Wyoming Water Resources Center
Annual Technical Report
FY 2002

Introduction

The NIWR/State of Wyoming Water Research Program (WRP), placed at the University of Wyoming, oversees the coordination of Wyomings participation in the NIWR program. The primary purposes of the program are to support and coordinate research relative to important water resources problems of the State and Region, support the training of scientists in relevant water resource fields, and promote the dissemination and application of the results of water-related research.

State support for the research program includes direct funding through the Wyoming Water Development Commission and active State participation in identifying research needs and project selection and oversight. Primary participants in the WRP are the USGS, the Wyoming Water Development Commission, and the University of Wyoming. A Priority and Selection Committee (P&S Committee)--consisting of representatives from agencies involved in water related activities in the State--solicits and identifies research needs, selects projects, and reviews and monitors progress. The Director serves as a point of coordination for all activities and serves to encourage research by the University of Wyoming addressing the needs identified by the P&S Committee. The State also provides direct funding for the administration of the WRP

The WRP supports faculty and students in University of Wyoming academic departments. Faculty acquire their funding through competitive, peer reviewed grants, submitted to the WRP. Since its inception in the year 2000, the WRP has funded researchers in six academic departments and has supported a total of thirteen research projects. Each project represents the education of one or more students. The WRP provides interaction from all the groups involved rather than being solely a University of Wyoming research program. Results of research are presented in peer-reviewed publications, project report and thesis format, and user oriented bulletins. Results are also available through the Wyoming Water Resources Data Systems library

Research Program

Erosion potential model development and channel monitoring

Basic Information

Title:	Erosion potential model development and channel monitoring
Project Number:	2002WY1B
Start Date:	3/1/2002
End Date:	2/28/2003
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Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Geomorphological Processes, Water Quantity, Management and Planning
Descriptors:	
Principal Investigators:	Gregory V. Wilkerson

Publication

1. Baxter, J. C., 2002. The channel geometry of Dead Horse Creek, Powder River Basin, Wyoming, MS Thesis, Geography and Recreation, A&S College, University of Wyoming, Laramie.
2. Baxter, J. C., G. V. Wilkerson, and J. H. Johnson, 2002. Erosion potential modeler (Version 3.0): Reference manual. Available at http://wwweng.uwyo.edu/civil/research/water/epmodeler.html. University of Wyoming, Laramie.
3. Wilkerson, G. V., J. C. Baxter, and J. H. Johnson, 2002. Erosion potential modeler (Version 3.0): Technical manual. Available at http://wwweng.uwyo.edu/civil/research/water/epmodeler.html. University of Wyoming, Laramie.
4. Wilkerson, G. V., 2002. A GIS model for evaluating the impacts of coal bed methane surface water discharges. Abstracts with Programs - 2002 Annual Meeting of the Geological Society of America, Boulder, CO.

Problem and Research Objectives:

Coal bed methane (CBM) development in the Powder River (structural) Basin (PRB), located in northeast Wyoming, has been increasing since about 1990 (WOGCC, 2000). As of March 2001, about 4,900 CBM gas wells were in production; about 9,600 wells have been drilled (600 of which have been plugged); and about 10 new wells are drilled every day (Bleizeffer, 2001).

CBM extraction involves pumping methane and ground water out of coal seams. The gas and water separate in the well and the gas is sent to a pipeline. On average, water from CBM wells is produced at a rate of 12 gpm per well (BLM, 1999).

In June 2000 the U.S. Bureau of Land Management (BLM) held public scoping meetings to facilitate development of a new resource management plan for oil and gas development in Johnson, Campbell, Sheridan, and Converse counties (Tollefson, 2000). At that time, the BLM was considering the development of up to 35,000 wells in a 10-year period (although as many as 70,000 wells may be constructed over the lifetime of the development). Assuming 33% of the 35,000 anticipated CBM wells are producing 12 gpm of water at a given time, surface water would be produced at an average rate of 140,000 gpm (312 cfs or 225,000 ac-ft/yr). For comparison, the storage capacities of Keyhole Reservoir and Lake de Smet Reservoir, in northeast Wyoming, are 340,000 acre-ft and 239,000 acre-ft, respectively.

