

# Testing of Hydrologic Models for Estimating Low Flows in Mountainous Areas of Wyoming

## Volume 1: User Guide



Wyoming Water Development  
Commission  
in cooperation with the  
U.S. Geological Survey and  
University of Wyoming

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**Wyoming Water Development Commission  
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## Conversion Factors

For the convenience of readers who may prefer to use metric (International System) units rather than inch-pound units used in this report, values may be converted by using the following factors:

<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )

# Testing of Hydrologic Models for Estimating Low Flows in Mountainous Areas of Wyoming

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## Abstract

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Accurate estimates of streamflow are commonly needed for streams in mountainous areas. This report summarizes results of a study done of low flows for streams in the Medicine Bow Mountains and Sierra Madre of Wyoming. Streamflow-discharge measurements were made at a large number of sites during the low-flow winter months. These discharge measurements were correlated with data from nearby long-term streamflow stations. Refinements were made to equations for estimating winter (low) flows of small mountain streams. Mean monthly flows can be estimated by using the equations in this report, which use drainage area and range in basin elevation as independent variables.

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## Introduction

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Projects involving streams often require flow data. The ideal situation during planning and design is to have at least 5 years of streamflow record available for the site. However, economic constraints commonly prevent gage installation and operation everywhere streamflow information may be needed. If no gaging station has operated at or near a study site, it may be necessary to estimate streamflows.

This report summarizes research results from testing and refining models for estimating low flows of small streams in the mountainous areas of southeast Wyoming. The Wyoming Water Development Commission (WWDC), the U.S. Geological Survey (USGS), and the University of Wyoming (UW) provided funding for the 3-year study, which began July 1, 2000. The final report is presented in two volumes. This report (*Volume 1, Users Guide*) provides a brief description of the study, presents the estimating equations, and gives an example for using the equations. Summaries of the planning and review meetings, descriptions of the field visits, and supplemental reports produced during the study are compiled in *Volume 2, Supplemental Information*.

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## Objectives

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The objectives of the study were to:

- Test the accuracy of various techniques for estimating streamflows at ungaged sites in mountainous areas, especially during the low-flow period of winter,
- Investigate methods for improving the accuracy of estimating techniques, and
- Provide research and technical experience for a University of Wyoming student.

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## Approach

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The study plan was coordinated with the Wyoming State Engineer's Office, U.S. Forest Service, and U.S. Geological Survey (USGS). Field visits and sharing of resources and data were coordinated with USGS. To minimize travel costs, a study area near Cheyenne and Laramie (home bases for the principal investigators and UW students) was chosen.

For the first year of the study, sites on the following drainages were selected for study and measurement:

- Brush Creek in the Medicine Bow Mountains, and
- Nash Fork Creek, tributary to Little Laramie River in the Medicine Bow Mountains

A review of data collected from these sites showed that additional drainages, with a greater diversity of basin characteristics, were needed to accomplish the study objectives. For the second year of the study, additional sites were selected in the following drainages:

- Encampment River in the Sierra Madre,
- Rock Creek and Little Laramie River in the Medicine Bow Mountains, and
- Douglas Creek in the Medicine Bow Mountains.

Figure 1 shows location of the drainage basins.



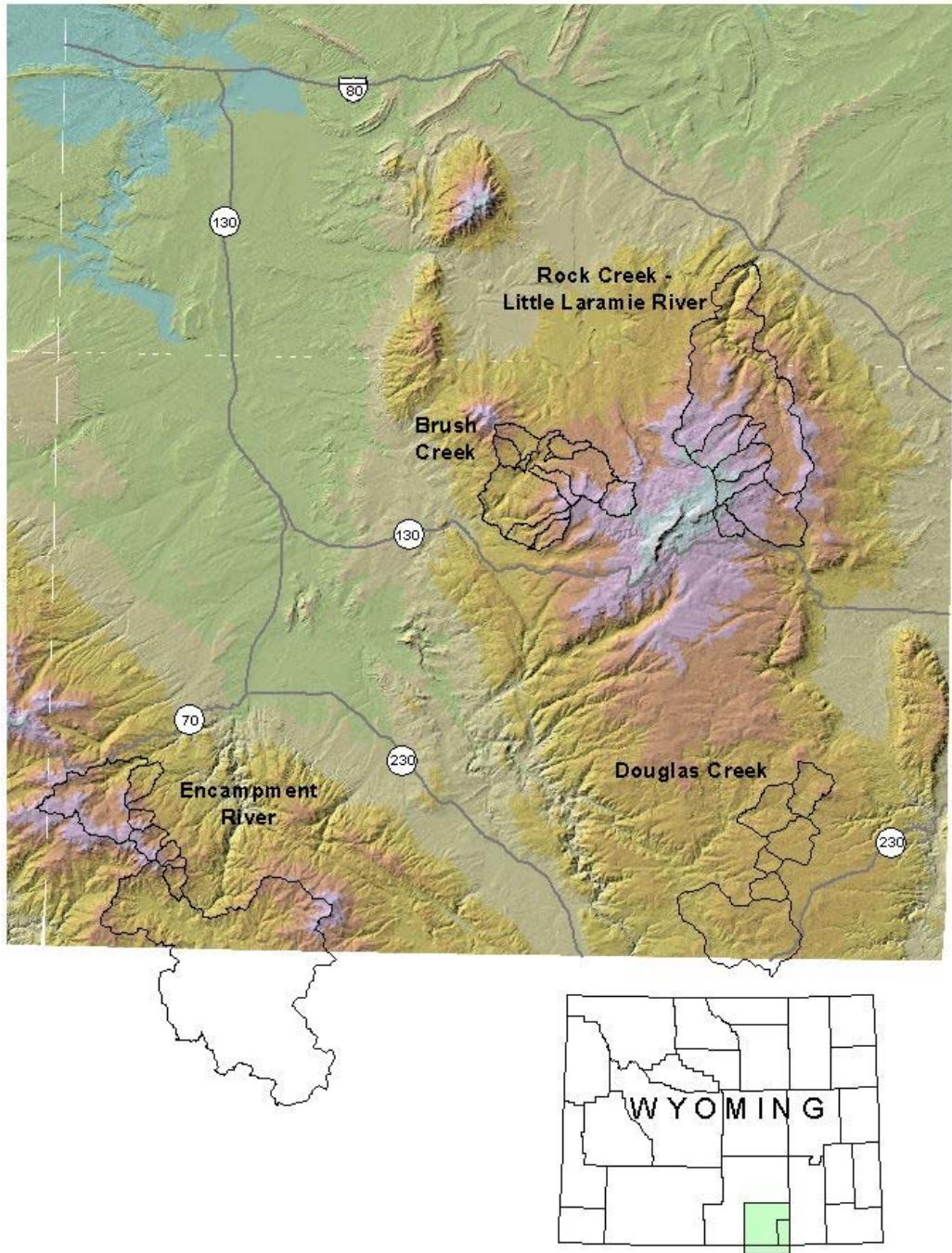


Figure 1. Location of the drainage basins selected for this study.

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## Previous Studies and Available Data

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Previous studies for estimating flows of mountainous streams include Lowham (1988) and Misalis, Wesche, and Lowham (1999). These studies used streamflow data from gaged sites with essentially natural flows, measurements of basin characteristics from topographic maps, and measurements of channel dimensions from field observations. Drainage area, basin elevation, and mean annual precipitation are the basin characteristics generally found to be significant in determining the magnitude of annual and monthly runoff. This study included these same data, but also used monthly streamflow measurements on numerous small streams and basin characteristics that were newly identified by technology such as geographic information systems (GIS).

Available USGS streamflow-station data include:

- Daily values of streamflow
- Summaries of flow statistics, including mean annual and monthly flows, and maximum and minimum flows.

Available basin data include:

- Basin characteristics and channel measurements at streamflow stations;
- Digital files reflecting elevation, slope, aspect, primary vegetation, surface soils, bedrock and surface geology, and land ownership (primarily federal); and
- Snow and precipitation measurements collected at SNOTEL (SNOpack TELemetry) and snowcourse sites operated by the Natural Resources Conservation Service, and at weather stations operated by the National Weather Service

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## Streamflow Data Collection

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Monthly measurements of streamflows were made at about mid-month from October through March or April at each of the selected sites (figs. 2-5) in the six drainage basins (Brush Creek and Little Laramie River during 2000-2001; Encampment River, Rock Creek, Little Laramie River, and Douglas Creek during 2001-2002). Streamflows at nearby gaged sites were measured concurrently.

Figures A-1 to A-6 (Appendix A) show locations of measurement sites and example maps developed through GIS technology for the Brush Creek area. Figures A-7 to A-10 (Appendix A) show locations of the measurement sites for the other study areas. Tables B-1 to B-3 (Appendix B) summarize locations and data for the sites.





*Figure 2. Data collection on Haden Creek, site BC-9, July 15, 2002.*



*Figure 3. Measurement of channel width on unnamed tributary to Fish Creek, site BC-5, July 15, 2002.*



*Figure 4. Streamflow measurement using a bucket at a culvert on Middle Fork Rock Creek, site MB-4, February 12, 2002.*



*Figure 5. Streamflow measurement using a current meter on Harden Creek, site BC-9, January 16, 2001.*



Initial visits were made to observe basin conditions at each site and to select measurement locations. Monthly measurements of discharge were made using standard procedures (Rantz, 1982). The sites were accessed during the winter using snowmobiles and snowshoes. A snow shovel and ice bar commonly were needed to clear the measurement section. Snow cover at the study sites can exceed depths of 5 feet (Brinkman and Lowham, 2001).

Volumetric measurements were made using a calibrated bucket and stopwatch at road crossings with culverts. Buckets of 6 to 12 gallons were used, with the size depending on the clearance between the streambed and the invert of the culvert. A current meter was used where suitable culvert sites were not available. Table B-2 summarizes the streamflow measurements.

