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

prepared for

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1. 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 0.9 miles of Flat Creek within Gallatin County, Montana. The Flat Creek study limits extend from the storm sewer inlet, just south of Hoffman Drive at the downstream limit to the upstream limit of approximately 4,555 feet upstream through Valley View Golf Course. The project area is displayed in **Figure 1-1**.

A Flood Insurance Study (FIS) has been completed for Gallatin County (**Reference 6**). Most of the Flat Creek study reach has been previously studied. Flood hazards are currently mapped as Zone A for the lower 1,700 feet and Zone AE upstream for approximately 2,700 feet through the golf course. A 160' section of Zone A is located upstream of the Zone AE and the remaining 500' is unmapped. The effective flooding for Flat Creek is shown in **Figure 1-2**.

The hydrologic analysis for Flat 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 Flat Creek watershed is located within the Bozeman Creek watershed (HUC 12 100200080905). At the downstream study limit, Flat Creek enters a subsurface conduit inlet that travels approximately 1,700 feet before it discharges into Bozeman Creek. Flat Creek flows in a northern direction from its developed headwaters in the City of Bozeman, through Valley View Golf Course and through Kagy Boulevard. Downstream of Kagy Boulevard, Flat Creek flows through a residential area and enters the subsurface conduit inlet. Flat Creek encompasses an area of 0.09 mi^2. Flat Creek is a spring-fed system and the topography of the watershed is low sloping valley. The watershed is comprised of residential developments and a golf course.