Legally, CBM product water can be discharged on the surface only at National Pollution Discharge Elimination System (NPDES) permitted points (BLM, 1999). It is expected that much of the water will be discharged from pipelines into existing surface drainages. It is impossible to know with certainty how much CBM produced water will be discharged into surface drainages since, in some areas, product water will be either reinjected or contained in surface reservoirs. Disposal into surface drainages is by far the least expensive alternative, and as the estimated productive life of a CBM well is 10 to 20 years (BLM, 1999), there is great potential for CBM produced water to cause erosion in affected stream channels and tributaries.

The State of Wyoming Department of Environmental Quality (DEQ) regulates erosion and other issues affecting the quality of water in Wyoming (BLM, 1999). The DEQ is also responsible for granting NPDES permits to discharge produced water. Recognizing the need to manage CBM product water, the DEQ asked the University of Wyoming to evaluate the erosion vulnerability of drainages in the PRB. **The primary objective of this study was to develop a computer program that would help DEQ policy managers formulate appropriate management decisions associated with the NPDES permitting process. This study had three components: (1) development of an analytical model for predicting the erosion potential of channels in the PRB, (2) channel monitoring, and (3) model verification.** The computer program and all data derived from this effort have been made available to the public so that others responsible for or concerned about watersheds affected by CBM development can use it to evaluate alternative CBM product water management development scenarios.

Methodology:

Model development and implementation

An analysis of hydrologic data published by the U.S. Geological Survey (Lowham, 1988) was performed to develop regression equations for estimating the erosion potential of channels in the PRB. The equations have been integrated into “Erosion Potential (EP) Modeler,” a computer program that runs inside of ArcView GIS (Version 3.2). EP Modeler utilizes USGS digital elevation models (DEMs), digital line graphs (DLGs), and other themes that collectively describe the geographic features of the basin. As such, users of EP Modeler must be familiar with ArcView GIS and procedures for working with ArcView GIS compatible themes. After selecting a point in the channel that is of interest and inputting an estimate of the CBM product water discharge in the watershed above the selected point, the erosion potential for the selected point is computed. To date, the erosion potential index has not been calibrated, that is, a threshold value of the erosion potential index at which increased erosion is imminent has not been determined.

Channel monitoring

The second component of this project consisted of monitoring erosion in two channels within the Powder River Basin: Deadhorse Creek and Burger Draw. Six reaches along Deadhorse Creek and its tributaries, and two reaches along Burger Draw were established. The reach lengths ranged from 500 ft to 1,200 ft. The study reaches were surveyed in 2000, 2001, and 2002 using a Sokkia SET 3110 total station. The channel thalweg and four to eight cross-sections were surveyed in each reach. The data provided by these surveys characterize the channels in their present (pre-CBM development) state.

Model verification and calibration

To achieve the third objective of this study, model verification and calibration, data from the channel monitoring effort was used. To date, the data has been used to correlate 2-year peak discharges and bankfull discharges—this calibration was required to get the model to yield reasonable predictions of post-CBM development, equilibrium channel widths.

Principal Findings and Significance:

Data from Lowham (1988) was used to develop a model for computing an index that reflects the potential for accelerated erosion because of CBM product water discharges. The model is applicable to channels located in the PRB and has been implemented as an ArcView GIS application called EP Modeler. The benefit to running EP Modeler within ArcView is that it facilitates access to geographic data that is required as input for EP Modeler. The EP Modeler program, and the corresponding reference and technical manuals are available, free of charge, via the Internet, at:

http://wwweng.uwyo.edu/civil/research/water/epmodeler.html

Data from three annual surveys, of reaches along Deadhorse Creek have been evaluated and will serve as baseline data for future studies of the basin. A comparison of the data indicated that one of the reaches is degrading and another is aggrading. The degrading reach is near the center of the basin and the aggrading reach is at the lower end of the basin. It is concluded that discharging significant volumes of CBM product water into Deadhorse Creek would accelerate the rate of change, respectively, in the degrading and aggrading reach.

It is intended that the model and data derived from this study will to policy managers charged with formulating resource management strategies, particularly in regards to managing CBM product water. In addition to policy managers, others concerned about the effects of CBM development will be able to use EP Modeler and the data derived over the course of this project since that information either is or will be made available to the public.

References:

Bleizeffer, D., 2001. Natural gas ups, downs; Prices a roller coaster ride for Wyo. Casper Star Tribune, April 4, pp. C1, C8.