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## **Basin and Channel Characteristics**

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Basin characteristics, such as drainage area, basin elevation, and basin slope, were determined using digital maps for each sub-basin (see figures A-1 through A-10, Appendix A). Aerial photographs and/or imagery were examined to determine unique characteristics of the sub-basins that would have an influence on the magnitude of monthly runoff. For example, digital orthophotos revealed patterns of timber harvest and meadows.

The physical variables included contributing drainage area and perimeter; basin slope and basin elevation, including measures of mean, maximum, minimum, and range of elevation and slope; aspect; and areas of clearcut and wetland. Climatic variables measured for each basin included average annual precipitation and long-term average January through April snow-water equivalents. Field measurements of channel width were also obtained for each stream site.

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## **Development of Estimating Equations**

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The selected basins were analyzed to determine features that could be used as parameters to develop estimating equations. The first step was to determine features of mountainous basins that could be identified and defined from existing data. Elevation, slope, aspect, vegetation type and percent of cover, and surface soil types are features that are relatively easy to identify using existing maps. The next step was to examine precipitation and geology maps and remote-sensing products to determine additional features that could be related to the magnitude of low flows.

For example, figure 6 is a graph that shows the relation of February mean flow to drainage area. The best-fit relation shows that discharge increases with drainage area. Some sites have relatively high yields, and thus plot above the best-fit line. Other sites have relatively low yields, and plot below the line. Parameters in addition to drainage area were subsequently investigated to determine why, for example, most of the streams in the North Brush Creek drainage would have

relatively high yields, while many in the Douglas Creek drainage would have relatively low yields.

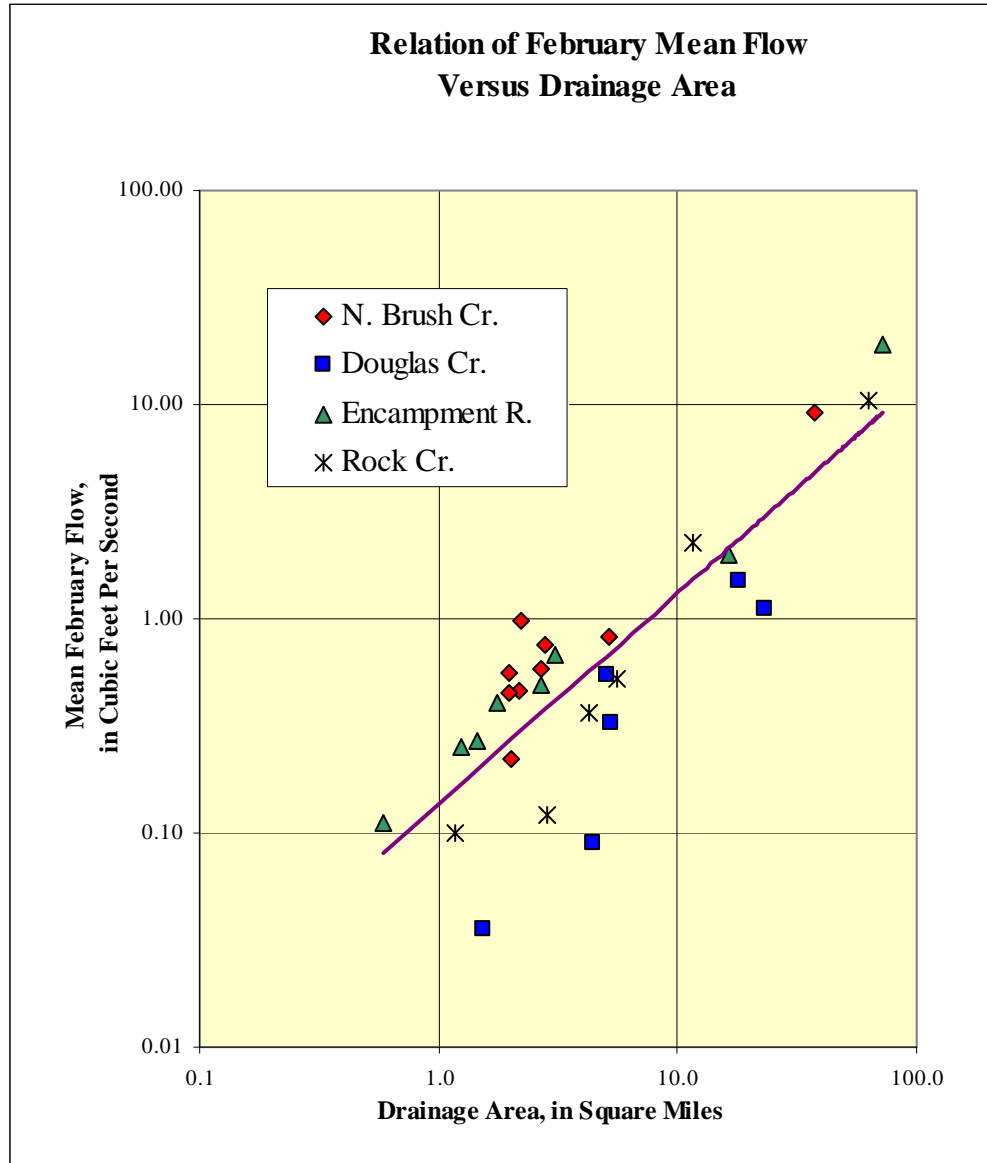


Figure 6. Graph showing relation of February mean flow to drainage area.

The streamflow data and basin characteristics were used to develop estimating equations through the use of multiple regression. The equations express flow characteristics (dependent variables) in relation to basin characteristics (independent variables). The data were transformed to logarithms before the regression analyses. Experience has shown that such transformation of hydrologic variables produces linear relations, which can be readily described by mathematical relations.

The following characteristics were determined as significant independent variables in the regression equations:

- **Contributing drainage area (Area)**, in square miles, measured from digital 1:24,000-scale topographic maps.
- **Range in elevation (Rng EI)**, in feet, measured as difference in elevations from stream channel at lowest end of basin to highest point in basin divide.

Data for the significant variables are summarized in table B-1 (Appendix B).

Large areas of clearcuts and wetland meadows exist in the North Brush Creek drainage, but not for the combined study areas as a whole. Accurately depicting clearcuts in the regression equations is difficult because the areas change as timber harvest and new growth occur.

A precipitation measure, snow-water equivalent for April, was found to be slightly less significant than range in elevation. As part of the study, maps were developed for the Medicine Bow Mountains and Sierra Madre showing lines of equal value for April snow-water equivalent. These maps could be useful in a future study for determining estimates of high flows, provided that data at additional streamflow stations could be obtained.

Equations for estimating mean monthly flows for October through March are summarized below:

	<b>Equation</b>	<b>R<sup>2</sup></b>
Q <sub>Oct</sub>	= 0.000066 Area <sup>0.80</sup> RngEI <sup>1.14</sup>	0.84
Q <sub>Nov</sub>	= 0.000023 Area <sup>0.61</sup> RngEI <sup>1.32</sup>	0.87
Q <sub>Dec</sub>	= 0.000073 Area <sup>0.67</sup> RngEI <sup>1.11</sup>	0.80
Q <sub>Jan</sub>	= 0.000099 Area <sup>0.68</sup> RngEI <sup>1.06</sup>	0.73
Q <sub>Feb</sub>	= 0.000149 Area <sup>0.71</sup> RngEI <sup>1.00</sup>	0.80
Q <sub>Mar</sub>	= 0.000522 Area <sup>0.79</sup> RngEI <sup>0.82</sup>	0.81

where

- Q<sub>m</sub> = mean monthly flow, in cubic feet per second, with <sub>m</sub> designating the month;
- Area = contributing drainage area, in square miles;
- RngEI = range in elevation, in feet; and
- R<sup>2</sup> = coefficient of determination.

The equations were developed using English units, and English units must be used unless applicable conversion factors are applied. The equations should be used for estimating low flows only within the ranges of data used for their development, which includes basins from about 2 to 70 square miles.

The regression equations were developed using data for streams with a wide variety of basin features. However, additional data collection and testing is necessary to confirm if the equations are applicable for streams in mountainous areas other than the Medicine Bow Mountains and Sierra Madre.

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## **Test of Estimating Methods**

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Mean monthly flows at the selected sites were determined using a concurrent-measurement method whereby correlation of the discharge measurements is made with daily mean discharges at a nearby streamflow-gaging station (Riggs, 1969; Parrett and Cartier, 1990, and Lowham, 1988, p. 35).

### **Concurrent-measurement method**

The concurrent-measurement method is used to estimate streamflow at selected sites by correlating with concurrent discharges at one or more nearby gaged sites. The flow rate of a small perennial mountain stream generally does not fluctuate much during the winter. Flow rates of similar streams in the same general area are highly correlated because the same basin and climatic features commonly affect them.

- The selected sites should be in the same general area as the gaged site and have drainage basins with hydrologic similarities.
- Streamflows are measured mid-month at each selected site and are correlated with concurrent daily mean flows at the gaged sites.
- The relation between measured streamflows at the two sites is then used to transfer the mean monthly streamflow characteristic at the gaged site to the selected site.

Streamflows fluctuate from year-to-year, depending on the weather. Monthly discharge measurements at the selected sites, therefore, need adjustment to account for dry or wet years. For example, the mean daily flow measured at the gaged site BC-1 was 9.6 cubic feet per second on October 23, 2000. The mean monthly discharge at the gage for water years 1961-2001 is 14.0 cubic feet per second, which is 1.46 times greater than 9.6 cubic feet per second. The measured discharge at each of the selected sites was therefore multiplied by 1.46 to determine the adjusted mean monthly discharge for October.