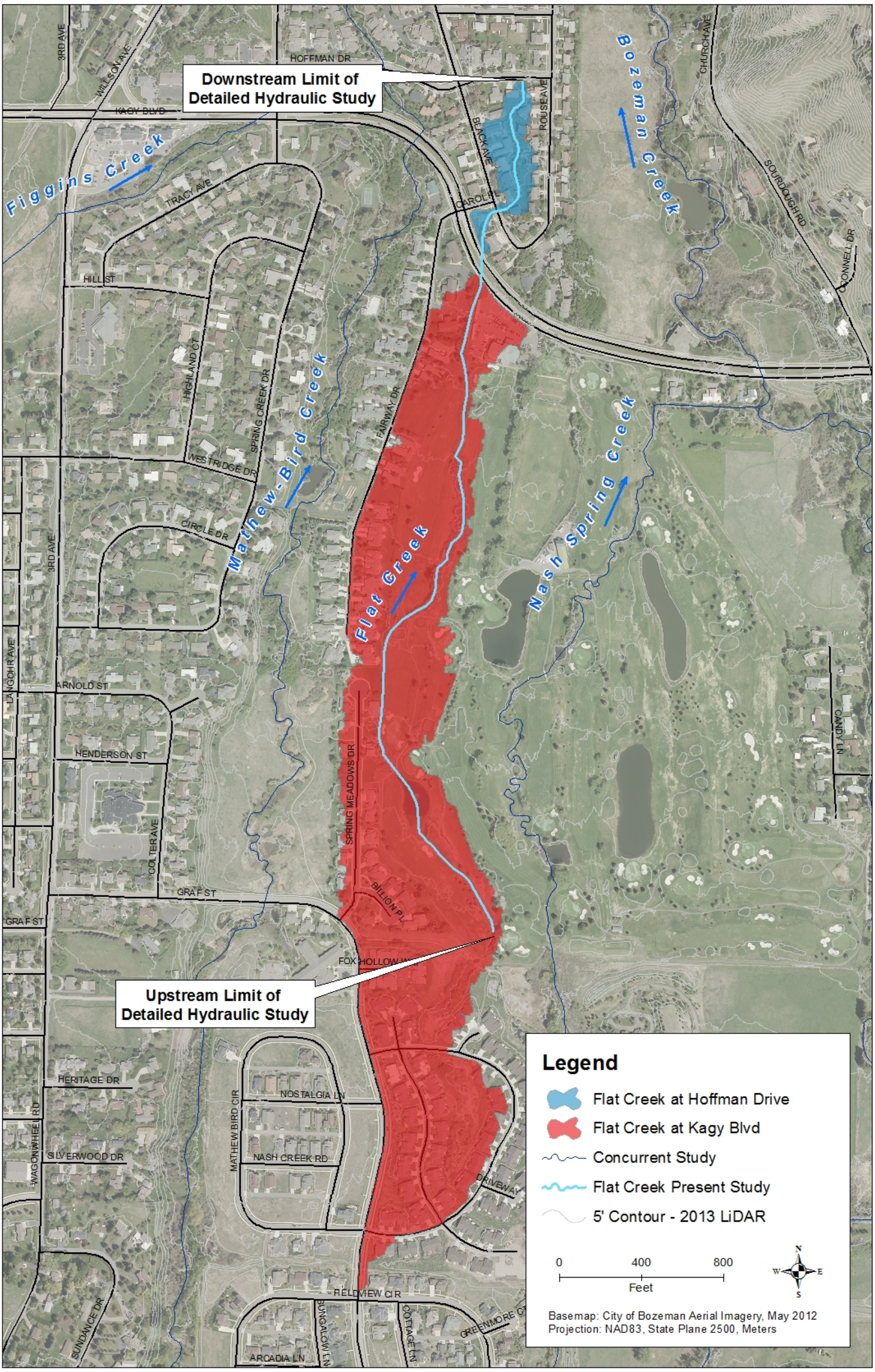

Figure 1-1. Flat Creek watershed

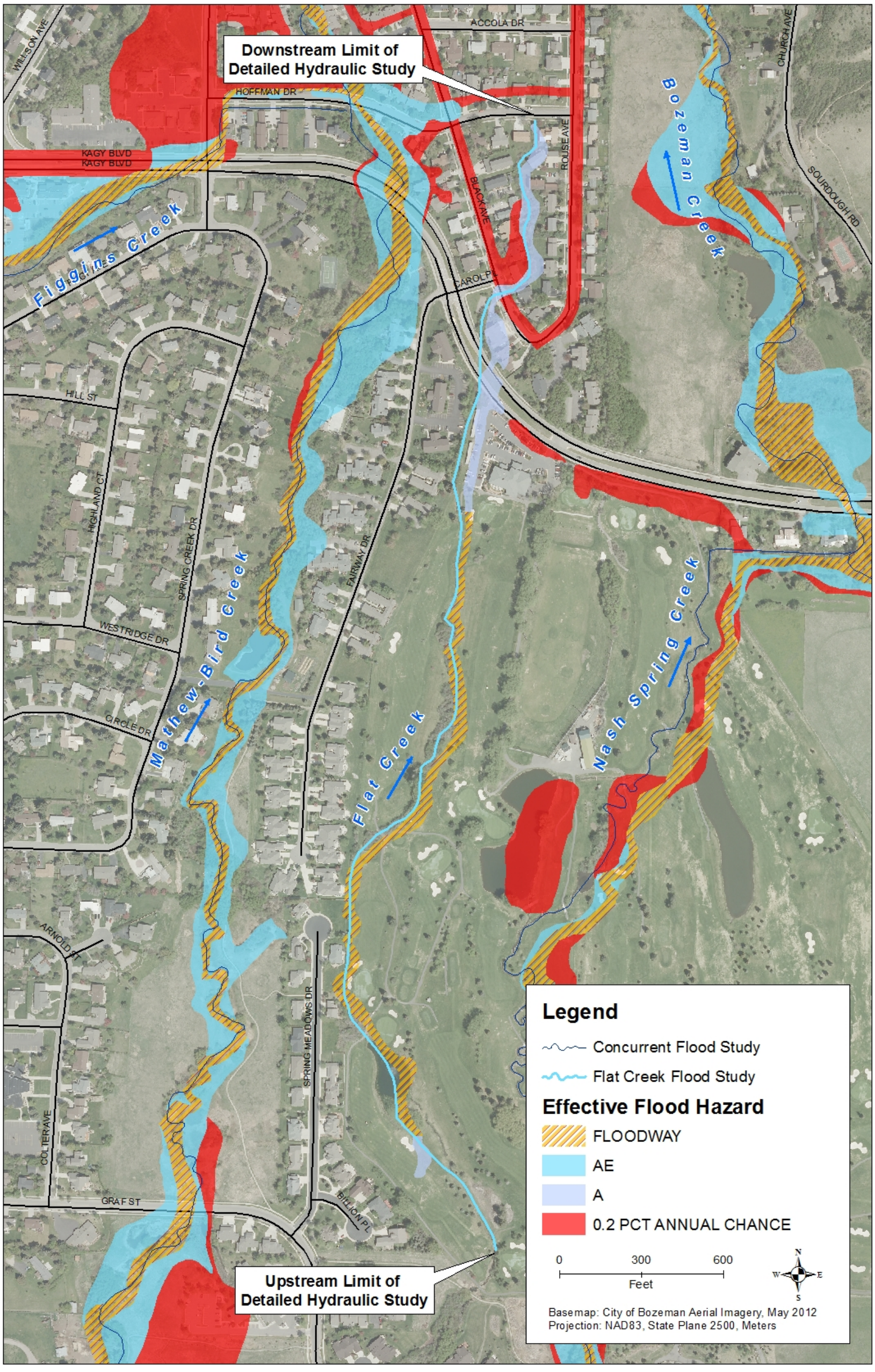

Figure 1-2. Effective flood hazard areas for Flat Creek

1.3 Effective Hydrologic Analysis

As previously mentioned, most of the Flat Creek study reach has been previously studied to the detailed level, bracketed by shorter reaches of approximate analyses at both extents. The Summary of Discharges Table in the FIS report for Gallatin County contains a footnote that suggests an independent hydrological analysis was not performed for Flat Creek and that the discharges reported are result of a diversion of discharge from Nash Spring Creek. Additionally, it is unclear whether the flood hazard for Flat Creek was identified during the original hydrologic analysis of Nash Spring Creek or the revised analysis. The initial analysis was completed in June 1979 by the U.S. Department of Agriculture, Natural Resources Conservation Service. The revised hydrologic analysis of Nash Spring Creek was completed in January 1985 by Morrison Maierle, Inc. The effective FIS states that peak discharges for Nash Spring Creek were computed using regression equations developed from 10 gages near the study area. However, the Summary of Discharges table states, "Peak discharges larger than computed by Regression Equations due to the transfer of flows to each basin by uncontrolled irrigation and road ditches." Regardless, the Summary of Discharges Table states that Flat Creek is a turnout from Nash Spring Creek. The turnout connection from Nash Spring Creek was not identified during field reconnaissance, nor was it observed in either the aerial imagery or topographic data used for the present study. It is likely that development in the watershed modified the irrigation infrastructure that existed during the effective study.

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 Flat Creek within the FIS and limited information available as to flooding along the other 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 of Bozeman was consulted for previous study information for Flat Creek. Unfortunately, hydrologic analyses were not required during the timeframe development occurred in the Flat Creek watershed. However, the city referred to the Montana Department of

Transportation (MDT) for as-built plans of Kagy Boulevard which was constructed in the 1980s. The as-built plans of Kagy Boulevard, included as Supplemental Data, were obtained and show four stream crossings through Kagy Boulevard: Middle Creek Ditch, Spring, Creek, Weed Creek, and Sourdough Creek. From those plans, it is perceived that the four streams correspond to the present study streams of Figgins Creek, Mathew-Bird Creek, Flat Creek, and Bozeman Creek, respectively. The as-built plans contain a Hydraulic Data Summary for the four streams showing their station along the alignment, the type of encroachment, frequency and discharge information, and flood of record information. Both the design flood and the basic flood information correspond to the 100-yr recurrence interval flood. According to the plans, the flood of record for all streams occurred in 1973. For Flat Creek (referred to as Weed Creek), the 100-yr discharge is reported as 74 cubic feet per second (cfs). No other hydrologic information was provided so their hydrologic methods and parameters utilized are unknown, complicating direct comparisons to the present study.

2. HYDROLOGIC ANALYSES

Because no gage data is available for Flat Creek, regional regression equations along with an HEC-HMS model and the Rational Method were used to calculate the peak discharges. Standards and guidance were followed from the Federal Emergency Management Agency (FEMA) Knowledge and Sharing Site (KSS), (**Reference 8**) and FEMA Guidelines and Specifications, Appendix C (**Reference 7**), respectively. Discharges were calculated at the downstream study limit and at Kagy Boulevard. The location at Kagy Boulevard is assumed to be the same location as the effective study. The two locations for the present study were chosen as to not over-conservatively apply discharges to upstream reaches during hydraulic modeling since the basin is small and without major inputs along the reach.

2.1 Regional Regression Equation Analysis

Regional regression equations were used to compute the annual peak discharge values for the Flat 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 14**). USGS WRIR 03-4308 separates Montana into eight different regions based on topography and climatic conditions. The entire drainage area for Flat 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.

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 basin characteristics equation for the Upper Yellowstone-Central Mountain Region requires drainage area (A) and the percentage of drainage area above elevation of 6000' (E_{6000}) as inputs. The drainage areas were delineated using 2 ft LiDAR contours (**Reference 9**) for the Flat Creek drainage basin. The entire Flat Creek watershed is below 6,000' so that percentage is zero. Drainage area delineations for the Flat Creek watershed are shown in **Figure 1-1.** The calculated basin parameters are shown in **Table** 2-1 along with the range of values utilized by USGS for development of the regression equations.

It should be noted that the applicability of the USGS basin characteristics regression estimates to Flat Creek is questioned. The minimum basin area utilized for development of the equations (**Table 2-1)** is 0.47 mi^2. The Flat Creek watershed area of 0.09 mi^2 is less than the

minimum basin area making calculation of a confident estimate not possible. Consequently, the basin characteristics regression equation methodology was excluded from this analysis.

The active-channel width and bankfull width for both basins were measured based on guidelines presented in USGS WRIR 03-4308 during field reconnaissance. 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
Flat Creek at Hoffman Drive	0.089	0	2.5	4
Flat Creek at Kagy Boulevard	0.085	0	2.5	4

Regression equations for active-channel width and bankfull width were calculated for Flat Creek. A weighted combination of the two channel characteristic methods was also computed for Flat Creek. 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 A**.

2.2 HEC-HMS Rainfall-Runoff Analysis

The Flat 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 Flat 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 was the Curve Number Method described in the National Engineering Handbook (**Reference 12**). 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 Flat 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 10)** 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 1**). 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 B**.

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. The subbasins utilized in the hydrologic modeling of Flat Creek are shown in **Figure 2-1**. Drainage areas for the various subbasins are presented in **Table 2-3**. Soils coverage for the Flat Creek watershed was obtained in Soil Survey Geographic (SSURGO) format from the Natural Resources Conservation Service (NRCS) Geospatial Data Gateway (**Reference 11**). The hydrologic soil groups present within the Flat Creek watershed are displayed in **Figure 2-2**. 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 Flat Creek watershed are displayed in **Figure 2-3**. 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 13**) 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 C**.

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 Flat Creek are shown in **Table 2-3** below. Calculations for the curve number method are included in **Appendix D**.