Lowham, H. W., 1988. Streamflows in Wyoming (Water-Resources Investigations Report 88-4045). Cheyenne, WY: USGS.

Tollefson, J., 2000. BLM extends development scoping period. Casper Star Tribune, July 3, pp. A1, A4.

U.S. Department of the Interior, Bureau of Land Management, 1999. Wyodak coal bed methane project: Final environmental impact statement. Buffalo, WY: Author.

Wyoming Oil and Gas Commission (WOGCC), 2000. Coal Bed Methane Wells. Acquired from the internet: <http://wogcc.state.wy.us/coal.html?RequestTimeout=3500>

Testing of hydrologic models for estimating streamflow in mountainous areas of Wyoming

Basic Information

Title:	Testing of hydrologic models for estimating streamflow in mountainous areas of Wyoming
Project Number:	2002WY2B
Start Date:	3/1/2002
End Date:	2/28/2003
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Research Category:	Not Applicable
Focus Category:	Hydrology, Models, Water Quantity
Descriptors:	
Principal Investigators:	Bruce Brinkman, Hugh W. Lowham, Lawrence M. Ostresh

Publication

1. Riley, James D., 2003. Hydrologic modeling of winter streamflow in mountainous areas of southeast Wyoming, Master of Arts Thesis in Geography/Water Resources, Dept. of Geography and Recreation, A&S College, University of Wyoming, Laramie.
2. Brinkman, B.R. and H. Lowham. Winter flow modeling for the mountainous areas of Wyoming, in Wyoming Water Flow, Vol. LXIV, Issue 1, pgs 1-2.
3. Lowham, Hugh, Lawrence Ostresh, James Riley, Bruce Brinkman, and Justin Montgomery, 2003. Testing of hydrologic models for estimating low flows in mountainous areas of WyomingVolume 1, User Guide, Project Report, Available from Wyoming Water Development Commission, 6920 Yellowtail Road, Cheyenne, WY, 82002 or University of Wyoming, Water Resources Data System, Laramie, WY, 82071.
4. Lowham, Hugh, Lawrence Ostresh, James Riley, Bruce Brinkman, and Justin Montgomery, 2003. Testing of hydrologic models for estimating low flows in mountainous areas of WyomingVolume 2, Supplemental Information, Supplemental to Project Report, Available from Wyoming Water Development Commission, 6920 Yellowtail Road, Cheyenne, WY, 82002 or University of Wyoming, Water Resources Data System, Laramie, WY, 82071.
5. Ostresh, Lawrence M., James D. Riley, Hugh Lowham, and Bruce Brinkman, 2002. Gridding winter precipitation data in Wyoming mountains, poster session presented at Great Plains/Rocky Mountain

Division of the Association of American Geographers, Missoula, MT, Oct. (presented by Ostresh), availability referenced in Volume 2, Supplemental Information Report.

6. Ostresh, Lawrence M., James D. Riley, Bruce Brinkman, and Hugh Lowham, 2003. Effect of land cover on winter streamflow in southeastern Wyoming mountains, poster session presented at the National Meetings of the Association of American Geographers, New Orleans, LA, March, (presented by Ostresh), availability referenced in Volume 2, Supplemental Information Report.

Preface

The following report is taken from a draft of Volume 1 of the final report for this project. The project's final report was being revised when this annual report was submitted. Both volumes of the final project report are discussed in the Introduction section shown below and are listed in the publications section of this annual report. The final project report will be available from the Wyoming Water Resources Data System and the Wyoming Water Development Commission.

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.

