319.	69.3	112.2	910.
25	522.	74.9	171.1	1590.
50	715.	81.1	218.2	2350.
100	945.	88.2	266.5	3350.
200	1220.	96.4	314.9	4720.
500	1660.	108.7	379.1	7240.

METHOD: Combined methods 1 and 2
Flood frequency estimates for
Nash Spring Creek at Mouth
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	60.	66.8	22.0	166.
5	118.	57.5	48.6	287.
10	159.	54.7	67.8	371.
25	206.	53.8	89.0	475.
50	238.	54.7	101.7	556.
100	271.	56.6	113.0	650.
200	306.	59.6	122.6	764.
500	388.	65.3	144.2	1040.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Mouth**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Basin and Climatic Characteristics and Bankfull width**
Drainage area in square miles:	**4.31**
Percent basin above 6,000 feet:	**32.46**
Width of bank full channel in feet:	**14**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on basin characteristics
 Flood frequency estimates for
 Nash Spring Creek at Mouth
Upper Yellowstone-Central Mountain Region: A =      4.31 E6 =    32.
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        28.        95.2              7.3             105.
     5        61.        72.8             20.7             181.
    10        93.        63.5             35.3             244.
    25       144.        57.2             59.3             347.
    50       189.        56.0             79.5             450.
   100       241.        56.9             99.9             579.
   200       299.        59.6            119.7             746.
   500       388.        65.3            144.2            1040.
```

```
 METHOD: Regression on bank full channel width
 Flood frequency estimates for
```

Nash Spring Creek at Mouth
Upper Yellowstone-Central Mountain Region: WBF = 14.00

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	77.	159.3	11.7	502.
5	164.	72.1	55.5	482.
10	264.	73.0	88.5	785.
25	433.	78.2	136.7	1370.
50	598.	84.4	175.6	2040.
100	795.	91.7	215.6	2930.
200	1030.	100.2	256.2	4150.
500	1410.	113.0	310.1	6420.

METHOD: Combined methods 1 and 3
Flood frequency estimates for
Nash Spring Creek at Mouth
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	35.	89.3	9.8	125.
5	101.	58.3	41.1	247.
10	141.	55.0	60.2	332.
25	191.	53.9	82.8	443.
50	227.	54.8	97.2	532.
100	263.	56.6	109.8	632.
200	301.	59.6	120.6	752.
500	388.	65.3	144.2	1040.

Montana Flood-Frequency and Basin-Characteristic Data

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Montana Flood-Frequency and Basin-Characteristic Data

Estimate Flood Discharges at Ungaged Sites in Montana – (continued)

Summary of Estimation Parameters Selected:

Name for this estimation:	**Nash Spring Creek at Mouth**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Active-channel width and Bankfull width**
Width of active channel in feet:	**10**
Width of bank full channel in feet:	**14**

Flood Discharge Estimation:

(In the Flood Discharge table, RI is the Recurrence Interval, in years; STD ERR is the Standard Error; and 90% PRED. INTERVAL is the 90% Prediction Interval, in cubic feet per second)

```
 METHOD: Regression on active channel width
 Flood frequency estimates for
 Nash Spring Creek at Mouth
Upper Yellowstone-Central Mountain Region: WAC =     10.00
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2         82.        71.3              28.0              238.
     5        200.        67.5              71.7              555.
    10        319.        69.3             112.2              910.
    25        522.        74.9             171.1             1590.
    50        715.        81.1             218.2             2350.
   100        945.        88.2             266.5             3350.
   200       1220.        96.4             314.9             4720.
   500       1660.       108.7             379.1             7240.
```

```
 METHOD: Regression on bank full channel width
 Flood frequency estimates for
          Nash Spring Creek at Mouth
Upper Yellowstone-Central Mountain Region: WBF =     14.00
```

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	77.	159.3	11.7	502.
5	164.	72.1	55.5	482.
10	264.	73.0	88.5	785.
25	433.	78.2	136.7	1370.
50	598.	84.4	175.6	2040.
100	795.	91.7	215.6	2930.
200	1030.	100.2	256.2	4150.
500	1410.	113.0	310.1	6420.

METHOD: Combined methods 2 and 3
Flood frequency estimates for
Nash Spring Creek at Mouth
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	82.	71.3	28.2	237.
5	191.	67.0	69.4	524.
10	308.	69.1	109.0	868.
25	512.	74.9	169.2	1550.
50	715.	81.1	219.7	2330.
100	945.	88.2	268.5	3330.
200	1220.	96.4	317.5	4690.
500	1660.	108.7	382.4	7180.