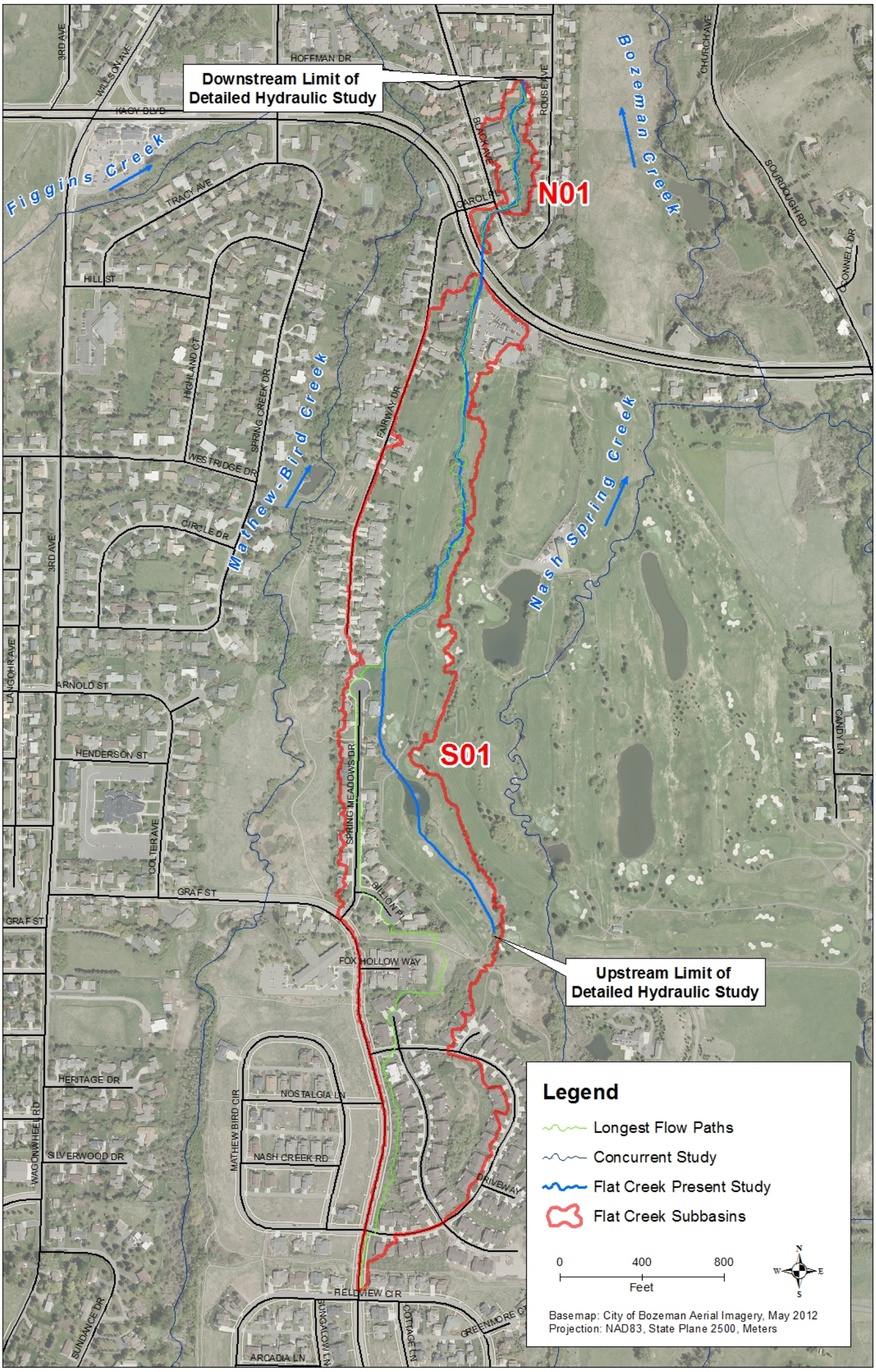

Figure 2-1. Subbasins and longest flow paths utilized for the hydrologic model

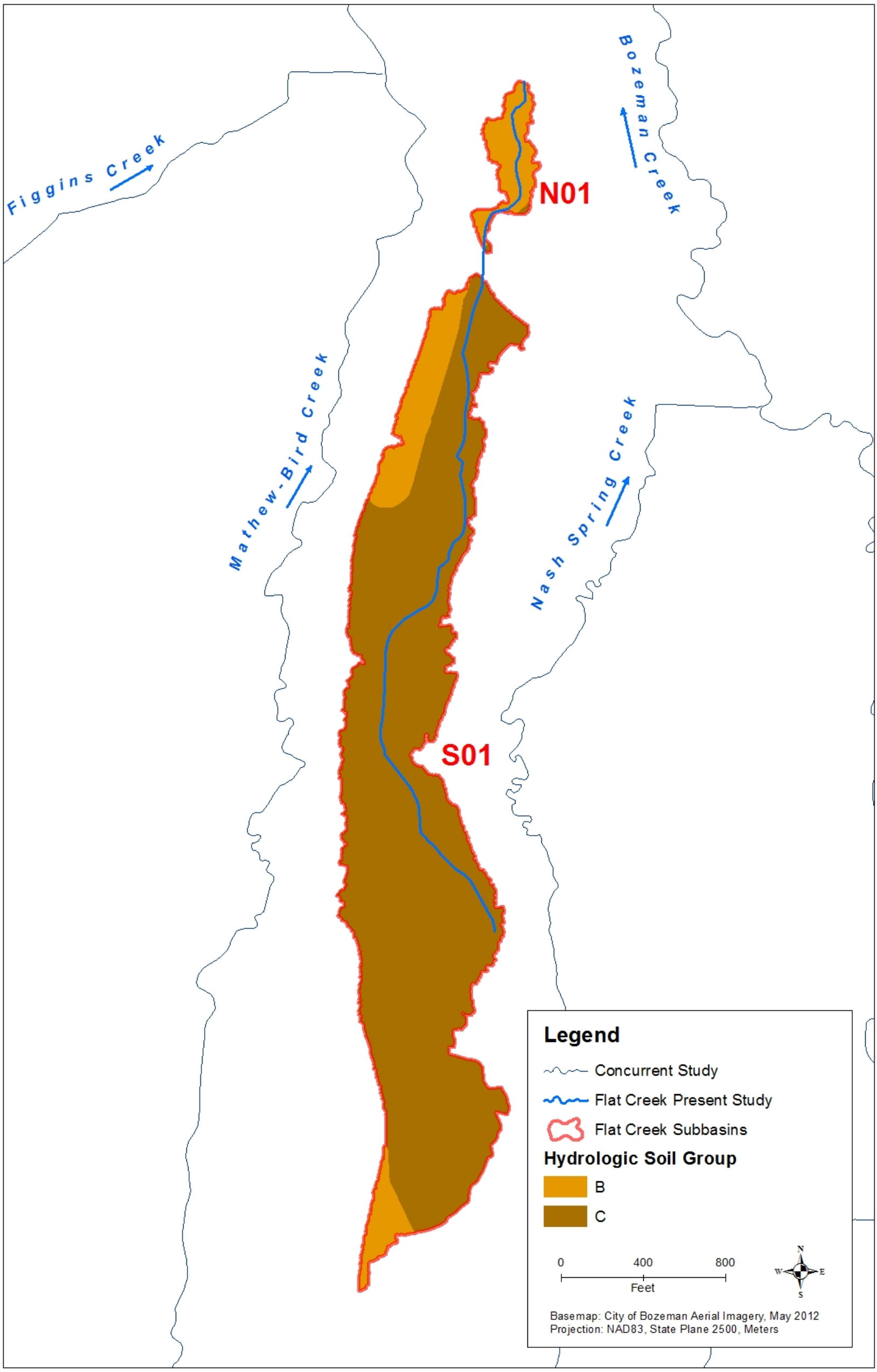

Figure 2-2. Hydrologic soil groups present within the Flat Creek watershed

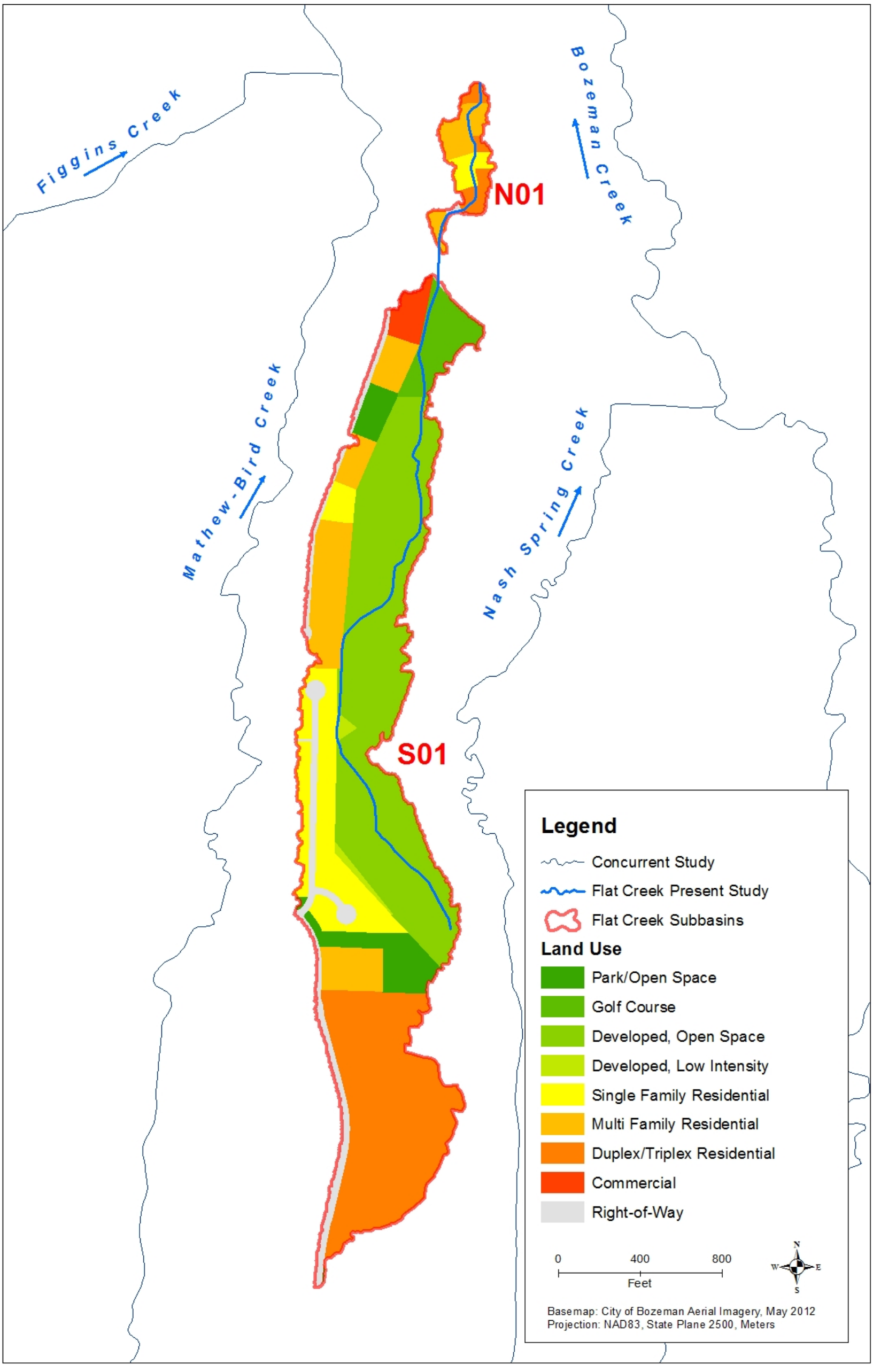

Figure 2-3. Descriptions of land uses present within the Flat Creek watershed

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 11**). 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 10m DEM datasets, respectively. The path of the hydraulic length for each subbasin is shown in **Figure 2-1**.

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 E**.

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	0.0043	83.4	1,053	1.65	13.8	23.1
S01	0.0848	82.3	6,935	1.44	69.6	116.0

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. One routing reach was delineated using ArcGIS 10.1. The eight-point channel cross section, length and slope was created for the reach utilizing the LiDAR topography. 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 reach was 0.04 for the channel to represent a meandering channel with stones and objects of variable form roughness. A Manning's value of 0.08 was assigned to the overbank portion of the section to describe the dense vegetation observed for this reach. In addition to an SCS based rainfall-runoff model computed within HEC-HMS, the Rational Method was used to calculated discharge.

2.3 Rational Method Rainfall-Runoff Analysis

The Rational Method, as described in the City of Bozeman Design Standards and Specifications (**Reference 22**), was also used to calculate runoff for the Flat Creek watershed. The Rational Method is ideal for small watersheds with simple drainage properties. Some sources suggest the method is applicable for watersheds up to 300 acres and other sources suggest a watershed area in the tens of acres is more appropriate. Engineering judgment is required for appropriate application of the Rational Formula. A correct application of the Rational Method requires engineering judgment but one square mile should be the maximum basin size for which the method is applied. Since the Flat Creek basin is not large and may be considered only somewhat complex, the Rational Method was explored.

The basic assumptions associated with the Rational Method are:

a. Rainfall is uniformly distributed over the area for the duration of the storm.
b. The peak runoff rate occurs when the duration of the storm equals the time of concentration.
c. The runoff coefficient for a particular watershed is constant for a similar land use.

The Rational Method is based on the following formula:

$$Q = CiA$$

where,

Q = Peak runoff rate (cfs)
C = Runoff Coefficient
i = Average rainfall intensity (in/hr)
A = Drainage area (acres)

An areal weighted-average runoff coefficient was established for Flat Creek at Kagy Boulevard and Flat Creek at Hoffman Drive. Individual runoff coefficients were extracted from Table I-1 of the City of Bozeman Design Standards and Specifications and assigned to each land use area in the same manner as described in Section 2.2.2 with the assigned coefficients shown in **Appendix C** and the area weighted-average coefficient calculations provided in **Appendix D**.

For the Rational Method, it is assumed that the peak runoff rate occurs when the duration of the storm is equal to the time of concentration. Time of concentration is computed according to the formula:

$$Tc = \frac{1.87(1.1-CC_f)\,D^{1/2}}{S^{1/3}}$$

Where,

Tc = Time of Concentration (min)
S = Slope of Basin (%)
C = Rational Method Runoff Coefficient
D = Length of Basin (feet)
Cf = Frequency Adjustment Factor (as described in City of Bozeman Design Standards and Specifications)

The parameters required to compute time of concentration for each flow change location are provided in **Table 2-4**.

Table 2-4. Summary of basin properties for each flow change location

Flow Change Location	Drainage Area (Acres)	Average Basin Slope, S (%)	Runoff Coefficient, C	Length of Basin, D (ft)
Flat Creek at Kagy Boulevard	54.3	1.44	0.37	6,935
Flat Creek at Hoffman Drive	57.0	1.45	0.37	8,093

Since the Frequency Adjustment Factor varies between storm return periods, a different time of concentration is computed for each event. Once the time of concentration is computed for each event, the average rainfall intensity can be computed according to the City of Bozeman Design Standards and Specifications Figure I-2 (or provided formulas) describing the relationship

between rainfall intensity and storm duration. The hydrologic parameters computed for both flow change locations are provided in **Table 2-5** and **Table 2-6**.