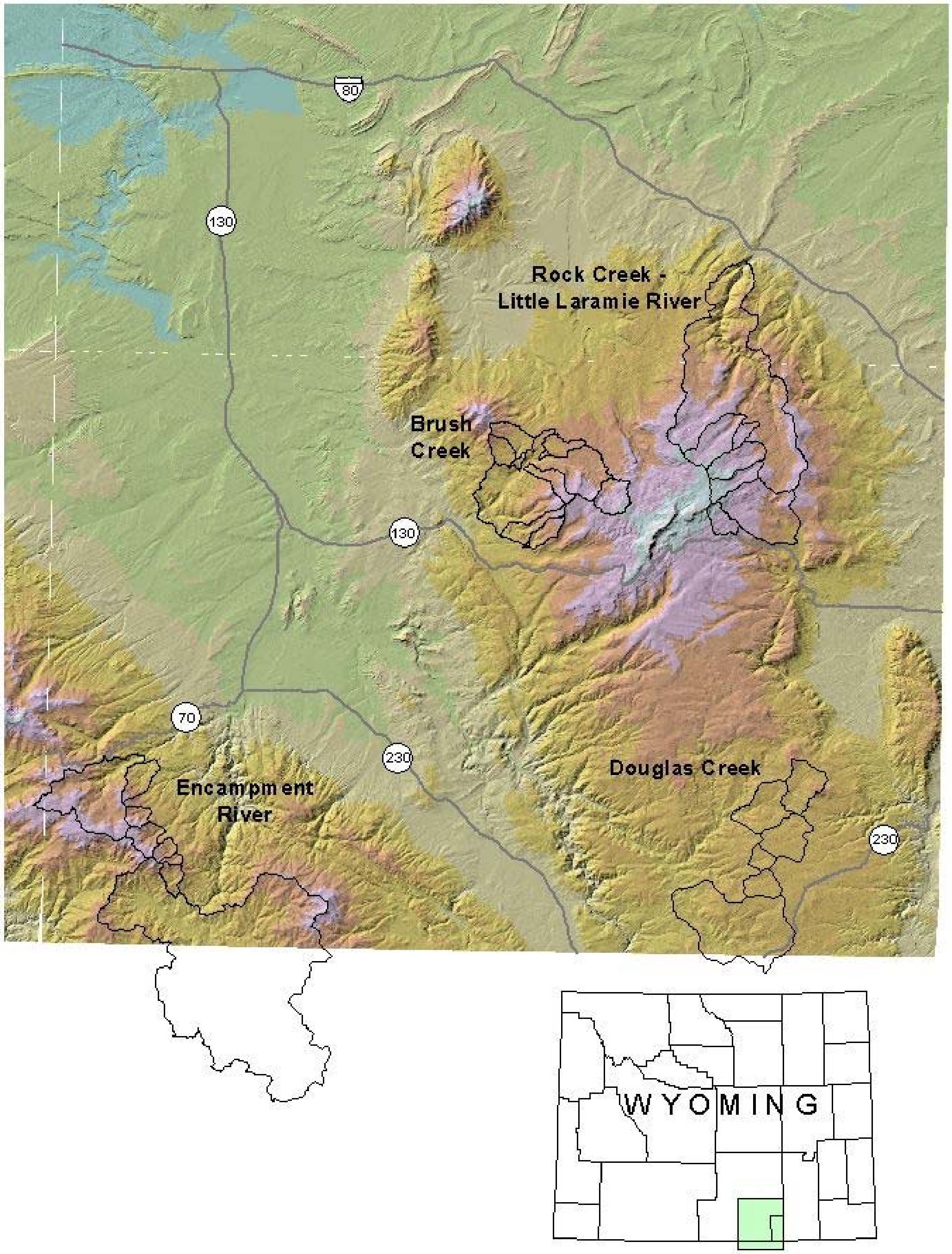


Figure 1. Location of the drainage basins selected for this study.

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.