Montana Flood-Frequency and Basin-Characteristic Data

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APPENDIX C

RAINFALL DEPTH CALCULATIONS AND REFERENCES

	2YR	5YR	10YR	25YR	50YR	100YR	500YR
5 min	0.17	0.26	0.33	0.42	0.49	0.57	0.72
15 min	0.31	0.49	0.61	0.77	0.92	1.06	1.35
1 hr	0.45	0.72	0.91	1.13	1.34	1.54	1.94
2 hr	0.52	0.79	0.98	1.22	1.42	1.60	2.04
3 hr	0.59	0.85	1.05	1.30	1.48	1.66	2.08
6 hr	0.75	1.00	1.20	1.50	1.65	1.80	2.25
12 hr	0.94	1.26	1.53	1.88	2.09	2.25	2.81
24 hr	1.20	1.60	1.90	2.30	2.60	2.80	3.37

Values taken from Figures 19-30 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

Values calculated using Equations 3 & 5 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana - East of the divide calcs*

Values interpolated between 2YR and 100YR using Figure 6 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

Values calculated using Equations 7 & 8 of *Precipitation-Frequency Atlas of the Western United States, Volume I*

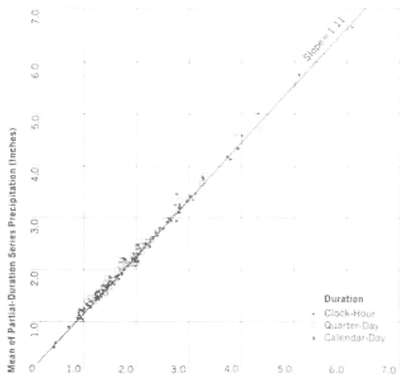
Values interpolated using Figure 17 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

Values calculated using Table 11 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

Values determined using ratios provided in *Short Duration Rainfall for the Western United States* (Arkell & Richards) - Front Face and High Plains North Region

Extrapolated using normal-probability relationship

Figure 5. *Relation between annual and partial-duration series.*



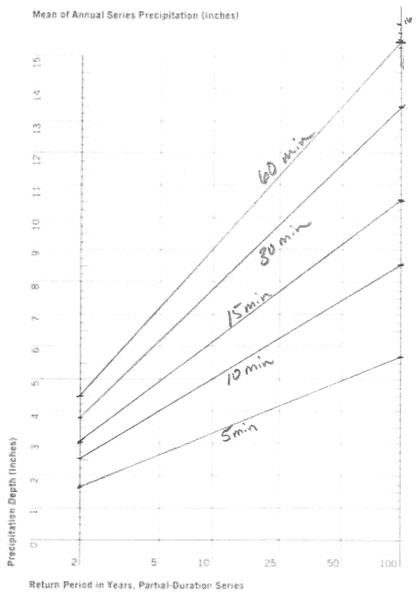
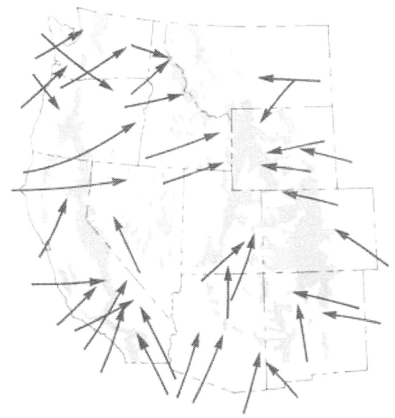


Figure 6. *Precipitation depth versus return period for partial-duration series.*

Figure 7. *Principal paths of moisture inflow in the western United States for storms producing large precipitation amounts. Timed areas are major orographic barriers.*



portant. Next, an examination was made of factors that combined topographic and meteorologic considerations, such as distance and direction to moisture sources. Each factor considered was a measure of some physical reality, and each was understandably related to variation in the precipitation-frequency regime.

Finally, various climatological and meteorological factors that could be indexes of variation of the precipitation-frequency values were considered. The procedure used for developing interpolating equations was a multiple-regression screening technique. This process was done by computer using a least-squares technique. The computer program was capable of accepting a total of 174 independent variables for as many locations as data were available. The number of variables screened for the various relations ranged between 60 and 100. This does not mean that 60 or more completely different factors could be identified. For example, several factors might involve different measures of slope. Moreover, these measures of slope might be over different distances or have different orientations. In each instance, the practice was to permit the computer to select the most critical of the various measures of each factor.

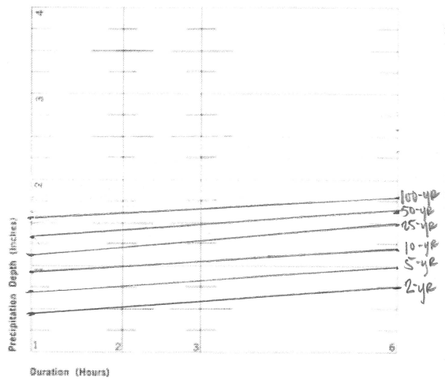
Although the computer program treated each variable as linear during the regression analysis, it was possible through internal computations to use logarithms, powers, roots, reciprocals, or combinations of any or all of the factors. The computer program selected the single variable most highly correlated with the precipitation-frequency value under investigation. The next step was to select the variable that, combined with the variable already selected, would explain the greatest variation in the precipitation-frequency values. The third, fourth, fifth, and further variables were selected in a similar manner. The program continued to select

Region of applicability	Corr. coeff.	No. of stations	Mean of computed stn. values (inches)	Standard error of estimate (inches)
Gila, Williams, and lower Colorado River Basins (1)	0.84	86	1.86	0.21
Little Colorado, San Juan, and Virgin River Basins, except higher elevations of south-facing slopes (2)[1]	0.81	105	1.36	0.20
Higher elevations of south-facing slopes of Little Colorado, San Juan, and Virgin River Basins (2)[1]	0.93	41	1.31	0.13
Rio Grande Basin north of El Paso, Tex. (3)	0.77	110	1.35	0.18
Crest of Continental Divide and Sangre de Cristo Mountains to generalized 7,000-ft contour from southern Wyoming to southern tip of Sangre de Cristo Mountains (4)	0.83	122	1.43	0.22
Upper Colorado and Gunnison River Basins and Green River Basin below confluence of Green and Yampa Rivers (5)	0.79	69	1.12	0.13
Yampa River Basin, Green River Basin above confluence of Green and Yampa Rivers, and Bear River Basin east of Wasatch Mountains (6)	0.83	29	1.03	0.08
Mountains of central Utah (7)	0.85	86	1.35	0.18
Western Utah and Nevada, except Snake and Virgin River Basins and spillover zone east of Sierra Nevada Crest (8)[1]	0.71	79	1.03	0.13
