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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Laramie, WY 82070

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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:

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

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Abstract

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.

Introduction

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*.

Objectives

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.

Approach

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.

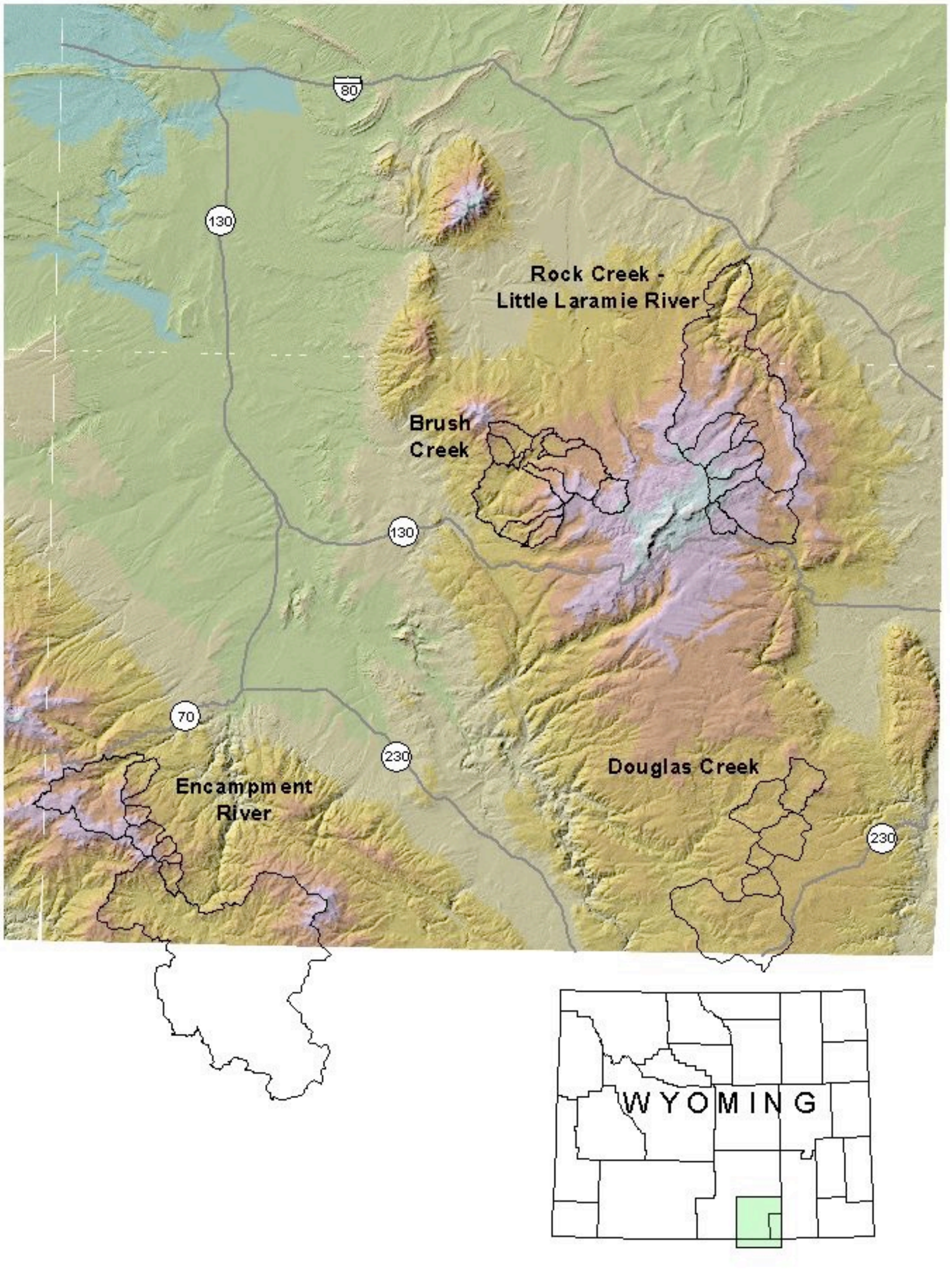

Figure 1. Location of the drainage basins selected for this study.

Previous Studies and Available Data

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

Streamflow Data Collection

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.

Basin and Channel Characteristics

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.

Development of Estimating Equations

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.

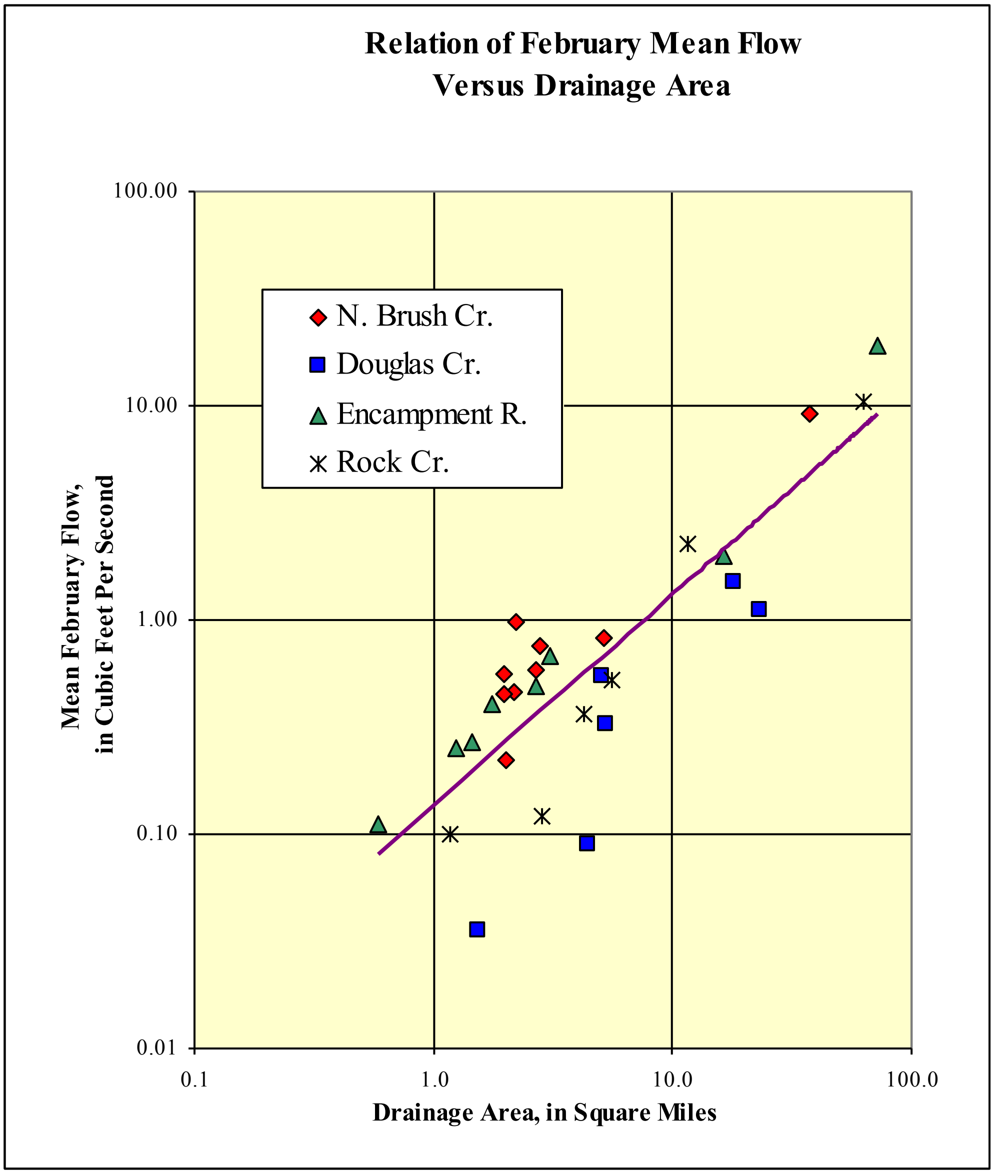

Figure 6. Graph showing relation of February mean flow to drainage area.

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 El)**, 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:

		Equation	**R^2**
Q_{Oct}	=	$0.000066 \text{ Area}^{0.80} \text{ RngEl}^{1.14}$	0.84
Q_{Nov}	=	$0.000023 \text{ Area}^{0.61} \text{ RngEl}^{1.32}$	0.87
Q_{Dec}	=	$0.000073 \text{ Area}^{0.67} \text{ RngEl}^{1.11}$	0.80
Q_{Jan}	=	$0.000099 \text{ Area}^{0.68} \text{ RngEl}^{1.06}$	0.73
Q_{Feb}	=	$0.000149 \text{ Area}^{0.71} \text{ RngEl}^{1.00}$	0.80
Q_{Mar}	=	$0.000522 \text{ Area}^{0.79} \text{ RngEl}^{0.82}$	0.81

where

Q_m = mean monthly flow, in cubic feet per second, with $_m$ designating the month;

Area = contributing drainage area, in square miles;

RngEl = range in elevation, in feet; and

R2 = 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.

Test of Estimating Methods

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	**a** Long-term mean discharge for water years 1961-2001 (ft^3/s)	**b** Mean daily discharge for measurement day (ft^3/s)	**a/b = c** Coefficient for determining adjusted mean monthly discharge (ft^3/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
Annual	**49.9**	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:

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

where

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

DA = contributing drainage area, in square miles.

A second set of estimating equations (Miselis, 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:

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

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

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:

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

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	**a** Long-term mean at gaged site BC-1 (station 06622700) for water years 1961-2001 (ft^3/s)	**b** Monthly flow/ annual runoff/ months a/49.9/12(100) (percent)	Mean monthly flow at selected site b × 3.35 × 12 (ft^3/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
Annual	**49.9**	**100**	**3.35**

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
Sum	**26**	**26**	**33**	**77**

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.

Using Estimating Equations

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:

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

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

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

Drainage Basin for Sourdough Creek

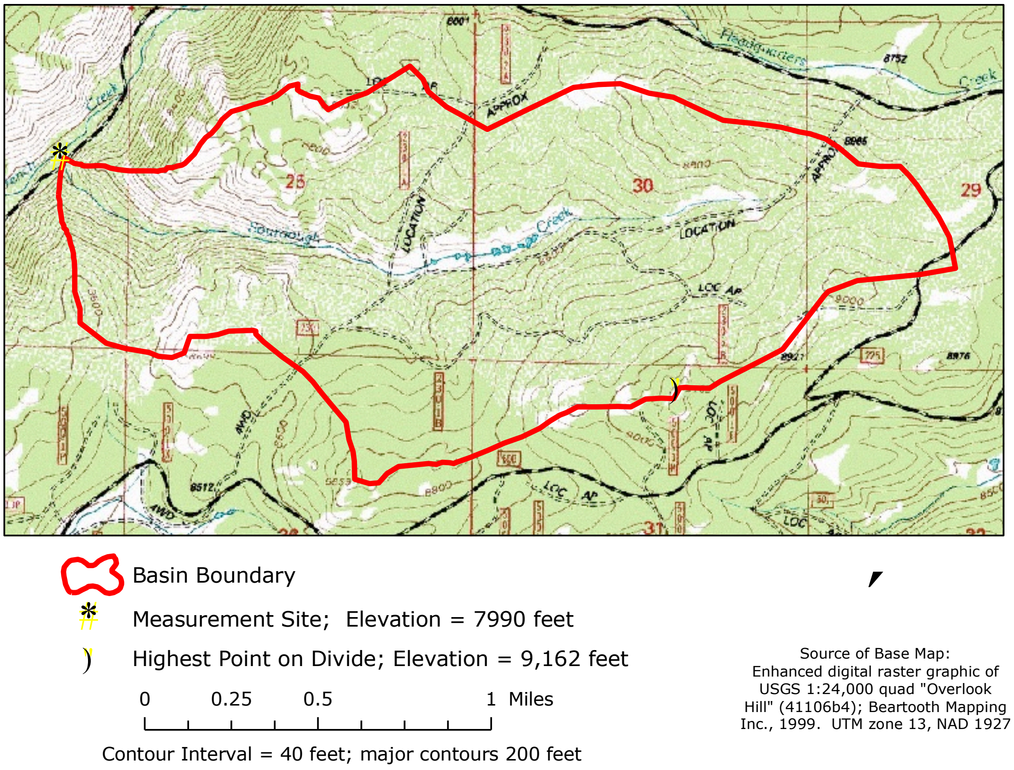

Figure 7. Map of drainage basin for Sourdough Creek.

Study Training

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*)

Summary

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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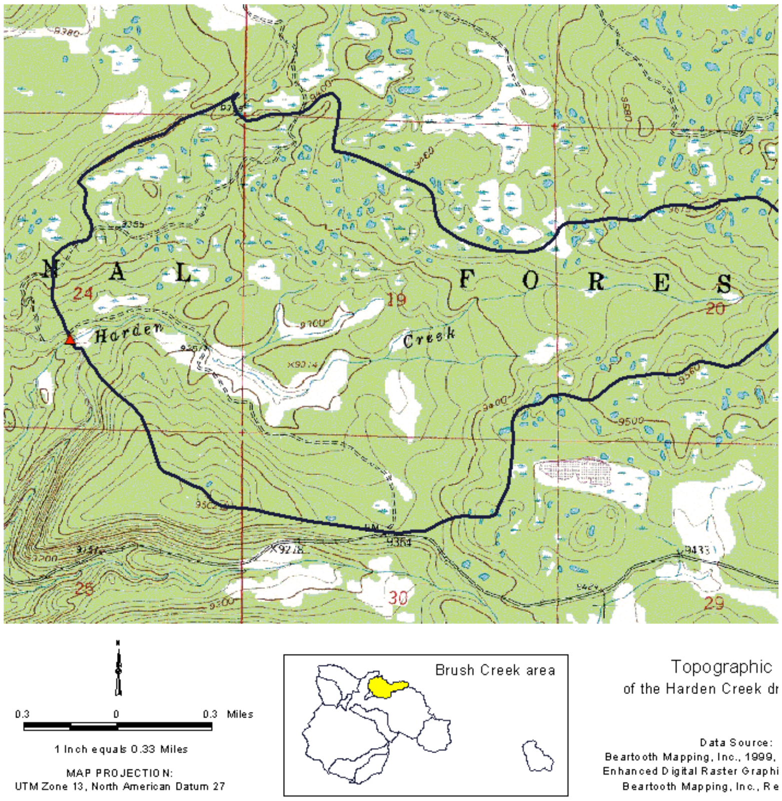
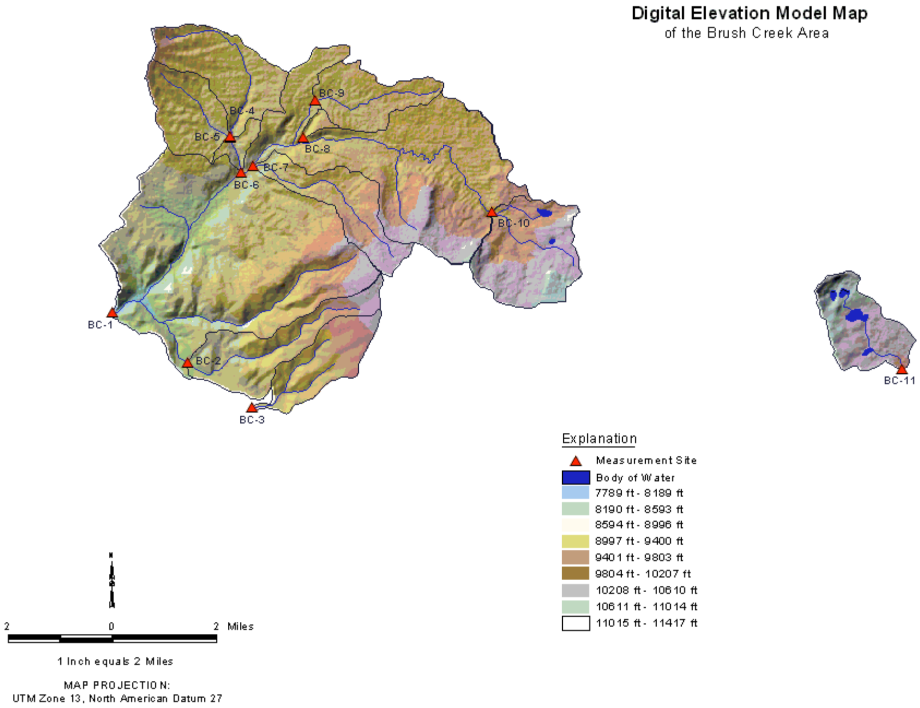
Riley, J.D., 2003, The use of geographic information systems to model winter low-flow stream discharge in mountainous areas of southeast Wyoming. Paper presentation. 99th Association of American Geographers Annual Meeting, New Orleans, LA.

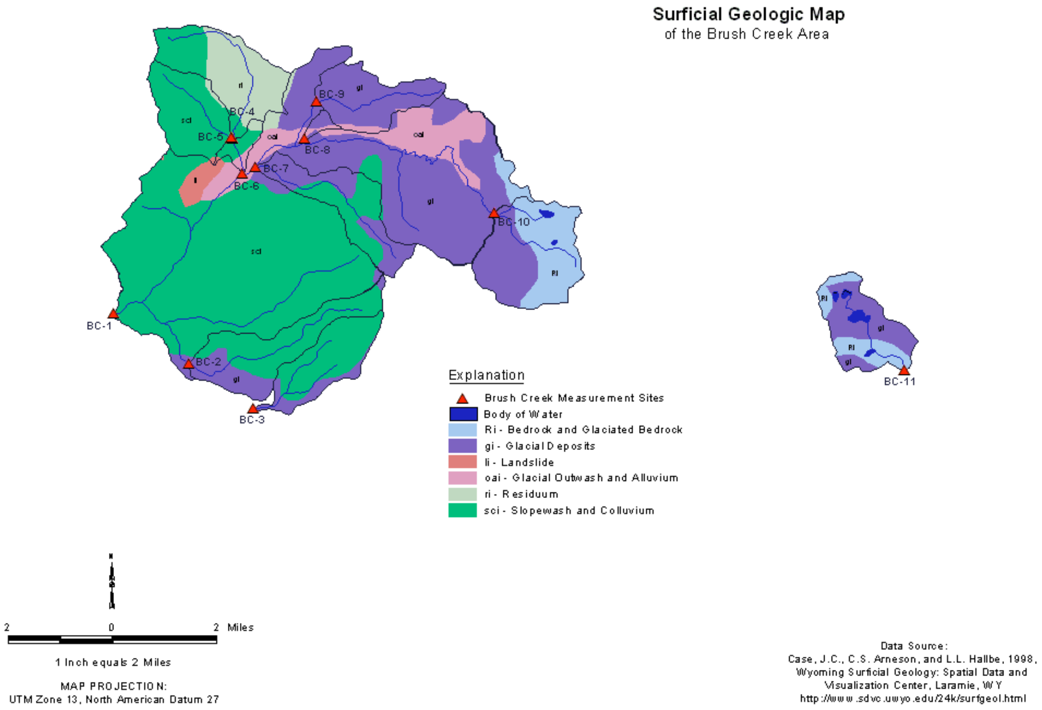
Appendix A – Drainage Basin Maps



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



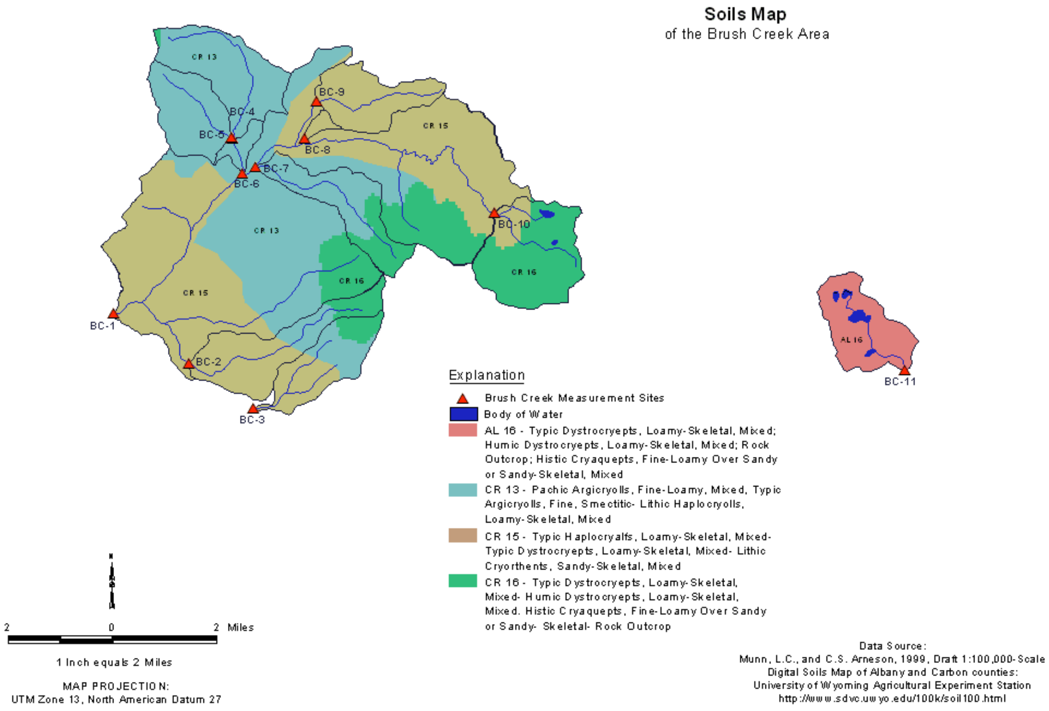
A-2 Digital elevation model map of drainage basins in Brush Creek area.