Table 2-5. Summary of hydrologic parameters for Flat Creek at Kagy Boulevard

	2YR	5YR	10YR	25YR	50YR	100YR
Frequency Adjustment Factor, Cf	1	1	1	1.1	1.2	1.25
Time of Concentration, Tc (hr)	1.69	1.69	1.69	1.60	1.52	1.47
Intensity, i (in/hr)	0.44	0.63	0.77	0.92	1.06	1.15

Table 2-6. Summary of hydrologic parameters for Flat Creek at Hoffman Drive

	2YR	5YR	10YR	25YR	50YR	100YR
Frequency Adjustment Factor, Cf	1	1	1	1.1	1.2	1.25
Time of Concentration, Tc (hr)	1.81	1.81	1.81	1.72	1.63	1.58
Intensity, i (in/hr)	0.46	0.64	0.79	0.95	1.09	1.18

Once these hydrologic parameters are obtained, the rational formula is used to calculate discharge for each event. Those results are provided in Section 3.

3. HYDROLOGIC ANALYSES RESULTS AND DISCUSSION

3.1 Summary of Discharges

The effective discharges for Flat Creek Near Kagy Boulevard are shown in **Table 3-1**.

Table 3-1. Effective discharges for Flat Creek

Location	Drainage Area (mi^2)[1]	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)
Flat Creek Near Kagy Boulevard	-	5	*N/A*	11	15	30

[1] *From the effective FIS, "No drainage area because ditch is turnout from Nash-Spring Creek"*

Very little specific information pertaining to the hydrologic methods and results is provided in the effective FIS. The drainage area footnote shown in **Table 3-1** suggests there was not an independent hydrological analysis performed for Flat Creek and that the discharges reported are result of a diversion of discharge analysis for Nash Spring Creek.

Results of the various methods described in **Section 2** are summarized in **Table 3-2** and **Table 3-3**. The results for the measured active-channel and bankfull widths and their weighted combination were the same for both flow change locations since channel properties for both locations were similar. Consequently, results presented in **Table 3-2** are not repeated for Flat Creek at Hoffman Drive as shown in **Table 3-3**.

Table 3-2. Resultant discharges for Flat Creek at Kagy Boulevard

Method	Description	10%-Annual-Chance	4%-Annual-Chance	2%-Annual-Chance	1%-Annual-Chance	0.2%-Annual-Chance
2004 USGS Regional Regression Equations - Active Channel Width	Discharge (cfs)	63	121	184	266	557
	SEP %	71.9	78.0	84.6	92.2	114.2
2004 USGS Regional Regression Equations - Bankfull Width	Discharge (cfs)	46	90	139	202	430
	SEP %	76.0	81.8	88.6	96.6	119.7
2004 USGS Regional Regression Equations - Weighted Active Channel & Bankfull Widths	Discharge (cfs)	59	118	184	266	557
	SEP %	71.7	78.0	84.6	92.2	114.2
HEC-HMS (HEC-HMS Element S01)	Discharge (cfs)	10	17	22	26	38
Rational Method	Discharge (cfs)	15	18	21	23	-[1]

[1] *Methodology not provided within City of Bozeman Design Standards and Specifications*

Table 3-3. Resultant discharges for Flat Creek at Hoffman Drive

Method	Description	10%-Annual-Chance	4%-Annual-Chance	2%-Annual-Chance	1%-Annual-Chance	0.2%-Annual-Chance
HEC-HMS (HEC-HMS Element Sink-1)	Discharge (cfs)	11	17	22	26	38
Rational Method	Discharge (cfs)	16	19	22	24	-[1]

[1] *Methodology not provided within City of Bozeman Design Standards and Specifications*

3.2 Discussion and Recommended Discharges

As mentioned, the Montana Department of Transportation (MDT) provided as-built plans of Kagy Boulevard which included hydraulic information for Flat Creek. Those plans suggest the 1%-annual-chance event peak discharge for Flat Creek is 74 cfs. In review of the discharges listed in **Table 3-2** through **Table 3-3**, it is apparent there is a vast difference in calculated discharges between regression methods, rainfall-runoff models, and what MDT utilized. Since peak discharge provided by MDT contains no supporting information and are about three times higher than present study results from rainfall-runoff modeling, sources of discrepancies to present study results are left to speculation. It is possible their analysis considered the "turnout" condition from Nash Spring Creek, as did the FIS, where additional drainage area outside the Flat Creek watershed may have been considered.

The differences in peak discharge results between various methodologies used for the present study warrant discussion. Since Flat Creek is located in an urban environment, it is suspected to have been altered from its natural geomorphic condition in the form of road crossings, developments, bank protection and grade control structures. This introduces uncertainty for estimates calculated from the active-channel and bankfull width regression equations. Furthermore, the number of spring-fed systems utilized for development of the regression equations is suspected to be minimal. The lack of a significant presence of valley spring-fed creeks in the Upper Yellowstone-Central Mountain Region sample pool introduces uncertainty as to whether their unique behavior is reflected in the equations developed for this mountain-stream dominated region. For both reasons, the regression estimates utilizing channel characteristics are less reliable than other methods.

Discharge estimates calculated by the HEC-HMS model and the Rational Method are in close proximity; within a few cubic feet per second for all events. Since no gages exist on the studied stream, model calibration was not possible. To ensure results generated by rainfall-runoff modeling are realistic, a discharge per unit area of the basin comparison between methods and the proximity of those estimates to select statistical gage analyses provided in WRIR 03-4308 is worthwhile. Although the Flat Creek basin does not well-resemble any gages used in WRIR 03-4308, some insight may be gleaned from a comparison. **Table 3-4** shows basin properties of select gages of similar area, elevation, and climactic characteristics extracted from WRIR 03-4308 for the Upper Yellowstone-Central Mountain Region.

Table 3-4. Basin properties for select gages from WRIR 03-4308

USGS Gage Number	Location Description	Area (mi^2)	Mean Elevation (ft)	E_{6000} (%)	MAP (in)
6112800	**Bull Creek tributary near Hilger**	0.99	4150	0	16
6124600	**East Fork Roberts Creek tributary near Judith Gap**	0.74	4850	0	16
6129400	**South Fork McDonald Creek tributary near Grassrange**	0.51	3850	0	17
6120600	**Antelope Creek tributary near Harlowton**	0.47	5400	0	15

E_{6000} = Percentage of basin area above 6000 ft elevation
MAP = Mean Annual Precipitation

The gages selected from USGS WRIR 03-4308 most closely resemble the Flat Creek watershed in area, mean elevation, percentage area above 6000' elevation, and mean annual precipitation of all gage results used. The mean annual precipitation for Bozeman, however, is higher than all gages used for comparison. As reported in WRIR 03-4308, the mean annual precipitation for USGS gage 06048000, East Gallatin River at Bozeman is 26", which is higher than the 18.5" reported by the Western Regional Climate Center (Reference 22).

Shown in **Table 3-5** are the discharge per unit area results for the HEC-HMS model for Flat Creek at Hoffman Drive, the Rational Method for Flat Creek at Hoffman Drive, and select USGS gages extracted from USGS WRIR 03-4308. This comparison is also presented graphically on **Figure 3-1**.