Western Utah and Nevada, except Snake and Virgin River Basins and spillover zone east of Sierra Nevada crest (8)[1]	0.71	55	1.04	0.15
Big Horn River Basin above Saint Xavier and minor portions of North Platte, Powder, Tongue, and Yellowstone River Basins (9)	0.78	55	1.25	0.21
Upper Missouri River Basin above Holter Dam, Mont.; Snake River Basin above Alpine, Wyo.; and upper Yellowstone River Basin above Springdale, Mont. (10)	0.76	57	1.19	0.16
From generalized 4,000-ft contour on east to crests of Crazy and Little Belt Mountains and Lewis Range on west (11)	0.80	52	1.67	0.26
West of Continental Divide, but east of Bitterroot Range and Cabinet and Selkirk Mountains (12)	0.85	44	1.36	0.12
Mountainous region of eastern Washington and Oregon and of Idaho west of Bitterroot Range crest and Continental Divide, and north of southern boundary of Snake River Basin—excluding Snake River Valley below a generalized 5,000-ft contour (13)	0.78	147	1.44	0.24
Orographic region east of crest of Cascade Range and west of Snake River Basin (14)	0.90	115	1.75	0.35
Western slopes of Coast Ranges, Olympic Mountains, and Cascade Range (15)	0.87	125	3.69	0.48
Eel River Basin; southern portion of Klamath River Basin, and Cottonwood, Elder, Thomas, and Gladstone Creeks (16)	0.91	39	4.19	0.50
Russian River, Cache and Putah Creeks, and coastal drainages west of Russian River (17)	0.84	63	5.31	0.78
Santa Cruz Mountains and La Panza, Santa Lucia, and Coast Ranges (18)	0.95	55	4.32	0.45
Diablo, Gabilan, and Temblor Ranges (19)	0.82	58	2.21	0.35
San Rafael, San Bernardino, Santa Monica, and San Gabriel Mountains (20)	0.88	149	3.98	0.59
Santa Ana, Santa Rosa, Coyote, and other extreme southern coastal mountains (21)	0.88	34	2.44	0.33
Northern Sierra Nevada north of Mokelumne River Basin (22)	0.92	84	4.56	0.53
Southern Sierra Nevada south of Consumnes River Basin (23)	0.88	61	3.43	0.53
Southeastern desert region of California (24)	0.89	41	1.07	0.16
Spillover zone east of Sierra Nevada crest (25)	0.94	41	2.05	0.27
Spillover zone east of crest of coastal mountains of southern California (26)	0.97	10	2.08	0.15

[1] Numbers in parentheses refer to geographic regions shown in figure 8.
[2] Two different equations were used in region 2. See text for explanation.
[3] Two different equations were used in region 8. See text for explanation.

Table 3. *Statistical parameters for relations used for interstation interpolation of 2-yr 24-hr precipitation values*

Figure 16. *Precipitation depth-duration diagram (1 to 6 hrs).*



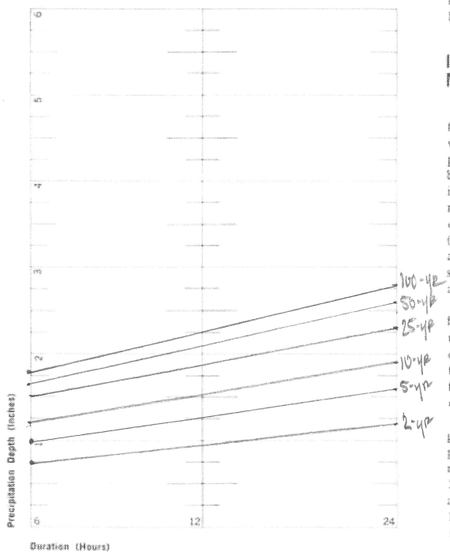


Figure 17. *Precipitation depth-duration diagram (6 to 24 hrs).*

Estimates for 2- and 3-hr (120- and 180-min) precipitation-frequency values. To obtain estimates of precipitation-frequency values for 2 or 3 hrs, plot the 6-hr value from the Atlas maps and the 1-hr value on the nomogram of figure 16. Then draw a straight line connecting the 1- and 6-hr values, and read the 2- and 3-hr values from the nomogram. This nomogram is independent of return period. It was developed using data from the same regions used to develop the 1-hr equations. The slight differences found in data from east and west of the Continental Divide were smaller than the sampling error inherent in the data, so one nomogram will serve for all sections of Montana. The mathematical solution from the data used to develop figure 16 gives the following equations for estimating the 2- and 3-hr values:

$$2\text{ hr} = 0.250\ (6\text{ hr}) + 0.750\ (1\text{ hr}), \qquad (7)$$

$$3\text{ hr} = 0.467\ (6\text{ hr}) + 0.533\ (1\text{ hr}). \qquad (8)$$

Estimates for 12-hr (720-min) precipitation. To obtain estimates for the 12-hr duration, plot values from the 6- and 24-hr maps on the nomogram of figure 17. The 12-hr estimates can then be read at the intersection of the line connecting these points with the 12-hr duration line of the nomogram.

Estimates for less than 1 hr. To obtain estimates for durations of less than 1 hr, the values in table 11 are applied to the 1-hr value for the return period of interest.

Illustration of Use of Precipitation-Frequency Maps, Diagrams, and Equations.

To illustrate the use of these maps, values were read from figures 19 to 30 for the point at 47°00′ N. and 110°00′ W. These values are shown in boldface type in table 12. Because not all points are as easy to locate as latitude-longitude intersections, and because there may be some slight registration differences in printing, precise interpolation between isolines is difficult; the values read from the maps should be plotted on the return-period diagram of figure 6. This has been done for the 24-hr values in table 12 (fig. 18a). On this nomogram the 25-yr value appears somewhat above the line, so the value read from the maps is corrected (as shown by the strikeout in table 12); such corrected values are adopted in preference to the original readings.