Surficial Geologic Map
of the Brush Creek Area

MAP PROJECTION:
UTM Zone 13, North American Datum 27

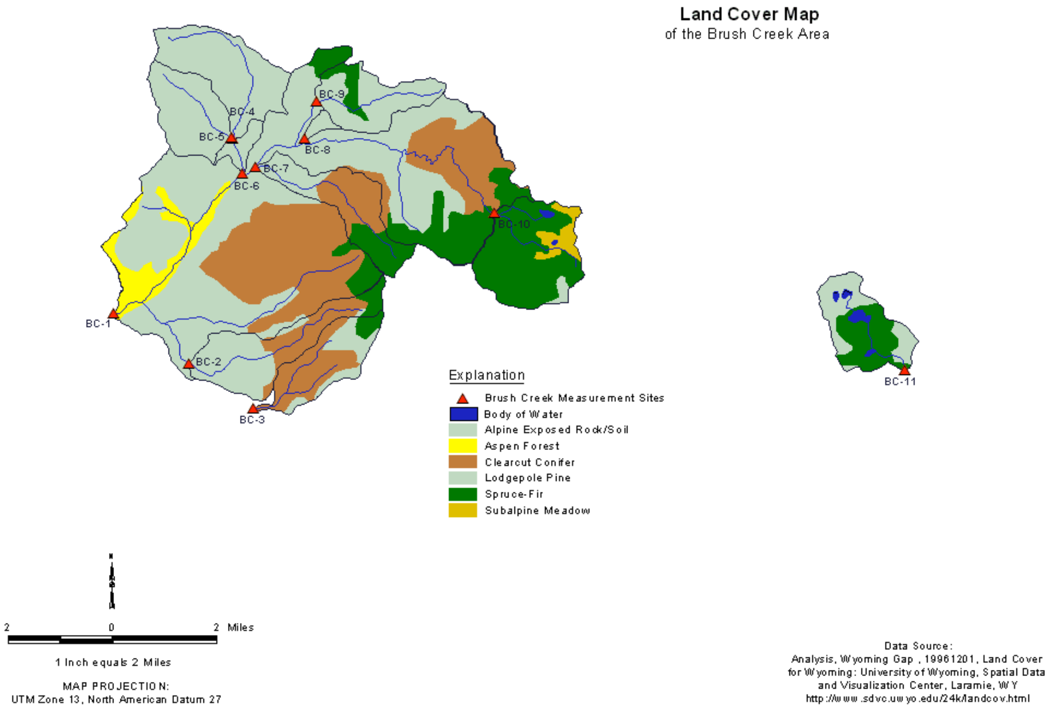
Data Source:
Case, J.C., C.S. Arneson, and L.L. Hallbe, 1998,
Wyoming Surficial Geology: Spatial Data and
Visualization Center, Laramie, WY
http://www.sdvc.uwyo.edu/24k/surfgeol.html

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



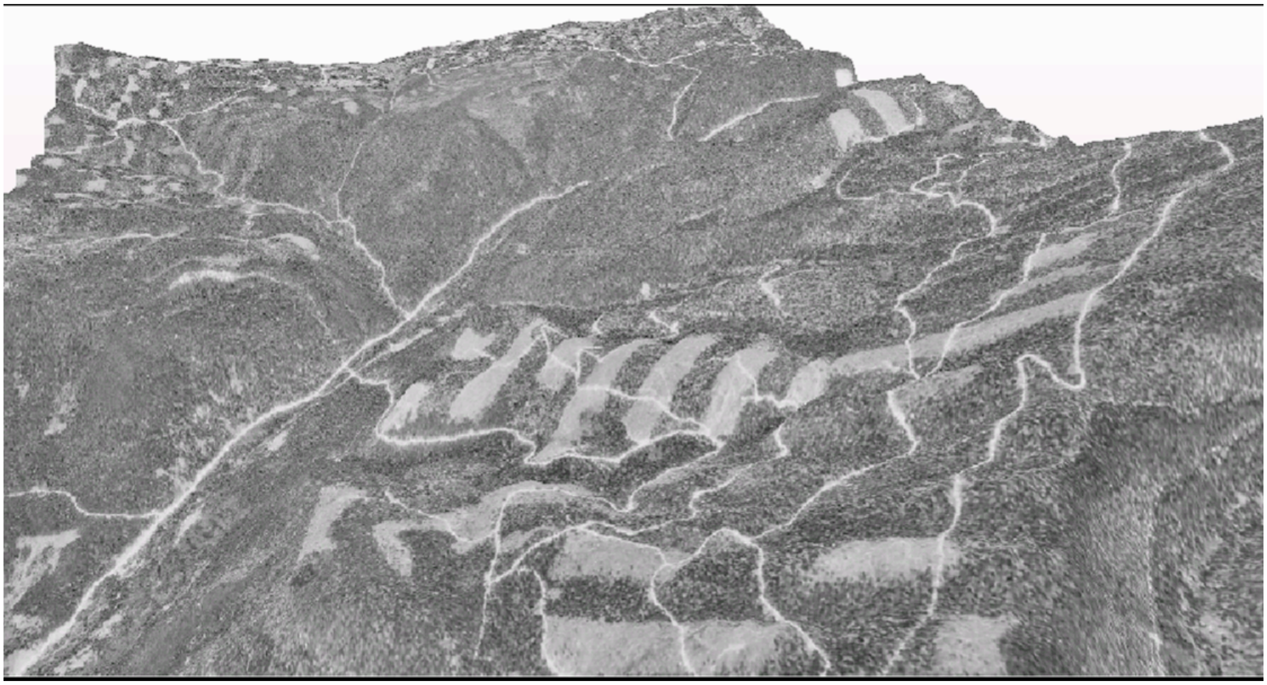
Data Source:
Munn, L.C., and C.S. Arneson, 1999, Draft 1:100,000-Scale
Digital Soils Map of Albany and Carbon counties:
University of Wyoming Agricultural Experiment Station
http://www.sdvc.uwyo.edu/100k/soil100.html

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

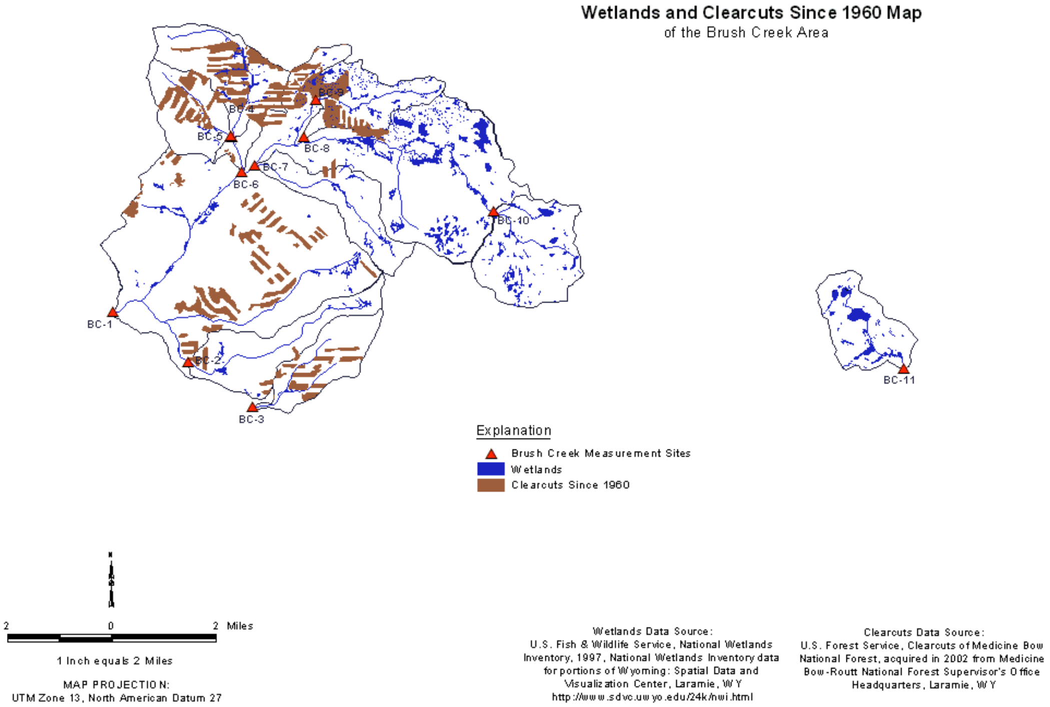


Data Source:
Analysis, Wyoming Gap , 19961201, Land Cover
for Wyoming: University of Wyoming, Spatial Data
and Visualization Center, Laramie, WY
http://www.sdvc.uwyo.edu/24k/landcov.html

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



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



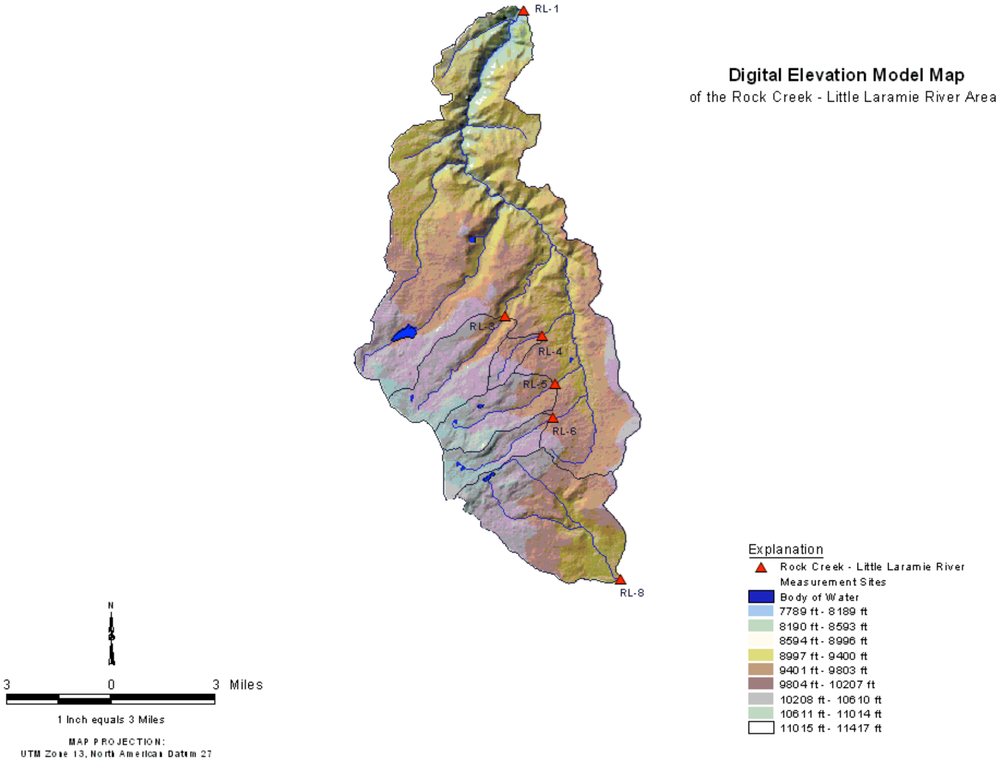
Wetlands and Clearcuts Since 1960 Map
of the Brush Creek Area

MAP PROJECTION:
UTM Zone 13, North American Datum 27

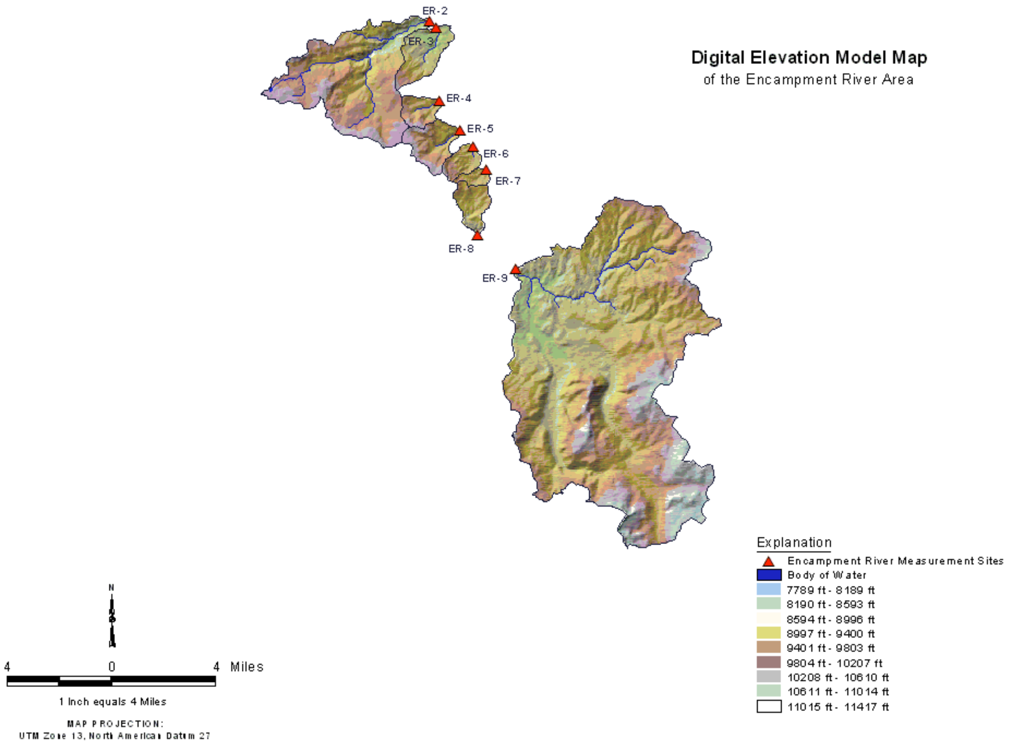
Wetlands Data Source:
U.S. Fish & Wildlife Service, National Wetlands Inventory, 1997, National Wetlands Inventory data for portions of Wyoming: Spatial Data and Visualization Center, Laramie, WY
http://www.sdvc.uwyo.edu/24k/nwi.html

Clearcuts Data Source:
U.S. Forest Service, Clearcuts of Medicine Bow National Forest, acquired in 2002 from Medicine Bow-Routt National Forest Supervisor's Office Headquarters, Laramie, WY

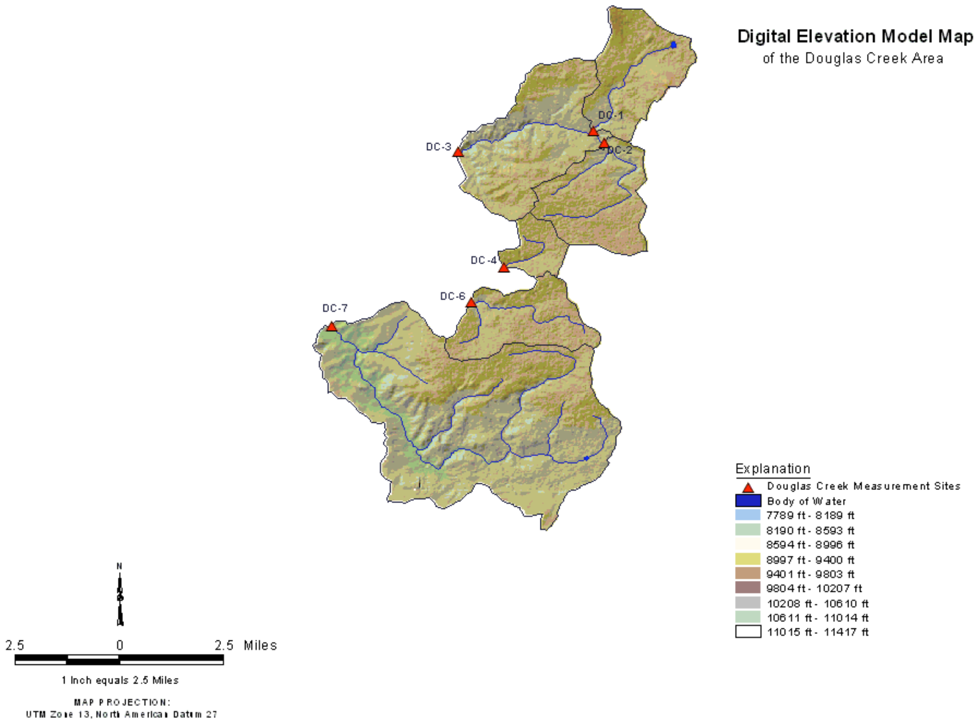
A-7 Clearcuts, group selection, and wetlands in drainage basins.



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.

Site	Site Name	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Area (mi^2)	RngEl (ft)
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]

Site	October (ft^3/s)	November (ft^3/s)	December (ft^3/s)	January (ft^3/s)	February (ft^3/s)	March (ft^3/s)
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]

Site	October (ft^3/s)	November (ft^3/s)	December (ft^3/s)	January (ft^3/s)	February (ft^3/s)	March (ft^3/s)
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

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Volume 2: Supplemental Information

May 24, 2003

Wyoming Water Development Commission
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University of Wyoming

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Volume 2 – Supplemental Information

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 1st and 2nd variables, and determine which variable occurs as the 3rd most significant. A review will be made of the residuals to help with the determination of the 3rd 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 1and 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 measurents at the Brush Creek gage site. Concurrent discharge measurements were conducted in order to test the accuracy of the pygmy versus electomagnetic 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

Prepared by

Lawrence M. Ostresh, Jr., PhD

Summary of Findings

1. **One independent variable.** Adjusted monthly discharge is positively related to basin area; the relationship is weakest in January and strongest in October and March. The same is true for measured monthly discharge. The regressions are stronger for adjusted flow than for measured flow.
2. **Two independent variables.** Adjusted monthly discharge is positively related to basin area. Good results were obtained with the following measures as the second independent variable:
    a. Basin elevation range.
    b. Trigonometric sine of average basin slope.
    c. March long-term precipitation gridded using Inverse Distance Weighting (IDW).
    d. A measure of long-term precipitation (ApAvPrec) calculated from the relationship of precipitation to elevation.

Measured monthly discharge is also positively related to basin area, coupled with any of the following as the second independent variable:

a. Basin elevation range.
b. Trigonometric sine of average basin slope.
c. Current-year April precipitation gridded using IDW.

The regressions are usually stronger for adjusted flow than for measured flow.

3. **Three independent variables.** Adjusted monthly discharge is positively related to basin area and ApAvPrec; it is negatively related to basin middle elevation. The same is true for measured monthly discharge. The regressions are stronger for adjusted flow than for measured flow.

4. Four independent variables. No quadruplet of independent variables is statistically significant for either adjusted or measured monthly discharge.

Methods

Multiple regression was used to analyze the relationship of adjusted monthly discharge and measured monthly discharge to a suite of twenty-six independent variables. The independent variables measured such basin characteristics as size, topography, precipitation, and land cover. All variables, dependent and independent, were transformed into logarithms (base 10) before the regressions were run.

All possible combinations of independent variables were regressed against each dependent variable. There were fourteen dependent variables (October through March, plus winter average, for both adjusted and measured discharge). Each was regressed against each of the twenty-six independent variables to find the single best independent predictor. Then each was regressed against all possible pairs of independent variables to find the best two predictors (there were 325 such pairs). This was repeated for the best three predictors (2,600 triplets) and for the best four predictors (14,950 quadruplets). Since none of the quadruplets was statistically significant, no further analysis was done.

Microsoft Excel© was used to perform the analysis; a Visual Basic for Applications program was embedded into the workbook to automate the task.

Data

Appendix C.1 contains a full listing of all the independent variables used, in original units and Log10; Appendix C.2 contains a short description of these variables. All of the analyses in this report were done with Log10 variables.

Basins used in this analysis:

Site	**Basin Name**
BC-1	North Brush Creek Gage, 06622700
BC-11	Nash Fork Creek, Above Brooklyn Lake Lodge
BC-2	Lincoln Creek
BC-3	Mill Creek
BC-4	Fish Creek, Upper Site
BC-5	Unnamed Tributary to Fish Creek
BC-6	Fish Creek, Lower Site
BC-7	Cassidy Creek
BC-9	Harden Creek
DC-1	Lake Creek at Lincoln Creek
DC-2	Lincoln Creek at Lake Creek
DC-3	Lake Creek at Douglas Creek
DC-4	Illinois Creek
DC-6	Park Run Creek
DC-7	Pelton Creek
ER-2	North Fork Encampment River
ER-3	Willow Creek
ER-4	Miner Creek
ER-5	South Fork Miner Creek
ER-6	North Soldier Creek
ER-7	South Soldier Creek
ER-8	Unnamed Creek
RL-1	Rock Creek Gage, 06632400
RL-3	North Fork Rock Creek
RL-4	Middle Fork Rock Creek
RL-5	Park Trail Creek
RL-6	South Fork Rock Creek
RL-8	North Fork Little Laramie River

Notes:

1. In the analysis for October, the Encampment River basins (ER-2 to ER-8), Nash Fork (BC-11), and Park Run (DC-6) were excluded due to lack of data.
2. In the analysis for December, Lower Fish Creek (BC-6) and Nash Fork (BC-11) were excluded due to lack of data.

Basins excluded from this analysis:

BC-8	Unnamed Tributary
ER-9	Hog Park Creek Gage, 06623800

One Independent Variable (Log10)

Adjusted Flow:
In October, basin perimeter had the highest correlation with adjusted flow (RSQ = .702); basin area was second highest. In November, basin elevation range was highest (RSQ = .634); basin area was second. In all other months, and for the winter average, basin area had the highest correlation with adjusted flow. Significance was better than .001 in all cases. Table 1 and Figures 1 and 2 summarize the relationship of adjusted flow to basin area.

Log10 Adjusted Flow, cfs	Log 10 Independent Variable	RSQ	Intercept	Slope
AdjOct	Area	0.691	-0.866	1.102
AdjNov	Area	0.618	-0.718	0.896
AdjDec	Area	0.628	-0.832	0.908
AdjJan	Area	0.586	-0.862	0.902
AdjFeb	Area	0.654	-0.840	0.922
AdjMar	Area	0.712	-0.841	0.968
AdjAvg	Area	0.672	-0.792	0.931

Table 1 – Regression statistics for relationship of adjusted flow to basin area.

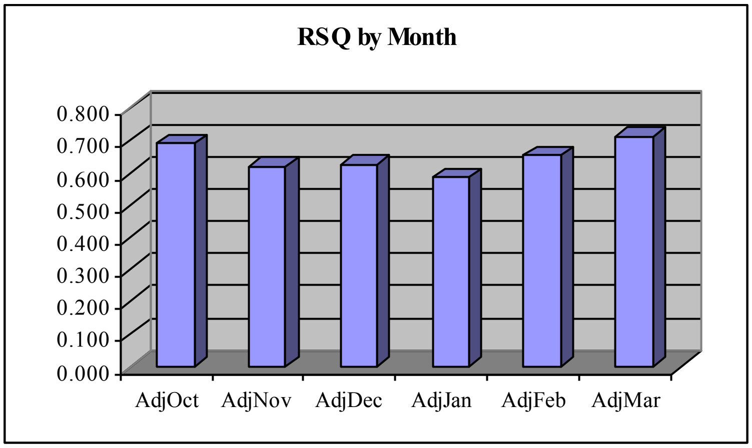


Figure 1 – Correlation coefficient for relationship of adjusted flow to basin area, by month.

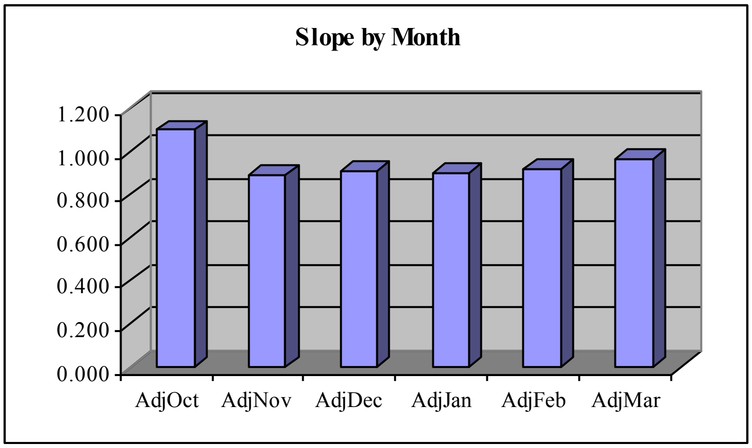


Figure 2 – Slope parameter for relationship of adjusted flow to basin area, by month.

Measured Flow:

In October, basin perimeter had the highest correlation with measured flow (RSQ = .631); basin area was second highest. In all other months, and for the winter average, basin area had the highest correlation with measured flow. Significance was better than .001 in all cases. Table 2 and Figures 3 and 4 summarize the relationship of measured flow to basin area.

Log10 Measured Flow, cfs	Log 10 Independent Variable	RSQ	Intercept	Slope
MeasOct	Area	0.619	-1.025	1.068
MeasNov	Area	0.572	-0.845	0.899
MeasDec	Area	0.506	-0.893	0.833
MeasJan	Area	0.471	-0.923	0.838
MeasFeb	Area	0.547	-0.944	0.876
MeasMar	Area	0.605	-0.957	0.914
MeasAvg	Area	0.577	-0.895	0.882

Table 2 – Regression statistics for relationship of measured flow to basin area.

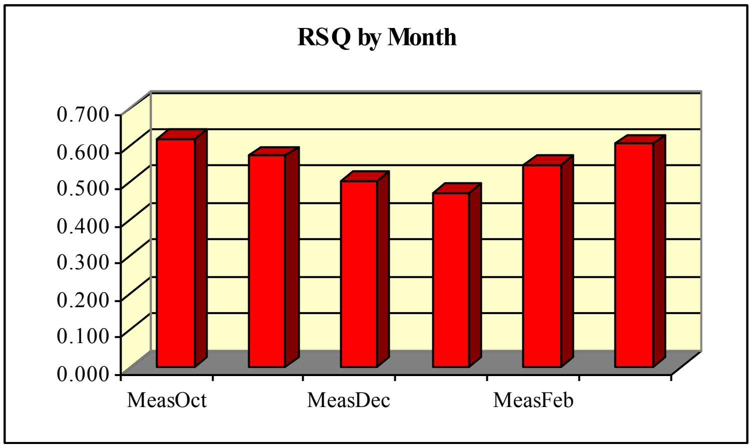


Figure 3 – Correlation coefficient for relationship of measured flow to basin area, by month.

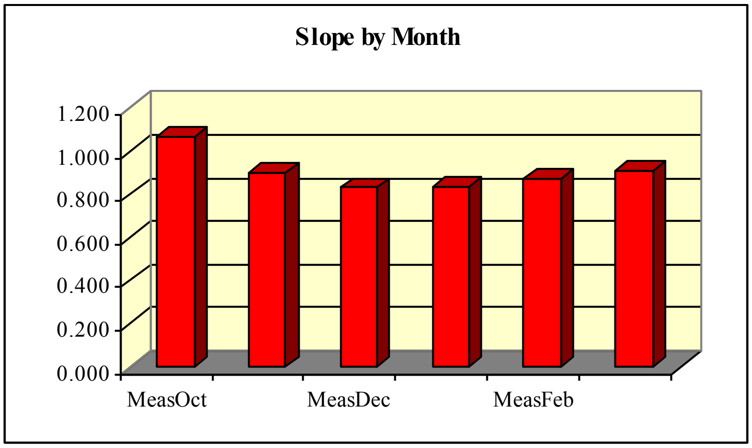


Figure 4 – Slope parameter for relationship of measured flow to basin area, by month.

Observation:
Adjusted monthly discharge is positively related to basin area; the relationship is weakest in January and strongest in October and March. The same is true for measured monthly discharge. In all cases, the relationship of adjusted flow to basin area is stronger than the relationship of measured flow to basin area.

Two Independent Variables (Log10)

Adjusted Flow:

I regressed all possible pairs of independent variables with adjusted flow for each month and for the winter average flow. (There were 325 separate regressions for each month.) The independent variables with the highest R square are shown in Table 3.

Dep. Var	IVar 1	IVar 2	RSQ
AdjOct	Area	IDW	0.870
AdjNov	Area	IDW	0.888
AdjDec	Area	sin(Slp)	0.836
AdjJan	Area	MeanSlp	0.778
AdjFeb	Area	IDW	0.847
AdjMar	Area	IDW	0.824
AdjAvg	Area	IDW	0.873

Table 3 – Independent variable pairs most strongly related to adjusted flow.

IDW is the "current year" precipitation gridded from April Snow Water Equivalent (SWE) data recorded at SNOTEL (SNOwpack TELemetry), snowcourse and weather stations using the ArcView© IDW gridding method. The gridded values within each basin were averaged to provide a single mean value for each basin. North Brush basins were gridded using April 2001 SWE while all other basins were gridded using April 2002 SWE. Units are inches. Sin(Slp) is the trigonometric sine of basin average slope, while MeanSlp is basin average slope.

Table 3 is given for comparison purposes only. In particular, current year IDW is NOT a valid independent variable to use to explain long-term adjusted stream flow.

Reduction of All Possible Relationships to a Manageable Level: There were 26 potential independent variables for explaining the variation in adjusted monthly flow; these can be combined into 325 unique pairs. I regressed each pair against adjusted flow for each month and for the winter average, obtaining 325 regression equations in each case.