Adjustment coefficients were determined for each month:

Month 2000- 2001	<b>a</b> Long-term mean discharge for water years 1961-2001 (ft <sup>3</sup> /s)	<b>b</b> Mean daily discharge for measurement day (ft <sup>3</sup> /s)	<b>a/b = c</b> Coefficient for determining adjusted mean monthly discharge (ft <sup>3</sup> /s)
Oct.	14.0	9.6	1.46
Nov.	11.5	8.2	1.40
Dec.	10.0	9	1.11
Jan.	9.27	8.4	1.10
Feb.	9.24	7.6	1.22
Mar.	10.5	7.7	1.36
Apr.	23.6	27	0.87
May	169	N/A	N/A
June	258	N/A	N/A
July	56.3	N/A	N/A
Aug	13.8	N/A	N/A
Sept	12.6	N/A	N/A
<b>Annual</b>	<b>49.9</b>	N/A	N/A

Similar computations were made for each of the selected sites. Table B-3 (Appendix B) summarizes the adjusted mean monthly flows.

The concurrent-measurement method uses field visits and discharge measurements to determine estimates of mean monthly flow. This method is considered relatively accurate compared with office methods that use measurements of basin characteristics from maps.

Data from the concurrent-measurement method were used to test mean monthly streamflows estimated from the following methods:

- Two sets of equations using basin characteristics as independent variables for estimating mean monthly flows, developed by Misalis, Wesche, and Lowham (1999, pp. 109, 85);
- Equations using basin characteristics as independent variables, for estimating mean annual flow, with monthly flows estimated on the basis of relative proportion of monthly flow for a nearby streamflow-gaging station (Lowham, 1988, p. 28); and
- Equations using basin characteristics as independent variables, developed for this study.

## Equations developed by Misalis and others

Equations developed by Misalis, Wesche, and Lowham (1999) use basin characteristics and channel width to estimate streamflow values. One set of estimating equations used by (Misalis, Wesche, and Lowham; 1999, p. 109) was developed using data for 24 gaged streams in the Medicine Bow Mountains. The equation from this data set for estimating October mean monthly flow using basin characteristics is:

$$Q_{\text{Oct}} = 0.77446 \text{ DA}^{.729} \quad ,$$

where

$Q_{\text{Oct}}$  = mean monthly flow, in cubic feet per second, and

DA = contributing drainage area, in square miles.

A second set of estimating equations (Misalis, Wesche, and Lowham, 1999, p. 85) was developed using data for 130 gaged streams in mountainous regions throughout Wyoming. Equations from this data set for estimating October mean monthly flow using basin characteristics are:

$$Q_{\text{Oct}} = 0.40148 \text{ DA}^{.907} \quad , \text{ and}$$

$$Q_{\text{Oct}} = 0.00351 \text{ DA}^{.891} \text{ p}^{1.57} \quad ,$$

where

P = average annual precipitation, in inches.

## Mean annual flow equations developed by Lowham

Mean annual flow was estimated using equations developed by Lowham (1988, p. 28). Data for 140 gaged streams in the mountainous regions of Wyoming were used. The equation using basin characteristics for estimating mean annual flow is:

$$Q_a = 0.013 \text{ A}^{0.93} \text{ PR}^{1.43}$$

where

$Q_a$  = mean annual flow, in cubic feet per second,

A = contributing drainage area, in square miles, and

PR = average annual precipitation, in inches.

Using the method described by Lowham (1988, p. 40, 41), the October mean monthly flow at site BC-1 (gaging station 06622700) is 14 cubic feet per second, which is 2.34 percent of the mean annual flow. Using the equation above, the estimated mean annual flow at site BC-4 is:

$$Q_a = 0.013 A^{0.93} PR^{1.43}$$

$$= 0.013 (2.77)^{0.93} (25)^{1.43}$$

$$= 3.35 \text{ cubic feet per second.}$$

Mean monthly flows for site BC-4 are then computed using percentages for each month as shown below:

Month	<b>a</b>	<b>b</b>	
	Long-term mean at gaged site BC-1 (station 06622700) for water years 1961-2001 (ft <sup>3</sup> /s)	Monthly flow/ annual runoff/ months a/49.9/12(100) (percent)	Mean monthly flow at selected site b × 3.35 × 12 (ft <sup>3</sup> /s)
Oct	14.0	2.338009	0.94
Nov	11.5	1.920508	0.77
Dec	10.0	1.670007	0.67
Jan	9.27	1.548096	0.62
Feb	9.24	1.543086	0.62
Mar	10.5	1.753507	0.70
Apr	23.6	3.941216	1.58
May	169	28.223113	11.3
June	258	43.086172	17.3
July	56.3	9.402138	3.78
Aug	13.8	2.304609	0.92
Sept	12.6	2.104208	0.84
<b>Annual</b>	<b>49.9</b>	<b>100</b>	<b>3.35</b>

The studies by Miselis, Wesche, and Lowham (1999) and Lowham (1988) also present equations using channel width to estimate streamflow.

### Comparison of estimating methods

The concurrent-measurement method uses discharge data obtained for each month at the site. It therefore is considered to be a relatively accurate means for determining streamflow, outside of operating a long-term gaging station. Estimates of the mean monthly flow were determined using each of the methods described above, including the equations developed as part of this study. These estimates were then compared with the estimates of mean monthly flow that were determined from the concurrent-measurement method.

The results are summarized below, by month and measurement site. Shown is the number of times that each estimating method was closest to the values obtained by the concurrent-measurement method.

	Miselis and others p. 109	Miselis and others p. 85	Lowham, 1988 p. 28	Regression relations developed in this study
Oct.	2	2	4	11
Nov.	2	6	6	14
Dec.	2	9	2	13
Jan.	9	5	4	10
Feb.	7	2	7	13
March	4	2	10	16
<b>Sum</b>	<b>26</b>	<b>26</b>	<b>33</b>	<b>77</b>

For example, in October, the Lowham (1988) method was best for 4 of the sites, while the equations developed for this study were closest for 11 sites. Comparisons were made for 28 sites, so, in principle, the row sums should equal this number. But in practice, in October and December data were not available while in other months two or more estimating methods were tied for closest and each was recorded in the table.

The equations developed for this study provide estimates of mean monthly flow that are closest to the mean monthly flows determined by the concurrent discharge method for a relatively large number of cases. Based on this comparison, it appears that an improved set of estimating equations has been developed for determining low flows in the mountains of southeast Wyoming. The new set of equations is based on a large amount of data for small streams with drainage areas smaller than about 70 square miles; whereas the previous methods were based on a set of data that included larger streams. For streams with drainage areas larger than about 70 square miles, either of the previous methods is considered appropriate.

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## Using Estimating Equations

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### Example

Estimates of monthly flows are needed for determining water rights for instream fisheries on Sourdough Creek, a tributary of South French Creek in the Medicine Bow Mountains (fig. 7). The contributing drainage area at the upstream end of the stream reach is 1.85 square miles, and the range in elevation is 1,172 feet. The estimated flow for February ( $Q_{Feb}$ ) using the regression equation based on the area (Area) and range of elevation (RngEl) of the basin is:

$$Q_{Feb} = 0.000149 \text{ Area}^{0.71} \text{ RngEI}^{1.00}$$

$$Q_{Feb} = 0.000149 (1.85)^{0.71} (1,172)^{1.00}$$

$$= 0.27 \text{ cubic feet per second}$$

### Drainage Basin for Sourdough Creek

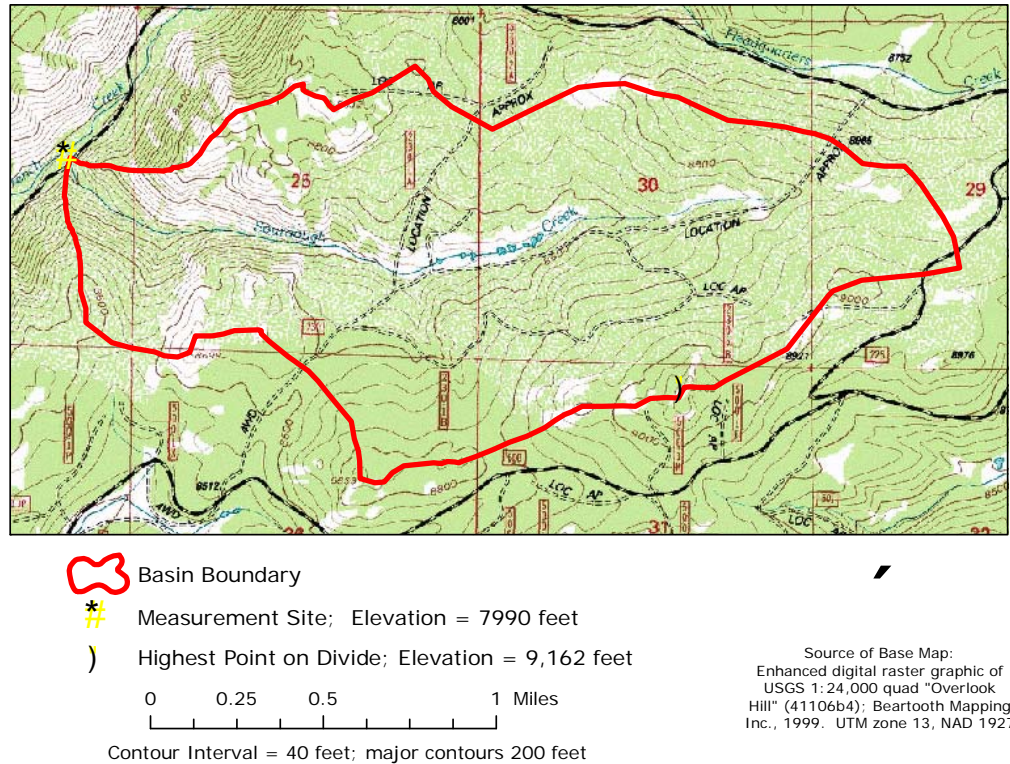


Figure 7. Map of drainage basin for Sourdough Creek.