The 2- and 100-yr 1-hr values for the point were computed from equations (3) and (5), since the point is east of the Continental Divide. The 2-yr 1-hr value is estimated at 0.50 in. from equation (3); using equation (5) (and an elevation of 4,400 ft), the 100-yr 1-hr value is 1.53 in. By plotting these 1-hr values on figure 6 and connecting them with a straight line, one can obtain estimates for return periods of 5, 10, 25, and 50 yrs.

The 2- and 3-hr values can be estimated by using the nomogram of figure 16. The 1- and 6-hr values for the desired return period are obtained as above. Plot these points on the figure 16 nomogram and connect them with a straight line; the estimates for 2 or 3 hrs can be read at the intersections of the connecting line and the 2- and 3-hr vertical lines. An example is shown in figure 18b for the 100-yr return period. The values of the 100-yr 2-hr (1.70 in.) and 100-yr 3-hr (1.85 in.) are in italics on table 12.

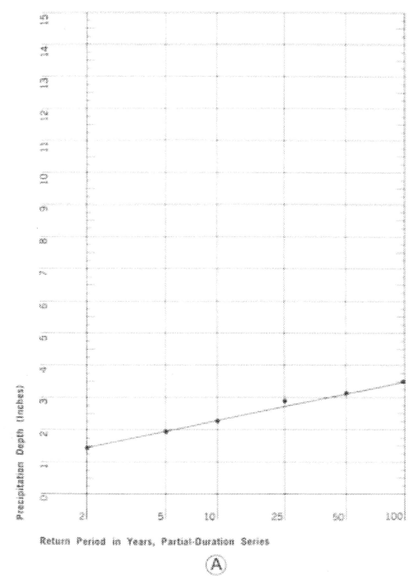
Table 11. *Adjustment factors to obtain n-minute estimates from 1-hr values*

Duration (min)	5	10	15	30
Ratio to 1-hr	0.29	0.45	0.57	0.79

(Adopted from *U.S. Weather Bureau Technical Paper* No. 40, 1961.)

Table 12. *Precipitation data for depth-frequency atlas computation point 47°00′ N., 110°00′ W.*

	1-hr	2-hr	3-hr	6-hr	24-hr
2-yr	0.50			**0.88**	**1.47**
5-yr				**1.19**	**1.96**
10-yr				**1.42**	**2.30**
25-yr				**1.78**	**2.77** ~~**2.84**~~
50-yr				**1.98**	**3.18**
100-yr	*1.53*	*1.70*	*1.85*	**2.18**	**3.50**



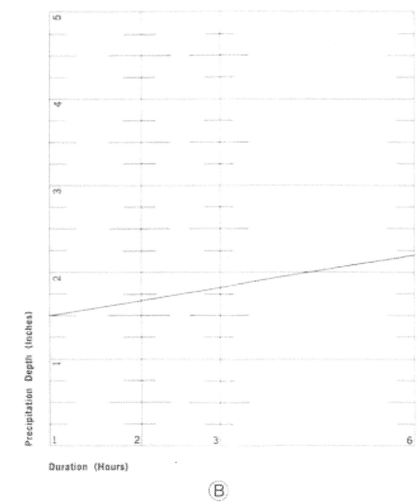


Figure 18. *Illustration of use of precipitation-frequency diagrams using values from precipitation-frequency maps and relations at 47°00′ N., 110°00′ W.*

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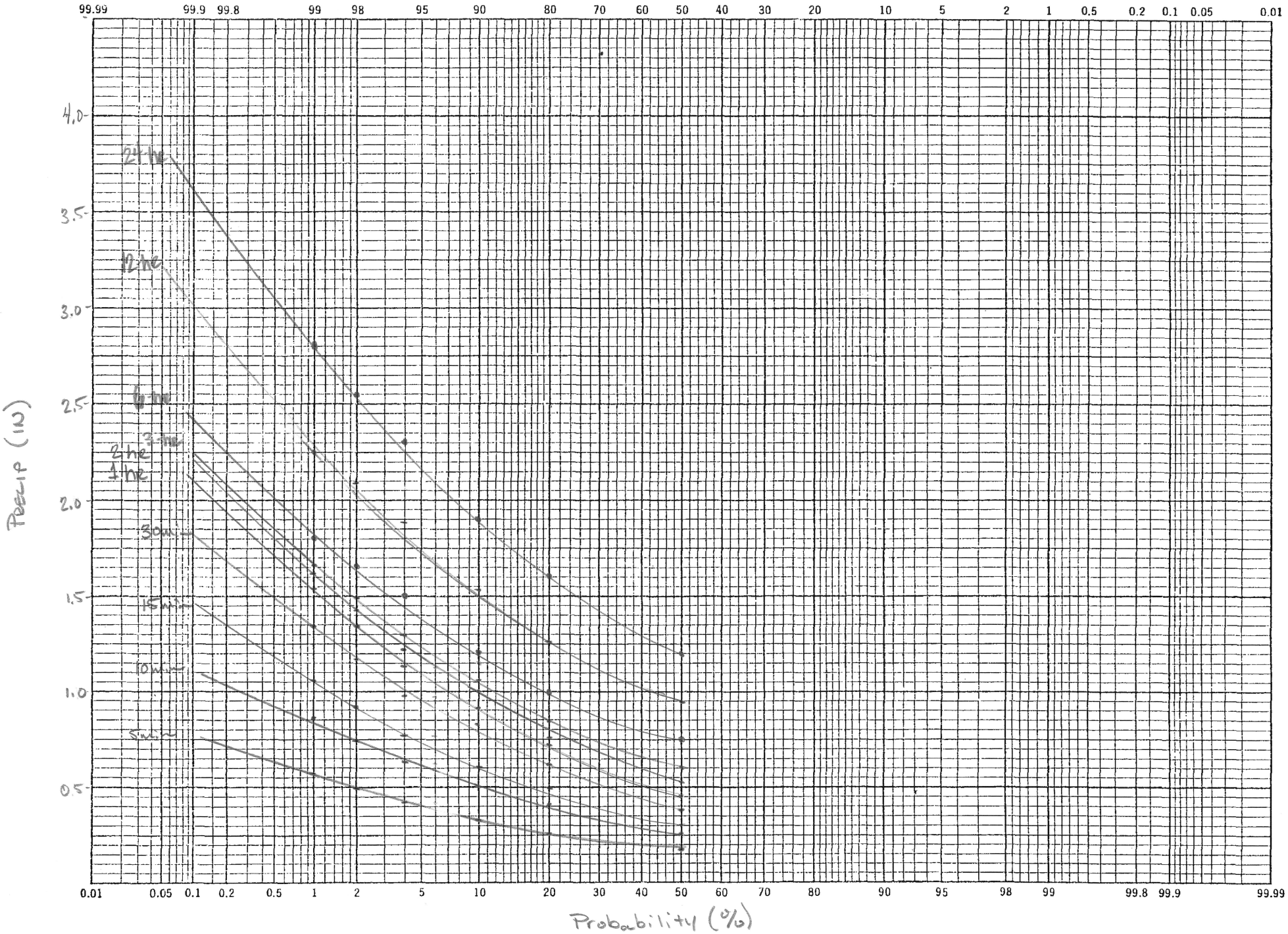

APPENDIX D

CURVE NUMBER LOOK-UP TABLE

Land Use Category	Hydrologic Soil Group				Description	Assumption	Reference	Source
	A	B	C	D				
Shrub/Scrub	30	48	65	73	Shrub/Scrub	Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	NLCD
Deciduous Forest	30	55	70	77	Deciduous Forest	Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	
Evergreen Forest	30	55	70	77	Evergreen Forest	Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	
Mixed Forest	30	55	70	77	Mixed Forest	Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	
Developed, Open Space	39	61	74	80	Developed, Open Space	Lawns, parks, cemeteries with vegetation established	Engineering Hydrology - Principles and Practices (Ponce)	
Hay/Pasture	39	61	74	80	Hay/Pasture	Pature, grassland or range for grazing - Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	
Herbaceuous		62	74	85	Herbaceuous	Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	
Developed, Low Intensity	60	70	80	85	Developed, Low Intensity	1/2 acre lots - vegetation established	Engineering Hydrology - Principles and Practices (Ponce)	
Cultivated Crops	58	72	81	85	Cultivated Crops	Close-seeded or broadcast legumes or rotation meadowstraight row	Engineering Hydrology - Principles and Practices (Ponce)	