To reduce this to a manageable level, I first sorted the equations by R Square, then filtered out the equations in which the significance of each independent variable was worse than .010 This still left a large number of equations: For example, for November adjusted flow there were 66 cases in which both independent variables had a significance of .010 or better.

The next step was to observe that in all cases the relationships with the highest R squares were those in which basin area or basin perimeter was one of the independent variables.

Next, precipitation variables based on current year (such as IDW) rather than long-term values were eliminated.

Finally, "redundancies" were filtered out. For example, one of the long-term precipitation measures was derived by gridding January SWE values; similar measures were derived by gridding February, March, and April values. These were highly correlated with each other (R > .98) and in a sense measure the same thing. The one with the strongest relationship to adjusted flow was kept, the others were filtered out. Another redundancy was basin area and basin perimeter – basin perimeter was filtered out.

This left three or four equations for each month, which are summarized in Table 4. In all cases, significance for both independent variables is better than .010

October

Dep. Var.	IVar 1	IVar 2	RSQ	B	M1	M2
AdjOct	Area	MarLTIDW	0.859	-2.752	1.152	1.626
AdjOct	Area	ApAvPrec	0.848	-2.349	1.250	1.099
AdjOct	Area	RngEl	0.844	-4.183	0.800	1.140
AdjOct	Area	sin(Slp)	0.830	1.167	0.959	2.197

November

Dep. Var.	IVar 1	IVar 2	RSQ	B	M1	M2
AdjNov	Area	RngEl	0.866	-4.642	0.613	1.319
AdjNov	Area	MarLTIDW	0.851	-2.672	1.000	1.613
AdjNov	Area	sin(Slp)	0.837	0.962	0.904	2.001
AdjNov	Area	ApAvPrec	0.818	-2.261	1.069	1.110

December

Dep. Var.	IVar 1	IVar 2	RSQ	B	M1	M2
AdjDec	Area	sin(Slp)	0.836	0.806	0.917	1.948
AdjDec	Area	RngEl	0.803	-4.136	0.668	1.114
AdjDec	Area	MarLTIDW	0.782	-2.415	0.989	1.312
AdjDec	Area	ApAvPrec	0.741	-1.995	1.033	0.844

January

Dep. Var.	IVar 1	IVar 2	RSQ	B	M1	M2
AdjJan	Area	sin(Slp)	0.778	0.763	0.911	1.936
AdjJan	Area	RngEl	0.735	-4.004	0.676	1.056
AdjJan	Area	MarLTIDW	0.711	-2.337	0.981	1.218

February

Dep. Var.	IVar 1	IVar 2	RSQ	B	M1	M2
AdjFeb	Area	MarLTIDW	0.803	-2.406	1.006	1.293
AdjFeb	Area	sin(Slp)	0.798	0.524	0.929	1.625
AdjFeb	Area	RngEl	0.797	-3.826	0.707	1.004
AdjFeb	Area	ApAvPrec	0.752	-1.922	1.043	0.778

March

Dep. Var.	IVar 1	IVar 2	RSQ	B	M1	M2
AdjMar	**Area**	**RngEl**	0.807	-3.283	0.792	0.821
AdjMar	**Area**	**sin(Slp)**	0.798	0.215	0.973	1.258
AdjMar	**Area**	**MarLTIDW**	0.784	-1.934	1.026	0.902

Average

Dep. Var.	IVar 1	IVar 2	RSQ	B	M1	M2
AdjAvg	**Area**	**RngEl**	0.843	-4.030	0.697	1.088
AdjAvg	**Area**	**sin(Slp)**	0.836	0.653	0.938	1.722
AdjAvg	**Area**	**MarLTIDW**	0.836	-2.418	1.017	1.342
AdjAvg	**Area**	**ApAvPrec**	0.798	-2.009	1.067	0.875

Table 4 – Regression statistics for relationship of adjusted flow with various pairs of independent variables, by month.

Notes:

1. Within each sub-table the statistics are ordered by R square.
2. B is the regression constant; M1 and M2 are the slopes for independent variables 1 and 2, respectively.
3. RngEl is basin elevation range in feet.

4. Sin(Slp) is the trigonometric sine of average basin slope.
5. MarLTIDW is a precipitation estimate for the basin, gridded from long-term March SNOTEL/snowcourse/weather station data using the IDW gridding method.
6. ApAvPrec is a precipitation estimate for the basin derived from long-term April SNOTEL/snowcourse data and basin-specific relationships to station elevation. See text (below).

Observations:

1. Inclusion of a second independent variable raises R square substantially, about 20 percentage points.
2. Elevation range (RngEl) is easily calculated and may be the method of choice by users of our data.
3. Sin(Slope) is only a marginally better independent variable than slope measured in feet per mile.
4. March long-term IDW (MarLTIDW) is only a marginally better independent variable than the long-term gridded values for January, February and April.
5. Except for October, ApAvPrec – a precipitation measure – resulted in lower R squares than the other independent variables, when coupled with basin area. I include it here because it is arguably the best measure of precipitation that we have, and because it performs very well when the analysis is extended to three independent variables.

Monthly Variation of Regression Statistics

Figures 5 through 8 show the monthly variation in the regression statistic for the independent variable pairs shown in Table 4.

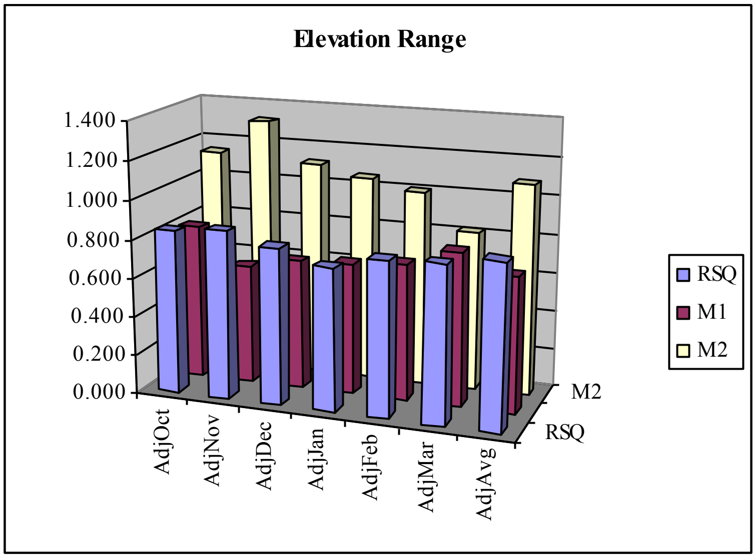


Figure 5 – M1 is the slope of basin area; M2 is the slope of basin elevation range.

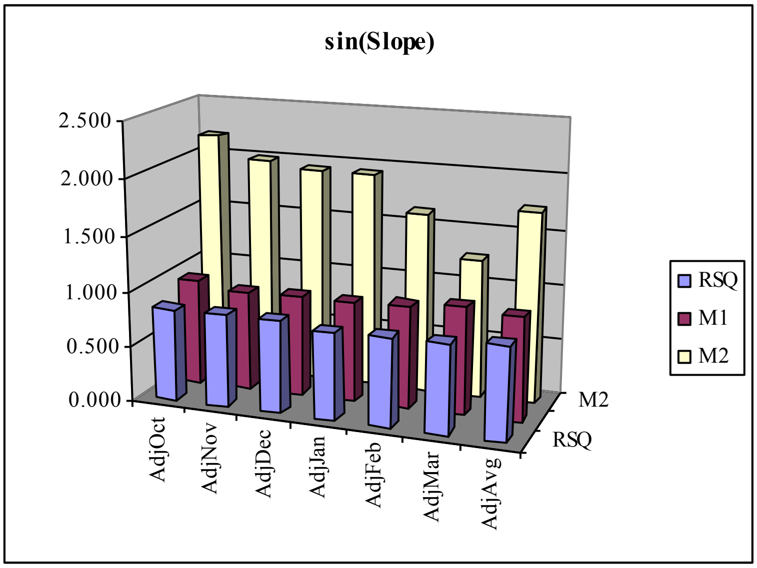


Figure 6 – M1 is the slope of basin area; M2 is the slope of the trigonometric sin of average basin slope.

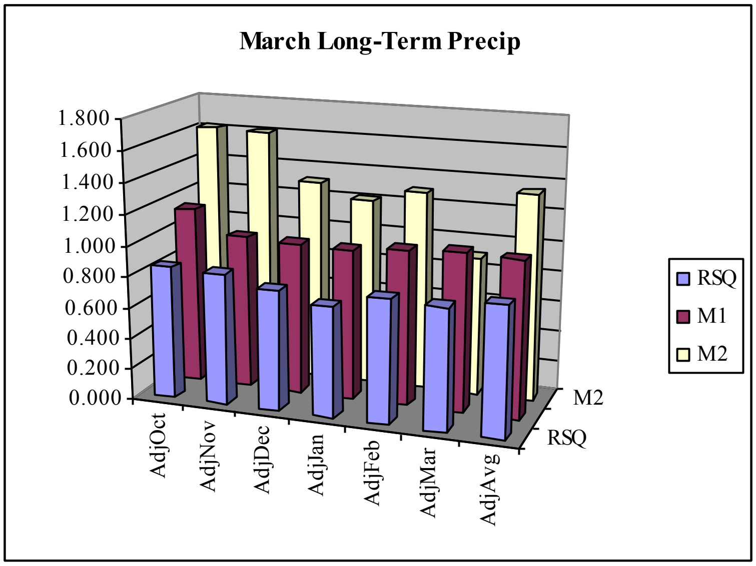


Figure 7 – M1 is the slope of basin area; M2 is the slope of March long-term SWE, gridded using IDW.

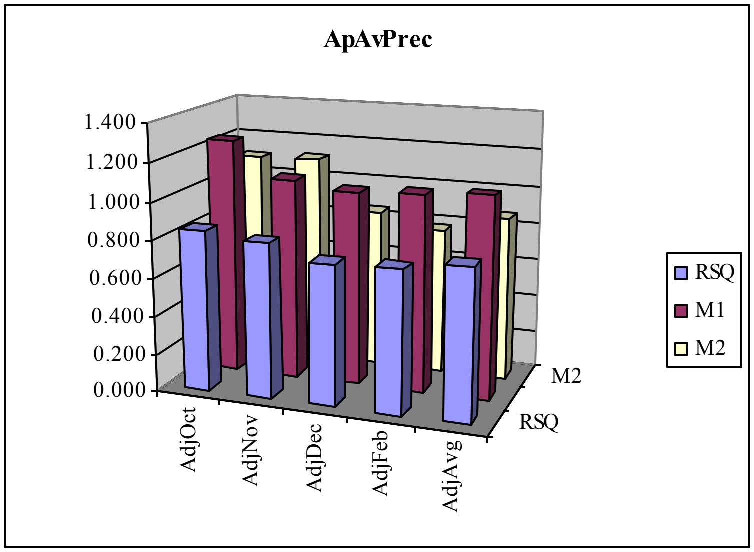


Figure 8 – M1 is the slope of basin area; M2 is the slope of ApAvPrec, a precipitation measure derived from the relationship of precipitation to elevation. In January and March, M2 was not significant at the .01 level or better; these months are omitted from the figure.

"ApAvPrec" – What is it?

ApAvPrec is a precipitation measure based on the relationship of precipitation to elevation. This relationship is demonstrated in Figures 9 though 13:

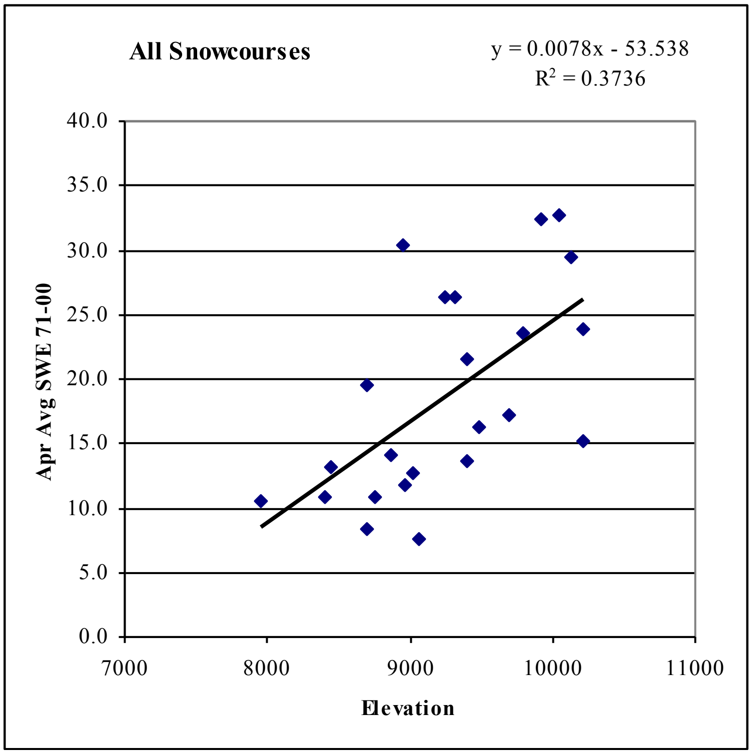


Figure 9 – Relationship of April average SWE (1971 to 2000) to elevation for all SNOTEL/snowcourse sites in the vicinity of our study area.

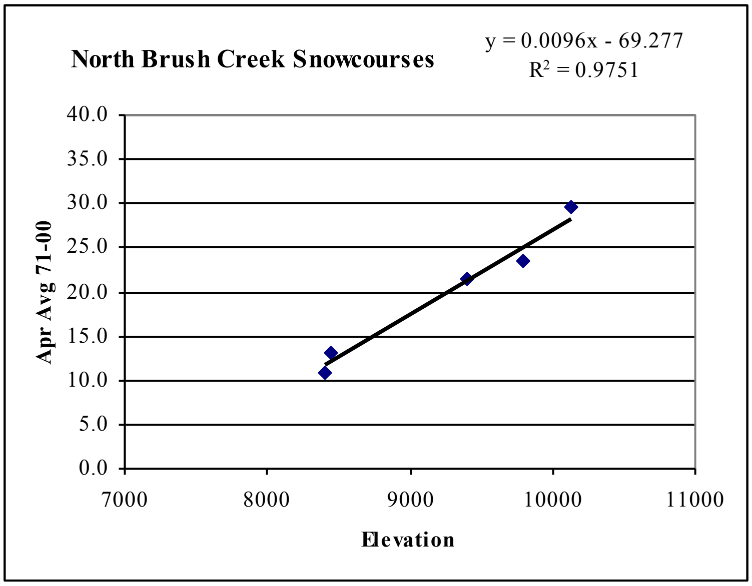


Figure 10 -- Relationship of April average SWE (1971 to 2000) to elevation for all SNOTEL/snowcourse sites in the vicinity of the North Brush Creek basins.

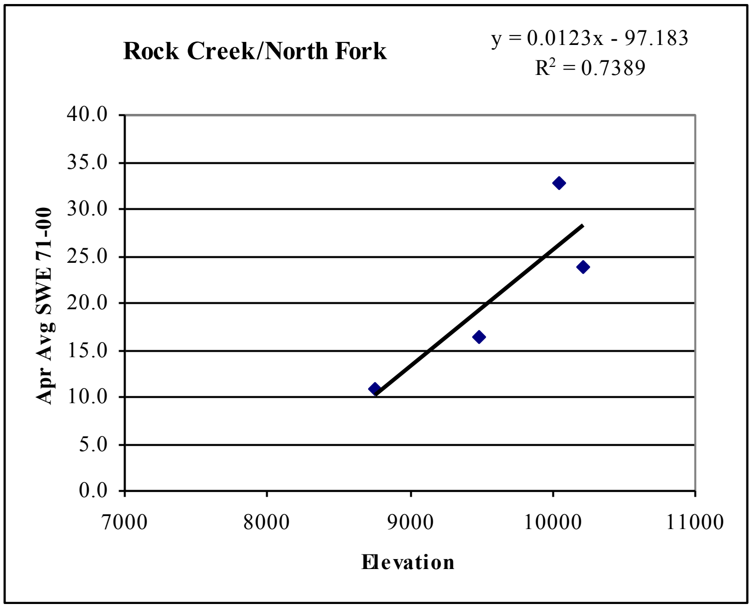


Figure 11 -- Relationship of April average SWE (1971 to 2000) to elevation for all SNOTEL/snowcourse sites in the vicinity of the Rock Creek/North Fork basins.

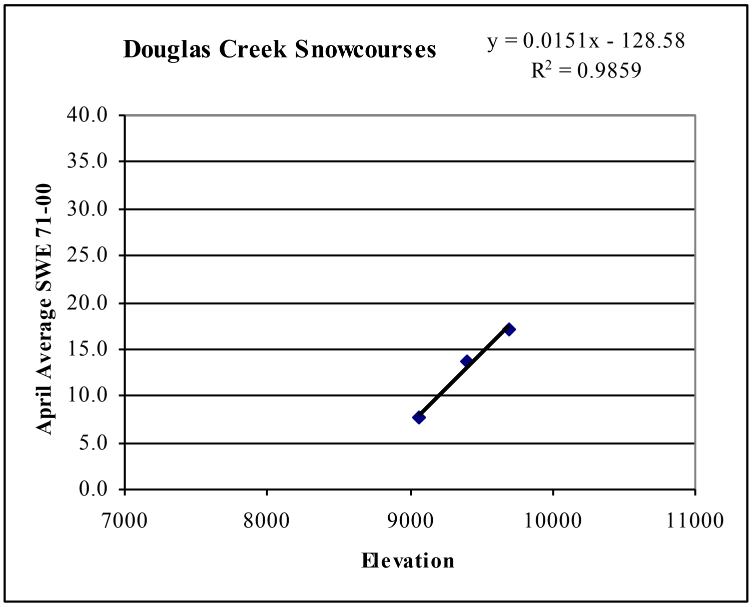


Figure 12 -- Relationship of April average SWE (1971 to 2000) to elevation for all SNOTEL/snowcourse sites in the vicinity of the Douglas Creek basins.

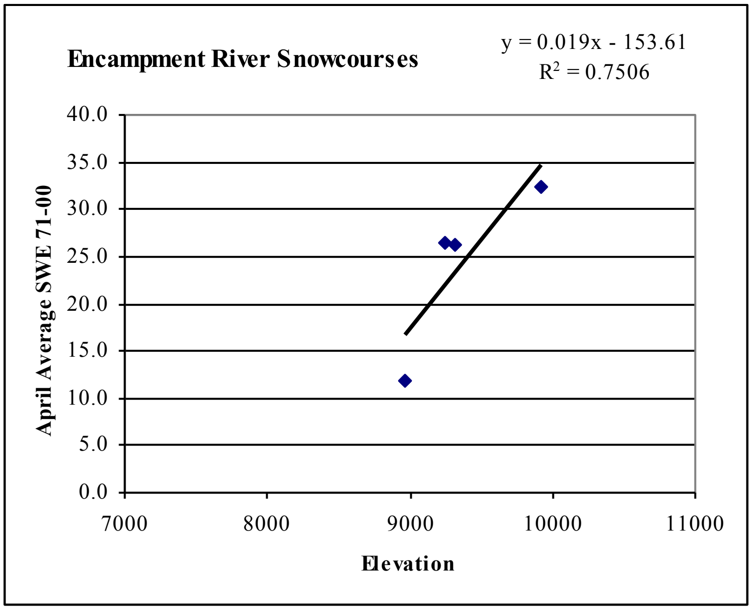


Figure 13 -- Relationship of April average SWE (1971 to 2000) to elevation for all SNOTEL/snowcourse sites in the vicinity of the Encampment River basins.

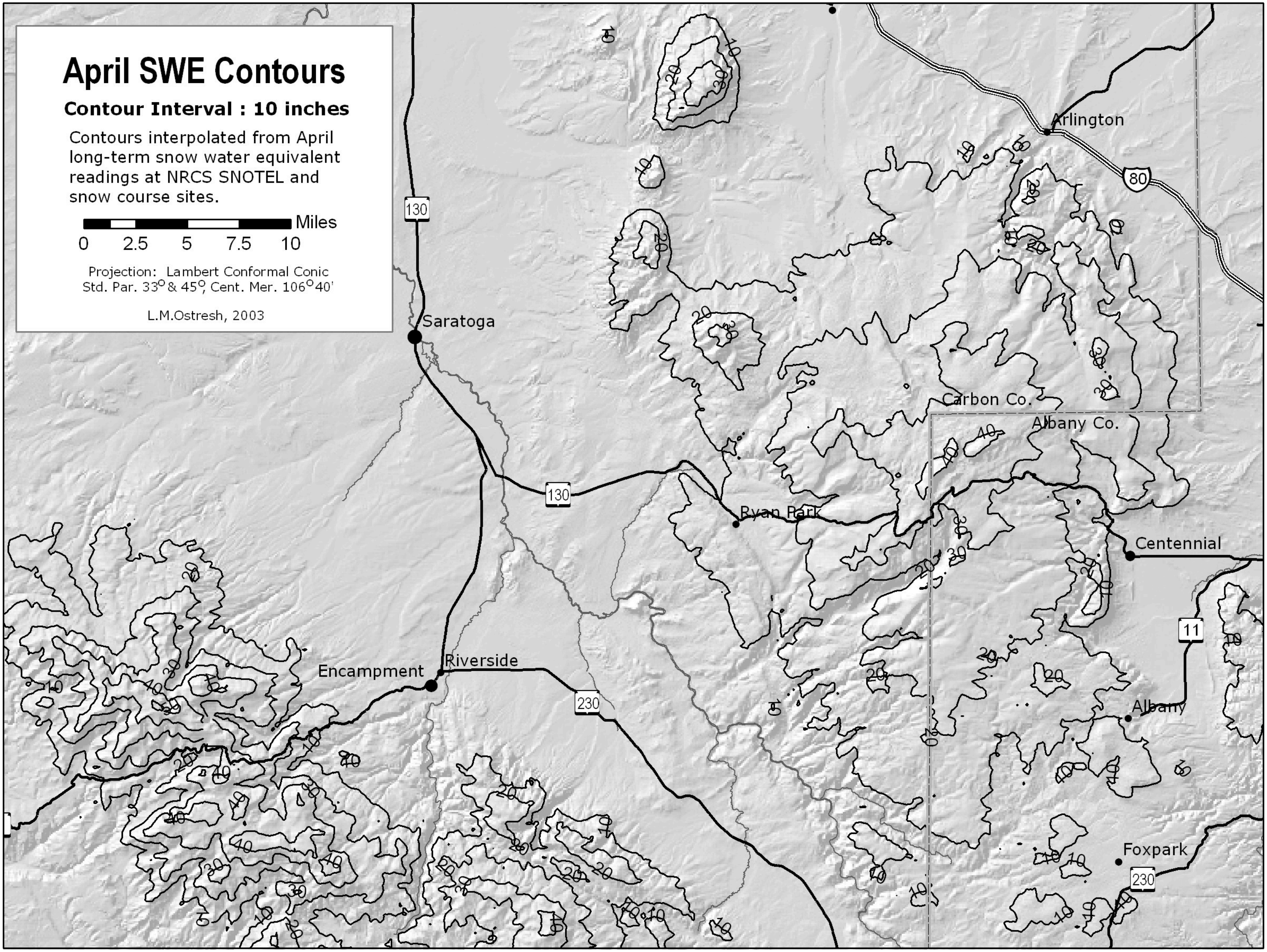
In order to determine ApAvPrec, I used the basin average precipitation with the basin specific relationship between elevation and long-term April SWE. For example, Cassidy Creek (BC-7) has an average basin elevation – as determined from a Digital Elevation Model – of 9,789 feet. It is part of the North Brush Creek drainage basin, so the data in Figure 6 was used:

ApAvPrec (Cassidy Creek) = .0096 * 9,789 – 69.277
= 25.1 inches SWE

As another example, Park Run Creek (DC-6) has an average elevation of 9,113 feet. It is part of the Douglas Creek drainage basin, so the data in Figure 8 was used:

ApAvPrec (Park Run Creek) = .0151 * 9,113 – 128.58
= 8.7 inches SWE

The "Precipitation Contours" map on the next page is a composite of all the basin-specific equations shown above in Figures 10 – 1



April SWE Contours

Contour Interval : 10 inches

Contours interpolated from April long-term snow water equivalent readings at NRCS SNOTEL and snow course sites.

Projection: Lambert Conformal Conic
Std. Par. 33° & 45°, Cent. Mer. 106°40'

L.M.Ostresh, 2003

Measured Flow:

All possible pairs of independent variables were regressed against measured flows for each month (325 regressions per month). Table 5 shows the independent variable pairs most strongly related to measured flow, and is given for comparison purposes only. As in the one-variable case, the relationships are stronger with adjusted (see Table 3 above) rather than measured flow.

Dep. Var	IVar 1	IVar 2	RSQ
MeasOct	Area	IDW	0.830
MeasNov	Area	IDW	0.867
MeasDec	Area	IDW	0.775
MeasJan	Area	sin(Slp)	0.696
MeasFeb	Area	IDW	0.776
MeasMar	Area	IDW	0.760
MeasAvg	Area	IDW	0.828

Table 5 – Independent variable pairs most strongly related to measured flow.