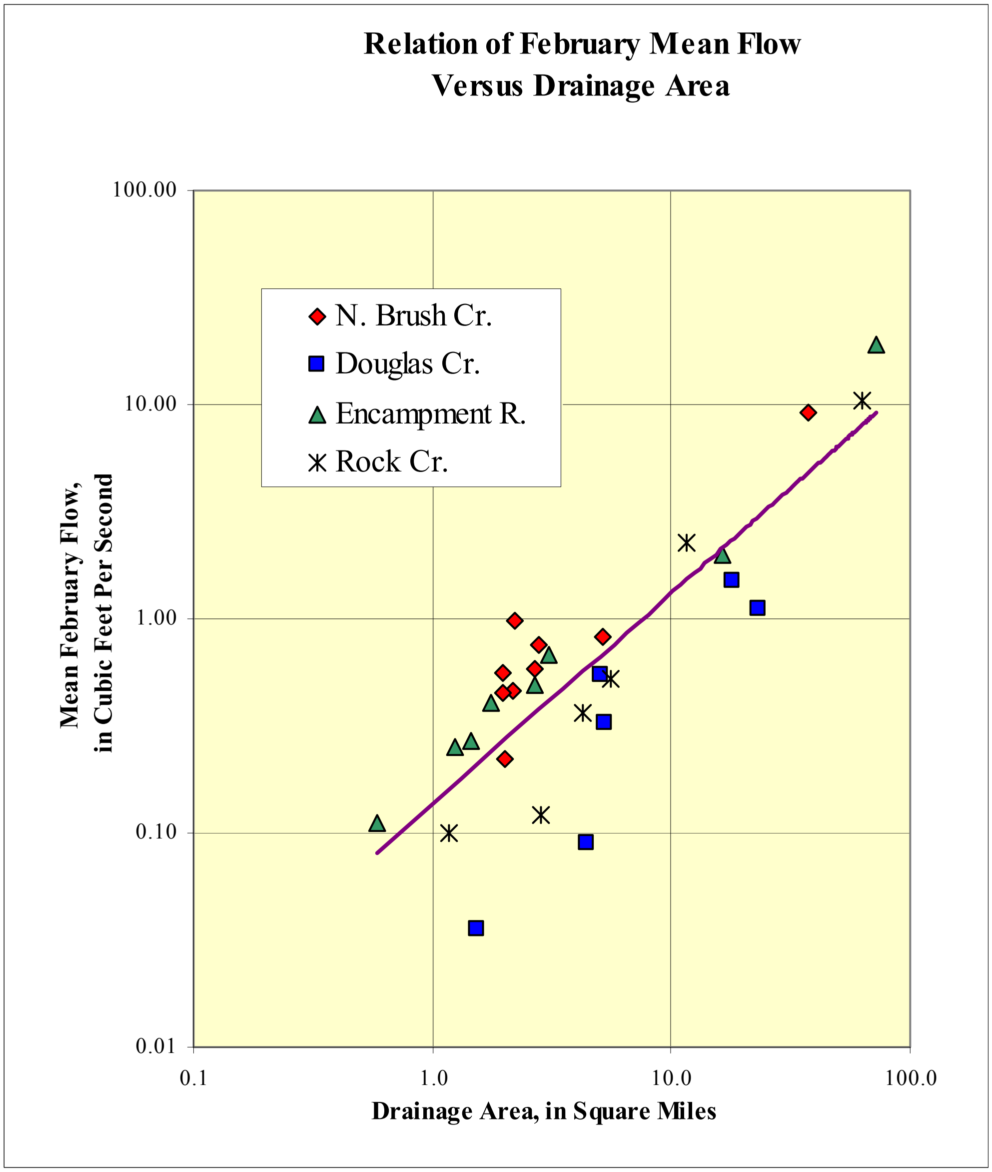


Figure 6. Graph showing relation of February mean flow to drainage area.

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

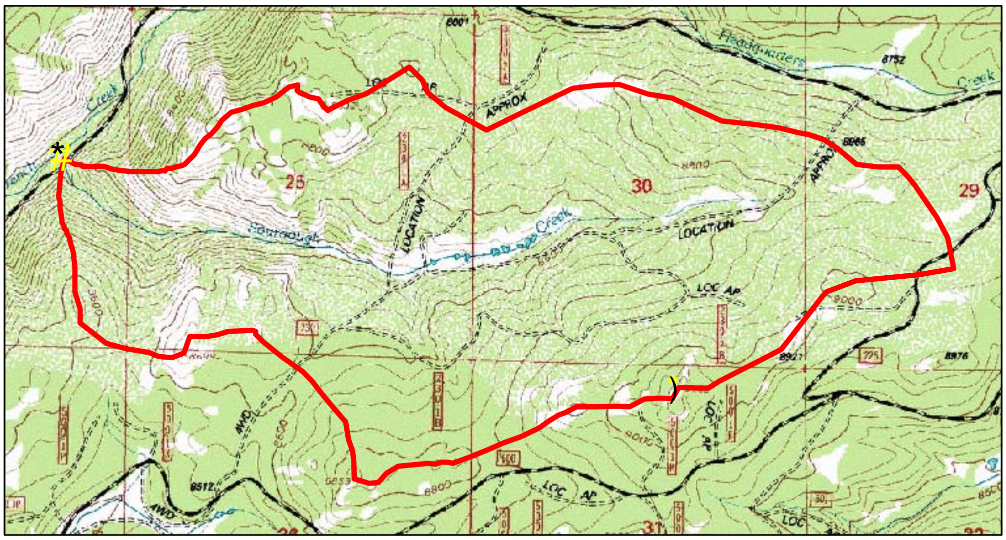
Estimates of monthly flows are needed for determining water rights for instream fisheries on Sourdough Creek, a tributary of South French Creek in the Medicine Bow Mountains (fig. 7). The contributing drainage area at the upstream end of the stream reach is 1.85 square miles, and the range in elevation 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