Emergent Herbaceuous Wetlands	78	78	78	78	Emergent Herbaceuous Wetlands		Michigan DEQ	
Woody Wetlands	78	78	78	78	Woody Wetlands		Michigan DEQ	
POS	39	61	74	80	Park or Open Space - Parks, trails, recreational areas and other places that are capable of being used by the public for recreation, relaxation and social purposes. May include private land serving a property owners association for similar purposes	Park/Open Space	Engineering Hydrology - Principles and Practices (Ponce)	City of Bozeman
SFR	61	75	83	87	Single-Household Residential - A building used for residential occupancy by one household, including multiple residences that share a common wall, as long as only one dwelling unit lies upon a single lot; townhomes. Also may include an accessory dwelling unit.	Single family residential - 1/4 acre lots - vegetation established	Engineering Hydrology - Principles and Practices (Ponce)	
MFR	77	85	90	92	Multi-Household Residential - A building, or portion thereof, used for occupancy by four or more households living independently of each other, with the units completely separated by a common wall, floor and/or ceiling; apartments, condos.	Multi-family residential - Town houses	Engineering Hydrology - Principles and Practices (Ponce)	
ROW	98	98	98	98	Rights-of-Way - A public way established or dedicated for public purposes by duly recorded plat, deed, grant, easement, governmental authority or by operation of law; roads; railroads.	Right-of-way/Paved roads: curbs and storm sewers	Engineering Hydrology - Principles and Practices (Ponce)	
CR	89	92	94	95	Commercial Retail sales, services, Banks - Uses involving the sale of goods or services carried out for profit.	Commercial	Engineering Hydrology - Principles and Practices (Ponce)	
DTR	77	85	90	92	Duplex/Triplex Residential - A building, or a portion thereof, used for occupancy by two or three households living independently of each other, with the units completely separated by a common wall, floor and/or ceiling and reside on one lot; including apartments and condos.	dual residential (?) - multi-family residential and town houses	Engineering Hydrology - Principles and Practices (Ponce)	
VACANT	77	86	91	94	Vacant - Land that is currently developed and ready to be occupied by buildings but is unoccupied; no buildings or buildings requiring significant improvement in order to be used.	Graded areas - pervious areas only with no vegetation	Engineering Hydrology - Principles and Practices (Ponce)	

APPENDIX E

CURVE NUMBER CALCULATIONS

BASIN	LAND USE CATEGORY	SOIL MAP UNIT #	SUBREGION CN	SUBREGION AREA (mi^2)	SUBBASIN AREA (mi^2)	PERCENT OF SUBBASIN	CUMULATIVE PERCENT	AREA-WEIGHTED CN	CUMULATIVE CN	COMPOSITE CN
N01	Cultivated Crops	C	81.0	0.01	0.12	4.26%	4.3%	3.4	3.4	
N01	Developed, Low Intensity	C	80.0	0.00	0.12	0.02%	4.3%	0.0	3.5	
N01	Developed, Low Intensity	D	85.0	0.00	0.12	0.10%	4.4%	0.1	3.5	