The regression equations were filtered as follows: Those in which either independent variable had significance worse than .01 were removed. When two independent variables "measured the same thing", the one with the higher R square was kept, the other(s) eliminated. Thus area was preferred over perimeter as a "size" measure and IDW over the other "precipitation" measures. The results, summarized in Table 6, are that area is coupled with precipitation (IDW), elevation (RngEl), or slope (sin(Slp)) in each month.

Dep. Var.	IVar 1	IVar 2	RSQ	B	M1	M2
MeasOct	Area	IDW	0.830	-2.845	1.243	1.581
MeasOct	Area	RngEl	0.803	-4.257	0.841	1.100
MeasOct	Area	sin(Slp)	0.796	0.965	0.991	2.184
MeasNov	Area	IDW	0.867	-2.865	1.107	1.714
MeasNov	Area	RngEl	0.839	-4.644	0.686	1.269
MeasNov	Area	sin(Slp)	0.803	0.736	0.965	1.911
MeasDec	Area	IDW	0.775	-2.787	1.028	1.616
MeasDec	Area	sin(Slp)	0.761	0.731	0.904	1.962
MeasDec	Area	RngEl	0.736	-4.358	0.638	1.160
MeasJan	Area	sin(Slp)	0.696	0.677	0.905	1.935
MeasJan	Area	IDW	0.683	-2.679	1.019	1.489
MeasJan	Area	RngEl	0.656	-4.172	0.656	1.085
MeasFeb	Area	IDW	0.776	-2.715	1.058	1.503
MeasFeb	Area	sin(Slp)	0.723	0.430	0.933	1.661
MeasFeb	Area	RngEl	0.717	-3.965	0.706	1.009
MeasMar	Area	IDW	0.760	-2.403	1.063	1.227
MeasMar	Area	sin(Slp)	0.738	0.230	0.964	1.434
MeasMar	Area	RngEl	0.737	-3.603	0.765	0.884
MeasAvg	Area	IDW	0.828	-2.712	1.068	1.542
MeasAvg	Area	RngEl	0.786	-4.184	0.697	1.099
MeasAvg	Area	sin(Slp)	0.781	0.556	0.942	1.755

Table 6 – Regression statistics for relationship of measured flow with various pairs of independent variables, by month.

Notes:

1. Within each sub-table the statistics are ordered by R square.
2. B is the regression constant; M1 and M2 are the slopes for independent variables 1 and 2, respectively.
3. IDW is the "current year" precipitation gridded from April SWE recorded at SNOTEL, snowcourse and weather stations using the ArcView© IDW gridding method. The gridded values within each basin were averaged for the basin. North Brush basins were gridded using April 2001 SWE while all other basins were gridded using April 2002 SWE. Units are inches.
4. RngEl is basin elevation range in feet.
5. Sin(Slp) is the trigonometric sine of average basin slope.

Observation: Comparison with Table 4 shows that for all equations except November, the R square for comparable independent variables is lower for measured than for adjusted flows. In November the variable pair for measured flow, [Area, IDW], had a higher R square

(.867) than its most similar comparator for adjusted flow ([Area, MarLTIDW]; R square = .851).

Three Independent Variables (Log10)

Adjusted Flow:

I regressed all possible triplets of independent variables with adjusted flow for each month and for the winter average flow. (There were 2,600 separate regressions for each month.) The independent variables with the highest R square – and for which all significance values were at .010 or better – are shown in Table 7; Table 8 shows similar information for measured flow.

Dep. Var	IVar 1	IVar 2	IVar 3	RSQ
AdjOct	TIN	FebLTIDW	Perimeter	0.893
AdjNov	Area	Proximity	sin(Slp)	0.892
AdjDec	Area	ApAvPrec	MiddleEl	0.882
AdjJan	Area	IDW	MiddleEl	0.845
AdjFeb	Area	TIN	IDW	0.900
AdjMar	Area	IDW	JanLTIDW	0.893
AdjAvg	Area	TIN	MarLTIDW	0.884

Table 7 – Independent variable triplets most strongly related to adjusted flow (in which all variables are significant at .010 or better).

Dep. Var	IVar 1	IVar 2	IVar 3	RSQ
MeasOct	FebLTIDW	MapPrec	Perimeter	0.887
MeasNov	Area	Proximity	MapPrec	0.880
MeasDec	Area	TIN	IDW	0.861
MeasJan	Area	IDW	MiddleEl	0.803
MeasFeb	Area	TIN	IDW	0.874
MeasMar	Area	IDW	JanLTIDW	0.862
MeasAvg	Area	IDW	MapPrec	0.882

Table 8 – Independent variable triplets most strongly related to measured flow (in which all variables are significant at .010 or better).

These tables are shown for comparison purposes only. In particular, Proximity, TIN, and IDW are current year estimates of precipitation and thus not appropriate for use in long-term adjusted flow regression equations (although they are suitable for the measured flow equations).

The 2,600 regression equations (for each month) were ranked by R square and filtered in a manner similar to the two independent variable situation. In October, no triplets survived this filtering process. Results for the other months are shown in Table 9:

November

Dep. Var.	IVar 1	IVar 2	IVar 3	RSQ	B	M1	M2	M3
AdjNov	Area	FebLTIDW	sin(Slp)	0.886	-0.896	0.961	1.022	1.128
AdjNov	Area	ApAvPrec	sin(Slp)	0.880	-0.496	1.002	0.644	1.332
AdjNov	Area	ApAvPrec	MiddleEl	0.879	33.345	1.143	1.861	-9.199
AdjNov	Area	TopEl	sin(Slp)	0.878	-19.692	0.873	5.040	1.478

December

Dep. Var.	IVar 1	IVar 2	IVar 3	RSQ	B	M1	M2	M3
AdjDec	Area	ApAvPrec	MiddleEl	0.882	56.931	1.170	2.039	-15.211
AdjDec	Area	FebLTIDW	BottomEl	0.850	26.728	0.745	1.387	-7.329
AdjDec	Area	MarLTIDW	BottomEl	0.850	25.223	0.763	1.352	-6.978
AdjDec	Area	MarLTIDW	MiddleEl	0.844	27.853	1.007	1.929	-7.788
AdjDec	Area	FebLTIDW	MiddleEl	0.843	29.915	0.998	2.009	-8.273

January

Dep. Var.	IVar 1	IVar 2	IVar 3	RSQ	B	M1	M2	M3
AdjJan	Area	ApAvPrec	MiddleEl	0.842	63.172	1.142	2.031	-16.780
AdjJan	Area	MarLTIDW	MiddleEl	0.827	37.216	0.988	2.052	-10.181
AdjJan	Area	FebLTIDW	MiddleEl	0.827	39.720	0.980	2.146	-10.778
AdjJan	Area	FebLTIDW	BottomEl	0.826	33.112	0.669	1.338	-8.928
AdjJan	Area	MarLTIDW	BottomEl	0.826	31.582	0.687	1.302	-8.569

February

Dep. Var.	IVar 1	IVar 2	IVar 3	RSQ	B	M1	M2	M3
AdjFeb	Area	ApAvPrec	MiddleEl	0.862	45.913	1.144	1.786	-12.358
AdjFeb	Area	FebLTIDW	MiddleEl	0.859	26.042	1.003	1.936	-7.281
AdjFeb	Area	MarLTIDW	MiddleEl	0.857	23.640	1.010	1.842	-6.704

March

Dep. Var.	IVar 1	IVar 2	IVar 3	RSQ	B	M1	M2	M3
AdjMar	Area	ApAvPrec	MiddleEl	0.844	37.934	1.144	1.433	10.232

Average

Dep. Var.	**IVar 1**	**IVar 2**	**IVar 3**	**RSQ**	**B**	**M1**	**M2**	**M3**
AdjAvg	Area	ApAvPrec	MiddleEl	0.878	38.593	1.152	1.731	10.489

Table 9 – Regression statistics for the relationship of adjusted flow with various triplets of independent variables, by month.

Notes:

1. Within each sub-table the statistics are ordered by R square.
2. B is the regression constant; M1, M2, and M3 are the slopes for independent variables 1, 2, and 3 respectively.
3. Area is basin elevation in square miles.
4. TopEl, BottomEl, and MiddleEl are the top, bottom and middle (halfway between top and bottom) basin elevations in feet.
5. Sin(Slp) is the trigonometric sine of average basin slope.
6. MarLTIDW is a precipitation estimate for the basin, gridded from long-term March SNOTEL/snowcourse/weather station data using the IDW gridding method. FebLTIDW is the corresponding measure for February.
7. ApAvPrec is a precipitation estimate for the basin derived from long-term April SNOTEL/snowcourse/weather station data and basin-specific relationships to station elevation. See text above.
8. IDW is the "current year" precipitation gridded from April SWE recorded at SNOTEL, snowcourse and weather stations using the ArcView© IDW gridding method. The gridded values within each basin were averaged for the basin. North Brush basins were gridded using April 2001 SWE while all other basins were gridded using April 2002 SWE. Units are inches.

Observation:

The triplet of independent variables Area, ApAvPrec, and Middle Elevation has the highest R square in all months except November. In November its R square compares favorably with the highest R square triplet. Figures 14 through 17 show the variation of regression statistics for this triplet by month.

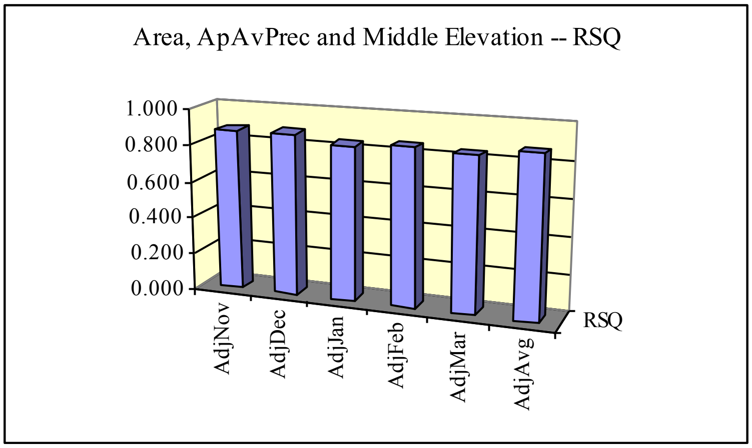


Figure 14 – Monthly variation of R square in the relationship of adjusted monthly flow to Area, ApAvPrec and Middle Elevation.

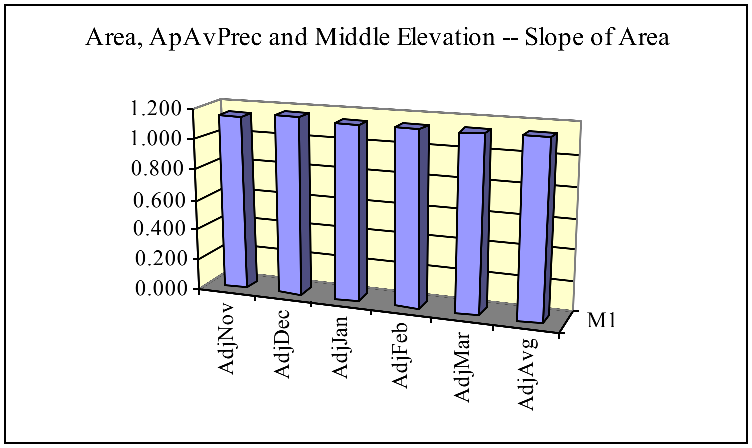


Figure 15 – Monthly variation of the slope of Area in the relationship of adjusted monthly flow to Area, ApAvPrec and Middle Elevation.

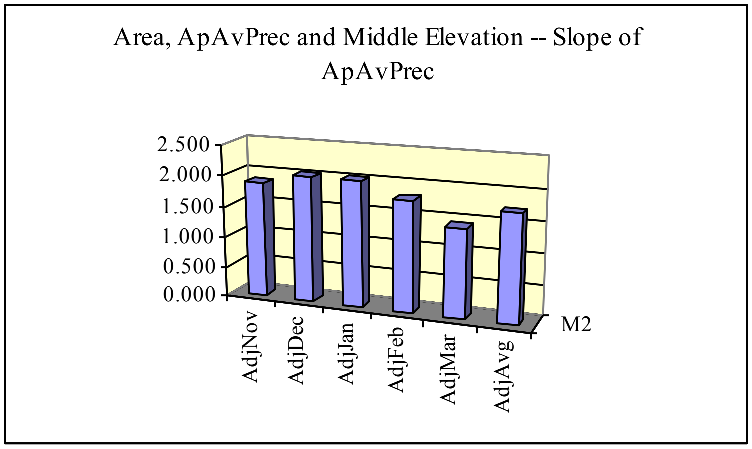


Figure 16 – Monthly variation of the slope of ApAvPrec in the relationship of adjusted monthly flow to Area, ApAvPrec and Middle Elevation.

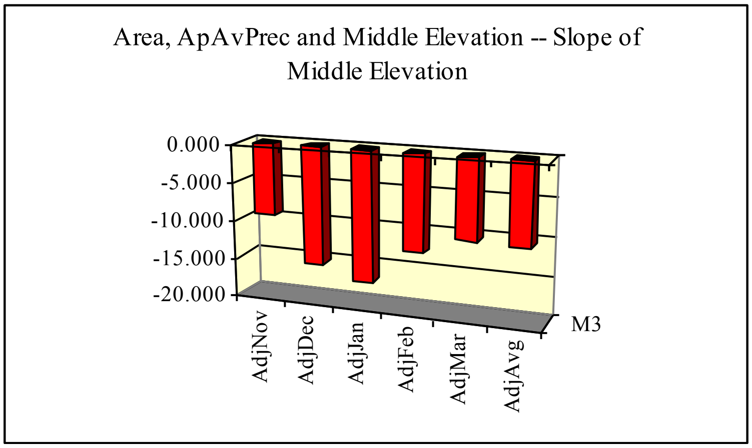


Figure 17 – Monthly variation of the slope of Middle Elevation in the relationship of adjusted monthly flow to Area, ApAvPrec and Middle Elevation.

Observations:

1. While R square and the slope of Area remain relatively constant from month to month, there is systematic variation in the slopes of ApAvPrec and Middle elevation.
2. The slope of ApAvPrec and Middle elevation work in tandem: When one is high, the other is low. There may be a simple statistical explanation for this: The simple R square between them is .34, so they are (at least weakly) correlated. On the other hand, perhaps there is a substantive explanation.

Measured Flow:

I regressed all possible combinations (2,600) of three independent variables against measured flow for each month, and then removed equations in which significance was worse than .01. Those remaining were filtered by removing variable pairs that measured the same thing. (For example, the highest R square equation for October [Table 8] had FebLTIDW and MapPrec – along with Perimeter – as independent variables; the first two measure the same thing, precipitation.) When two or more equations contained triplets of independent variables that measured the same thing, the one with the highest R square was kept, and the others were eliminated. With these removals, no triplet of independent variables was significant for October. The results for the other months are shown in Table 10.

Dep. Var	**IVar 1**	**IVar 2**	**IVar 3**	**RSQ**	**B**	**M1**	**M2**	**M3**
MeasNov	Area	Proximity	sin(Slp)	0.875	-0.988	1.105	0.836	1.052
MeasNov	Area	TopEl	sin(Slp)	0.858	-21.250	0.957	5.369	1.388
MeasNov	Area	ApAvPrec	MiddleEl	0.858	31.096	1.217	1.808	-8.655
MeasDec	Area	ApAvPrec	MiddleEl	0.840	57.211	1.177	2.118	-15.331
MeasDec	Area	Proximity	BottomEl	0.802	26.587	0.861	1.167	-7.284
MeasJan	Area	IDW	MiddleEl	0.803	31.402	1.006	2.064	-8.719
MeasJan	Area	ApAvPrec	MiddleEl	0.793	64.545	1.137	2.087	-17.165
MeasFeb	Area	IDW	MiddleEl	0.846	22.492	1.048	1.928	-6.449
MeasFeb	Area	ApAvPrec	MiddleEl	0.812	51.174	1.158	1.865	-13.737
MeasMar	Area	ApAvPrec	MiddleEl	0.803	44.239	1.155	1.599	-11.906
MeasAvg	Area	ApAvPrec	MiddleEl	0.840	41.700	1.173	1.804	-11.327

Table 10 – Regression statistics for the relationship of measured flow with various triplets of independent variables, by month.

Notes:

1. Within each sub-table the statistics are ordered by R square.
2. B is the regression constant; M1, M2, and M3 are the slopes for independent variables 1, 2, and 3 respectively.
3. Area is basin elevation in square miles.
4. TopEl, BottomEl, and MiddleEl are the top, bottom and middle (halfway between top and bottom) basin elevations in feet.
5. Sin(Slp) is the trigonometric sine of average basin slope.
6. ApAvPrec is a precipitation estimate for the basin derived from long-term April SNOTEL/snowcourse data and basin-specific relationships to station elevation. See text above.
7. Proximity is a precipitation estimate for the basin derived from current-year April SNOTEL/snowcourse SWE. The basin is assigned the value of the nearest recording station. Units are inches.
8. IDW is the current-year precipitation gridded from April SWE recorded at SNOTEL/ snowcourse sites using the ArcView© IDW gridding method. The gridded values within each basin were averaged for the basin. Units are inches.

Observations:

1. The triplet Area, ApAvPrec and MiddleEl is a good choice for all months for measured flow; this same triplet is also best for adjusted flow.
2. Comparison with Table 9 shows that for comparable triplets, the R square values for measured flow are less than for adjusted flow.

Four Independent Variables (Log10)

Adjusted and Measured Flow:

I regressed all possible quadruples of independent variables with adjusted flow for each month and for the winter average flow. (There were 14,950 separate regressions for each month.) The independent variables with the highest R square – and in which all independent variables are significant at .010 or better – are shown in Table 11.

Dep. Var	IVar 1	IVar 2	IVar 3	IVar 4	RSQ
AdjOct	Area	JanLTIDW	FebLTIDW	%GCW	0.937
AdjNov	Area	IDW	TopEl	MiddleEl	0.920
AdjDec	Area	Proximity	TIN	MeanSlp	0.914
AdjJan	Area	TIN	IDW	%GCW	0.858
AdjFeb	Area	IDW	Prism	%GCW	0.901
AdjMar	IDW	Prism	BottomEl	RngSlp	0.750
AdjAvg	Area	Proximity	TIN	sin(Slp)	0.909

Table 11 – Independent variable quadruplets most strongly related to adjusted flow (in which all variables are significant at .010 or better).

Table 12 displays similar information for measured flow:

Dep. Var	IVar 1	IVar 2	IVar 3	IVar 4	RSQ
MeasOct	Area	JanLTIDW	FebLTIDW	%GCW	0.922
MeasNov	Area	IDW	TopEl	MiddleEl	0.907
MeasDec	Area	Proximity	TIN	MeanSlp	0.888
MeasJan	Area	Proximity	TIN	MeanSlp	0.799
MeasFeb	Area	IDW	MarLTIDW	AprLTIDW	0.880
MeasMar	Area	Proximity	TIN	SDevSlp	0.849
MeasAvg	Area	Proximity	TIN	sin(Slp)	0.883

Table 12 – Independent variable quadruplets most strongly related to measured flow (in which all variables are significant at .010 or better).

It will be noted in both tables that in each month there is a pair of variables that measure the same thing. For example, in Table 11, October, the variable pair JanLTIDW and FebLTIDW occurs – they are highly correlated measures of long-term precipitation. When such variable pairs occurred in an equation, the equation was removed from consideration. The result is that **NO** equation survived this filtering process for either adjusted or measured flow. In other words, no quadruplet of independent variables used is statistically significant.

Appendix C.1

Values of Variables Used

Table C.1.1 Measurement Sites and Basin Names

Site	Basin Name
BC-1	North Brush Creek Gage, 06622700
BC-11	Nash Fork Creek, Above Brooklyn Lake Lodge
BC-2	Lincoln Creek
BC-3	Mill Creek
BC-4	Fish Creek, Upper Site
BC-5	Unnamed Tributary to Fish Creek
BC-6	Fish Creek, Lower Site
BC-7	Cassidy Creek
BC-8	Unnamed Tributary
BC-9	Harden Creek
DC-1	Lake Creek at Lincoln Creek
DC-2	Lincoln Creek at Lake Creek
DC-3	Lake Creek at Douglas Creek
DC-4	Illinois Creek
DC-6	Park Run Creek
DC-7	Pelton Creek
ER-2	North Fork Encampment River
ER-3	Willow Creek
ER-4	Miner Creek
ER-5	South Fork Miner Creek
ER-6	North Soldier Creek
ER-7	South Soldier Creek
ER-8	Unnamed Creek
ER-9	Hog Park Creek Gage, 06623800
RL-1	Rock Creek Gage, 06632400
RL-3	North Fork Rock Creek
RL-4	Middle Fork Rock Creek
RL-5	Park Trail Creek
RL-6	South Fork Rock Creek
RL-8	North Fork Little Laramie River

Table C.1.2 Dependent Variables -- Original Units

	Measured Monthly Flow							Adjusted Monthly Flow						
	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs
Site	**MeasOct**	**MeasNov**	**MeasDec**	**MeasJan**	**MeasFeb**	**MeasMar**	**MeasAvg**	**AdjOct**	**AdjNov**	**AdjDec**	**AdjJan**	**AdjFeb**	**AdjMar**	**AdjAvg**
BC-1	10.10	12.50	9.08	9.00	8.00	7.78	9.41	14.00	11.50	10.00	9.27	9.24	10.50	10.75
BC-11	-	0.58	-	0.42	0.38	0.52	0.48	-	0.81	-	0.46	0.46	0.71	0.61
BC-2	0.40	0.47	0.49	0.44	0.48	0.46	0.46	0.58	0.66	0.54	0.48	0.59	0.63	0.58
BC-3	0.14	0.19	0.20	0.19	0.18	0.18	0.18	0.20	0.27	0.22	0.21	0.22	0.24	0.23
BC-4	0.39	0.71	0.64	0.55	0.62	0.56	0.58	0.57	0.99	0.71	0.61	0.76	0.76	0.73
BC-5	0.41	0.39	0.56	0.27	0.37	0.38	0.40	0.60	0.55	0.62	0.30	0.45	0.51	0.50
BC-6	0.78	1.03	-	0.96	0.67	0.90	0.87	1.14	1.44	-	1.06	0.82	1.22	1.14
BC-7	1.08	0.88	0.82	0.81	0.80	0.76	0.86	1.58	1.23	0.91	0.89	0.98	1.03	1.10
BC-8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	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	0.32	0.32	0.28	0.34	0.42	0.56	0.47	0.40
DC-1	0.68	0.34	0.28	0.29	0.42	0.34	0.39	0.96	0.41	0.38	0.38	0.54	0.48	0.53
DC-2	0.22	0.27	0.19	0.24	0.25	0.32	0.25	0.32	0.32	0.26	0.31	0.33	0.45	0.33
DC-3	0.85	1.19	1.49	0.71	1.15	1.80	1.20	1.20	1.42	2.01	0.92	1.51	2.59	1.61
DC-4	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.03	0.04	0.05	0.06	0.04	0.05	0.04
DC-6	-	0.08	0.06	0.07	0.07	0.12	0.08	-	0.10	0.08	0.09	0.09	0.17	0.10
DC-7	0.87	0.97	0.77	1.09	0.85	0.83	0.90	1.23	1.15	1.03	1.42	1.11	1.20	1.19
ER-2	-	1.96	1.69	2.11	1.48	1.420	1.73	-	2.72	2.23	2.81	2.00	1.78	2.31
ER-3	-	0.57	0.37	0.72	0.50	0.306	0.49	-	0.79	0.49	0.96	0.67	0.38	0.66
ER-4	-	0.26	0.24	0.23	0.20	0.211	0.23	-	0.35	0.32	0.30	0.27	0.26	0.30
ER-5	-	0.45	0.47	0.35	0.36	0.289	0.38	-	0.63	0.62	0.46	0.49	0.36	0.51
ER-6	-	0.30	0.32	0.28	0.19	0.183	0.25	-	0.42	0.42	0.37	0.25	0.23	0.34
ER-7	-	0.12	0.12	0.10	0.08	0.076	0.10	-	0.16	0.15	0.14	0.11	0.10	0.13
ER-8	-	0.38	0.34	0.30	0.30	0.347	0.33	-	0.53	0.44	0.40	0.40	0.43	0.44
ER-9	-	17.60	-	15.2	-	-	16.40	-	25.10	22.50	20.00	18.90	20.00	21.30
RL-1	-	-	-	-	-	-	-	16.90	13.80	11.80	10.80	10.40	10.60	12.38
RL-3	0.67	0.65	0.39	0.13	0.35	0.32	0.42	1.13	0.81	0.46	0.16	0.53	0.50	0.60
RL-4	0.07	0.10	0.07	0.07	0.07	0.06	0.07	0.12	0.12	0.09	0.09	0.10	0.10	0.10
RL-5	0.75	0.76	0.39	0.32	0.24	0.24	0.45	1.27	0.95	0.46	0.40	0.36	0.37	0.64
RL-6	0.20	0.26	0.09	0.04	0.08	0.08	0.12	0.33	0.33	0.11	0.05	0.12	0.12	0.17
RL-8	2.63	2.36	1.82	1.53	1.49	1.60	1.91	4.44	2.95	2.15	1.90	2.28	2.50	2.70