Basin Boundary

Measurement Site; Elevation = 7990 feet

Highest Point on Divide; Elevation = 9,162 feet

0 0.25 0.5 1 Miles

Contour Interval = 40 feet; major contours 200 feet

Source of Base Map:
Enhanced digital raster graphic of USGS 1:24,000 quad "Overlook Hill" (41106b4); Beartooth Mapping Inc., 1999. UTM zone 13, NAD 1927

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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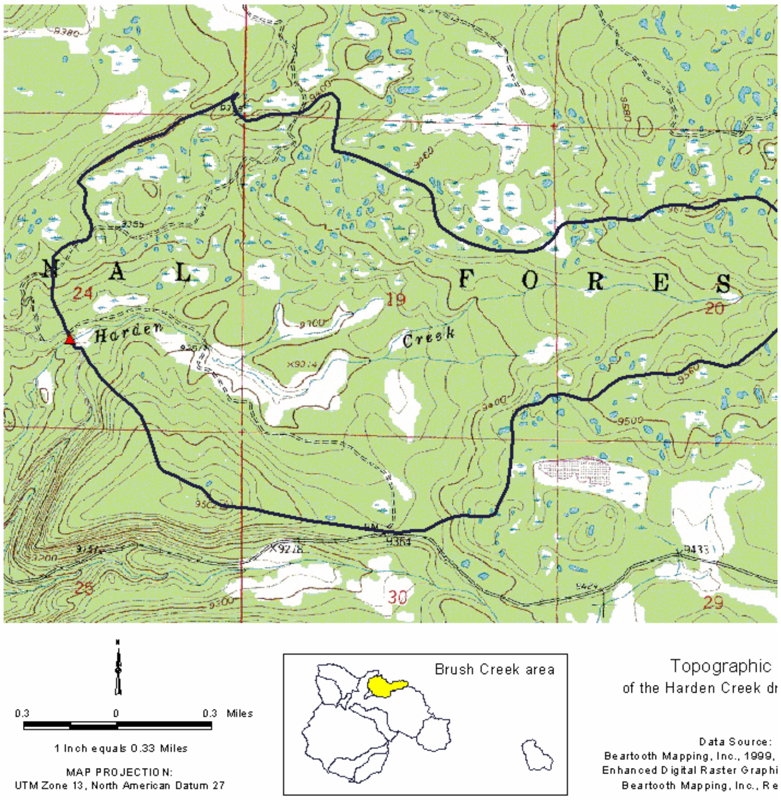
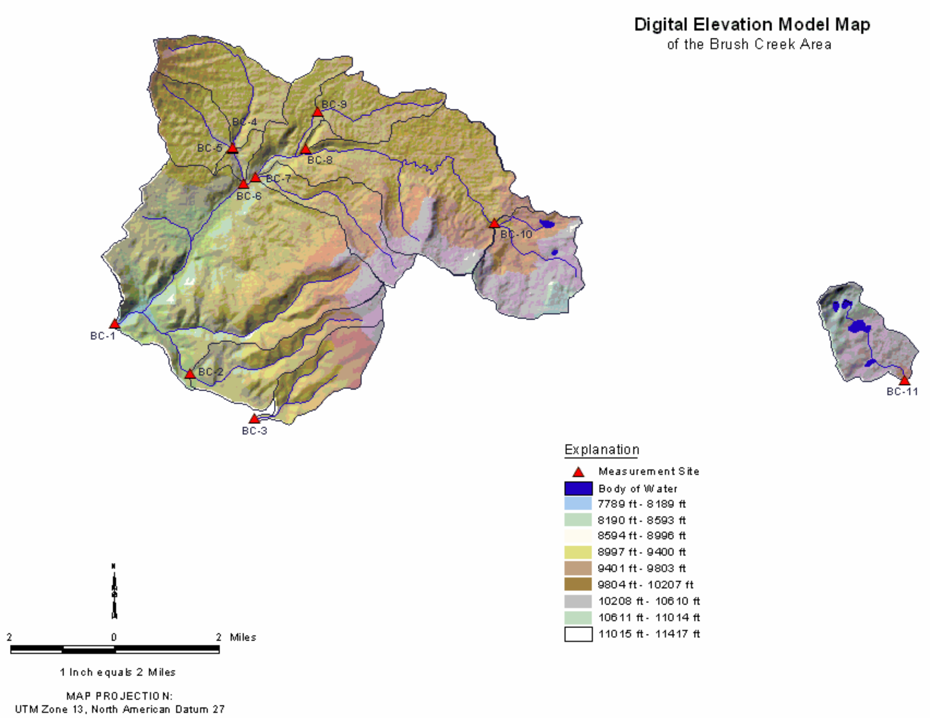
Riley, J.D., 2003, Hydrologic modeling of winter streamflow in mountainous areas of southeast Wyoming. M.A. thesis, Department of Geography and Recreation, University of Wyoming, Laramie, WY.