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## Study Training

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During the first year of the study, technical experience in hydrology and GIS was provided to Justin Montgomery, an undergraduate student. Justin was an active participant in data collection and analysis. He participated in the August 14, 2000 field site visit and compiled digital map files of the study area.

The second year of the study, graduate student James Riley was assigned to the project. During the summer 2001, he worked with Dr. Larry Ostresh to compile a digital database of the study areas. Beginning in the fall 2001, he assisted with developing an analysis to determine the effect of various parameters, such as clearcut areas and snow-water equivalent on base flows. This work continued through the spring 2003.

Mr. Riley completed (May 2003) a Masters Degree from the Department of Geography and Recreation at the University of Wyoming under the direction of Dr. Ostresh. His thesis topic, "Hydrologic modeling of winter streamflow in mountainous areas of Wyoming," stems directly from his work on this study. In addition to the thesis, Mr. Riley presented two papers related to this study at meetings of professional societies. (See *Volume 2, Supplemental Information, Appendix C*)

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## Summary

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The initial plan for the study was to use sites in the Brush Creek drainage to identify basin characteristics for improving low-flow estimates at ungaged sites. The procedure involved (1) making monthly discharge measurements at selected sites during the winter low-flow months and (2) identifying measurable basin features that cause differences in low flows. The sites selected and measured during the first year of the study had relatively uniform basin characteristics and streamflow yields. During the second year, new sites in three additional drainages were selected to obtain a greater variety of basin features.

Numerous basin characteristics were measured for each of the selected sites. Digital topographic maps, and aerial photographs and imagery were used to quantify physical and climatic variables of the basins. Maps were prepared that showed surface geology, soil cover, land cover, precipitation, areas of wetlands, and areas of forest harvest.

Estimates of mean monthly flows were made using discharge measurements at the selected sites, which were correlated with the flows of nearby long-term streamflow-gaging stations. Streamflow for the selected sites were then related to basin characteristics to develop regression equations for estimating low flows at ungaged sites. Drainage area and range in basin elevation were found to be the most significant and consistent variables for estimating low flows. Several basin measurements, including April snow-water equivalent, area of wetlands and forest harvest showed promising results for individual drainage areas, but not for the drainages as a whole.

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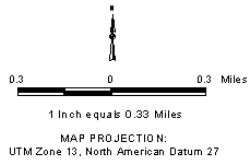
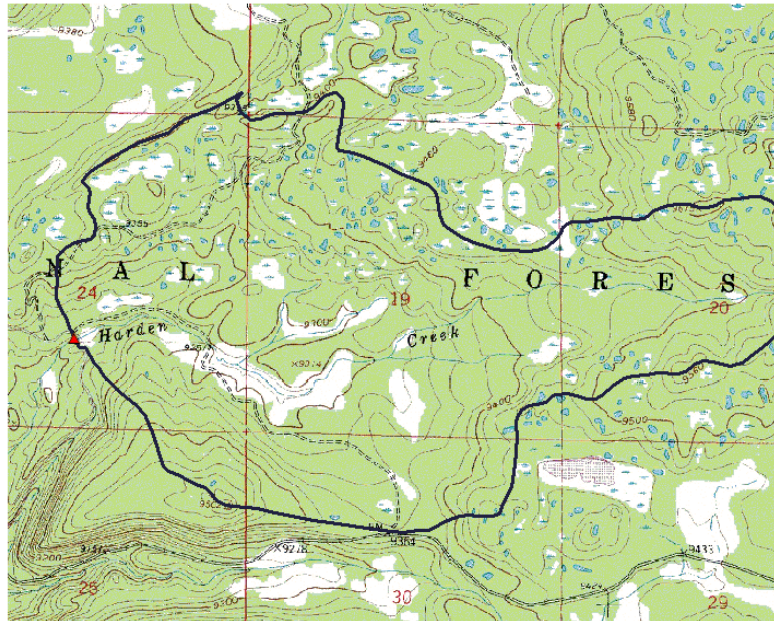
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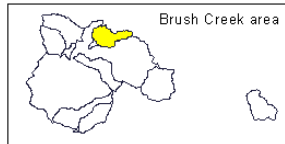
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## ***Appendix A – Drainage Basin Maps***





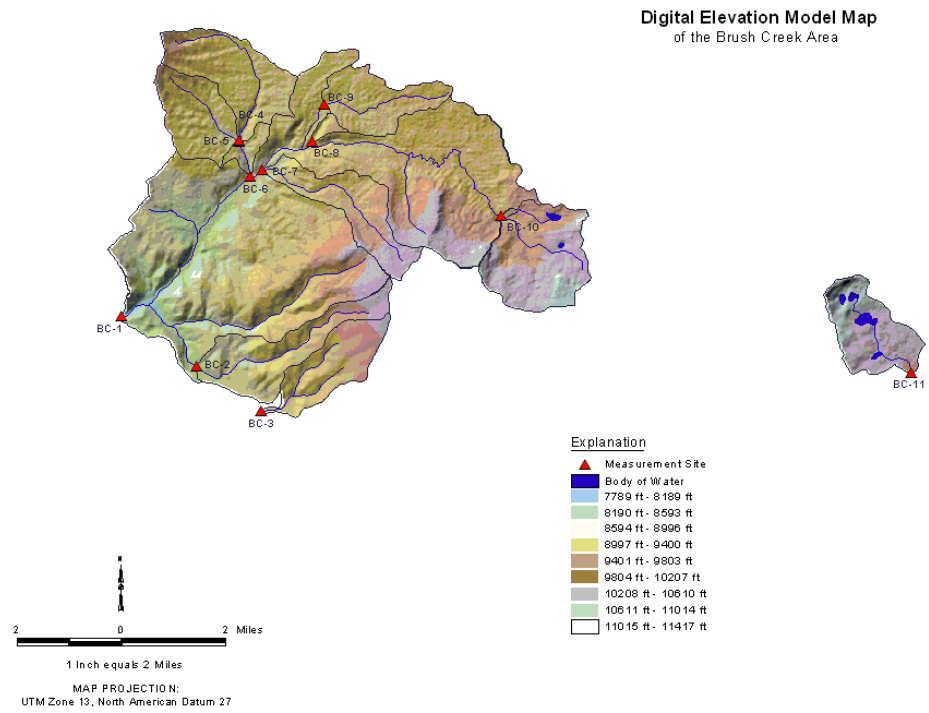
MAP PROJECTION:  
UTM Zone 13, North American Datum 27



Topographic  
of the Harden Creek di

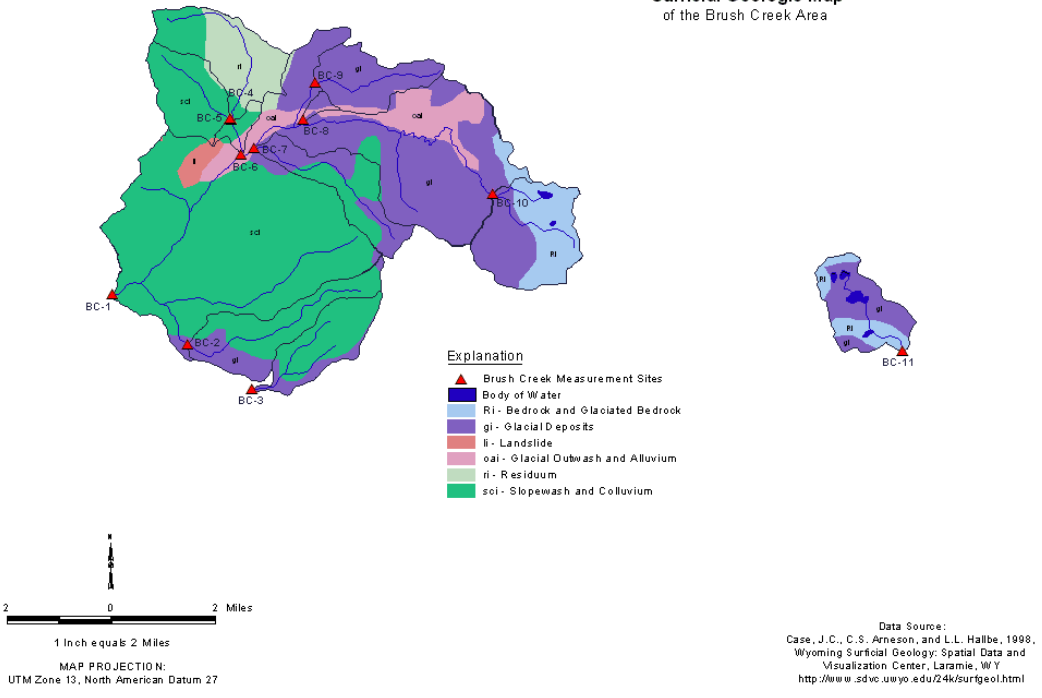
Data Source:  
Beartooth Mapping, Inc., 1999,  
Enhanced Digital Raster Graph  
Beartooth Mapping, Inc., Re