Table C.1.3 Topographic Variables -- Original Units

Site	Sq. Mi. Area	Miles Perimeter	Feet TopEl	Feet MiddleEl	Feet BottomEl	Feet MeanEl	Feet RngEl	Feet SDevEl	Ft./Mi. MaxSlp	Ft./Mi. MinSlp	Ft./Mi. RngSlp	Ft./Mi. MeanSlp	Ft./Mi. SDevSlp	sin(Slp)
BC-1	37.8	32.2	10,837	9,393	8,015	9,414	2,822	573	4,235	0	4,235	963	558	0.180
BC-11	2.2	6.5	11,417	10,525	10,128	10,562	1,289	236	4,870	0	4,870	773	565	0.145
BC-2	2.7	10.2	10,597	9,183	8,425	9,282	2,172	550	2,825	0	2,825	1,050	515	0.195
BC-3	2.0	7.3	10,456	9,639	8,760	9,633	1,696	373	2,718	31	2,687	829	379	0.155
BC-4	2.8	8.3	10,305	9,331	8,835	9,413	1,470	231	2,658	0	2,658	743	442	0.139
BC-5	2.0	5.9	10,052	9,255	8,871	9,281	1,181	216	2,952	0	2,952	928	435	0.173
BC-6	5.1	9.8	10,305	9,301	8,638	9,335	1,667	246	2,952	0	2,952	835	460	0.156
BC-7	2.2	9.0	10,607	9,757	8,727	9,789	1,880	448	2,988	0	2,988	895	423	0.167
BC-8	0.2	2.0	9,491	9,380	9,039	9,331	453	124	3,449	31	3,418	1,099	824	0.204
BC-9	2.0	6.9	9,636	9,396	9,229	9,414	407	84	1,611	0	1,611	460	251	0.087
DC-1	5.0	10.1	9,774	9,177	8,786	9,176	988	160	2,304	0	2,304	609	354	0.115
DC-2	5.2	10.3	9,272	9,075	8,819	9,069	453	77	2,391	0	2,391	412	289	0.078
DC-3	18.0	21.2	9,774	9,068	8,553	9,055	1,220	162	2,815	0	2,815	591	378	0.111
DC-4	1.5	5.6	9,423	9,144	8,976	9,154	446	60	1,822	0	1,822	482	294	0.091
DC-6	4.4	10.4	9,426	9,114	8,835	9,113	591	76	2,046	0	2,046	453	290	0.086
DC-7	23.1	24.0	9,288	8,822	8,340	8,841	948	209	4,968	0	4,968	657	403	0.124
ER-2	16.2	22.8	10,564	9,882	8,189	9,746	2,375	502	6,342	0	6,342	1,053	623	0.196
ER-3	3.1	8.1	10,325	8,799	8,333	8,953	1,991	497	2,825	0	2,825	1,005	461	0.187
ER-4	1.4	4.9	10,410	9,760	9,134	9,774	1,276	319	3,608	44	3,564	1,201	549	0.222
ER-5	2.7	7.5	10,453	9,987	8,999	9,907	1,453	361	3,374	31	3,343	1,158	519	0.214
ER-6	1.3	4.5	10,413	9,570	9,239	9,628	1,175	311	4,500	0	4,500	979	566	0.182
ER-7	0.6	3.7	10,167	9,570	9,255	9,568	912	189	2,583	0	2,583	963	426	0.179
ER-8	1.8	6.3	10,079	9,311	8,491	9,317	1,588	309	3,080	0	3,080	1,053	445	0.196
ER-9	72.4	-	-	-	-	-	-	-	-	-	-	-	-	-
RL-1	62.9	44.8	11,237	9,885	7,789	9,800	3,448	610	13,080	0	13,080	1,003	740	0.187
RL-3	5.6	11.2	10,945	10,446	9,705	10,406	1,240	232	3,581	0	3,581	646	425	0.121
RL-4	1.2	5.2	10,587	10,190	9,774	10,210	814	198	1,894	0	1,894	578	286	0.109
RL-5	4.3	9.3	11,115	10,463	9,757	10,428	1,358	313	2,616	0	2,616	698	349	0.131
RL-6	2.9	9.5	11,237	10,663	10,020	10,635	1,217	269	3,968	0	3,968	668	443	0.126
RL-8	11.7	15.3	11,188	10,066	9,049	10,026	2,139	418	3,305	0	3,305	768	457	0.144

Table C.1.4 Precipitation Variables -- Original Units

	Inches	Inches	Inches	Inches	Inches	Inches	Inches	mm	cm	Inches	Inches
Site	**Proximity**	**TIN**	**IDW**	**JanLTIDW**	**FebLTIDW**	**MarLTIDW**	**AprLTIDW**	**Prism**	**Daymet**	**ApAvPrec**	**MapPrec**
BC-1	13.8	11.7	15.5	9.0	12.4	16.1	19.8	890	79	21.5	28
BC-11	17.0	17.3	16.3	10.7	14.4	17.9	22.4	886	97	32.5	30
BC-2	13.0	10.9	14.2	7.4	10.7	14.1	17.5	854	80	20.2	25
BC-3	18.4	12.9	16.1	8.6	11.9	15.6	19.4	940	84	23.6	28
BC-4	15.7	10.2	15.7	8.8	12.1	15.7	19.3	882	77	21.4	23
BC-5	10.8	10.5	15.2	8.3	11.6	15.0	18.6	859	77	20.2	19
BC-6	13.6	10.3	15.5	8.6	11.9	15.4	19.0	871	76	20.7	22
BC-7	16.0	11.8	16.4	9.5	13.0	16.8	20.7	982	82	25.1	30
BC-8	16.0	10.3	16.2	9.4	12.9	16.7	20.6	913	77	20.7	26
BC-9	16.0	11.3	16.5	9.9	13.6	17.5	21.5	914	79	21.5	27
DC-1	7.5	6.8	8.0	4.6	7.7	9.7	11.5	519	73	9.7	19
DC-2	4.5	5.5	5.6	3.5	5.3	6.6	8.0	556	72	8.1	20
DC-3	5.7	6.2	7.0	4.2	6.5	8.2	9.9	551	72	7.8	25
DC-4	4.5	5.1	5.5	3.7	5.2	6.6	8.1	621	73	9.3	22
DC-6	4.5	5.7	5.8	3.9	5.4	6.8	8.3	685	71	8.7	22
DC-7	4.5	6.8	7.4	4.7	6.0	7.6	9.3	669	67	4.6	23
ER-2	18.3	18.4	17.8	12.6	17.3	22.8	28.3	1341	107	31.5	39
ER-3	16.0	15.4	16.5	11.8	16.0	21.1	26.2	1203	90	16.4	26
ER-4	16.0	16.4	16.8	11.7	15.7	20.7	25.7	1379	106	32.0	28
ER-5	16.6	16.6	16.8	11.4	15.3	20.0	24.9	1362	110	34.5	27
ER-6	19.0	16.2	16.4	10.9	14.5	19.0	23.8	1350	110	29.2	23
ER-7	20.0	16.2	16.4	10.7	14.3	18.7	23.4	1333	109	28.1	23
ER-8	20.0	16.6	17.0	10.7	14.9	19.4	24.4	1319	104	23.3	23
ER-9	17.8	15.0	15.3	8.2	11.3	14.7	18.5	1030	108	24.8	23
RL-1	19.8	18.9	16.2	12.4	15.7	19.8	25.1	779	81	23.1	24
RL-3	21.0	18.7	17.2	13.3	16.7	21.2	26.9	946	90	30.5	32
RL-4	21.0	19.2	16.1	12.6	15.6	19.8	25.0	914	87	28.1	31
RL-5	18.2	17.1	14.4	11.6	14.4	18.2	22.8	930	92	30.8	31
RL-6	14.0	15.6	13.3	10.9	13.8	17.3	21.5	922	94	33.3	30
RL-8	12.3	12.4	11.7	9.9	12.5	15.7	19.2	776	88	25.9	25

Table C.1.5 Land Cover Variables -- Original Units

Site	%GS	%CC	%WL	%GSCC	%GCW	Aspect[1]
BC-1	1.0%	5.6%	5.0%	6.6%	11.6%	289.30 (W)
BC-11	0.0%	0.0%	11.1%	0.0%	11.1%	144.20 (SE)
BC-2	0.0%	11.3%	2.6%	11.3%	14.0%	244.61 (SW)
BC-3	0.0%	16.1%	0.3%	16.1%	16.4%	236.43 (SW)
BC-4	7.7%	2.5%	3.9%	10.2%	14.1%	125.23 (SE)
BC-5	5.6%	4.5%	0.9%	10.1%	11.0%	121.27 (SE)
BC-6	6.3%	3.1%	2.5%	9.4%	11.9%	125.96 (SE)
BC-7	0.0%	1.5%	4.1%	1.5%	5.5%	303.42 (NW)
BC-8	0.3%	0.0%	2.0%	0.3%	2.3%	290.68 (W)
BC-9	1.1%	0.0%	9.7%	1.1%	10.8%	254.49 (W)
DC-1	0.0%	2.6%	10.1%	2.6%	12.7%	173.10 (S)
DC-2	0.0%	11.3%	6.6%	11.3%	17.9%	64.47 (NE)
DC-3	0.0%	10.5%	6.8%	10.5%	17.3%	27.00 (NE)
DC-4	0.0%	0.7%	8.2%	0.7%	8.9%	154.32 (SE)
DC-6	0.0%	15.7%	6.9%	15.7%	22.5%	325.46 (NW)
DC-7	0.0%	5.0%	4.3%	5.0%	9.3%	216.32 (SW)
ER-2	0.0%	0.0%	5.5%	0.0%	5.5%	29.58 (NE)
ER-3	0.0%	0.0%	2.7%	0.0%	2.7%	38.40 (NE)
ER-4	0.0%	0.0%	0.5%	0.0%	0.5%	48.76 (NE)
ER-5	0.0%	0.0%	2.2%	0.0%	2.2%	63.36 (NE)
ER-6	0.0%	0.0%	5.9%	0.0%	5.9%	59.38 (NE)
ER-7	0.0%	0.0%	0.4%	0.0%	0.4%	43.48 (NE)
ER-8	0.0%	0.0%	1.3%	0.0%	1.3%	184.97 (S)
ER-9	-	-	-	-	-	-
RL-1	0.1%	11.6%	5.2%	11.7%	16.9%	
RL-3	0.0%	3.2%	10.7%	3.2%	13.8%	36.21 (NE)
RL-4	0.0%	12.8%	6.0%	12.8%	18.8%	40.78 (NE)
RL-5	0.8%	11.6%	8.8%	12.4%	21.2%	56.14 (NE)
RL-6	0.2%	9.5%	9.0%	9.7%	18.8%	56.83 (NE)
RL-8	0.1%	2.7%	3.7%	2.8%	6.5%	119.93 (SE)

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[1] In degrees clockwise from north; not used in analysis, provided for reference only.

Table C.1.6 Dependent Variables -- Log10

	Measured Monthly Flow							Adjusted Monthly Flow						
	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs
Site	**MeasOct**	**MeasNov**	**MeasDec**	**MeasJan**	**MeasFeb**	**MeasMar**	**MeasAvg**	**AdjOct**	**AdjNov**	**AdjDec**	**AdjJan**	**AdjFeb**	**AdjMar**	**AdjAvg**
BC-1	1.00	1.10	0.96	0.95	0.90	0.89	0.97	1.15	1.06	1.00	0.97	0.97	1.02	1.03
BC-11	-	-0.24	-	-0.38	-0.42	-0.28	-0.32	-	-0.09	-	-0.34	-0.33	-0.15	-0.21
BC-2	-0.40	-0.33	-0.31	-0.36	-0.32	-0.34	-0.34	-0.23	-0.18	-0.26	-0.32	-0.23	-0.20	-0.24
BC-3	-0.85	-0.72	-0.70	-0.72	-0.74	-0.74	-0.74	-0.69	-0.58	-0.65	-0.68	-0.66	-0.61	-0.64
BC-4	-0.41	-0.15	-0.19	-0.26	-0.21	-0.25	-0.24	-0.24	0.00	-0.15	-0.22	-0.12	-0.12	-0.14
BC-5	-0.39	-0.41	-0.25	-0.57	-0.43	-0.42	-0.40	-0.22	-0.26	-0.21	-0.53	-0.35	-0.29	-0.30
BC-6	-0.11	0.01	-	-0.02	-0.17	-0.05	-0.06	0.06	0.16	-	0.02	-0.09	0.09	0.06
BC-7	0.03	-0.06	-0.09	-0.09	-0.10	-0.12	-0.07	0.20	0.09	-0.04	-0.05	-0.01	0.01	0.04
BC-8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BC-9	-0.66	-0.70	-0.51	-0.42	-0.34	-0.46	-0.50	-0.49	-0.55	-0.46	-0.38	-0.25	-0.33	-0.40
DC-1	-0.17	-0.47	-0.55	-0.54	-0.38	-0.47	-0.41	-0.02	-0.39	-0.42	-0.42	-0.26	-0.32	-0.28
DC-2	-0.65	-0.57	-0.71	-0.62	-0.60	-0.50	-0.60	-0.50	-0.50	-0.58	-0.51	-0.48	-0.34	-0.48
DC-3	-0.07	0.08	0.17	-0.15	0.06	0.26	0.08	0.08	0.15	0.30	-0.04	0.18	0.41	0.21
DC-4	-1.59	-1.49	-1.40	-1.37	-1.57	-1.48	-1.47	-1.49	-1.36	-1.27	-1.25	-1.45	-1.32	-1.35
DC-6	-	-1.09	-1.24	-1.15	-1.16	-0.94	-1.10	-	-1.01	-1.11	-1.03	-1.04	-0.78	-0.98
DC-7	-0.06	-0.02	-0.12	0.04	-0.07	-0.08	-0.05	0.09	0.06	0.01	0.15	0.05	0.08	0.08
ER-2	-	0.29	0.23	0.32	0.17	0.152	0.24	-	0.44	0.35	0.45	0.30	0.25	0.36
ER-3	-	-0.24	-0.43	-0.14	-0.30	-0.514	-0.31	-	-0.10	-0.31	-0.02	-0.17	-0.42	-0.18
ER-4	-	-0.59	-0.61	-0.64	-0.70	-0.676	-0.64	-	-0.45	-0.49	-0.52	-0.57	-0.58	-0.52
ER-5	-	-0.35	-0.33	-0.46	-0.44	-0.539	-0.41	-	-0.20	-0.20	-0.33	-0.31	-0.44	-0.29
ER-6	-	-0.52	-0.50	-0.55	-0.73	-0.738	-0.60	-	-0.37	-0.38	-0.43	-0.60	-0.64	-0.47
ER-7	-	-0.93	-0.93	-0.99	-1.08	-1.119	-1.00	-	-0.79	-0.81	-0.87	-0.95	-1.02	-0.88
ER-8	-	-0.42	-0.47	-0.52	-0.53	-0.460	-0.48	-	-0.27	-0.35	-0.39	-0.40	-0.36	-0.35
ER-9	-	-	-	-	-	-	-	1.2	1.14	1.07	1.03	1.02	1.03	1.09
RL-1	-0.17	-0.19	-0.41	-0.90	-0.46	-0.49	-0.38	0.05	-0.09	-0.34	-0.81	-0.28	-0.30	-0.22
RL-3	-1.15	-1.01	-1.14	-1.13	-1.18	-1.21	-1.13	-0.93	-0.91	-1.06	-1.04	-1.00	-1.01	-0.99
RL-4	-0.13	-0.12	-0.41	-0.49	-0.63	-0.62	-0.35	0.10	-0.02	-0.33	-0.40	-0.44	-0.43	-0.20
RL-5	-0.71	-0.59	-1.05	-1.41	-1.10	-1.12	-0.91	-0.48	-0.49	-0.98	-1.32	-0.92	-0.93	-0.76
RL-6	0.42	0.37	0.26	0.18	0.17	0.20	0.28	0.65	0.47	0.33	0.28	0.36	0.40	0.43
RL-8	-	1.25	-	1.18	-	-	1.21	-	1.40	1.35	1.30	1.28	1.30	1.33

Table C.1.7 Topographic Variables -- Log10

Site	Sq. Mi. Area	Miles Perimeter	Feet TopEl	Feet MiddleEl	Feet BottomEl	Feet MeanEl	Feet RngEl	Feet SDevEl	Ft./Mi. MaxSlp	Ft./Mi. MinSlp	Ft./Mi. RngSlp	Ft./Mi. MeanSlp	Ft./Mi. SDevSlp	sin(Slp)
BC-1	1.58	1.51	4.03	3.97	3.90	3.97	3.45	2.76	3.63	-	3.63	2.98	2.75	-0.75
BC-11	0.33	0.81	4.06	4.02	4.01	4.02	3.11	2.37	3.69	-	3.69	2.89	2.75	-0.84
BC-2	0.43	1.01	4.03	3.96	3.93	3.97	3.34	2.74	3.45	-	3.45	3.02	2.71	-0.71
BC-3	0.30	0.87	4.02	3.98	3.94	3.98	3.23	2.57	3.43	1.49	3.43	2.92	2.58	-0.81
BC-4	0.44	0.92	4.01	3.97	3.95	3.97	3.17	2.36	3.42	-	3.42	2.87	2.65	-0.86
BC-5	0.29	0.77	4.00	3.97	3.95	3.97	3.07	2.33	3.47	-	3.47	2.97	2.64	-0.76
BC-6	0.71	0.99	4.01	3.97	3.94	3.97	3.22	2.39	3.47	-	3.47	2.92	2.66	-0.81
BC-7	0.35	0.95	4.03	3.99	3.94	3.99	3.27	2.65	3.48	-	3.48	2.95	2.63	-0.78
BC-8	-0.78	0.31	3.98	3.97	3.96	3.97	2.66	2.09	3.54	1.49	3.53	3.04	2.92	-0.69
BC-9	0.29	0.84	3.98	3.97	3.97	3.97	2.61	1.92	3.21	-	3.21	2.66	2.40	-1.06
DC-1	0.70	1.01	3.99	3.96	3.94	3.96	2.99	2.20	3.36	-	3.36	2.78	2.55	-0.94
DC-2	0.72	1.01	3.97	3.96	3.95	3.96	2.66	1.89	3.38	-	3.38	2.62	2.46	-1.11
DC-3	1.26	1.33	3.99	3.96	3.93	3.96	3.09	2.21	3.45	-	3.45	2.77	2.58	-0.95
DC-4	0.19	0.75	3.97	3.96	3.95	3.96	2.65	1.78	3.26	-	3.26	2.68	2.47	-1.04
DC-6	0.65	1.02	3.97	3.96	3.95	3.96	2.77	1.88	3.31	-	3.31	2.66	2.46	-1.07
DC-7	1.36	1.38	3.97	3.95	3.92	3.95	2.98	2.32	3.70	-	3.70	2.82	2.61	-0.91
ER-2	1.21	1.36	4.02	3.99	3.91	3.99	3.38	2.70	3.80	-	3.80	3.02	2.79	-0.71
ER-3	0.49	0.91	4.01	3.94	3.92	3.95	3.30	2.70	3.45	-	3.45	3.00	2.66	-0.73
ER-4	0.16	0.69	4.02	3.99	3.96	3.99	3.11	2.50	3.56	1.64	3.55	3.08	2.74	-0.65
ER-5	0.43	0.87	4.02	4.00	3.95	4.00	3.16	2.56	3.53	1.49	3.52	3.06	2.72	-0.67
ER-6	0.10	0.65	4.02	3.98	3.97	3.98	3.07	2.49	3.65	-	3.65	2.99	2.75	-0.74
ER-7	-0.23	0.57	4.01	3.98	3.97	3.98	2.96	2.28	3.41	-	3.41	2.98	2.63	-0.75
ER-8	0.24	0.80	4.00	3.97	3.93	3.97	3.20	2.49	3.49	-	3.49	3.02	2.65	-0.71
ER-9	1.80	1.65	4.05	3.99	3.89	3.99	3.54	2.79	4.12	-	4.12	3.00	2.87	-0.73
RL-1	0.74	1.05	4.04	4.02	3.99	4.02	3.09	2.37	3.55	-	3.55	2.81	2.63	-0.92
RL-3	0.07	0.72	4.02	4.01	3.99	4.01	2.91	2.30	3.28	-	3.28	2.76	2.46	-0.96
RL-4	0.63	0.97	4.05	4.02	3.99	4.02	3.13	2.50	3.42	-	3.42	2.84	2.54	-0.88
RL-5	0.46	0.98	4.05	4.03	4.00	4.03	3.09	2.43	3.60	-	3.60	2.82	2.65	-0.90
RL-6	1.07	1.19	4.05	4.00	3.96	4.00	3.33	2.62	3.52	-	3.52	2.89	2.66	-0.84
RL-8	1.86	-	-	-	-	-	-	-	-	-	-	-	-	-

Table C.1.8 Precipitation Variables -- Log10

	Inches	Inches	Inches	Inches	Inches	Inches	Inches	mm	cm	Inches	Inches
Site	**Proximity**	**TIN**	**IDW**	**JanLTIDW**	**FebLTIDW**	**MarLTIDW**	**AprLTIDW**	**Prism**	**Daymet**	**ApAvPrec**	**MapPrec**
BC-1	1.14	1.07	1.19	0.95	1.09	1.21	1.30	2.95	1.90	1.33	1.45
BC-11	1.23	1.24	1.21	1.03	1.16	1.25	1.35	2.95	1.99	1.51	1.48
BC-2	1.11	1.04	1.15	0.87	1.03	1.15	1.24	2.93	1.90	1.30	1.40
BC-3	1.26	1.11	1.21	0.94	1.07	1.19	1.29	2.97	1.93	1.37	1.45
BC-4	1.20	1.01	1.20	0.94	1.08	1.19	1.29	2.95	1.89	1.33	1.36
BC-5	1.03	1.02	1.18	0.92	1.06	1.18	1.27	2.93	1.88	1.30	1.28
BC-6	1.14	1.01	1.19	0.93	1.08	1.19	1.28	2.94	1.88	1.32	1.34
BC-7	1.20	1.07	1.21	0.98	1.11	1.23	1.32	2.99	1.91	1.40	1.48
BC-8	1.20	1.01	1.21	0.97	1.11	1.22	1.31	2.96	1.89	1.31	1.41
BC-9	1.20	1.05	1.22	1.00	1.13	1.24	1.33	2.96	1.90	1.33	1.43
DC-1	0.88	0.83	0.90	0.66	0.89	0.98	1.06	2.72	1.86	0.98	1.28
DC-2	0.65	0.74	0.75	0.54	0.72	0.82	0.91	2.75	1.86	0.91	1.30
DC-3	0.76	0.80	0.85	0.62	0.82	0.91	0.99	2.74	1.86	0.89	1.40
DC-4	0.65	0.71	0.74	0.57	0.72	0.82	0.91	2.79	1.86	0.97	1.34
DC-6	0.65	0.76	0.77	0.60	0.73	0.83	0.92	2.84	1.85	0.94	1.34
DC-7	0.65	0.83	0.87	0.67	0.78	0.88	0.97	2.83	1.83	0.66	1.36
ER-2	1.26	1.26	1.25	1.10	1.24	1.36	1.45	3.13	2.03	1.50	1.59
ER-3	1.20	1.19	1.22	1.07	1.20	1.33	1.42	3.08	1.95	1.22	1.41
ER-4	1.20	1.22	1.22	1.07	1.20	1.32	1.41	3.14	2.02	1.50	1.45
ER-5	1.22	1.22	1.22	1.06	1.18	1.30	1.40	3.13	2.04	1.54	1.43
ER-6	1.28	1.21	1.22	1.04	1.16	1.28	1.38	3.13	2.04	1.47	1.36
ER-7	1.30	1.21	1.21	1.03	1.16	1.27	1.37	3.12	2.04	1.45	1.36
ER-8	1.30	1.22	1.23	1.03	1.17	1.29	1.39	3.12	2.02	1.37	1.36
ER-9	1.30	1.28	1.21	1.09	1.20	1.30	1.40	2.89	1.91	1.36	1.38
RL-1	1.32	1.27	1.24	1.12	1.22	1.33	1.43	2.98	1.96	1.48	1.51
RL-3	1.32	1.28	1.21	1.10	1.19	1.30	1.40	2.96	1.94	1.45	1.49
RL-4	1.26	1.23	1.16	1.07	1.16	1.26	1.36	2.97	1.96	1.49	1.49
RL-5	1.15	1.19	1.13	1.04	1.14	1.24	1.33	2.96	1.97	1.52	1.48
RL-6	1.09	1.09	1.07	0.99	1.10	1.19	1.28	2.89	1.95	1.41	1.40
RL-8	1.25	1.17	1.19	0.92	1.05	1.17	1.27	3.01	2.03	1.39	1.36

Table C.1.9 Land Cover Variables -- Log10

Site	%GS	%CC	%WL	%GSCC	%GCW
BC-1	-1.98	-1.25	-1.31	-1.18	-0.94
BC-11	-	-	-0.96	-	-0.96
BC-2	-	-0.95	-1.58	-0.95	-0.86
BC-3	-	-0.79	-2.48	-0.79	-0.78
BC-4	-1.11	-1.60	-1.41	-0.99	-0.85
BC-5	-1.25	-1.35	-2.03	-1.00	-0.96
BC-6	-1.20	-1.51	-1.61	-1.03	-0.93
BC-7	-	-1.83	-1.39	-1.83	-1.26
BC-8	-2.60	-	-1.69	-2.60	-1.64
BC-9	-1.96	-	-1.01	-1.96	-0.97
DC-1	-	-1.59	-1.00	-1.59	-0.90
DC-2	-	-0.95	-1.18	-0.95	-0.75
DC-3	-	-0.98	-1.17	-0.98	-0.76
DC-4	-	-2.15	-1.09	-2.15	-1.05
DC-6	-	-0.81	-1.16	-0.81	-0.65
DC-7	-	-1.30	-1.36	-1.30	-1.03
ER-2	-	-	-1.26	-	-1.26
ER-3	-	-	-1.58	-	-1.58
ER-4	-	-	-2.28	-	-2.28
ER-5	-	-	-1.66	-	-1.66
ER-6	-	-	-1.23	-	-1.23
ER-7	-	-	-2.40	-	-2.40
ER-8	-	-	-1.88	-	-1.88
ER-9	-3.20	-0.94	-1.28	-0.93	-0.77
RL-1	-	-1.50	-0.97	-1.50	-0.86
RL-3	-	-0.89	-1.22	-0.89	-0.73
RL-4	-2.12	-0.93	-1.06	-0.91	-0.67
RL-5	-2.67	-1.02	-1.04	-1.01	-0.73
RL-6	-3.07	-1.56	-1.43	-1.55	-1.19
RL-8	-	-	-	-	-

Appendix C.2

Description of Variables

by
Lawrence M. Ostresh, Jr., PhD

Dependent Variables

Measured Flow – primary data collected by Lowham and Brinkman; see Appendix A for methods used; units = cfs.