N01	Developed, Open Space	C	74.0	0.10	0.12	84.88%	89.3%	62.8	66.4	
N01	Developed, Open Space	D	80.0	0.00	0.12	0.33%	89.6%	0.3	66.6	
N01	Emergent Herbaceuous Wetlands	C	78.0	0.00	0.12	0.04%	89.6%	0.0	66.7	
N01	Evergreen Forest	C	70.0	0.00	0.12	0.27%	89.9%	0.2	66.8	
N01	Hay/Pasture	C	74.0	0.01	0.12	4.64%	94.5%	3.4	70.3	
N01	Herbaceuous	C	74.0	0.00	0.12	0.85%	95.4%	0.6	70.9	
N01	Mixed Forest	C	70.0	0.00	0.12	2.20%	97.6%	1.5	72.4	
N01	POS	C	74.0	0.00	0.12	0.00%	97.6%	0.0	72.4	
N01	Shrub/Scrub	C	65.0	0.00	0.12	2.14%	99.7%	1.4	73.8	
N01	Woody Wetlands	C	78.0	0.00	0.12	0.27%	100.0%	0.2	74.1	**74.1**
N02	Developed, Open Space	C	74.0	0.00	0.08	0.37%	0.4%	0.3	0.3	
N02	DTR	C	90.0	0.02	0.08	19.88%	20.2%	17.9	18.2	
N02	DTR	B	85.0	0.00	0.08	1.75%	22.0%	1.5	19.6	
N02	POS	C	74.0	0.01	0.08	12.59%	34.6%	9.3	29.0	
N02	POS	B	61.0	0.01	0.08	10.02%	44.6%	6.1	35.1	
N02	ROW	C	98.0	0.01	0.08	6.43%	51.0%	6.3	41.4	
N02	ROW	B	98.0	0.01	0.08	11.39%	62.4%	11.2	52.5	
N02	SFR	C	83.0	0.01	0.08	13.86%	76.3%	11.5	64.0	
N02	SFR	B	75.0	0.02	0.08	21.39%	97.7%	16.0	80.1	
N02	VACANT	C	91.0	0.00	0.08	0.49%	98.2%	0.5	80.5	
N02	VACANT	B	86.0	0.00	0.08	1.83%	100.0%	1.6	82.1	**82.1**
N03	Cultivated Crops	C	81.0	0.00	0.11	1.60%	1.6%	1.3	1.3	
N03	Developed, Low Intensity	D	85.0	0.00	0.11	0.03%	1.6%	0.0	1.3	
N03	Developed, Open Space	C	74.0	0.00	0.11	1.48%	3.1%	1.1	2.4	
N03	Developed, Open Space	D	80.0	0.00	0.11	0.04%	3.1%	0.0	2.4	
N03	DTR	C	90.0	0.00	0.11	2.46%	5.6%	2.2	4.7	
N03	Evergreen Forest	C	70.0	0.00	0.11	3.49%	9.1%	2.4	7.1	
N03	Hay/Pasture	C	74.0	0.03	0.11	26.37%	35.5%	19.5	26.6	
N03	Hay/Pasture	D	80.0	0.00	0.11	0.40%	35.9%	0.3	26.9	
N03	Herbaceuous	C	74.0	0.00	0.11	1.19%	37.1%	0.9	27.8	
N03	MFR	C	90.0	0.00	0.11	0.37%	37.4%	0.3	28.2	
N03	MFR	B	85.0	0.00	0.11	0.31%	37.7%	0.3	28.4	
N03	Mixed Forest	C	70.0	0.00	0.11	0.07%	37.8%	0.0	28.5	
N03	POS	C	74.0	0.02	0.11	21.47%	59.3%	15.9	44.3	
N03	POS	B	61.0	0.02	0.11	15.32%	74.6%	9.3	53.7	
N03	POS	D	80.0	0.01	0.11	5.05%	79.6%	4.0	57.7	
N03	ROW	C	98.0	0.00	0.11	1.37%	81.0%	1.3	59.1	
N03	ROW	B	98.0	0.00	0.11	0.40%	81.4%	0.4	59.5	
N03	ROW	D	98.0	0.00	0.11	0.07%	81.5%	0.1	59.5	
N03	SFR	C	83.0	0.01	0.11	4.73%	86.2%	3.9	63.5	
N03	SFR	B	75.0	0.00	0.11	1.30%	87.5%	1.0	64.4	
N03	Shrub/Scrub	C	65.0	0.00	0.11	0.14%	87.7%	0.1	64.5	
N03	VACANT	C	91.0	0.00	0.11	0.59%	88.3%	0.5	65.1	
N03	VACANT	B	86.0	0.00	0.11	0.33%	88.6%	0.3	65.4	
N03	Woody Wetlands	C	78.0	0.01	0.11	5.48%	94.1%	4.3	69.6	
N03	Woody Wetlands	B	78.0	0.00	0.11	0.01%	94.1%	0.0	69.6	
N03	Woody Wetlands	D	78.0	0.01	0.11	5.93%	100.0%	4.6	74.3	**74.3**
N04	Cultivated Crops	C	81.0	0.14	0.23	61.50%	61.5%	49.8	49.8	
N04	Cultivated Crops	D	85.0	0.00	0.23	0.73%	62.2%	0.6	50.4	
N04	Developed, Low Intensity	C	80.0	0.01	0.23	2.28%	64.5%	1.8	52.3	

BASIN	LAND USE CATEGORY	SOIL MAP UNIT #	SUBREGION CN	SUBREGION AREA (mi^2)	SUBBASIN AREA (mi^2)	PERCENT OF SUBBASIN	CUMULATIVE PERCENT	AREA-WEIGHTED CN	CUMULATIVE CN	COMPOSITE CN
N04	Developed, Open Space	C	74.0	0.02	0.23	9.72%	74.2%	7.2	59.5	