**A-1 Topographic map of Harden Creek drainage basin, Brush Creek area.**

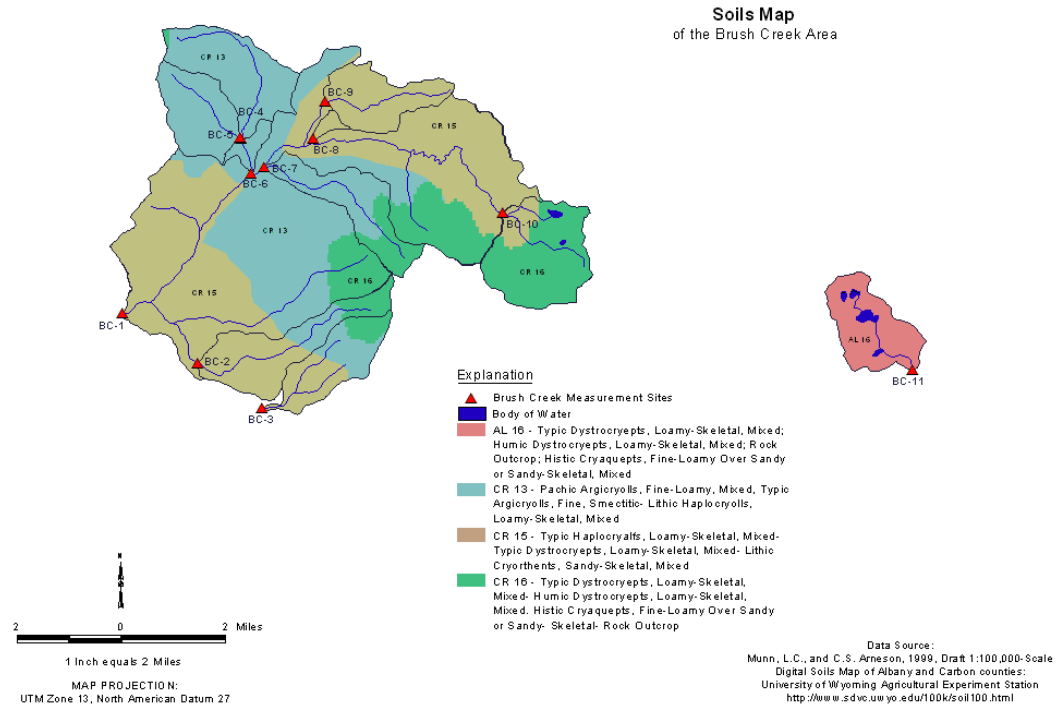


**A-2 Digital elevation model map of drainage basins in Brush Creek area.**

**Surficial Geologic Map  
of the Brush Creek Area**

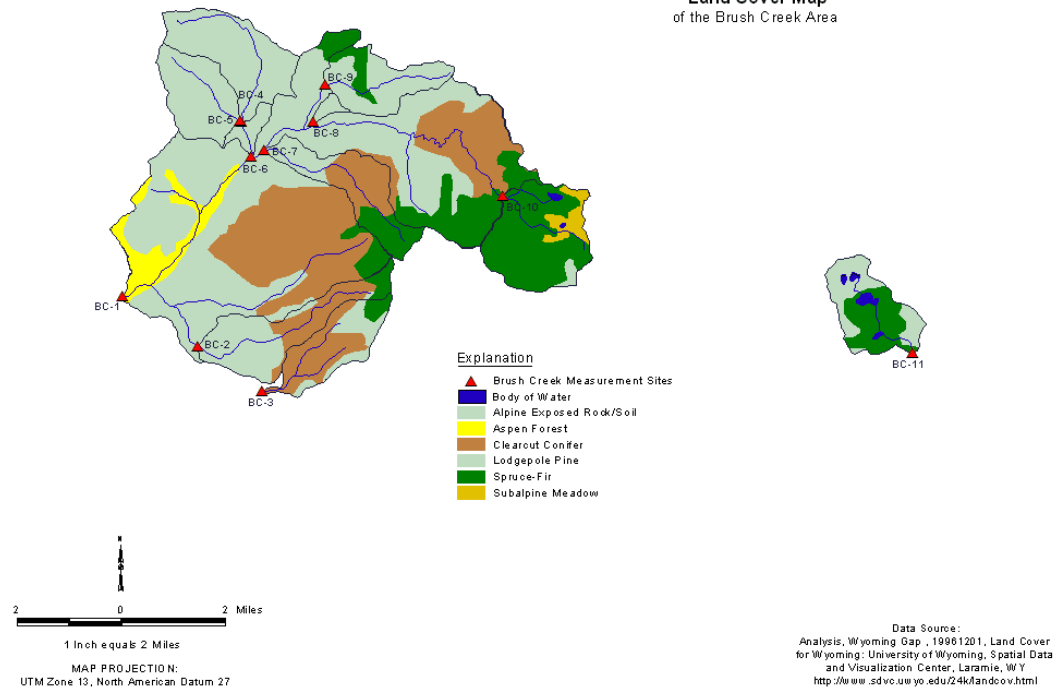


**A-3 Surface geology map of drainage basins in  
Brush Creek area.**

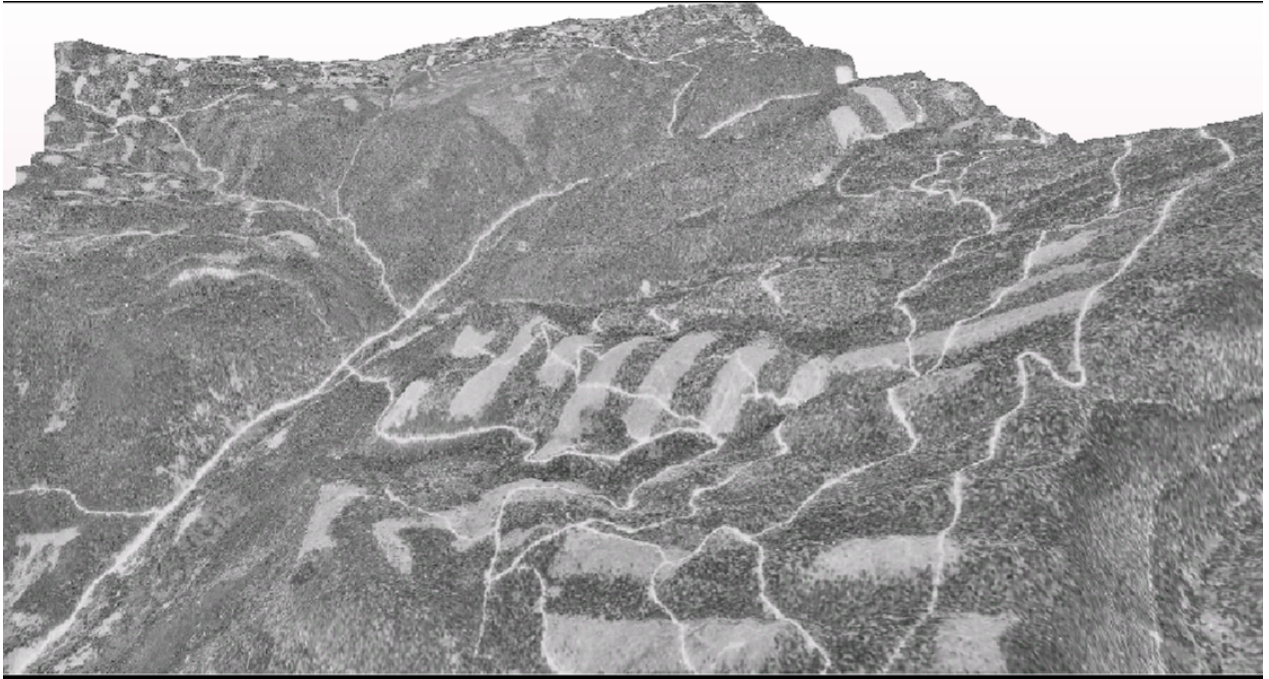


**A-4 Soils map of drainage basins in Brush Creek area.**

**Land Cover Map  
of the Brush Creek Area**

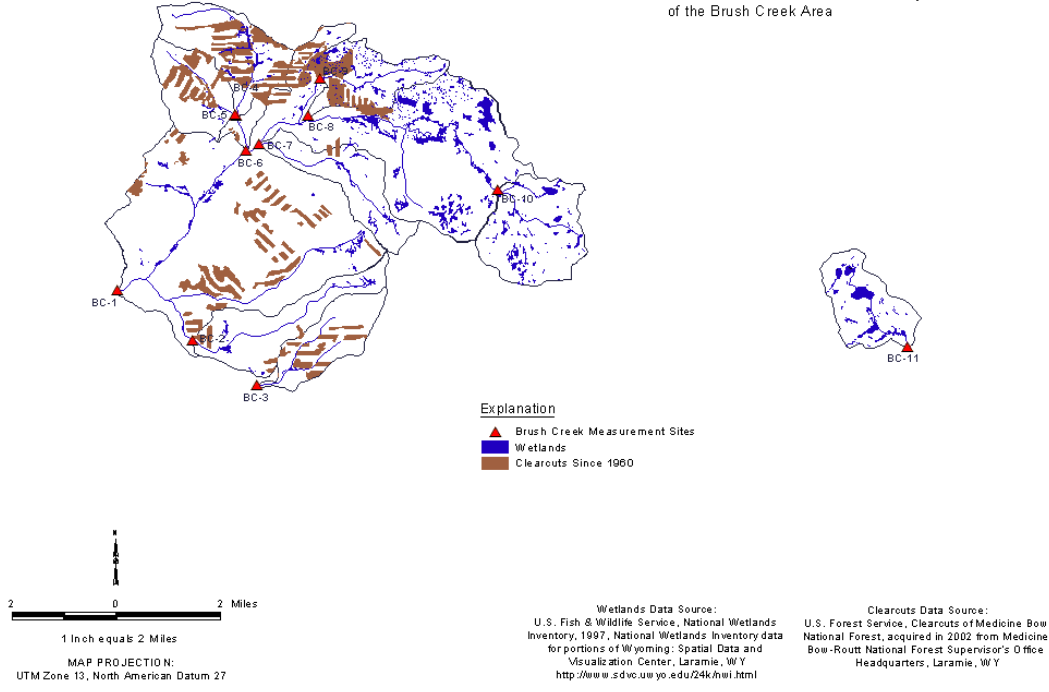


**A-5 Land cover map of drainage basins in Brush Creek area.**

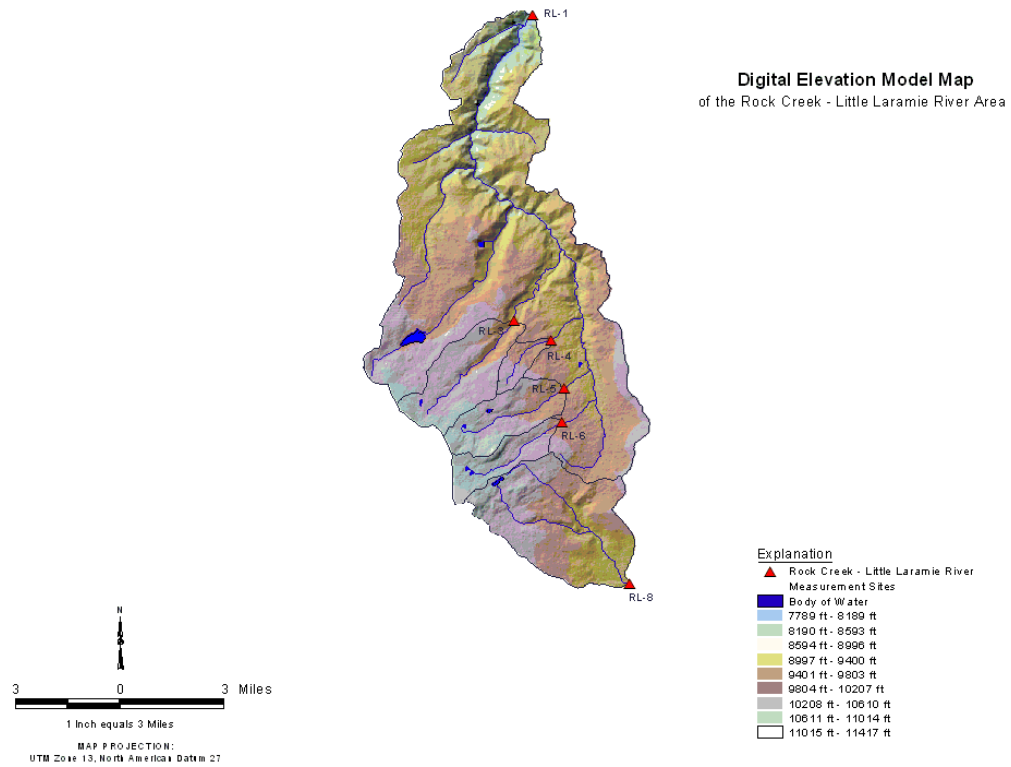


**A-6** *Aerial photograph of clearcuts in Brush Creek area.*

**Wetlands and Clearcuts Since 1960 Map  
of the Brush Creek Area**

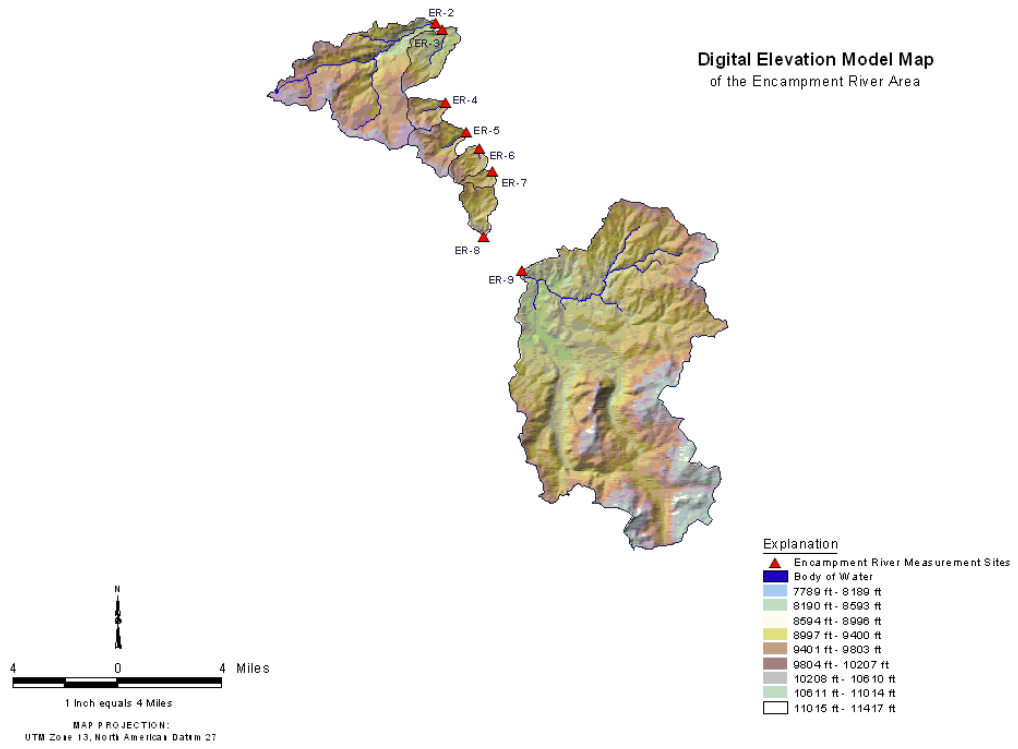


**A-7 Clearcuts, group selection, and wetlands in drainage basins.**

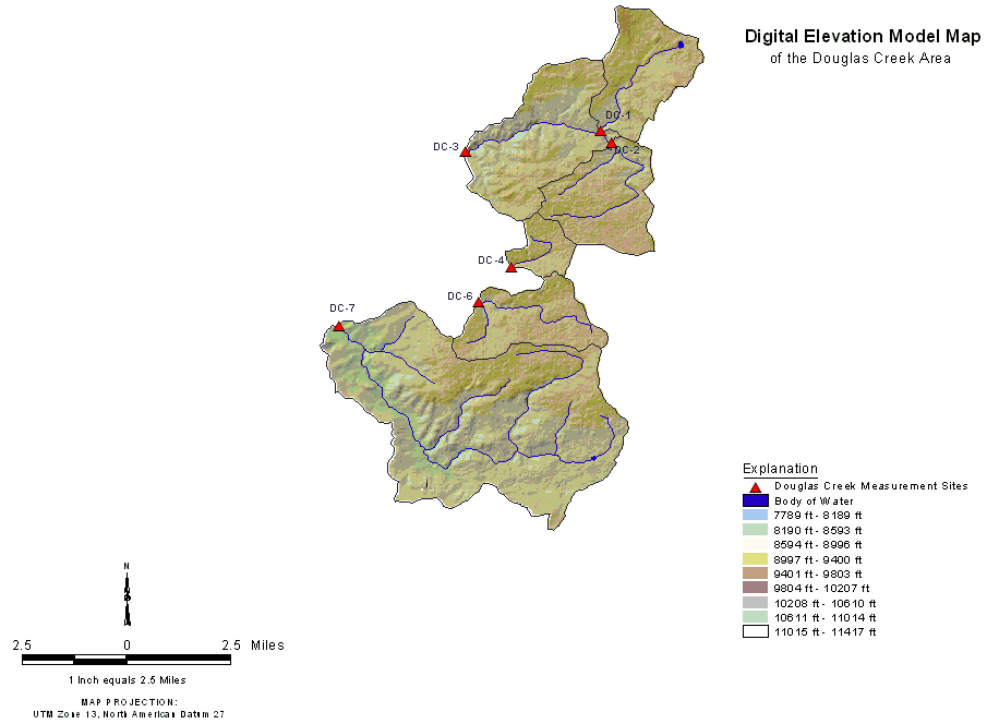


**A-8 Digital elevation model map of drainage basins in Rock Creek— Little Laramie River area.**





**A-9 Digital elevation model map of drainage basins in Encampment River area.**



***A-10 Digital elevation model map of drainage basins in Douglas Creek area.***

***Appendix B – Tables***

**Table B-1 Summary of streamflow sites and basin characteristics.**

<b>Site</b>	<b>Site Name</b>	<b>Latitude (degrees, minutes, seconds)</b>	<b>Longitude (degrees, minutes, seconds)</b>	<b>Area (mi<sup>2</sup>)</b>	<b>RngEI (ft)</b>
BC-1	North Brush Creek Gage, 06622700	41 22 09	106 31 22	37.8	2822
BC-2	Lincoln Creek	41 21 20	106 29 41	2.71	2172