- **MeasOct, MeasNov, MeasDec, MeasJan, MeasFeb,** and **MeasMar** – measured mid-month discharge, October through March. Sites in the North Brush Creek drainage, and Nash Fork, were measured in the winter of 2000 – 2001; remaining sites were measured in the winter of 2001 – 2002.
- **MeasAvg** – Arithmetic mean of the monthly data. In cases of missing data, a mean was calculated based on available data, with no further adjustment.

Adjusted Flow – the measured values were adjusted by the concurrent-measurement method described in the main body of this document, using USGS gauge data downloaded from USGS Real-Time Data for the Nation website; units = cfs.

- **AdjOct, AdjNov, AdjDec, AdjJan, AdjFeb,** and **AdjMar** – adjusted mid-month discharge, October through March.
- **AdjAvg** – Arithmetic mean of the monthly data. In cases of missing data, a mean was calculated based on available data, with no further adjustment.

Measures of Basin Size

Basin boundaries upstream of the measurement sites were delimited by Ostresh as a set of digitized points, and then converted to polygons by Riley. The points and polygons were captured using heads-up digitizing with ArcView© software by ESRI. Digital Raster Graphics – Enhanced (DRG-Es) created by Beartooth Mapping, Inc. from USGS Digital Raster Graphics (DRGs) of 1:24,000 quadrangles were the source data. The DRG-Es were downloaded from a website maintained by the Wyoming Geographic Information Advisory Council (WGIAC). Where possible, the boundaries so delimited were checked against those delimited by Steeves, Peter and Douglas Nebert; 19948, Hydrologic units map of Wyoming, modified from USGS fourth level units, USGS, and downloaded from a website maintained by the University of Wyoming Geographic Information Science Center (WyGISC).

Area (square miles) and **Perimeter** (miles) were calculated using ArcView©.

Measures of Basin Topography

A Digital Elevation Model (DEM) from the 30 meter National Elevation Dataset, 1999, USGS EROS Data Center, was downloaded from the WyGISC website. This was used with the ArcView© Spatial Analyst extension and the basin polygons to calculate the following measures for each basin:

Elevation: TopEl, MiddleEl, BottomEl, MeanEl, RngEl, SDevEl – top, middle, bottom, mean, range, and standard deviation of the DEM within each basin. The top elevation is the highest point of the DEM within the basin – in all cases on the basin divide. The bottom is the lowest point – in all cases the same elevation as the discharge measurement site. MiddleEl is halfway between the top and bottom elevations; RngEl is the difference in elevation between the top and bottom. Units are feet.

Slope: MaxSlp, MinSlp, RngSlp, MeanSlp, SDevSlp – the maximum, minimum, range, mean and standard deviation of slopes within each basin, calculated from the DEM by ArcView©; units are feet per mile. An additional slope measure, **sin(Slp)** – trigonometric sine (unitless) – was calculated directly from the mean slope. In most of the basins, minimum slope was zero, and thus its logarithm is undefined. It was not used for analysis. A value of zero for minimum slope also implies that in most cases **RngSlp** is the same as **MaxSlp**.

Aspect – average basin aspect, calculated by ArcView©; in degrees clockwise from north. It was not used in the regression analysis, but was reviewed by the investigators as a potential reason why some basins had higher yields than others. No obvious relationship was found.

Measures of Basin Precipitation

The following three variables are derived from "current year" precipitation values for SNOTEL/snowcourse sites in the vicinity of our study area. The data may be freely downloaded from a Web site maintained by the Natural Resources Conservation Service (NRCS), US Department of Agriculture. Mr. Dave Taylor (NRCS, Casper, WY) provided additional data and information. April, 2001, Snow Water Equivalent (SWE) was used for sites whose flow was measured during the winter of 2000 – 2001; April, 2002, SWE, was used for all other sites. The point data was then gridded using several different methods available in ArcView© and basin averages were calculated; the grid resolution is 30 meters; units are inches:

- **Proximity** – grid value is that of the nearest recording station.
- **TIN** – a Triangular Irregular Network (TIN) was created for the recording station points; the TIN was then converted to a grid.
- **IDW** – Inverse Distance Weighting method of gridding; default values were used for the exponent and other parameters.

The following four variables are derived from long-term precipitation SWE values for SNOTEL, snowcourse and weather stations in the vicinity of our study area. In general "long-term" refers to the collection period 1971 to 2000, but in some cases the record was incomplete. I then used the longest available period. The point values were gridded using IDW and basin averages were calculated; grid resolution is 30 meters; units are inches:

- **JanLTIDW** – uses January SWE.
- **FebLTIDW** – uses February SWE.
- **MarLTIDW** – uses March SWE.
- **AprLTIDW** – uses April SWE.

Prism – This is derived from the PRISM (**P**arameter-elevation **R**egressions on **I**ndependent **S**lopes **M**odel) developed at the Spatial Climate Analysis Service, Oregon State University. PRISM uses long-term annual precipitation values in a model that explicitly incorporates elevation and windward/leeward effects. It is a national data set available as a grid with a 4 kilometer resolution; the Wyoming portion may be freely downloaded from the WyGISC web site. I resampled the grid to a 30 meter resolution then calculated basin averages.

Daymet – This is similar to the PRISM model but has a finer (1 kilometer) resolution. It is based on long-term annual precipitation values, was developed at the Numerical Terradynamic Simulation Group, School of Forestry, University of Montana, and is available for free download on the web. I resampled the grid to a 30 meter resolution then calculated basin averages.

ApAvPrec – This is based on long-term SNOTEL/snowcourse April SWE data and its relationship to elevation. The text in this appendix gives a detailed explanation of its derivation.

MapPrec – James Riley derived these values from a map of Wyoming annual precipitation by J.D. Alyea, 1980, reprinted in H. Lowham, *Streamflows in Wyoming, Water Resources Investigations Report 88-4045*, Plate 1, 1988, Cheyenne. The scale of the map used was approximately 1:1,700,000.

Measures of Basin Land Cover

These variables were added because preliminary visual and statistical analysis suggested that "barelands" (i.e., unforested land) were a factor in basin discharge. Further analysis, as described in the body of this Appendix, casts doubt on this early supposition.

%WL – percentage of each basin that is a designated "wetland" (including lakes and ponds) in the National Wetlands Inventory (NWI), 1997, US Fish & Wildlife Service; ArcView© NWI shapefiles for Wyoming are available for free download from WyGISC.

%CC – percentage of each basin designated as a clearcut in an ArcInfo file made available by the US Forest Service, Medicine Bow-Route Division, Laramie, Wyoming. The file includes the date of the clearcut; only those harvested in 1960 or later were used. In many basins this value was zero; its logarithm is undefined and the variable was not directly used.

%GC – percentage of each basin interpreted as "group selection" clearcuts. These were not part of the Forest Service clearcut file; they were created by Ostresh using heads up digitizing of Digital Orthophoto Quarter Quads created by USGS and available for free download from WyGISC. In most basins this value was zero; its logarithm is undefined and the variable was not directly used.

%GSCC – the sum of **%GS** and **%CC** (percentage any type of clearcut). In many basins this value was zero; its logarithm is undefined and the variable was not directly used.

%GCW – the sum of **%GS, %CC** and **%WL**; an estimate of the percentage of unforested land, whether natural (wetlands) or man-created (clearcuts).

Gridding Winter Precipitation Data in Wyoming Mountains

Lawrence M. Ostresh, Jr.
James D. Riley
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Hugh Lowham
Lowham Consulting

Bruce Brinkman
Adjunct Professor, U. Wyoming

Presented at the Great Plains/Rocky Mountain Division
of the Association of American Geographers
Missoula, MT., October, 2002.
Poster Session, presented by Ostresh.

Contents

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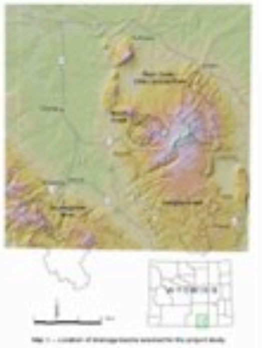

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Winter Precipitation Recording Stations

Model: We assume that over an extended period of time, the volume of water leaving a basin equals the volume leaving it. If human or natural trans-basin diversions are not a factor, then

VIn = Area * Prec

where
VIn = Volume of water in
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Prec = Average basin precipitation

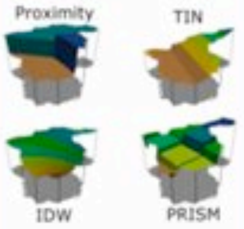
The volume of water leaving the basin does so as flow, as evapotranspiration, or as groundwater recharge. In the winter, most of it accumulates as snow. The simplest water balance models for winter base flow are:

FOut = c * VIn (proportional)
FOut = a + b * VIn (linear)

where
FOut is stream flow at the measurement site
a, b, and c are empirical constants

Gridding Methods Applied to Brush Creek Drainage

(From SW; vertical scale varies)



Goodness of Fit

Of the various precipitation gridding methods in the equation

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Method	Corr. Coeff.	
	Linear	Log10
Proximity	.89	(.89)
TIN	.84	(.85)
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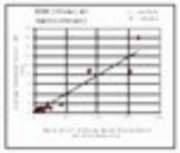
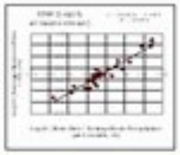
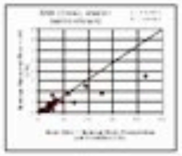
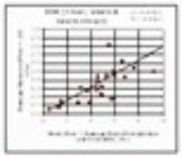
Often it is not possible to choose among competing gridding methods. In our case, however, we could choose the method that best fit the previously discussed water balance model. We used the Correlation Coefficient (RSQ) as our criterion. IDW gave the best fit, but the other methods gave nearly as good results.

We also tested the goodness of fit for the PRISM* (Parameter-elevation Regressions on Independent Slopes Model) precipitation model for Wyoming. This method has the advantage of explicitly accounting for the effect of elevation on precipitation, but the drawback of (currently) only being available for annual long-term averages. Results of the RSQ testing are shown in the table to the left (the values in parentheses are for logarithmic versions of the equations).









Cassidy Creek – High yield

Are CLEARCUTS bad for trout?

Are WETLANDS bad for trout?

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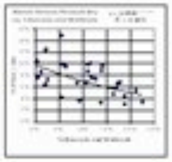

Results: The graphs above plot the relationship of **FOut** with **VIn** using average basin precipitation estimated from the **IDW** gridding method. **FOut** is the average of the monthly measured streamflows (cfs) in the various basins. An "offset" of .05 cfs is added in; its purpose is to recognize that a certain minimum volume of precipitation into a basin is required before flow will occur. Its value is based on an examination of our two smallest basins (the smallest had no flow, the other did). SNOTEL and snowcourse data are available monthly, January to June. We used the April 1 water content data, whose accumulation roughly coincides with the October to March collection period of the streamflows. Basin area multiplied by precipitation for a time period yields a volume per time period. We converted this product to cfs so that **VIn** and **FOut** would be measured in the same units.

Thus, **winter base flow = 8% winter precipitation.**

Patton Creek – Low yield

Mill Creek – Low yield

Gridding Winter Precipitation Data in Wyoming Mountains

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Map 1. -- Location of drainage basins selected for the project study.

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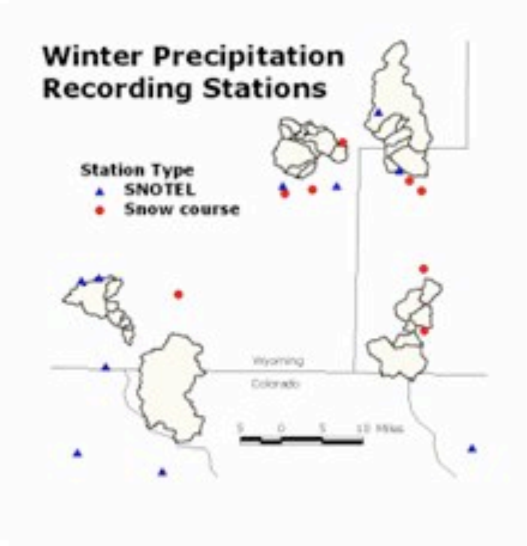

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Area = Basin area
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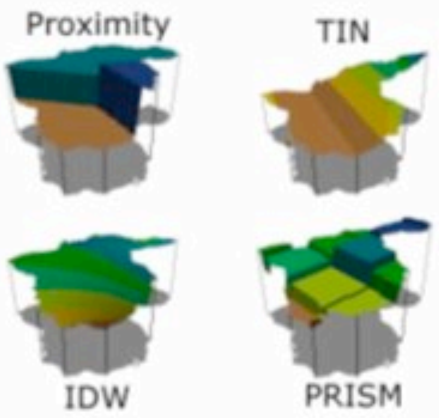
(From SW; vertical scale varies)



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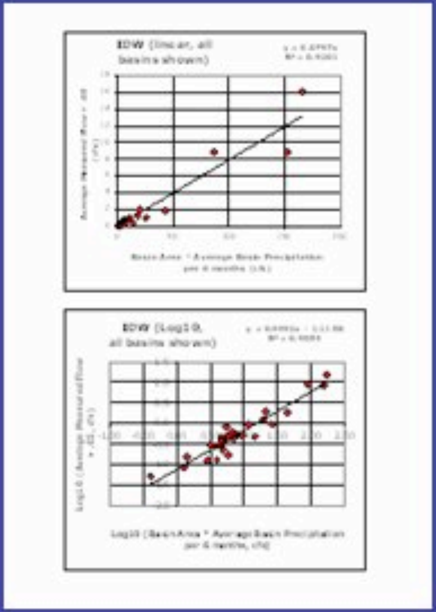
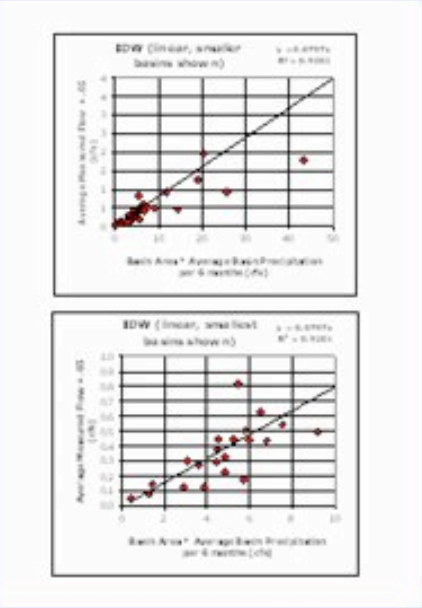
[illegible]





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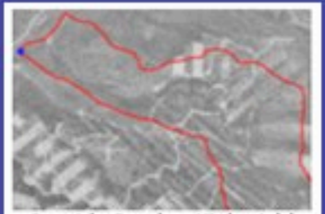

Cassidy Creek – High yield

Clearcuts pre-date 1960, except for two strips on northern drainage divide

Are CLEARCUTS bad for trout?

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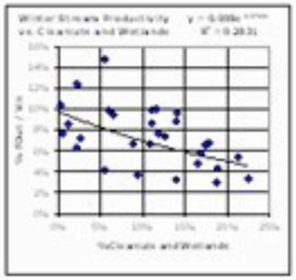
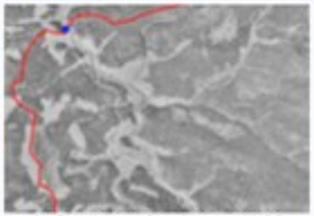
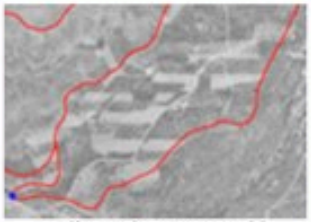




Pelton Creek – Low yield

Numerous wetlands and sagebrush meadows, particularly along the main watercourse.



Mill Creek – Low yield

Numerous clearcuts throughout the drainage.

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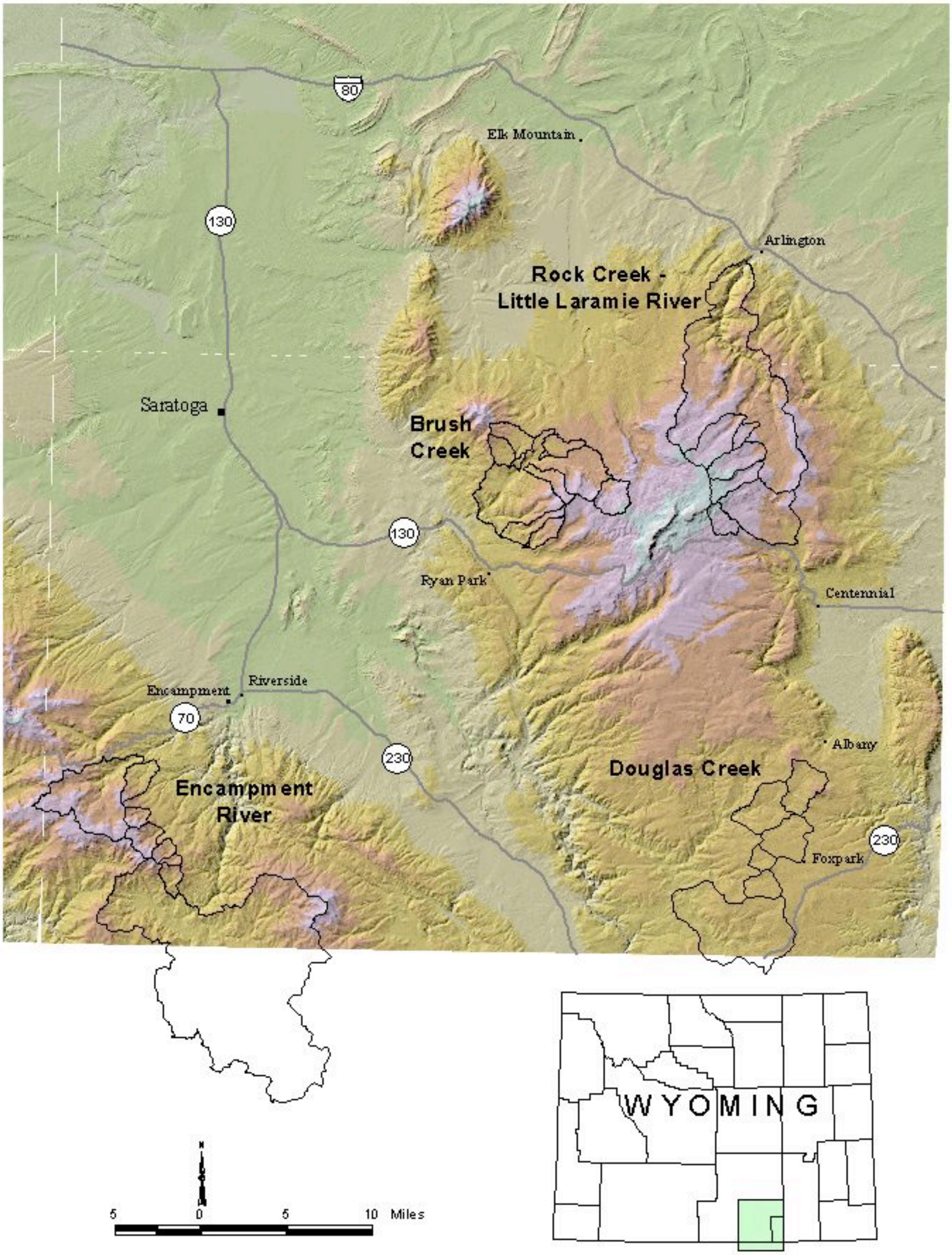

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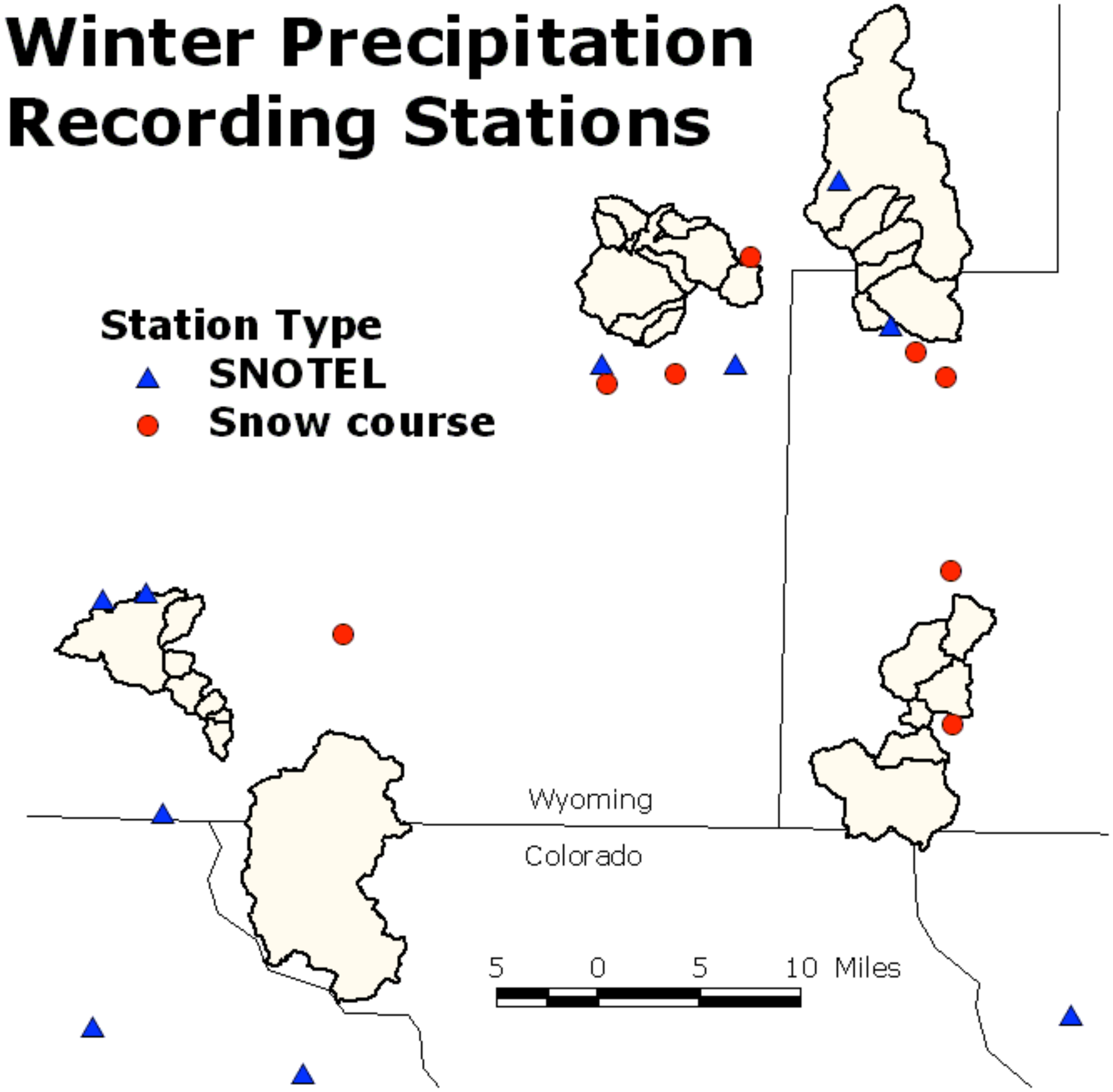

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Gridding Methods Applied to Brush Creek Drainage