N04	Developed, Open Space	D	80.0	0.00	0.23	0.10%	74.3%	0.1	59.5	
N04	Emergent Herbaceuous Wetlands	C	78.0	0.00	0.23	0.43%	74.8%	0.3	59.9	
N04	Emergent Herbaceuous Wetlands	D	78.0	0.00	0.23	0.08%	74.8%	0.1	59.9	
N04	Hay/Pasture	C	74.0	0.05	0.23	22.69%	97.5%	16.8	76.7	
N04	Hay/Pasture	D	80.0	0.00	0.23	0.00%	97.5%	0.0	76.7	
N04	ROW	C	98.0	0.00	0.23	0.15%	97.7%	0.1	76.9	
N04	Shrub/Scrub	C	65.0	0.00	0.23	1.14%	98.8%	0.7	77.6	
N04	Woody Wetlands	C	78.0	0.00	0.23	0.51%	99.3%	0.4	78.0	
N04	Woody Wetlands	D	78.0	0.00	0.23	0.67%	100.0%	0.5	78.5	**78.5**
N05	Cultivated Crops	C	81.0	0.02	0.13	16.14%	16.1%	13.1	13.1	
N05	Cultivated Crops	D	85.0	0.05	0.13	37.31%	53.5%	31.7	44.8	
N05	Developed, Open Space	C	74.0	0.00	0.13	0.12%	53.6%	0.1	44.9	
N05	Hay/Pasture	C	74.0	0.05	0.13	40.46%	94.0%	29.9	74.8	
N05	Hay/Pasture	D	80.0	0.01	0.13	5.97%	100.0%	4.8	79.6	
N05	Hay/Pasture	C	74.0	0.00	0.13	0.00%	100.0%	0.0	79.6	**79.6**
N06	Cultivated Crops	C	81.0	0.01	0.02	60.15%	60.2%	48.7	48.7	
N06	Hay/Pasture	C	74.0	0.01	0.02	39.85%	100.0%	29.5	78.2	**78.2**
N07	Cultivated Crops	C	81.0	0.00	0.27	0.25%	0.2%	0.2	0.2	
N07	Cultivated Crops	D	85.0	0.00	0.27	0.10%	0.3%	0.1	0.3	
N07	Developed, Low Intensity	C	80.0	0.00	0.27	0.50%	0.8%	0.4	0.7	
N07	Developed, Open Space	C	74.0	0.00	0.27	1.57%	2.4%	1.2	1.9	
N07	Hay/Pasture	C	74.0	0.19	0.27	68.63%	71.1%	50.8	52.6	
N07	Hay/Pasture	B	61.0	0.07	0.27	27.05%	98.1%	16.5	69.1	
N07	Hay/Pasture	D	80.0	0.00	0.27	1.18%	99.3%	0.9	70.1	
N07	Shrub/Scrub	B	48.0	0.00	0.27	0.71%	100.0%	0.3	70.4	
N07	Hay/Pasture	C	74.0	0.00	0.27	0.00%	100.0%	0.0	70.4	
N07	Hay/Pasture	C	74.0	0.00	0.27	0.00%	100.0%	0.0	70.4	**70.4**
N08	Cultivated Crops	C	81.0	0.00	0.12	0.13%	0.1%	0.1	0.1	
N08	Developed, Low Intensity	C	80.0	0.00	0.12	0.26%	0.4%	0.2	0.3	
N08	Developed, Open Space	C	74.0	0.00	0.12	0.34%	0.7%	0.3	0.6	
N08	Hay/Pasture	C	74.0	0.10	0.12	80.75%	81.5%	59.8	60.3	
N08	Hay/Pasture	D	80.0	0.02	0.12	14.58%	96.1%	11.7	72.0	
N08	Shrub/Scrub	C	65.0	0.00	0.12	0.22%	96.3%	0.1	72.1	
N08	Shrub/Scrub	D	73.0	0.00	0.12	1.58%	97.9%	1.2	73.3	
N08	Woody Wetlands	C	78.0	0.00	0.12	0.07%	97.9%	0.1	73.3	
N08	Woody Wetlands	D	78.0	0.00	0.12	2.07%	100.0%	1.6	74.9	**74.9**
N09	Cultivated Crops	C	81.0	0.03	0.08	40.53%	40.5%	32.8	32.8	
N09	Cultivated Crops	D	85.0	0.00	0.08	2.30%	42.8%	2.0	34.8	
N09	Developed, Open Space	C	74.0	0.00	0.08	0.90%	43.7%	0.7	35.4	
N09	Developed, Open Space	D	80.0	0.00	0.08	0.02%	43.7%	0.0	35.5	
N09	Hay/Pasture	C	74.0	0.02	0.08	28.10%	71.8%	20.8	56.3	
N09	Hay/Pasture	D	80.0	0.01	0.08	18.29%	90.1%	14.6	70.9	
N09	Herbaceuous	C	74.0	0.00	0.08	3.81%	93.9%	2.8	73.7	
N09	Herbaceuous	D	85.0	0.00	0.08	0.86%	94.8%	0.7	74.4	
N09	Woody Wetlands	C	78.0	0.00	0.08	1.06%	95.9%	0.8	75.3	
N09	Woody Wetlands	D	78.0	0.00	0.08	4.13%	100.0%	3.2	78.5	**78.5**
N10	Cultivated Crops	C	81.0	0.09	0.36	24.13%	24.1%	19.5	19.5	
N10	Developed, Low Intensity	C	80.0	0.02	0.36	5.63%	29.8%	4.5	24.0	
N10	Developed, Open Space	C	74.0	0.06	0.36	16.13%	45.9%	11.9	36.0	
N10	Developed, Open Space	B	61.0	0.00	0.36	0.14%	46.0%	0.1	36.1	