BC-3	Mill Creek	41 20 37	106 28 15	2.01	1696
BC-4	Fish Creek, Upper Site	41 25 04	106 28 49	2.77	1470
BC-5	Unnamed Tributary to Fish Creek	42 25 05	106 28 51	1.97	1181
BC-6	Fish Creek, Lower Site	41 24 29	106 28 35	5.13	1667
BC-7	Cassidy Creek	41 24 35	106 28 19	2.24	1880
BC-8	Unnamed Tributary	41 25 05	106 27 14	0.17	453
BC-9	Harden Creek	41 25 42	106 26 58	1.96	407
BC-10	North Brush Creek, Upper Site	41 23 54	106 23 03	3.31	1171
BC-11	Nash Fork Creek, Above Brooklyn Lake Lodge	41 21 25	106 13 57	2.16	1289
RL-1	Rock Creek Gage, 06632400	41 35 09	106 13 17	62.9	3448
RL-3	North Fork Rock Creek	41 27 33	106 13 45	5.56	1240
RL-4	Middle Fork Rock Creek	41 27 05	106 12 30	1.19	814
RL-5	Park Trail Creek	41 25 53	106 12 03	4.26	1358
RL-6	South Fork Rock Creek	41 25 03	106 12 07	2.86	1217
RL-8	North Fork Little Laramie River	41 21 03	106 09 47	11.65	2139
DC-1	Lake Creek at Lincoln Creek	41 07 29	106 10 22	5.03	988
DC-2	Lincoln Creek at Lake Creek	41 07 14	106 10 03	5.24	453
DC-3	Lake Creek at Douglas Creek	41 07 00	106 14 02	18.04	1220
DC-4	Illinois Creek	41 04 36	106 12 45	1.55	446
DC-6	Park Run Creek	41 03 55	106 13 38	4.42	591
DC-7	Pelton Creek	41 03 23	106 17 27	23.06	948
ER-2	North Fork Encampment River	41 09 35	106 53 25	16.24	2375
ER-3	Willow Creek	41 09 23	106 53 06	3.08	1991
ER-4	Miner Creek	41 06 56	106 52 53	1.45	1276
ER-5	South Fork Miner Creek	41 05 59	106 51 57	2.71	1453
ER-6	North Soldier Creek	41 05 27	106 51 21	1.25	1175
ER-7	South Soldier Creek	41 04 41	106 50 50	0.59	912
ER-8	Unnamed Creek	41 02 31	106 51 07	1.76	1588
ER-9	Hog Park Creek Gage, 06623800	41 01 50	106 49 29	72.4	3140