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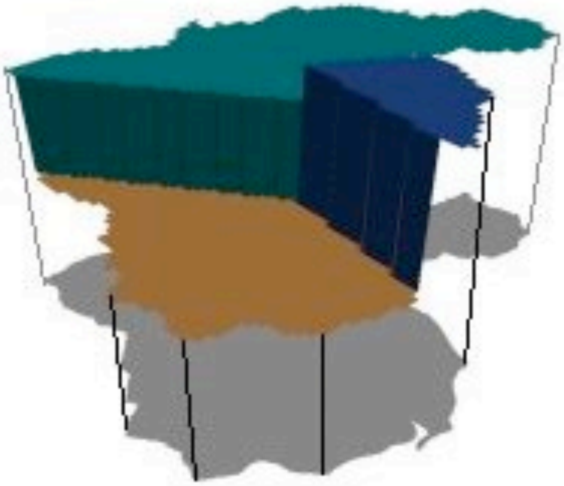
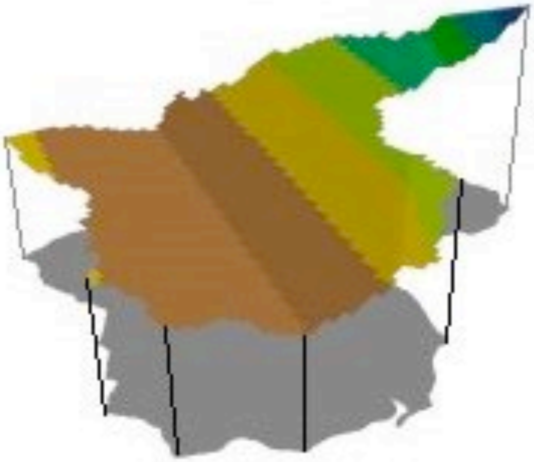
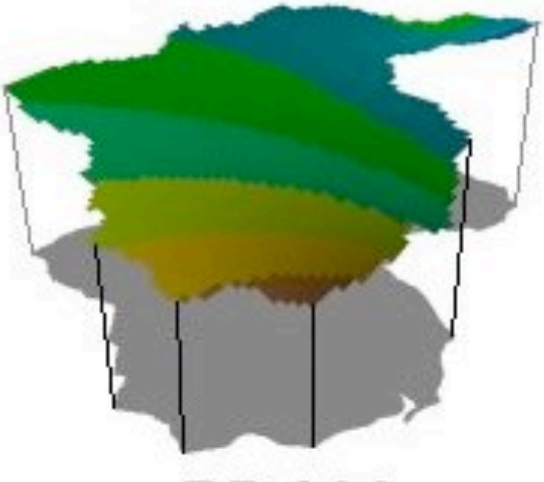


TIN





IDW

PRISM

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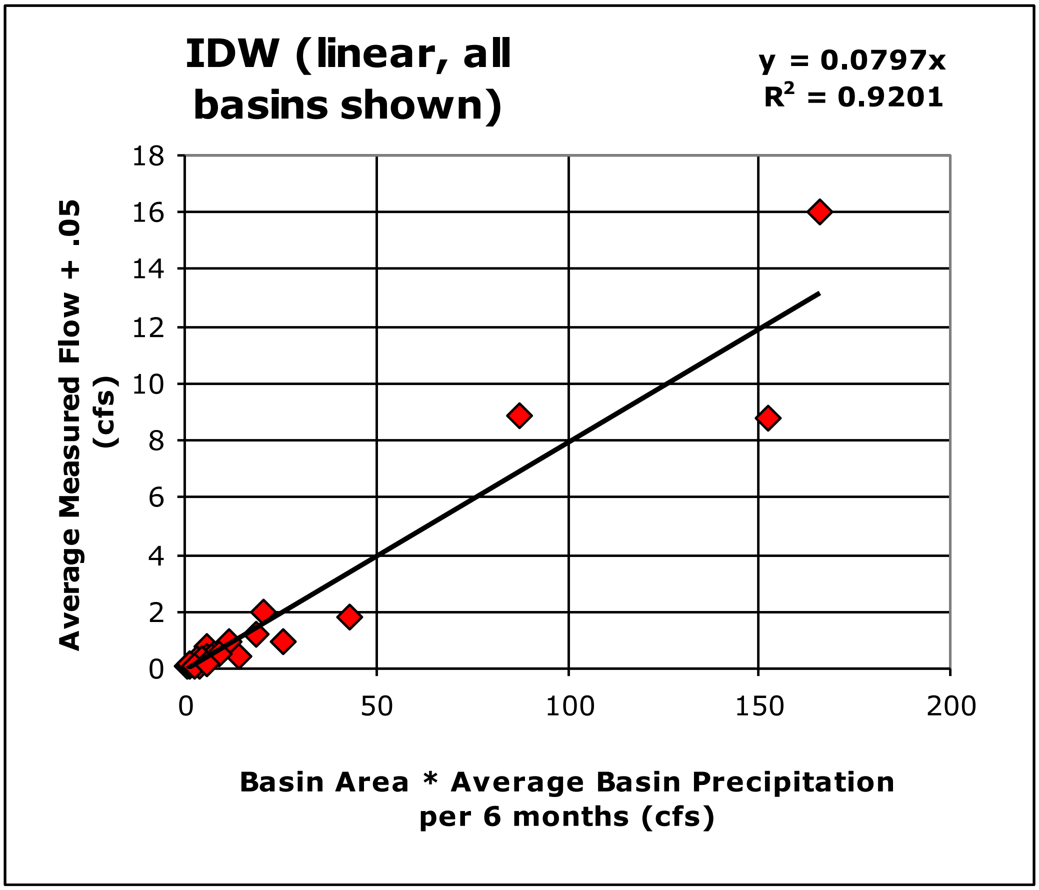
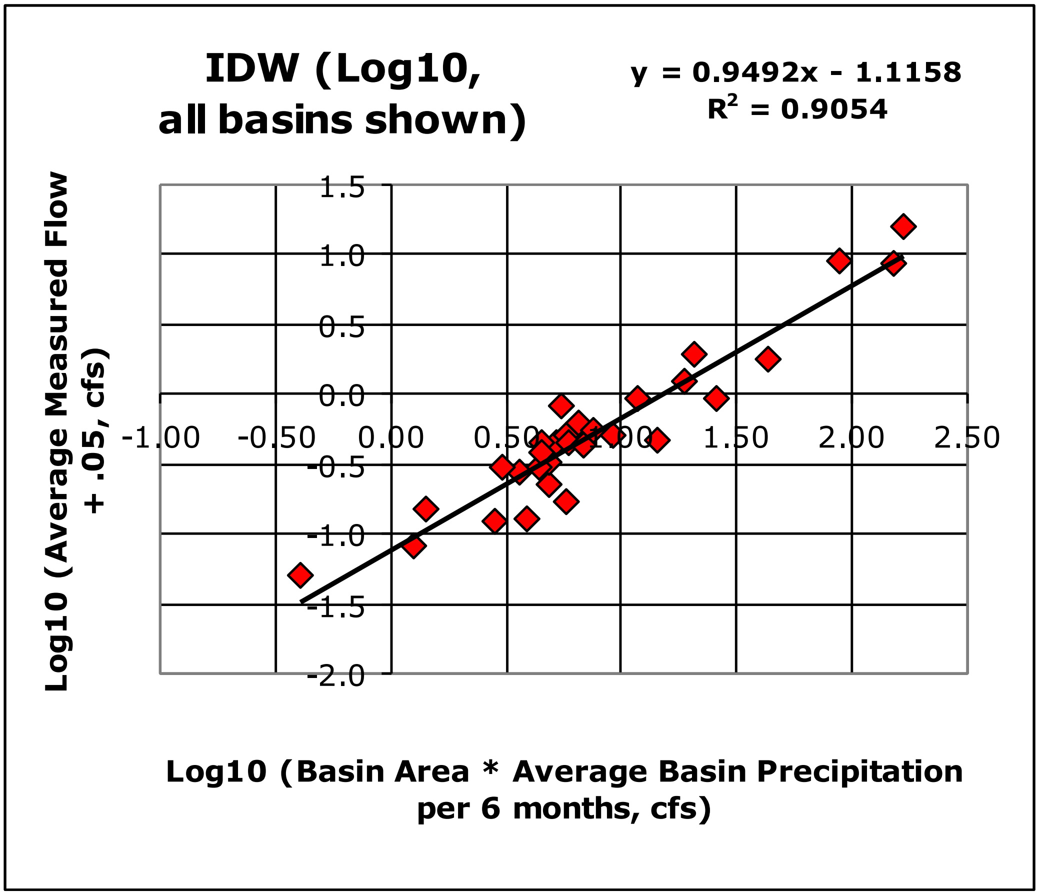
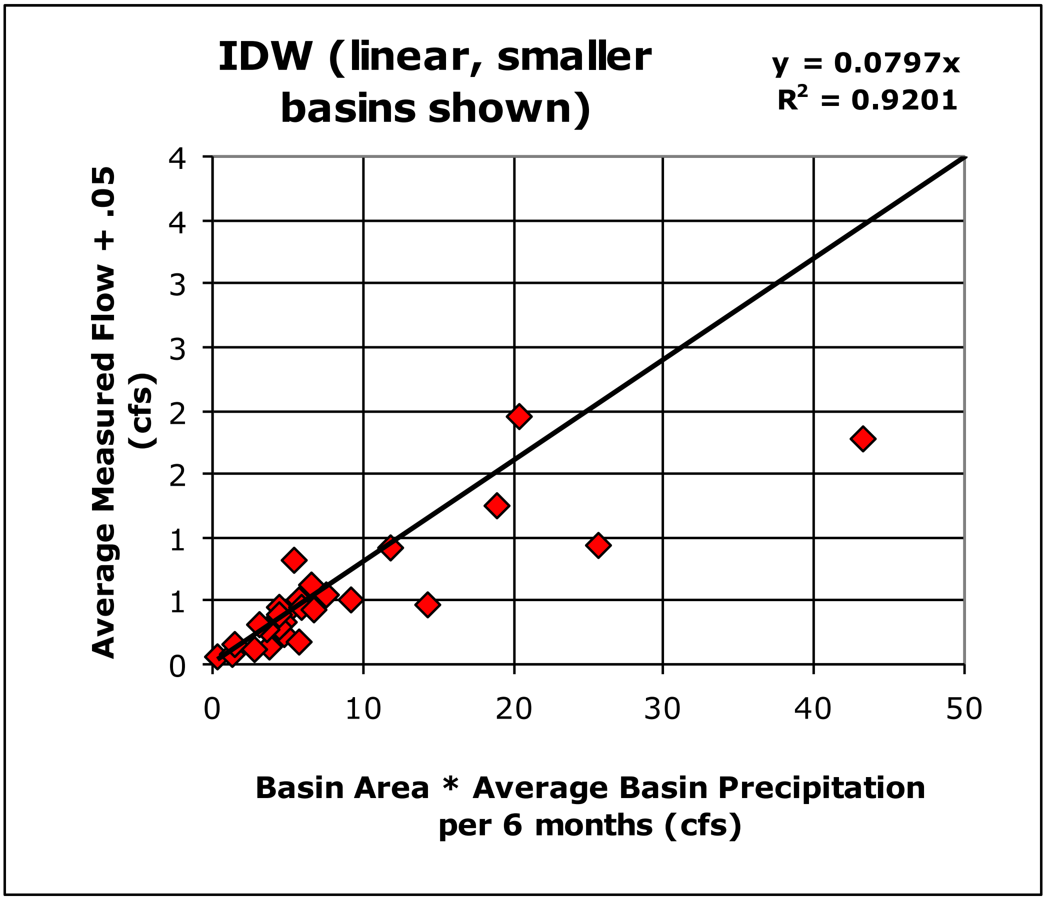
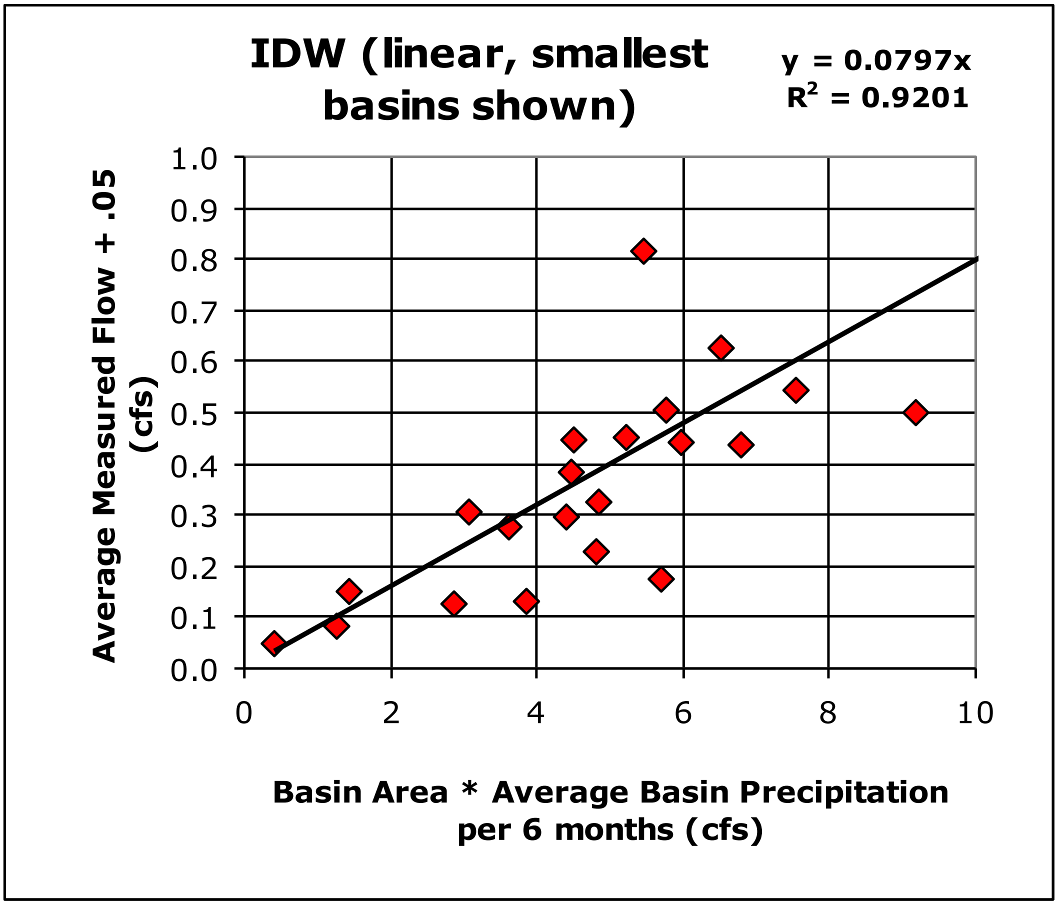

IDW (linear, all basins shown)
y = 0.0797x
R2 = 0.9201
Average Measured Flow + .05 (cfs)
Basin Area * Average Basin Precipitation per 6 months (cfs)
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200


IDW (Log10, all basins shown)
y = 0.9492x - 1.1158
R^2 = 0.9054
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
Log10 (Average Measured Flow + .05, cfs)
Log10 (Basin Area * Average Basin Precipitation per 6 months, cfs)


IDW (linear, smaller basins shown)
y = 0.0797x
R^2 = 0.9201
4
4
3
3
2
2
1
1
0
0
10
20
30
40
50
Average Measured Flow + .05 (cfs)
Basin Area * Average Basin Precipitation per 6 months (cfs)


IDW (linear, smallest basins shown)
y = 0.0797x
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Average Measured Flow + .05 (cfs)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
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Results: The graphs above plot the relationship of **FOut** with **VIn** using average basin precipitation estimated from the **IDW** gridding method. **FOut** is the average of the monthly measured streamflows (cfs) in the various basins. An "offset" of .05 cfs is added in; its purpose is to recognize that a certain minimum volume of precipitation into a basin is required before flow will occur. Its value is based on an examination of our two smallest basins (the smallest had no flow, the other did). SNOTEL and snowcourse data are available monthly, January to June. We used the April 1 water content data, whose accumulation roughly coincides with the October to March collection period of the streamflows. Basin area multiplied by precipitation for a time period yields a volume per time period. We converted this product to cfs so that **VIn** and **FOut** would be measured in the same units.

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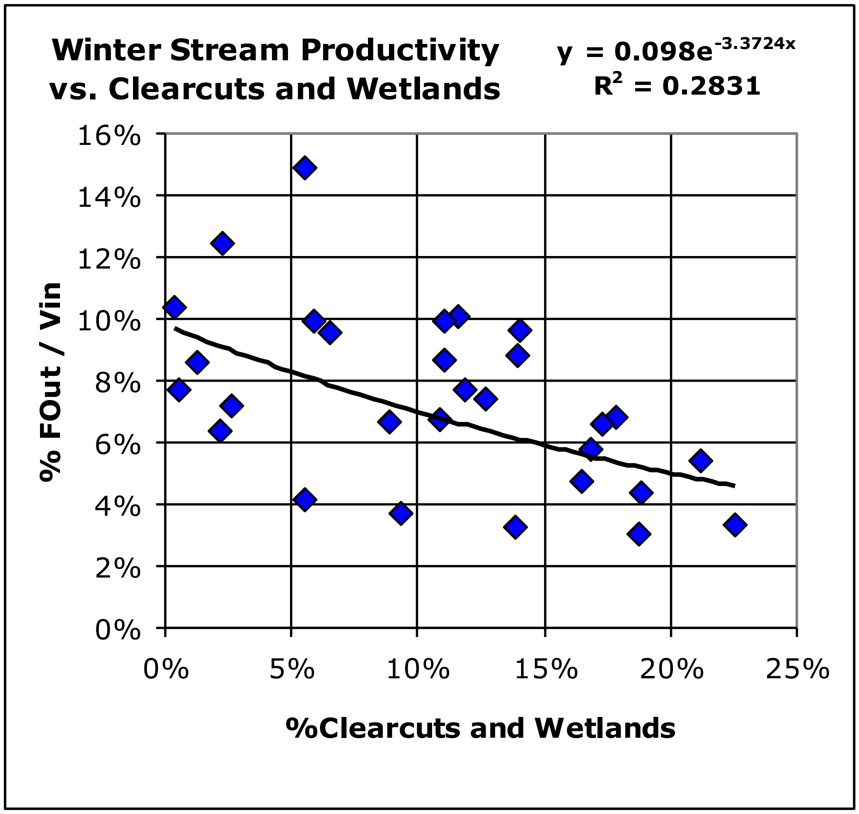
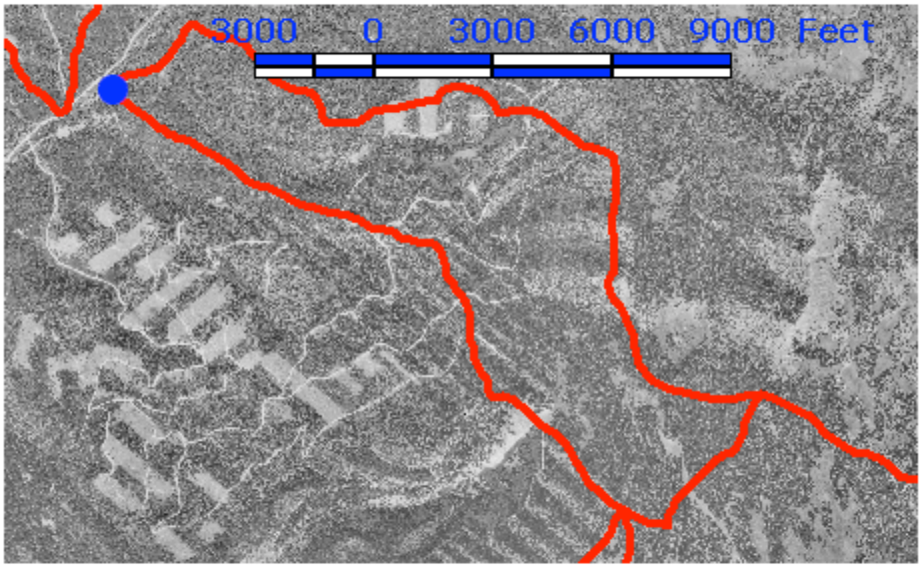
Are CLEARCUTS bad for trout?

Are WETLANDS bad for trout?

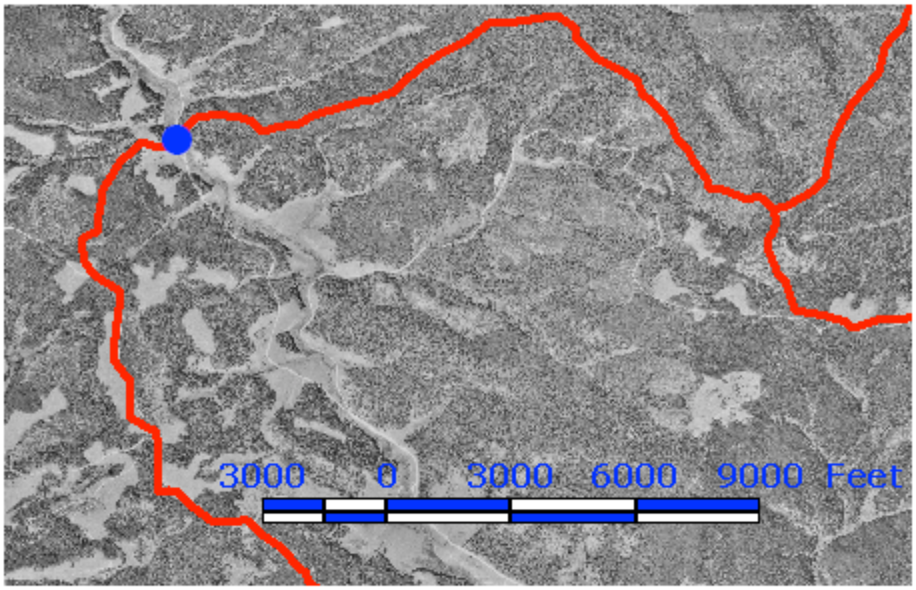
Some of the variation in the graphs to the left may be attributable to the percentage of clearcuts and wetlands in the basins. Ask the presenter for details.





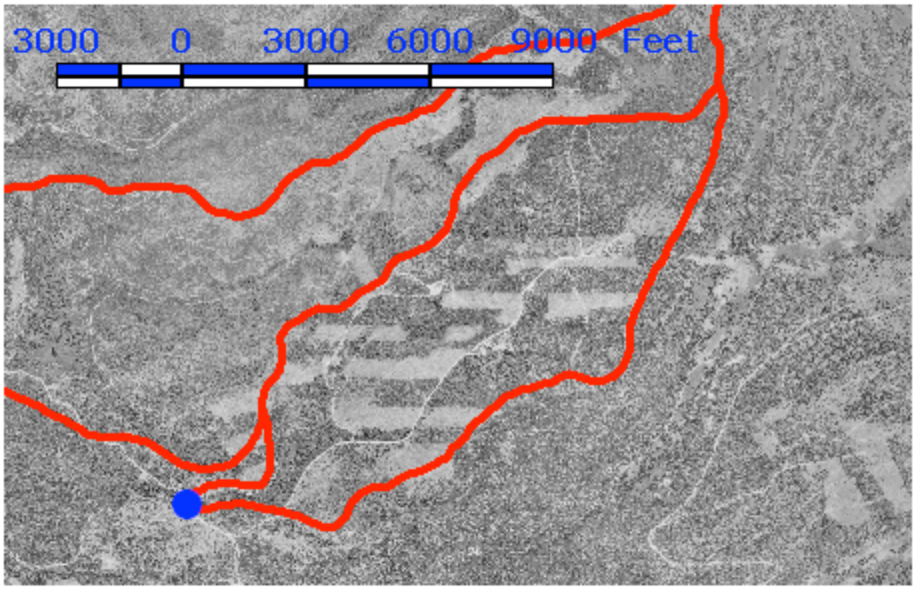
Cassidy Creek -- High Productivity

Clearcuts predate 1960, except for
two strips along the northern divide



Pelton Creek -- Low Productivity

Numerous wetlands and sagebrush meadows,
particularly along the main watercourse.



Mill Creek -- Low Productivity

Numerous clearcuts throughout the drainage.

Effect of Land Cover on Winter Streamflow in Southeastern Wyoming Mountains

Lawrence M. Ostresh, Jr.
James D. Riley
Dept. of Geography, U. Wyoming

Bruce Brinkman
Adjunct Professor, U. Wyoming

Hugh Lowham
Lowham Consulting

Presented at the National meetings
of the Association of American Geographers
New Orleans, LA, March 2003
Poster Session, presented by Ostresh.

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Abstract: Winter low-flow stream discharge in the Medicine Bow and Sierra Madre mountains of Southeastern Wyoming appears to be affected by landcover in the stream catchment areas. Basins with large amounts of non-forested areas, whether natural such as wetlands and sagebrush meadows, or human-caused such as clearcuts, appear to reduce winter discharge; forest cover increases it.

Map 1 – Location of drainage basins selected for the project study.

Introduction: When streamflow information is needed for mountainous basins, especially for low flows that occur during the winter months, there often is very little recorded data available. Most gaging stations are located on streams at lower elevations out of the mountainous areas. The ideal situation for planning water-related projects is to have long-term data available for nearby gaging stations, but if this is not the case then estimates of streamflows are useful.

This project is a joint research project of the Wyoming Water Development Commission, University of Wyoming, and the U.S. Geological Survey to analyze flow determination methods of mountain streams in the winter months. The project officially began July 1, 2000.