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.

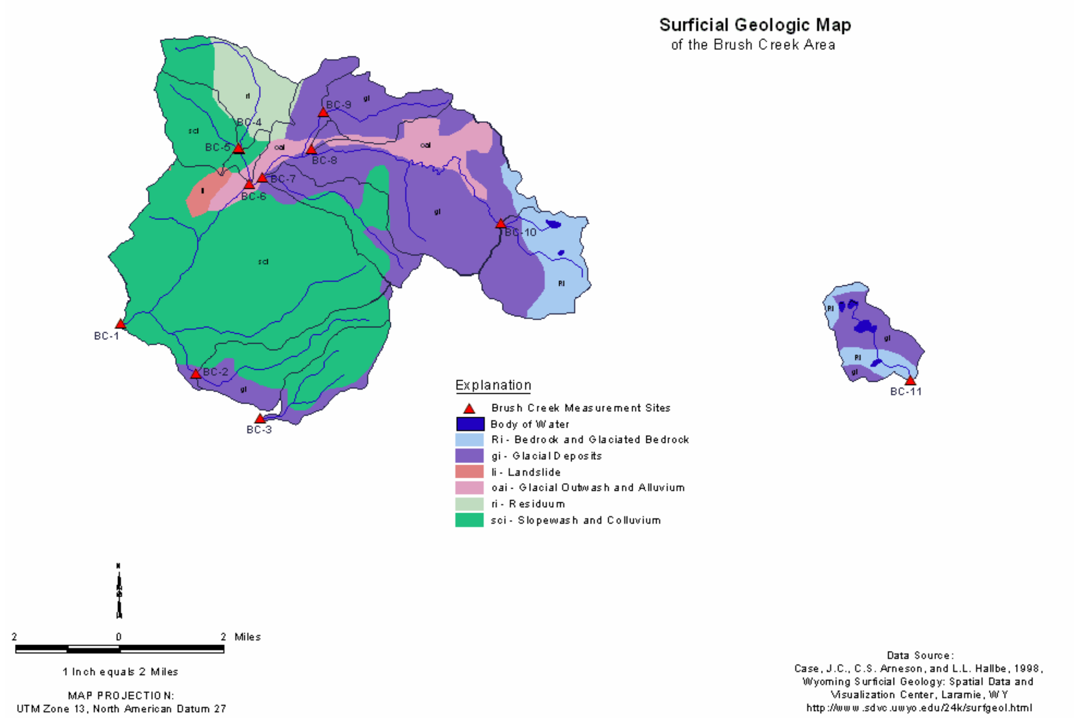
Appendix A – Drainage Basin Maps



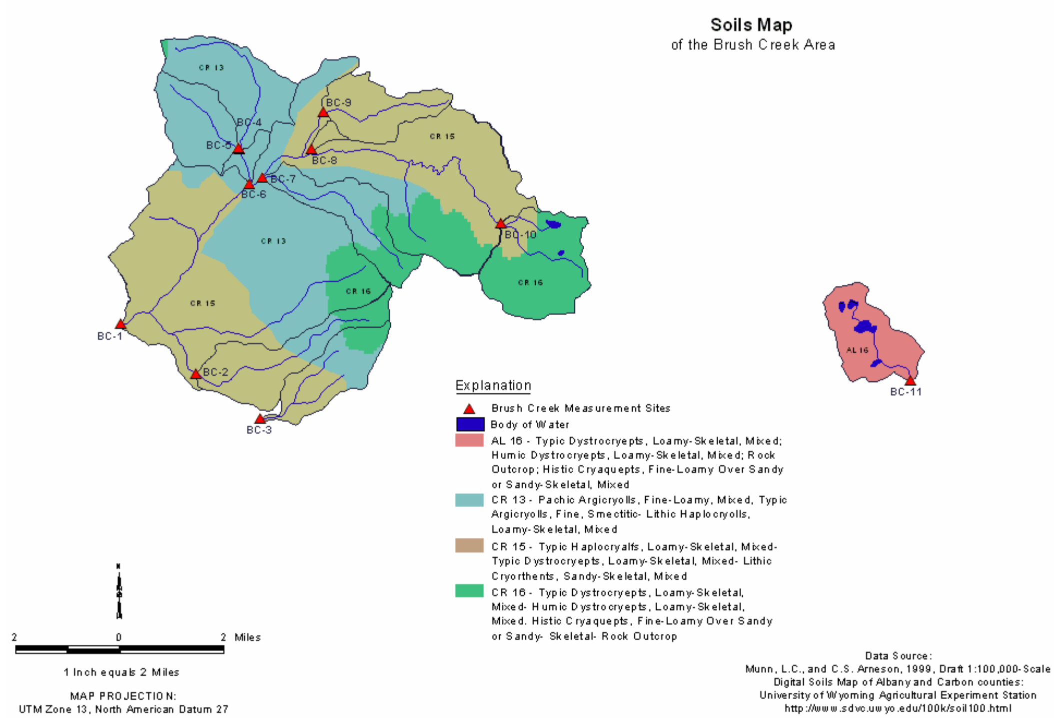