**Table B-2 Summary of streamflow measurements.**

[Brush Creek (BC) sites were measured during 2000-2001. Rock Creek - Little Laramie River (RL), Douglas Creek (DC), and Encampment River (ER) sites were measured during 2001-2002]

<b>Site</b>	<b>October (ft<sup>3</sup>/s)</b>	<b>November (ft<sup>3</sup>/s)</b>	<b>December (ft<sup>3</sup>/s)</b>	<b>January (ft<sup>3</sup>/s)</b>	<b>February (ft<sup>3</sup>/s)</b>	<b>March (ft<sup>3</sup>/s)</b>
BC-1	10.10	12.50	9.08	9.00	8.00	7.78
BC-2	0.40	0.47	0.49	0.44	0.48	0.46
BC-3	0.14	0.19	0.20	0.19	0.18	0.18
BC-4	0.39	0.71	0.64	0.55	0.62	0.56
BC-5	0.41	0.39	0.56	0.27	0.37	0.38
BC-6	0.78	1.03	-	0.96	0.67	0.90
BC-7	1.08	0.88	0.82	0.81	0.80	0.76
BC-8	0.00	0.00	0.00	0.00	0.00	0.00
BC-9	0.22	0.20	0.31	0.38	0.46	0.34
BC-10	0.35	-	-	-	-	-
BC-11	-	0.58	-	0.42	0.38	0.52
RL-1	-	-	-	-	-	-
RL-3	0.67	0.65	0.39	0.13	0.35	0.32
RL-4	0.07	0.10	0.07	0.07	0.07	0.06
RL-5	0.75	0.76	0.39	0.32	0.24	0.24
RL-6	0.20	0.26	0.09	0.04	0.08	0.08
RL-8	2.63	2.36	1.82	1.53	1.49	1.60
DC-1	0.68	0.34	0.28	0.29	0.42	0.34
DC-2	0.22	0.27	0.19	0.24	0.25	0.32
DC-3	0.85	1.19	1.49	0.71	1.15	1.80
DC-4	0.03	0.03	0.04	0.04	0.03	0.03
DC-6	-	0.08	0.06	0.07	0.07	0.12
DC-7	0.87	0.97	0.77	1.09	0.85	0.83
ER-2	-	1.96	1.69	2.11	1.48	1.42
ER-3	-	0.57	0.37	0.72	0.50	0.31
ER-4	-	0.26	0.24	0.23	0.20	0.21
ER-5	-	0.45	0.47	0.35	0.36	0.29
ER-6	-	0.30	0.32	0.28	0.19	0.18
ER-7	-	0.12	0.12	0.10	0.08	0.08
ER-8	-	0.38	0.34	0.30	0.30	0.35
ER-9	-	17.60	-	15.20	-	-

**Table B-3. Summary of adjusted mean monthly flows.**

[Brush Creek (BC) sites were measured during 2000-2001. Rock Creek - Little Laramie River (RL), Douglas Creek (DC), and Encampment River (ER) sites were measured during 2001-2002]

<b>Site</b>	<b>October (ft<sup>3</sup>/s)</b>	<b>November (ft<sup>3</sup>/s)</b>	<b>December (ft<sup>3</sup>/s)</b>	<b>January (ft<sup>3</sup>/s)</b>	<b>February (ft<sup>3</sup>/s)</b>	<b>March (ft<sup>3</sup>/s)</b>
BC-1	14.00	11.50	10.00	9.27	9.24	10.50
BC-2	0.58	0.66	0.54	0.48	0.59	0.63
BC-3	0.20	0.27	0.22	0.21	0.22	0.24
BC-4	0.57	0.99	0.71	0.61	0.76	0.76
BC-5	0.60	0.55	0.62	0.30	0.45	0.51
BC-6	1.14	1.44	-	1.06	0.82	1.22
BC-7	1.58	1.23	0.91	0.89	0.98	1.03
BC-8	0.00	0.00	0.00	0.00	0.00	0.00
BC-9	0.32	0.28	0.34	0.42	0.56	0.47
BC-10	0.51	-	-	-	-	-
BC-11	-	0.81	-	0.46	0.46	0.71
RL-1	16.90	13.80	11.80	10.80	10.40	10.60
RL-3	1.13	0.81	0.46	0.16	0.53	0.50
RL-4	0.12	0.12	0.09	0.09	0.10	0.10
RL-5	1.27	0.95	0.46	0.40	0.36	0.37
RL-6	0.33	0.33	0.11	0.05	0.12	0.12
RL-8	4.44	2.95	2.15	1.90	2.28	2.50
DC-1	0.96	0.41	0.38	0.38	0.54	0.48
DC-2	0.32	0.32	0.26	0.31	0.33	0.45
DC-3	1.20	1.42	2.01	0.92	1.51	2.59
DC-4	0.03	0.04	0.05	0.06	0.04	0.05
DC-6	-	0.10	0.08	0.09	0.09	0.17
DC-7	1.23	1.15	1.03	1.42	1.11	1.20
ER-2	-	2.72	2.23	2.81	2.00	1.78
ER-3	-	0.79	0.49	0.96	0.67	0.38
ER-4	-	0.35	0.32	0.30	0.27	0.26
ER-5	-	0.63	0.62	0.46	0.49	0.36
ER-6	-	0.42	0.42	0.37	0.25	0.23
ER-7	-	0.16	0.15	0.14	0.11	0.10
ER-8	-	0.53	0.44	0.40	0.40	0.43
ER-9	-	25.10	22.50	20.00	18.90	20.00

# Testing of Hydrologic Models for Estimating Low Flows in Mountainous Areas of Wyoming

Volume 2:  
Supplemental Information



Wyoming Water Development  
Commission  
in cooperation with the  
U.S. Geological Survey and  
University of Wyoming

# **Testing of Hydrologic Models for Estimating Low Flows in Mountainous Areas of Wyoming**

## **Volume 2: Supplemental Information**

**May 24, 2003**

**Wyoming Water Development Commission**  
**in cooperation with**  
**U.S. Geological Survey and**  
**University of Wyoming**

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## **Appendix A. Summary of Meetings and Project Reviews**

Bruce Brinkman and Hugh Lowham (principal investigators) met on May 30, 2000, and reviewed the available streamflow data and the project approach.

Bruce Brinkman, Hugh Lowham, Larry Pochop (Director, Water Research Program, University of Wyoming), and Justin Montgomery (undergraduate student, University of Wyoming) met at the WWDC Office on July 31, 2000, and discussed the project approach and possible study areas. Justin presented Arc View maps of the Brush Creek area in the Medicine Bow Mountains. Excellent digital coverage of vegetation, geology, and other basin features is available for this area. Based on the available digital coverage and potential low travel costs, the Medicine Bow Mountains appear to be the best choice for the project study.

On November 14, 2000, following a field trip to the Medicine Bow Mountains, Bruce Brinkman and Hugh Lowham met with Larry Polchop and Dennis Feeney in Laramie and discussed the project.

On November 27, 2000, Bruce Brinkman and Hugh Lowham met in Cheyenne to develop the progress report.

On November 28, 2000, Bruce Brinkman, Hugh Lowham, and Larry Pochop presented progress to the Priority and Selection Committee.

A telephone conference was held on February 23, 2001, between Bruce Brinkman, Hugh Lowham, Larry Pochop, and Larry Ostrech to discuss a replacement for Justin Montgomery, who had accepted work on another project.

Bruce Brinkman and Hugh Lowham met with Larry Ostresh, Larry Pochop, and student James Riley in Laramie on April 19 to discuss the project and to plan for the next field trip.

Ken Lindskov was contracted by Hugh Lowham to meet with staff from the EROS Data Center. Mr. Lindskov, a hydrologist and retired USGS employee, lives in Rapid City, South Dakota, and was able to make a one-day trip to the Center. He met with the Chief of the Center, and the Chief of the Scientific Application Branch, and discussed the availability of digital-map files that would depict ground-water storage. Remote-sensing data such as thermal or radar imagery collected during September or October might depict significant ground-water reservoirs that contribute to low flows. A summary report (April 30, 2001) by Mr. Lindskov showed that no such existing data were available for the project area.

John Newton was contracted to compute watershed characteristics for project basins in the Medicine Bow area using 1:24,000 digital elevation models at 30-meter pixel resolution. Mr. Newton is a hydrologist and former USFS employee, familiar with GIS data for the Medicine Bow Mountains. He computed basin area, relief, drainage density, source density, and a shape factor for the sites, and applied regression techniques to relate the measured low flows to the basin characteristics. A summary report (May 18, 2001) showed drainage area to be

highly correlated with the low flows; however, none of the other basin characteristics were found to be significant.

On September 17, 2001, Hugh Lowham and Bruce Brinkman met to discuss preparation of the progress report and to plan the October field visit.

On October 17, 2001, Hugh Lowham met with Larry Ostresh and James Riley to discuss progress on preparation of maps and compilation of basin data. Hugh Lowham also met with Mike Winters of the USFS, Laramie Ranger District, to determine what procedures were necessary in order to install weirs for measuring discharge in stream channels within the National Forest. It was determined that a letter request, complete with map and sketch plan, would be sufficient application for such installations, and that the fee would be waived for such scientific research.