Table 3-5. Discharge per unit area comparison between HEC-HMS hydrological model, Rational Method, and select USGS gages from WRIR 03-4308

	Discharge per unit Area (cfs/mi^2)				
Method	**10%-Annual-Chance**	**4%-Annual-Chance**	**2%-Annual-Chance**	**1%-Annual-Chance**	**0.2%-Annual-Chance**
HEC-HMS (HEC-HMS Element Sink-1)	121	195	257	310	448
Rational Method	181	217	249	270	-[1]
USGS 6120600	23	53	98	172	594
USGS 6129400	116	194	273	367	669
USGS 6124600	105	172	234	309	543
USGS 6112800	79	168	276	433	1101

[1] *Methodology not provided within City of Bozeman Design Standards and Specifications*

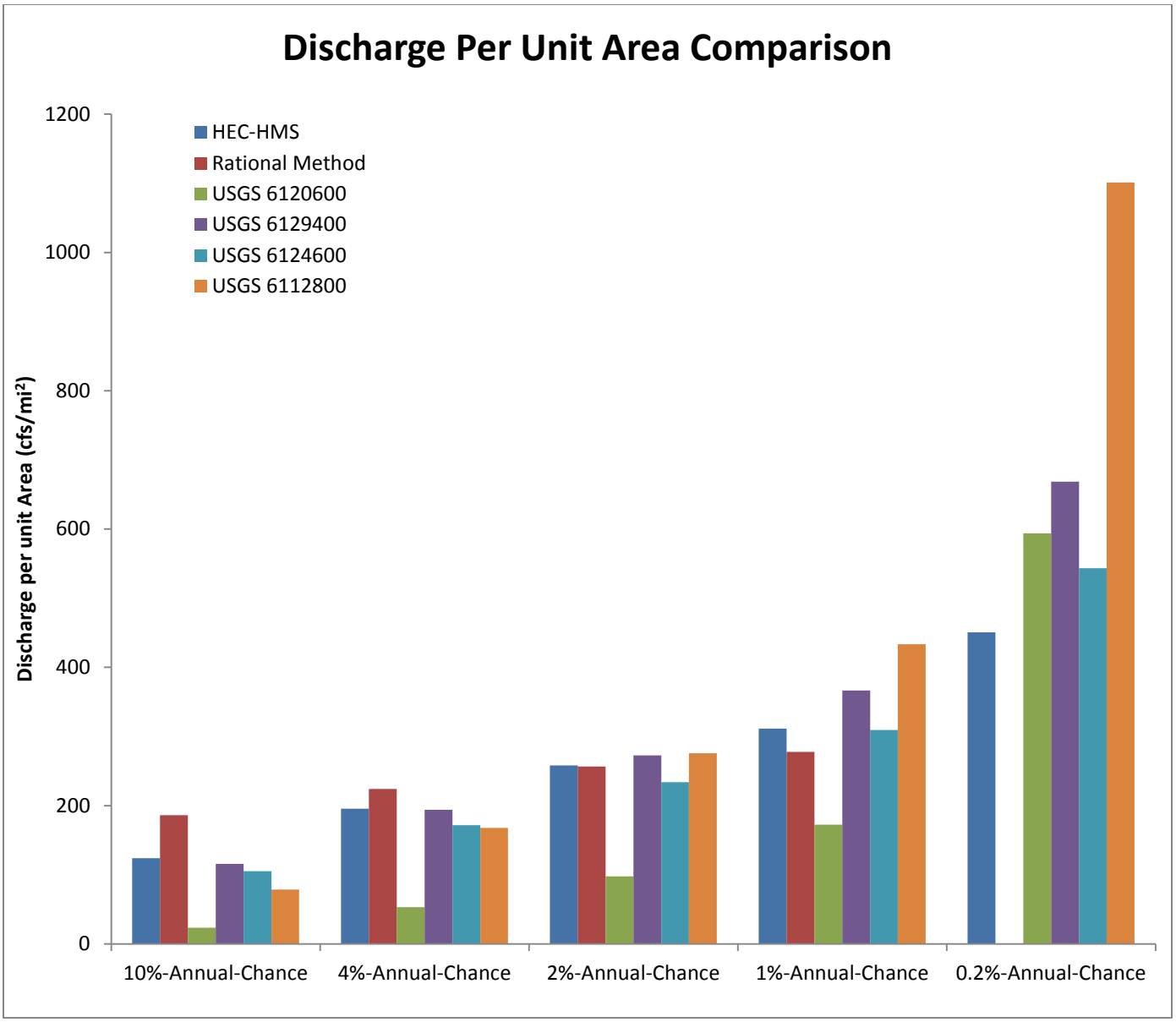

Figure 3-1. Discharge per unit area comparison between HEC-HMS hydrological model, Rational Method, and select USGS gages from WRIR 03-4308

As mentioned, the Flat Creek watershed area is about 20% of the area of the smallest USGS gage compared. Other watershed differences like mean annual precipitation in addition to a watershed's geographic proximity to storm patterns greatly influence the comparison. Watershed aspect and shape greatly influence the runoff characteristics as well as the soils and land uses, none of which are considered in this comparison. The runoff characteristics of any watershed are complex and depend on many more variables than these basic parameters reviewed. Nonetheless, this comparison draws on readily available data and is useful for a check of reasonableness. The most distinct observation is that the HEC-HMS model and Rational Method results are similar and bracketed by most gage unit discharges, suggesting that results from rainfall-runoff modeling are reasonable. The Rational Method results are higher than the

HEC-HMS results for more frequent flood events but are slightly lower for less frequent events. The Rational Method utilized for the present study was modified by the City of Bozeman to be specific to this area. Since the HEC-HMS model results agree well to the area-specific Rational Method results, the HEC-HMS results are slightly more conservative than the Rational Method results for less frequent (and regulatory) events, and the HEC-HMS results are bracketed by USGS gage comparisons, it is recommended that discharge estimates from the HEC-HMS model be utilized in the hydraulic analysis of Flat Creek. Furthermore, use of the HEC-HMS results ensures model consistency with the adjacent concurrent flood studies.

It is noted that the recommended discharges are considerably higher than the effective discharges for Flat Creek. It is suspected that the effective discharges, as mentioned, do not consider an event based storm for the Flat Creek watershed but rather are results of a diversion of discharge from the Nash Spring Creek study.

Since the HEC-HMS results calculated for both flow change locations shown in **Table 3-2** through **Table 3-3** are identical when rounded to the whole cubic feet per second (with the exception of a 1 cfs difference for the 10%-annual-chance event), the proposed flow change location at Kagy Boulevard was discarded. The discharge estimates calculated at Hoffman Drive are recommended for use throughout the entire study length.

Recommended 10-, 4-, 2-, 1- and 0.2-percent-annual-chance discharges for the entire length of Flat Creek are presented below in **Table 3-6**.

Table 3-6. Recommended discharges for Flat Creek

Location	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)
Flat Creek at Hoffman Drive	11	17	22	26	38

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Appendix A. Regression Analysis

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:	**Flat Creek Weighted Channel Regr**
Region:	**Upper Yellowstone**
Estimation method:	**Weighted estimate based on Active-channel width and Bankfull width**
Width of active channel in feet:	**2.5**
Width of bank full channel in feet:	**4**

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
 Flat Creek Weighted Channel Regr
Upper Yellowstone-Central Mountain Region: WAC =      2.50
 RI       DISCHARGE  STD ERR OF              90% PRED. INTERVAL
            (cfs)      PREDICTION(%)
     2        10.        73.4              3.3              30.
     5        33.        69.8             11.6              95.
    10        63.        71.9             21.3             184.
    25       121.        78.0             38.2             382.
    50       184.        84.6             54.0             628.
   100       266.        92.2             71.9             987.
   200       373.       101.0             91.9            1510.
   500       557.       114.2            121.2            2560.