N10	Hay/Pasture	C	74.0	0.14	0.36	38.56%	84.6%	28.5	64.6	
N10	Hay/Pasture	B	61.0	0.01	0.36	1.76%	86.4%	1.1	65.7	

BASIN	LAND USE CATEGORY	SOIL MAP UNIT #	SUBREGION CN	SUBREGION AREA (mi^2)	SUBBASIN AREA (mi^2)	PERCENT OF SUBBASIN	CUMULATIVE PERCENT	AREA-WEIGHTED CN	CUMULATIVE CN	COMPOSITE CN
N10	Hay/Pasture	D	80.0	0.02	0.36	6.01%	92.4%	4.8	70.5	
N10	Herbaceuous	C	74.0	0.00	0.36	1.34%	93.7%	1.0	71.5	
N10	Shrub/Scrub	C	65.0	0.02	0.36	6.29%	100.0%	4.1	75.6	
N10	Hay/Pasture	C	74.0	0.00	0.36	0.00%	100.0%	0.0	75.6	**75.6**
N11	Cultivated Crops	C	81.0	0.17	2.77	6.23%	6.2%	5.0	5.0	
N11	Cultivated Crops	B	72.0	0.08	2.77	2.76%	9.0%	2.0	7.0	
N11	Cultivated Crops	D	85.0	0.00	2.77	0.01%	9.0%	0.0	7.0	
N11	Deciduous Forest	C	70.0	0.00	2.77	0.05%	9.0%	0.0	7.1	
N11	Deciduous Forest	A	30.0	0.06	2.77	2.31%	11.4%	0.7	7.8	
N11	Deciduous Forest	B	55.0	0.11	2.77	3.98%	15.3%	2.2	10.0	
N11	Developed, Low Intensity	C	80.0	0.01	2.77	0.48%	15.8%	0.4	10.3	
N11	Developed, Low Intensity	B	70.0	0.01	2.77	0.31%	16.1%	0.2	10.6	
N11	Developed, Open Space	C	74.0	0.26	2.77	9.35%	25.5%	6.9	17.5	
N11	Developed, Open Space	B	61.0	0.07	2.77	2.54%	28.0%	1.6	19.0	
N11	Developed, Open Space	D	80.0	0.00	2.77	0.02%	28.0%	0.0	19.0	
N11	Evergreen Forest	C	70.0	0.02	2.77	0.70%	28.7%	0.5	19.5	
N11	Evergreen Forest	A	30.0	0.36	2.77	13.01%	41.8%	3.9	23.4	
N11	Evergreen Forest	B	55.0	1.10	2.77	39.65%	81.4%	21.8	45.2	
N11	Evergreen Forest	D	77.0	0.24	2.77	8.55%	90.0%	6.6	51.8	
N11	Hay/Pasture	C	74.0	0.04	2.77	1.55%	91.5%	1.1	53.0	
N11	Hay/Pasture	B	61.0	0.00	2.77	0.08%	91.6%	0.1	53.0	
N11	Hay/Pasture	D	80.0	0.00	2.77	0.04%	91.6%	0.0	53.1	
N11	Herbaceuous	C	74.0	0.01	2.77	0.34%	92.0%	0.2	53.3	
N11	Herbaceuous	B	62.0	0.01	2.77	0.20%	92.2%	0.1	53.4	
N11	Herbaceuous	D	85.0	0.00	2.77	0.01%	92.2%	0.0	53.4	
N11	Shrub/Scrub	C	65.0	0.09	2.77	3.22%	95.4%	2.1	55.5	
N11	Shrub/Scrub	A	30.0	0.03	2.77	1.19%	96.6%	0.4	55.9	
N11	Shrub/Scrub	B	48.0	0.06	2.77	2.17%	98.8%	1.0	56.9	
N11	Shrub/Scrub	D	73.0	0.03	2.77	0.99%	99.7%	0.7	57.7	
N11	Woody Wetlands	C	78.0	0.01	2.77	0.22%	100.0%	0.2	57.8	
N11	Evergreen Forest	A	30.0	0.00	2.77	0.00%	100.0%	0.0	57.8	
N11	Evergreen Forest	B	55.0	0.00	2.77	0.00%	100.0%	0.0	57.8	
N11	Evergreen Forest	A	30.0	0.00	2.77	0.00%	100.0%	0.0	57.8	
N11	Evergreen Forest	D	77.0	0.00	2.77	0.00%	100.0%	0.0	57.8	
N11	Evergreen Forest	B	55.0	0.00	2.77	0.01%	100.0%	0.0	57.8	
N11	Evergreen Forest	D	77.0	0.00	2.77	0.01%	100.0%	0.0	57.8	**57.8**

APPENDIX F

LAG TIME CALCULATIONS

Basin	CN	Avg Basin Slope (%)	Longest Flow Path (ft)	Lag (hr)	Lag (min)	Tc (min)
1	74.1	1.49	7249.19	1.51	90.78	151.30
2	82.1	1.43	8213.69	1.34	80.40	133.99
3	74.3	1.38	6826.45	1.49	89.34	148.91
4	78.5	1.98	6259.98	1.03	61.56	102.60
5	79.6	1.68	4976.88	0.90	53.74	89.57
6	78.2	1.52	2719.17	0.61	36.33	60.55
7	70.4	1.92	7374.72	1.50	89.92	149.87
8	74.9	1.73	3753.71	0.81	48.60	81.00
9	78.5	1.76	4343.41	0.81	48.71	81.19
10	75.6	2.06	6815.15	1.17	70.46	117.43
11	57.8	29.29	22335.22	1.29	77.37	128.96