On November 28, 2001, Bruce Brinkman presented progress to the Priority and Selection Committee. The Committee had two comments: 1) Question on how data collection in the project relates to a statewide effort, and 2) suggestion to pay close attention to error estimates associated with current meter measurements. These comments were addressed by Hugh Lowham on December 31, 2001.

A progress meeting was conducted on December 14, 2001, in Laramie. A discussion was held on the effects of clear cutting on winter flows.

A progress meeting was conducted on February 11, 2002, in Laramie. Discussion was held on developing the data set and applying multiple regression techniques to obtain an improved set of estimating relations. It is planned that James Riley will participate in the March streamflow measurement trip.

Hugh Lowham met with Jimmy Riles on March 12, 2002, to discuss channel-geometry measurements and multiple regression techniques that will be used in the study project.

On April 12, 2002, a progress meeting was held in Laramie. An annotated outline was developed for the progress report. Task assignments were made for completing the project study. A progress report will be assembled by June 5, 2002, for submittal to the USGS-WWDC supported Water Research Program. The summary report for the project study has target dates of October 1 (draft) and December 1, 2002 (final).

A progress meeting was conducted on July 17, 2002, in Laramie, following two days of field investigations to measure channel geometry. The data set was discussed, and it was decided to use all data sites for the areas, including the gage sites. Three reports prepared by Dr Ostresh were reviewed. It was decided that page-size maps would be used for the final report.

On August 30, 2002, a progress meeting was held in Laramie. Funding, progress on the study, and the final report were discussed. Dr. Ostresh and James Riley will both make technical presentations during October. An annotated outline has been developed for the final report.

A progress meeting was held on December 10, 2002, in Laramie. Inconsistencies were found by James on several measurements on North Brush Creek; these were later determined to be the result of the meter readings being in Metric, rather than English units. Regressions are being run using snowpack measurements. Discussion was held on what data to use for adjusting the discharge data for the Douglas Creek sites. It was decided to use an average of the North Brush, Rock Creek, and Encampment River gage data.

On January 23, 2003, Hugh Lowham met with Bruce Brinkman and discussed the project. It was decided to include the supplemental reports being prepared by Dr. Ostresh and James Riley into an Appendix. Bruce noted that additional funding for the project may be available for data analysis and research, but not for travel, etc., for conferences.

A progress meeting was held on March 13, 2003, in Laramie, between Dr. Ostresh, James Riley, and Hugh Lowham. Excellent results are being made with the regressions and data summaries. The regressions show drainage area and range in basin elevation to be significant independent variables in most of the equations. Additional regressions will be conducted holding drainage area and range in basin elevation as the 1<sup>st</sup> and 2<sup>nd</sup> variables, and determine which variable occurs as the 3<sup>rd</sup> most significant. A review will be made of the residuals to help with the determination of the 3<sup>rd</sup> variable. It was decided that the report would be in English units, with a table of English/metric conversions.

## Appendix B. Summary of Field Data Collection

Bruce Brinkman, Hugh Lowham, and Justin Montgomery made a field visit to the Medicine Bow Mountains on August 14, 2000, and met with Water Hydrographer-Commissioner Jack Gibson at the North Brush Creek gaging station. Streamflow-gaging station 06622700, North Brush Creek near Saratoga, has a drainage area of 37.4 square miles, and 41-year period of record (May 1960 to current year). Eight ungaged sites were selected in the North Brush drainage basin (see figures 1 and 2, and table 1). An additional site was selected on Mill Creek, which is a tributary of South Brush Creek. The selected sites are accessible by snowmobile during winter months.

Bruce Brinkman and Hugh Lowham made a field visit by vehicle to the North Brush Creek area on October 23, 2000, and collected discharge measurements at each of the nine sites. A preliminary summary of the October data is shown in table 2 and figure 2. Following a review of the data, it was determined that additional basins, with a greater diversity of basin characteristics, could help with the analysis. The nine existing sites have relatively similar basin characteristics and water yields.

Bruce Brinkman and Hugh Lowham made a field visit by snow machines on November 13 and 14, 2000. Discharge measurements were made at eight of the sites in the North Brush Creek area. Site 4 was not measured due to shortage of time and poor access conditions. A review of the US Forest Service and Colorado State University research site on air quality was made on November 14, with Allen Elsworth and other staff. Although some streamflow data are being collected as part of the research study, none was applicable to this study. Sites on Nash Fork were investigated for possible addition to the streamflow sites. A measurement was made at the discontinued University of Wyoming streamflow site, Nash Fork Creek above Brooklyn Lodge (site BC-11).

Bruce Brinkman and Hugh Lowham made a field visit by snow machines on December 14, 2000. All sites except for BC-10 and BC-11 were measured. New powder snow about 3 feet deep made access to the sites difficult. Very little ice was encountered beneath the deep snowpack. Anchor ice was attached to the culverts, and it was cleared before the bucket measurements were made.

Bruce Brinkman and Hugh Lowham made a field visit by snow machines on January 16, 2001. All sites except for S-10 were measured. The North Brush Creek drainage had about two feet of new powder snow. It was noted in the gage house that USGS/WSE personnel had measured the streamflow at site BC-1 on December 15, the day after Brinkman and Lowham measured.

Bruce Brinkman and Hugh Lowham made a field visit by snow machines on February 20, 2001. All sites except for BC-10 were measured. The weather was partly cloudy and warm. The snow was very sugary, not set up.

An attempt was made to make a field visit on March 14, 2001; however, the trip was cancelled due to heavy snow conditions. A field visit was made on March 16,

and all sites were measured except for BC-10. Very little ice has formed at the measuring sites since the last visit. The weather was partly cloudy with light snow in the afternoon.

On April 20, Bruce, Hugh, Larry Ostrech, and James made a field visit by snow machines. The group met with USGS hydrologist Wilford Sadler, and made concurrent measurements at the Brush Creek gage site. Concurrent discharge measurements were conducted in order to test the accuracy of the pygmy versus electromagnetic meters.

On August 1, 2001, Bruce Brinkman, Hugh Lowham, Larry Ostresh, and James Riley made a site visit to the Rock Creek area and selected potential new sites to be added to the project data-collection effort.

A site visit was made on October 15, 2001, to the Rock Creek sites by Bruce Brinkman and Hugh Lowham. Heavy snow had occurred the previous day, with about 18-inches of accumulation. On October 16, sites near Foxpark on Lake Creek, Lincoln Creek, and Pelton Creek were selected for addition to the study, and discharge was measured at each site. The sites near Foxpark have basins with significant sage brush cover, and thus offer a variety of land cover.

On October 18, 2001, Hugh Lowham conducted a site visit on Illinois Creek and Park Run near Foxpark, and selected three sites for addition to the project. These sites will require a weir for discharge measurement. Weirs will be installed following approval by the USFS.

The November measurements were made during November 12-14, 2001. Very little snow was present, and snow machines were not necessary. Streams in the Foxpark area were measured on November 12, streams in the Medicine Bow area were measured on November 13, and streams in Sierra Madre on Encampment River tributaries were measured on November 14. Measurements were made by Hugh Lowham, with assistance from Mike Lowham. On November 14, Mike Lowham assisted Wil Sadler of the USGS to measure the site at streamflow gaging station 06623800 Encampment River above Hog Park Creek, near Encampment. Two weirs were constructed by for assistance in measuring the small flows on Illinois Creek. However, the installation cut across the channel was rocky, and difficulty was experienced in achieving a suitable seal. Bentonite chips could be added to help provide a seal at future installations.

Hugh Lowham and Mike Lowham made the December measurements during December 17-20, and Dec 24, 2001. Streams in the Medicine Bow area were measured on December 18. The weather was cold and windy. Bare spots were encountered on the road, making snowmobiling difficult. GPS locations were checked on all sites. The Sierra Madre sites were measured on December 19. There was light snow on the north side of the project area, but moderate snow cover on the south end. Streams in the Foxpark area were measured on December 24.

The January 2002 measurements were made during January 15-20. Mike Lowham assisted Wil Sadler in measuring the Rock Creek and North Brush Creek sites on January 15. Bruce Brinkman and Hugh Lowham measured the

Sierra Madre project sites on January 16, while Mike Lowham assisted Wil Sadler in streamgaging for Encampment River. The Rock Creek sites were measured by Hugh Lowham and Mike Lowham on January 17. Very cold and windy conditions were encountered at the Foxpark sites, which were measured by Hugh Lowham and Mike Lowham on January 19 and 20. Heavy ice was encountered on sites DC-1 to DC-3. It is likely that freezeup is occurring resulting in erratic flows.

Hugh Lowham and Mike Lowham made the February 2002 measurements during February 12-14. Photographs were obtained for each site, and GPS locations were checked and found to be the same as previously noted. Only light snow had occurred since last month. The snowpack was greatly below normal. The Sierra Madre sites were measured on February 12, and the snowpack increased from north to south. The Rock Creek sites were measured on February 13, and significant reaches of bare road were encountered, making snowmobiling difficult. Foxpark sites were measured on February 14, with heavy ice conditions encountered at DC-1 and DC-2, due to light snow and cold temperatures.

Heavy snow occurred just prior to the March 2002 measurements. Hugh Lowham and Mike Lowham made the measurements during March 13-15. The Sierra Madre sites were measured on March 13, with very heavy snow accumulation since the last visit. The Foxpark sites were measured on March 14, with heavy new snow. The Rock Creek sites were measured on March 15, with heavy new snow, and 5 to 6 feet of snow depth at most of the measurement sites.

On July 15 and 16, 2002, all of the project members visited the measurement sites. Photographs, measurements of channel width, and GPS locations were obtained at each of the sites.



## Appendix C. Supplemental Reports

*Analysis of the Relationship of Winter Discharge to Independent Variables* by Lawrence M. Ostresh, Jr., PhD

[PDF version](#)

[DOC version](#)

April SWE Contour Map by Lawrence M. Ostresh, Jr., PhD

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