 METHOD: Regression on bank full channel width
 Flood frequency estimates for
          Flat Creek Weighted Channel Regr
Upper Yellowstone-Central Mountain Region: WBF =      4.00
```

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	8.	162.0	1.2	55.
5	24.	74.8	8.0	74.
10	46.	76.0	15.0	143.
25	90.	81.8	27.3	298.
50	139.	88.6	38.9	494.
100	202.	96.6	52.1	783.
200	285.	105.8	67.0	1210.
500	430.	119.7	89.0	2080.

METHOD: Combined methods 2 and 3
Flood frequency estimates for
Flat Creek Weighted Channel Regr
Region 7

RI	DISCHARGE (cfs)	STD ERR OF PREDICTION(%)	90% PRED. INTERVAL	
2	10.	73.4	3.3	29.
5	31.	69.4	10.9	88.
10	59.	71.7	20.4	173.
25	118.	78.0	37.7	372.
50	184.	84.6	54.4	624.
100	266.	92.2	72.5	979.
200	373.	101.0	92.7	1500.
500	557.	114.2	122.3	2540.

Montana Flood-Frequency and Basin-Characteristic Data

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Appendix B. 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*

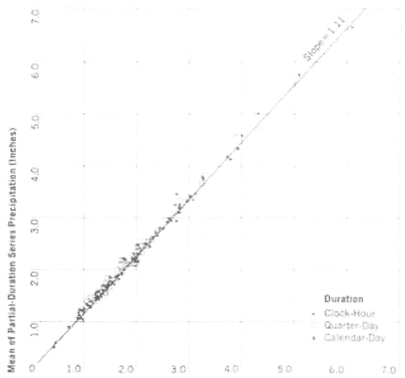
Values interpolated using Figure 17 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

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.*



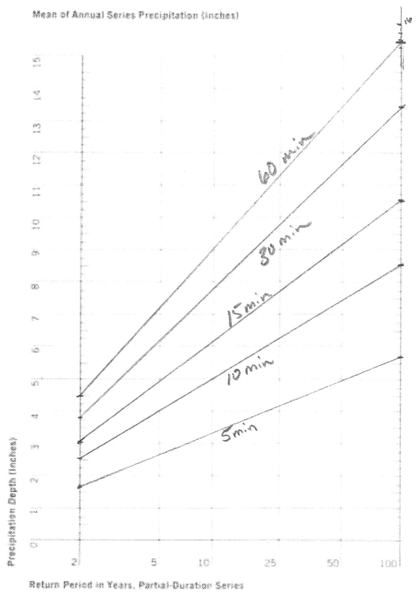
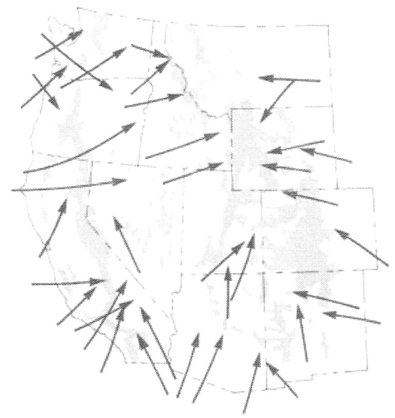


Figure 6. *Precipitation depth versus return period for partial-duration series.*

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.

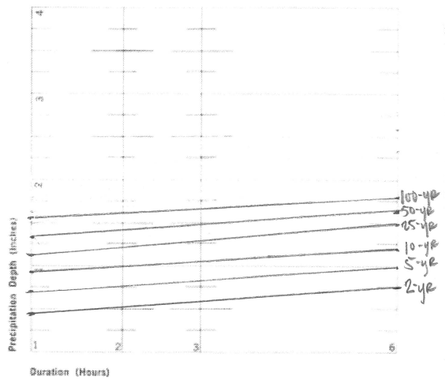
Although the computer program treated each variable as linear during the regression analysis, it was possible through internal computations to use logarithms, powers, roots, reciprocals, or combinations of any or all of the factors. The computer program selected the single variable most highly correlated 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).*



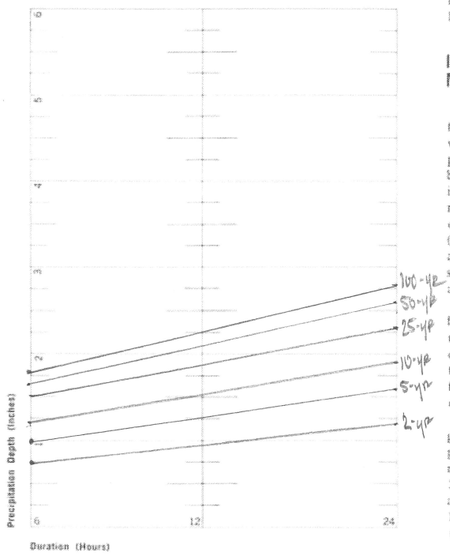


Figure 17. *Precipitation depth-duration diagram (6 to 24 hrs).*

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.

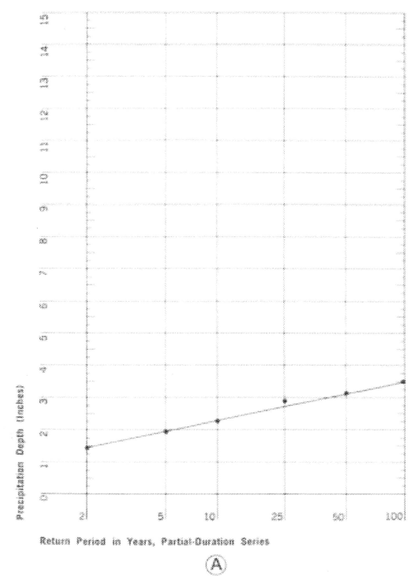
Table 11. *Adjustment factors to obtain n-minute estimates from 1-hr values*

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**



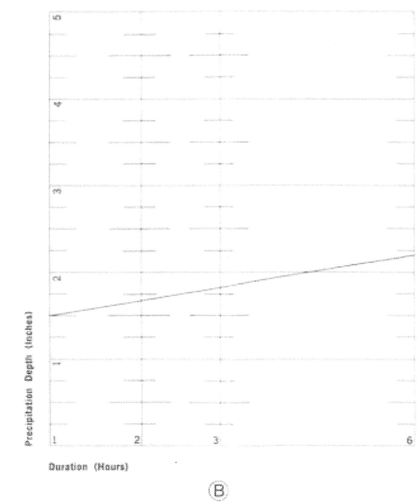


Figure 18. *Illustration of use of precipitation-frequency diagrams using values from precipitation-frequency maps and relations at 47°00′ N., 110°00′ W.*

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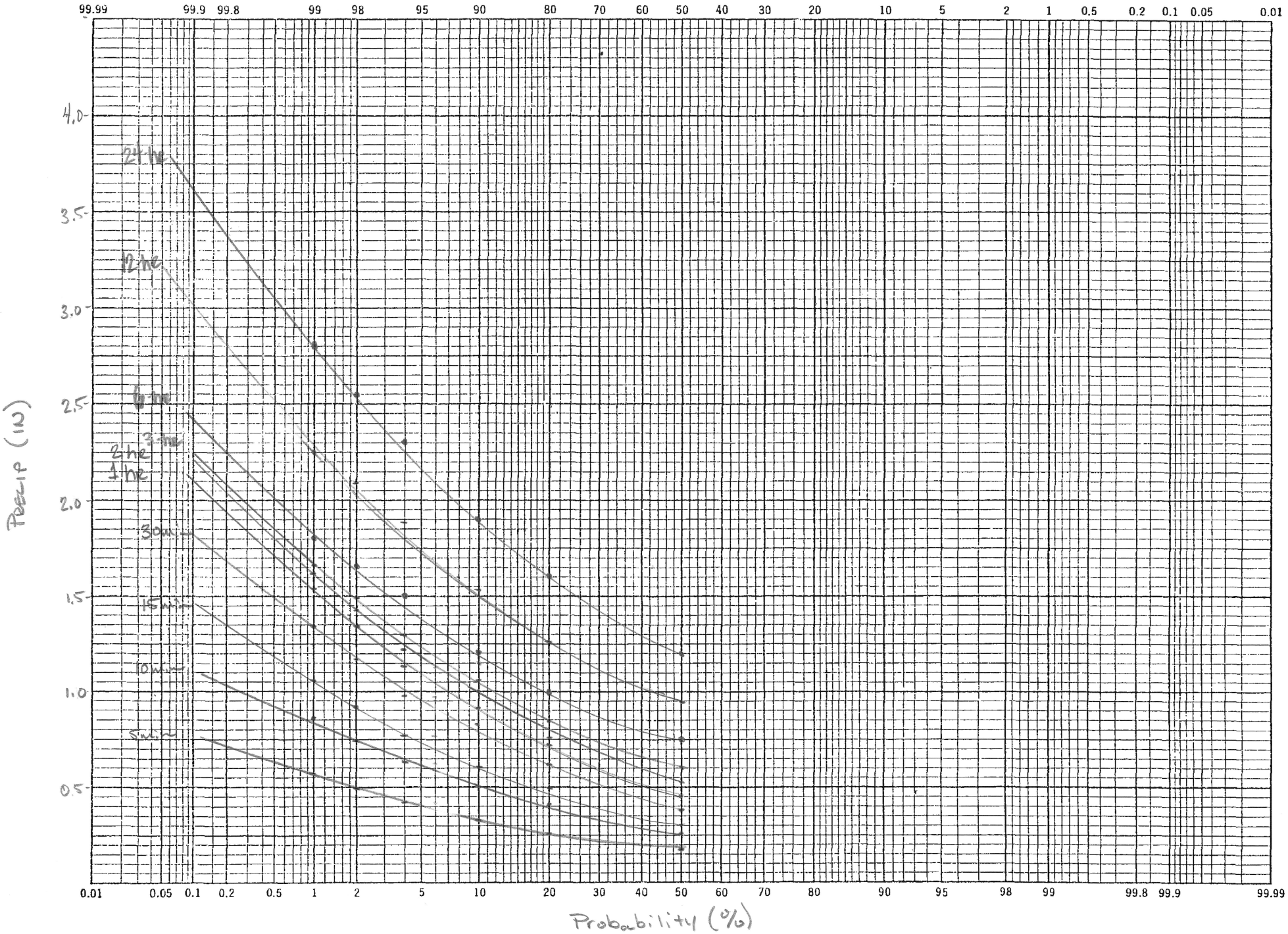

Appendix C. Curve Number Look-Up Table

Land Use Category	Hydrologic Soil Group				Rational C	Description	Assumption	Reference	Source
	A	B	C	D					
Developed, Open Space	39	61	74	80	0.2	Developed, Open Space	Lawns, parks, cemeteries with vegetation established	Engineering Hydrology - Principles and Practices (Ponce)	NLCD
Developed, Low Intensity	60	70	80	85	0.35	Developed, Low Intensity	1/2 acre lots - vegetation established	Engineering Hydrology - Principles and Practices (Ponce)	
GOLF	89	92	94	95	0.8	Golf Course - Clubhouse and parkinglot.	Commercial	Engineering Hydrology - Principles and Practices (Ponce)	City of Bozeman