Data: Lowham and Brinkman measured stream flow (**FOut**) at a variety of sites in Wyoming's Medicine Bow and Sierra Madre mountains during the winters of 2000 – 01 and 2001 – 02. They did this monthly from October to March, using snow mobiles (and sometimes snowshoes) to access the remote locations. Riley and Ostresh delimited the basins upstream of the measurement sites (**Area**) using Enhanced Digital Raster Graphics of USGS 1:24,000 quads. They also estimated average basin precipitation (**Prec**) by gridding point data from SNOTEL (SNOwpack TElemetry) and snowcourse stations maintained by the Natural Resources Conservation Service.

Analysis: We use the term "winter productivity" (or simply "productivity") to refer to the ratio

FOut / VIn

Where:
FOut is adjusted measured flow[1]
VIn is the product of basin area and precipitation[2]

Both **FOut** and **VIn** are volumes of water per unit time, so their ratio, productivity, is unitless. Productivity varies considerably from basin to basin, from a low of under 2% to a high of over 16%. What accounts for this variability?

To answer this, we examined a number of factors such as geology, vegetation cover, and soils, as well as basin topographic properties such as elevation, slope, and aspect. Morphometric indices were also considered.

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[1] The adjustment is made basin wide using a nearby USGS gaging station. The purpose is obtain a long term average of flows by compensating for wet or dry years. Ask the presenter for details.

[2] Precipitation is estimated by gridding long-term March SNOTEL/snowcourse data.

Model: We assume that over an extended period of time, the volume of water leaving a basin equals the volume entering it. If human or natural trans-basin diversions are not a factor, then

VIn = Area * Prec

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Prec = Average basin precipitation

The volume of water leaving the basin does so as flow, as evapotranspiration, or as groundwater recharge. In the winter, in Wyoming, most of it accumulates as snow. The simplest water balance models for winter base flow are:

FOut = c * VIn (proportional)
FOut = a + b * VIn (linear)

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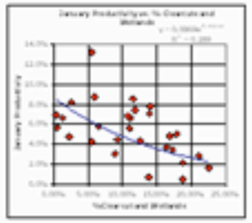
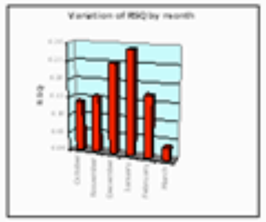
a, b, and c are empirical constants

One possible factor for explaining the variation in productivity is land cover, more specifically the presence or absence of forest: Basins with large amounts of non-forested areas, whether natural such as wetlands and sagebrush meadows, or human-caused such as clearcuts, appear to reduce winter productivity; forest cover increases it. An example is shown below:



Discussion: Winter stream productivity appears to be related to land cover: As percentage non-forested area increases, productivity decreases. The effect varies by month, however, as seen in the following graph – the relationship is weak in October, peaks in January, and all but disappears by March.



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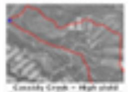
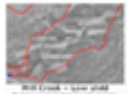


Cassidy Creek – High yield



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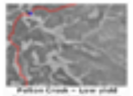

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Overview of Poster Layout – Individual Elements are on the Following Pages

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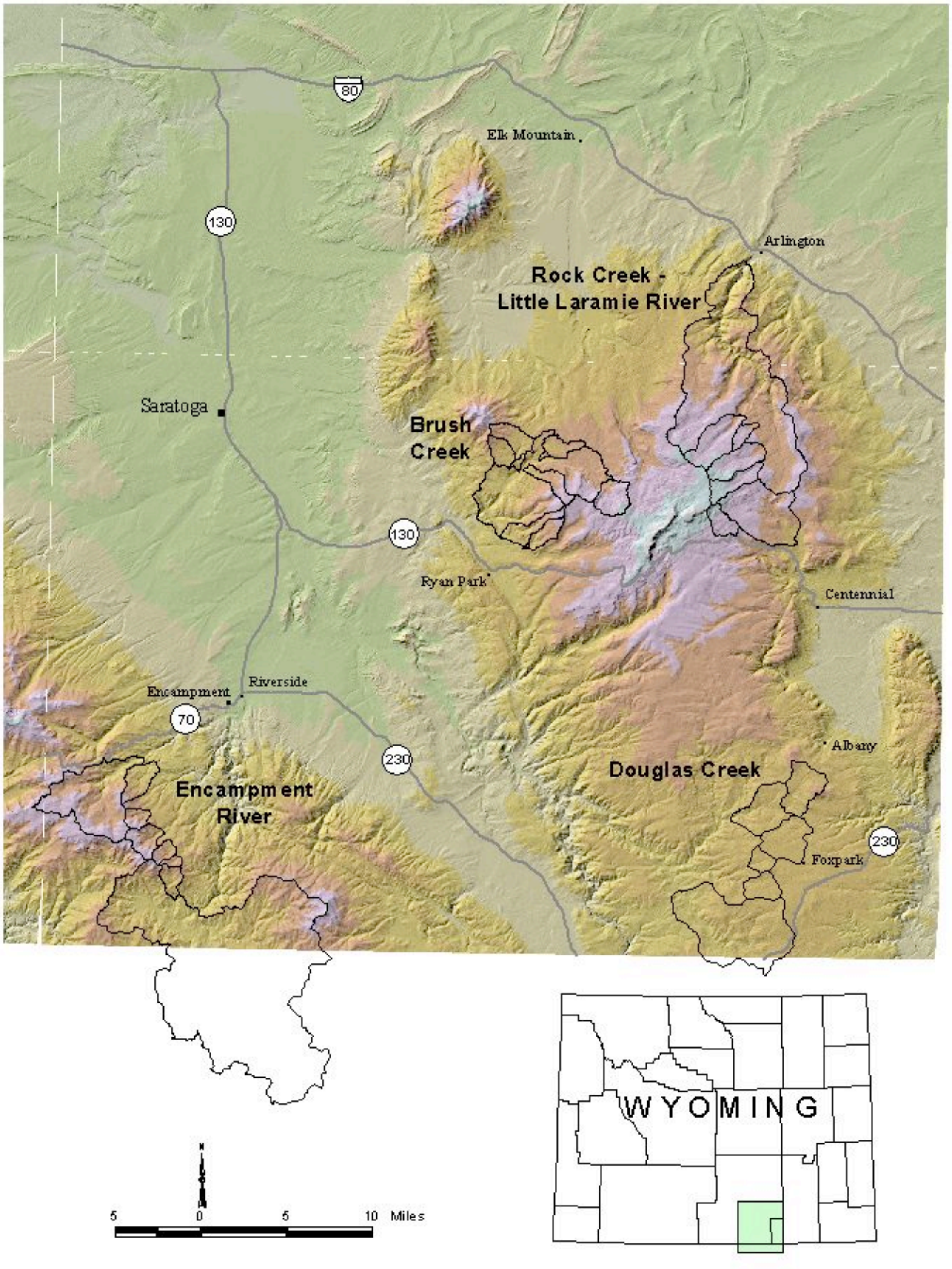

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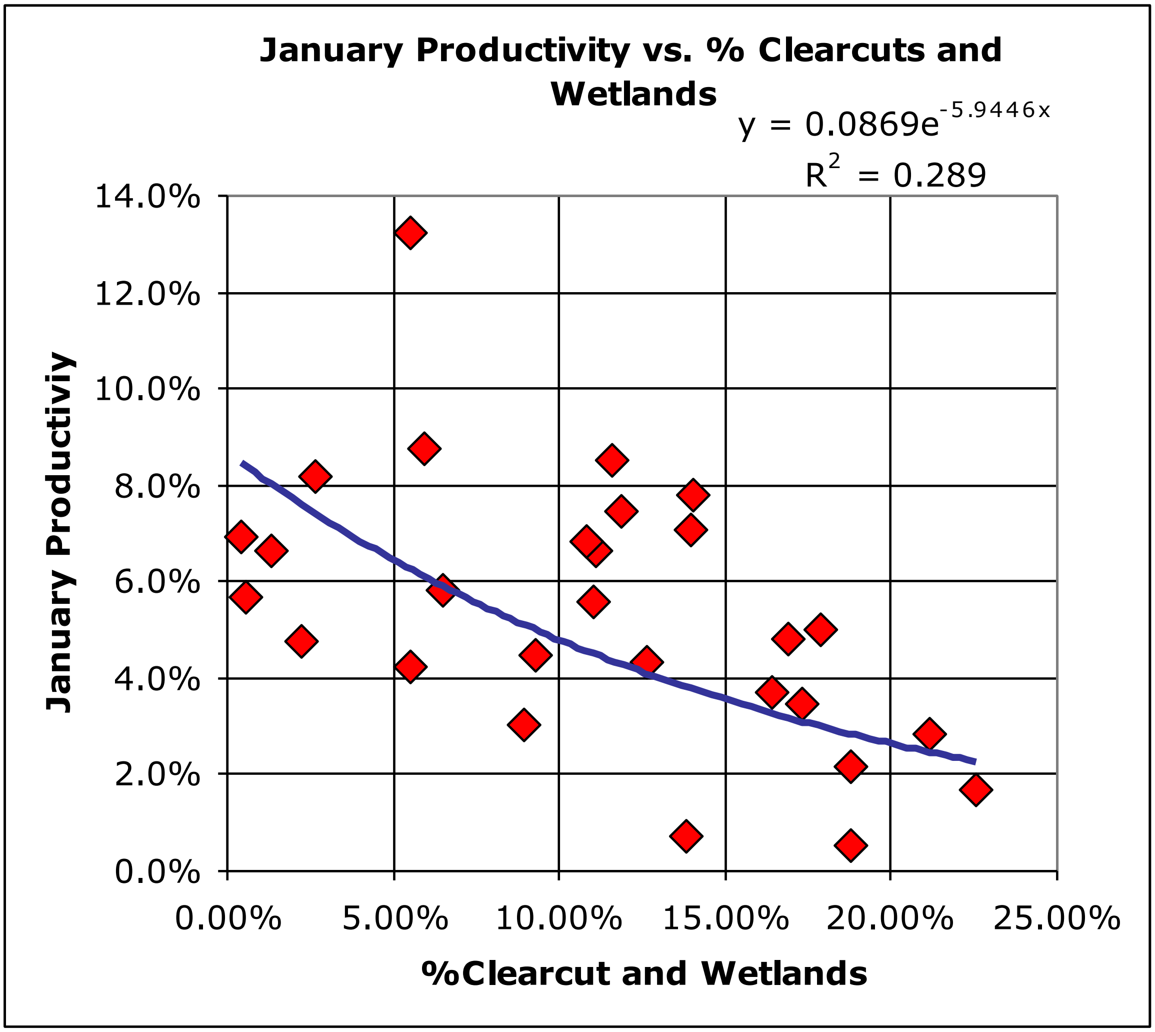

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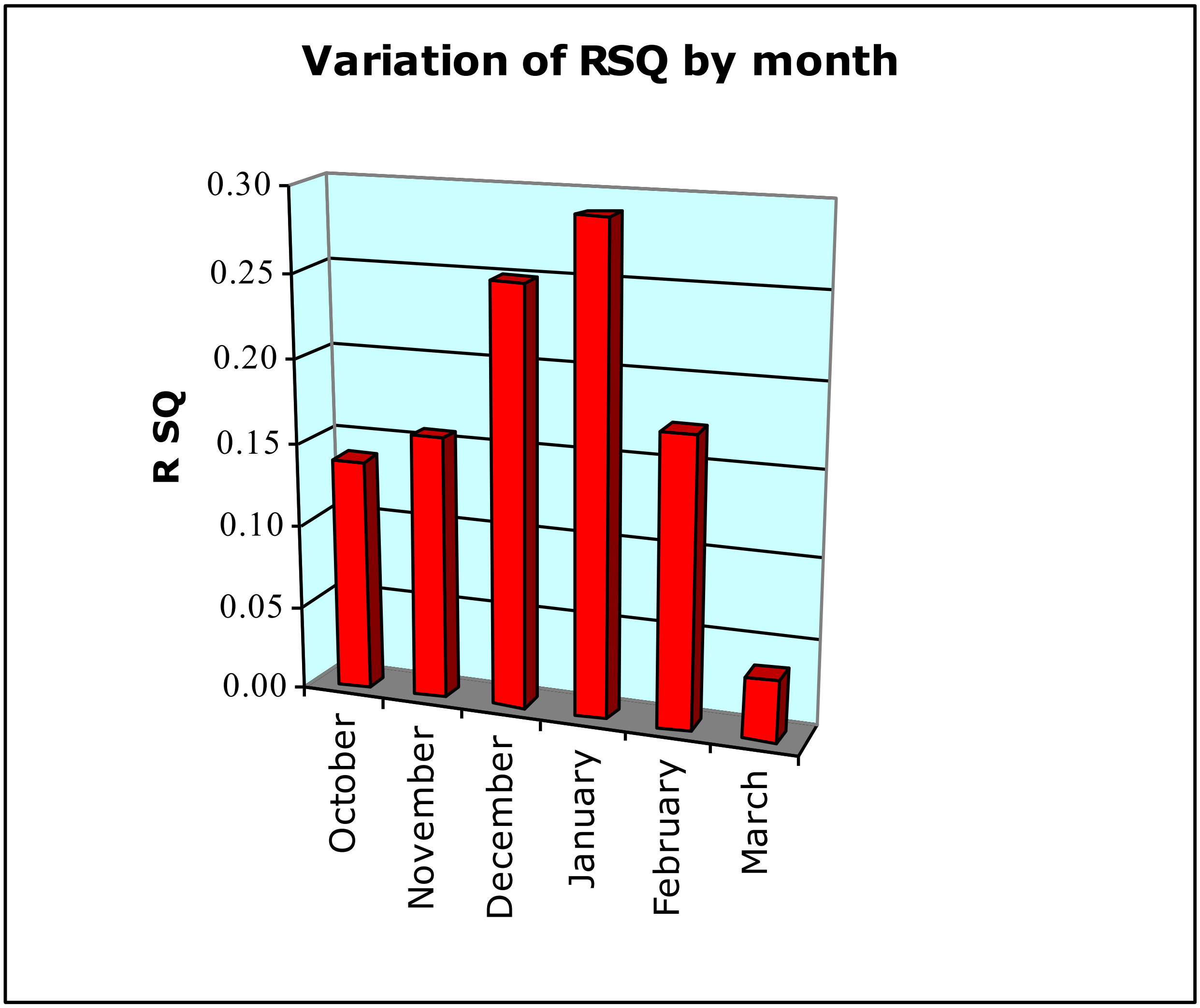

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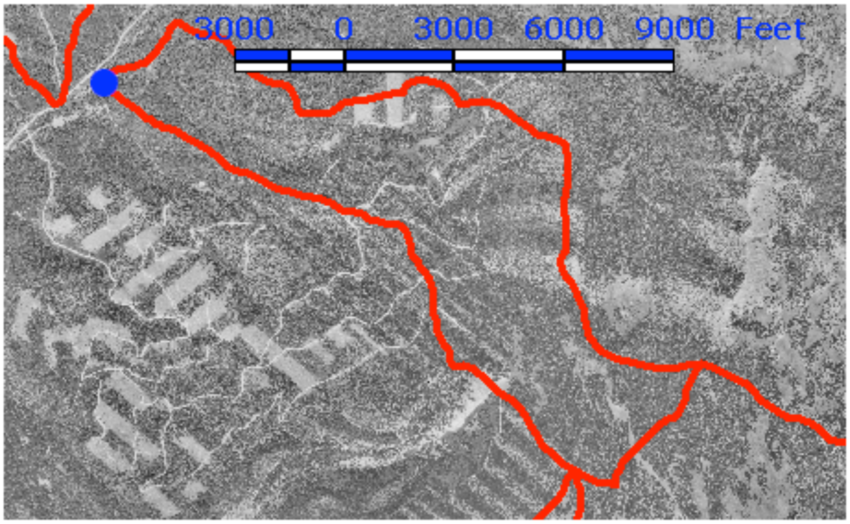

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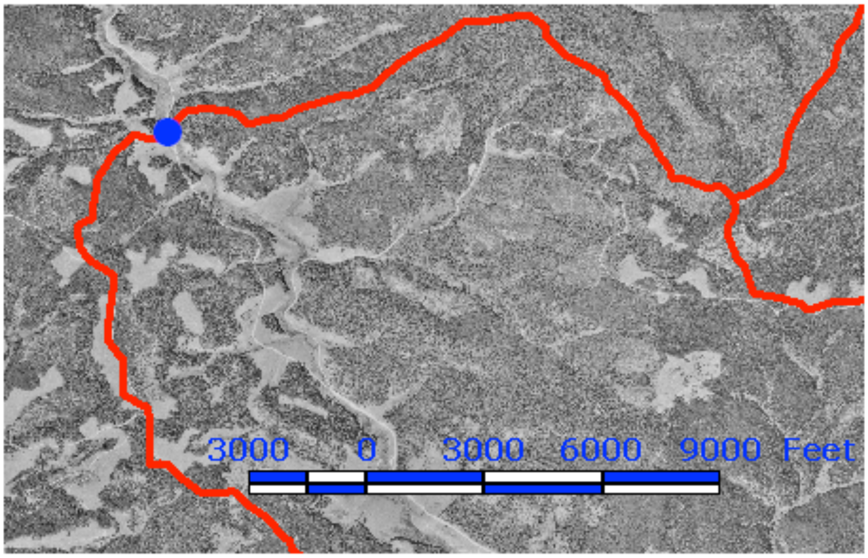

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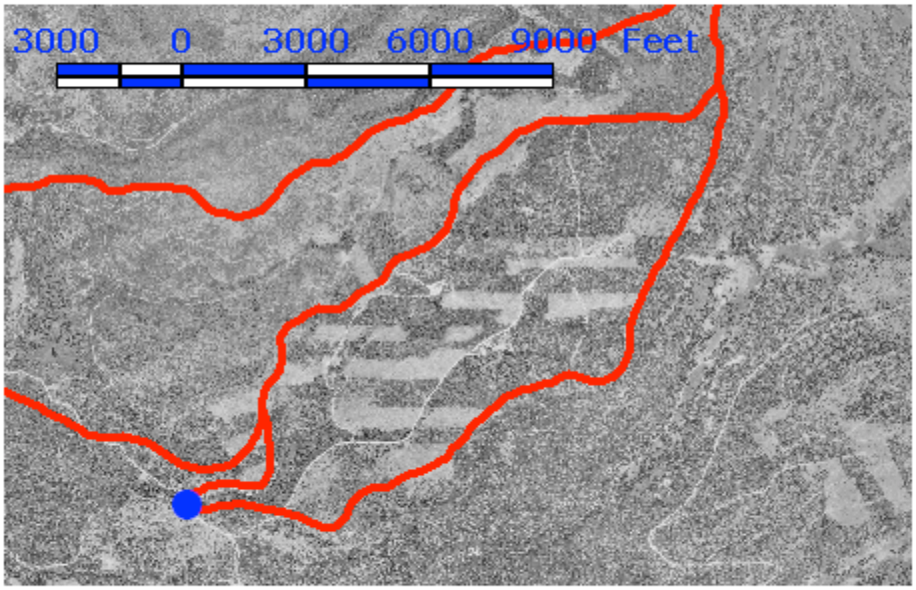

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HYDROLOGIC MODELING OF WINTER STREAMFLOW IN MOUNTAINOUS AREAS OF SOUTHEAST WYOMING

by
James D. Riley

A thesis submitted to the Department of Geography and Recreation
and The Graduate School of The University of Wyoming
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS
in
GEOGRAPHY/WATER RESOURCES

Laramie, Wyoming
May, 2003

(Note: Theses are available from the University of Wyoming Library)

Winter Flow Modeling for the Mountainous Areas of Wyoming

by

Bruce R. Brinkman and Hugh W. Lowham –

In Wyoming Water Flow, Volume LXIV, Issue 1, 2 pgs.
Wyoming Water Flow is published by the Wyoming Water Association

In 2000, the University of Wyoming jointly with the United States Geologic Survey solicited research projects relating to water resources in Wyoming. One project that emerged is the 'Testing of Hydrologic Models for Estimating Winter Streamflows in Mountainous Areas of Wyoming' submitted and jointly funded by the Wyoming Water Development Commission. This research project looks at the problem faced by hydrologists of determining flow amounts in high mountain streams in the winter. The primary purpose of the project is to determine and document the accuracy of currently available hydrologic models while providing training and practical experience to university students. The secondary purpose of this project is to review the possibilities of using emerging technologies such as remote analysis using Geographic Information Systems (GIS) that may help in the determination of a basin's characteristics.

Streamflows in the mountainous areas of Wyoming are receiving increased interest in their role as source water for allocation for the state of Wyoming as well as down stream states. Approximately 70% of the surface water originating in Wyoming comes in the form of snow (Jacobs and Brosz, 1993) with snowfall amounts varying radically from year to year. The timing and volume of the water released from remote mountains in Wyoming, as in other states, is becoming a greater interest to water users every day. These mountain streams are the major source of water for an increasing number of competing consumptive and non-consumptive water uses located within and downstream of the high mountain basins. The remoteness and inaccessibility of these high mountain basins in the winter makes flow determinations very difficult. The ideal situation for planning and management of this water resource is to have long-term data available from an existing gage for each stream. However, economic as well as physical constraints prevent the installation and operation of gages on most mountain streams. In the absence of a gage, some sort of model is needed to make a best estimate of the flow volumes in these basins.

There are flow models available but most do not look at high mountain basin winter flows. Through this research project, by actually making test sets of flow measurements throughout the winter, in a group of high mountain basins and collecting as many characteristics of the basins as possible, we hope to not only test existing equations but to possibly create a set of working equations that can be calibrated to other basin characteristics and area gages to provide a better estimating model of the year round flows for mountain basins. This model will reduce the amount of actual field work required to do mountain basin modeling in the future.

Four main methods will be tested for estimating streamflows: equations of mean-annual flow versus drainage- basin characteristics (Lowham, 1988), equations of mean-annual flow versus channel width (Lowham, 1988), equations of monthly flow versus drainage -basin (Misalis, Wesche, and Lowham, 1999), and equations of monthly flow versus channel width (Misalis, Wesche, and Lowham, 1999). The approach used for determining the accuracy of these available techniques is to use the year round North Brush Creek gage records for model calibration and proofing of the select ungaged sites which are located both upstream of the gage and in adjoining basins.

The ungaged test sites were selected on the basis of:

- Economic considerations assuming travel from Cheyenne.
- Differences between the sites that provide ranges in drainage area, elevation, basin slope and aspect, and other pertinent basin features.
- Location with respect to the existing streamflow gage that has suitable long-term year round periods of record.

The preliminary ungaged sites selected are the North Brush Creek Basin at the gage, Fish Creek Tributary, Upper Fish Creek, Lower Fish Creek, Dry Gulch, Harden Creek, Upper North Brush Creek, Cassidy Creek and Lincoln Creek in the North Brush Creek Basin. Two additional sites Mill Creek and Nash Fork are located just outside of the basin.

The actual ungaged site streamflow measurements will also be made near mid-month for October through March. The estimated mean monthly streamflows at each ungaged site will also be modeled for the months of October through March. These months typically have the lowest flows for undeveloped mountain streams, which are critical periods for instream flows. The actual flow measurements will then be compared to the modeled estimates for model testing.

The monthly field measurements are currently being made at these sites by principal investigators Brinkman and Lowham. The flow measurements are made at the gage and at each ungaged site as time and conditions permit. Due to the mountainous winter site conditions, the sites are accessed using snowmobiles and snowshoes. The discharge measurements being made also require special procedures required for winter and ice conditions. Starting in November, an ice bar is the major equipment required to clear a measuring section. Later in the season a snow shovel is used more extensively than the ice bar. Ice cover has ranged up to 4 inches thick while the snow cover has ranged up to 5 feet deep as of the January measurements.

These flow measurements will be collected for a minimum of two winter seasons, so that at least two discharge measurements can be made for each month, October through March, at each site. The flow measurements made at the gage will be used to calibrate the field flow measurements with the annual records of the North Brush Creek gage obtained from the United States Geologic Survey.

Then the ungaged site measurements will be correlated with the gage records to establish a record for each ungaged site. These records will in turn be matched with the other basin characteristics to establish modeling parameters for the individual sub basins.

The field basin characteristics will be combined with the basin characteristics found using the emerging technologies such as analysis of aerial or satellite photos, color or infrared photos, and other Geographic Information System (GIS) features to compare the relative differences in the sub basins. Comparisons of runoff per square mile and runoff per foot of channel width will be made with the respective basin boundaries on the photographs. If a particular color or feature appears related to the magnitude of the flow, then measurements of the characteristic within the drainage area will be related to the flow characteristic. As each individual basin characteristic's impacts are determined, they will be added as variables to the basin model. These updated variables should improve the capabilities of models to determine the flows of mountain streams in the winter.

The applications for these models which estimate stream flows in Wyoming are increasing all the time. With greater demand on water year round for both consumptive and non-consumptive uses, water planners and managers of all aspects federal, state, county, city, and private are looking at better ways to analyze these water resources and make more knowledgeable management decisions for both peak and low flows. Upon completion of this project a final report detailing the hydrologic models will be published and made available through many water resource related governmental entities.

Several governmental agencies including the United States Geologic Survey, United States Forest Service, Wyoming Water Development Commission, Wyoming State Engineers Office, and the University of Wyoming have participated in joint field work related to this project. Through the first year's joint funding, the project provided for the services of a University of Wyoming Student, Justin Montgomery, in data research, collection, inventory, analysis and presentation. We are hopeful that other students from other closely related disciplines will be able to participate, in one form or another throughout the remainder of this project.