GOLF2	39	61	74	80	0.2	Golf Course - A tract of land laid out for playing golf with at least nine holes; and improved with tees, greens, fairways and hazards; and which may include a clubhouse and/or shelter. Resembles commercial areas based on majority of the land use area being impervious.	Park/Open Space	Engineering Hydrology - Principles and Practices (Ponce)	
POS	39	61	74	80	0.2	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)	
SFR	61	75	83	87	0.35	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	0.35	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	0.8	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	0.8	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	0.5	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)	

Appendix D. Curve Number Calculations

BASIN	LAND USE CATEGORY	SOIL MAP UNIT #	SUBREGION CN	Rational C	SUBREGION AREA (mi^2)	SUBBASIN AREA (mi^2)	PERCENT OF SUBBASIN	CUMULATIVE PERCENT	AREA-WEIGHTED CN	AREA-WEIGHTED Rational C	CUMULATIVE CN	CUMULATIVE Rational C	COMPOSITE CN	COMPOSITE Rational C
N01	DTR	B	85.0	0.5	0.0012	0.0043	28.95%	28.9%	24.6	0.145	24.6	0.14		
N01	MFR	B	85.0	0.4	0.0020	0.0043	45.42%	74.4%	38.6	0.159	63.2	0.30		
N01	ROW	B	98.0	0.8	0.0001	0.0043	2.41%	76.8%	2.4	0.019	65.6	0.32		
N01	SFR	B	75.0	0.4	0.0009	0.0043	20.42%	97.2%	15.3	0.071	80.9	0.39		
N01	DTR	C	90.0	0.5	0.0001	0.0043	1.75%	98.9%	1.6	0.009	82.5	0.40		
N01	MFR	C	90.0	0.4	0.0000	0.0043	1.05%	100.0%	0.9	0.004	83.4	0.41	**83.4**	**0.41**
S01	CR	B	92.0	0.8	0.0010	0.0848	1.15%	1.1%	1.1	0.009	1.1	0.01		
S01	Developed, Open Space	B	61.0	0.2	0.0004	0.0848	0.47%	1.6%	0.3	0.001	1.3	0.01		
S01	DTR	B	85.0	0.5	0.0015	0.0848	1.76%	3.4%	1.5	0.009	2.8	0.02		
S01	MFR	B	85.0	0.4	0.0022	0.0848	2.59%	6.0%	2.2	0.009	5.0	0.03		
S01	POS	B	61.0	0.2	0.0013	0.0848	1.52%	7.5%	0.9	0.003	6.0	0.03		
S01	ROW	B	98.0	0.8	0.0017	0.0848	2.03%	9.5%	2.0	0.016	8.0	0.05		
S01	SFR	B	75.0	0.4	0.0005	0.0848	0.56%	10.1%	0.4	0.002	8.4	0.05		
S01	CR	C	94.0	0.8	0.0005	0.0848	0.57%	10.7%	0.5	0.005	8.9	0.05		
S01	Developed, Open Space	C	74.0	0.2	0.0006	0.0848	0.71%	11.4%	0.5	0.001	9.4	0.06		
S01	Developed, Open Space	C	74.0	0.2	0.0303	0.0848	35.75%	47.1%	26.5	0.072	35.9	0.13		
S01	DTR	C	90.0	0.5	0.0182	0.0848	21.46%	68.6%	19.3	0.107	55.2	0.23		
S01	GOLF	C	94.0	0.8	0.0021	0.0848	2.48%	71.1%	2.3	0.020	57.5	0.25		
S01	GOLF2	C	74.0	0.2	0.0016	0.0848	1.93%	73.0%	1.4	0.004	59.0	0.26		
S01	MFR	C	90.0	0.4	0.0046	0.0848	5.38%	78.4%	4.8	0.019	63.8	0.28		
S01	POS	C	74.0	0.2	0.0034	0.0848	4.07%	82.4%	3.0	0.008	66.8	0.28		
S01	ROW	C	98.0	0.8	0.0040	0.0848	4.75%	87.2%	4.7	0.038	71.5	0.32		
S01	SFR	C	83.0	0.4	0.0086	0.0848	10.14%	97.3%	8.4	0.035	79.9	0.36		
S01	MFR	C	90.0	0.4	0.0023	0.0848	2.69%	100.0%	2.4	0.009	82.3	0.37	**82.3**	**0.37**
													Combined	**0.37**

Appendix E. Lag Time Calculations

Basin	CN	Area (sqmi)	Avg Basin Slope (%)	Longest flow path (ft)	Lag (hr)	Lag (min)	Tc (min)
N01	83.4	0.0043	1.65	1053	0.23	13.8	23.1
S01	82.3	0.0848	1.44	6935	1.16	69.6	116.0
Combined	82.4	0.0891	1.45	8093	1.31	78.3	130.51