A-1 Topographic map of Harden Creek drainage basin, Brush Creek area.



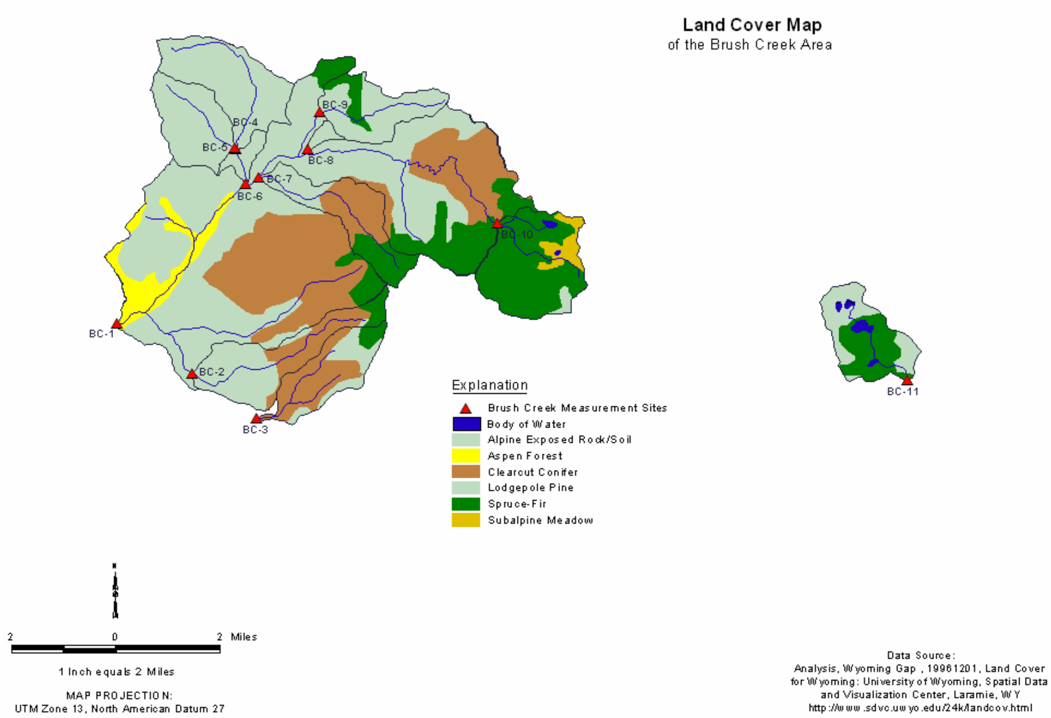
A-2 Digital elevation model map of drainage basins in Brush Creek area.



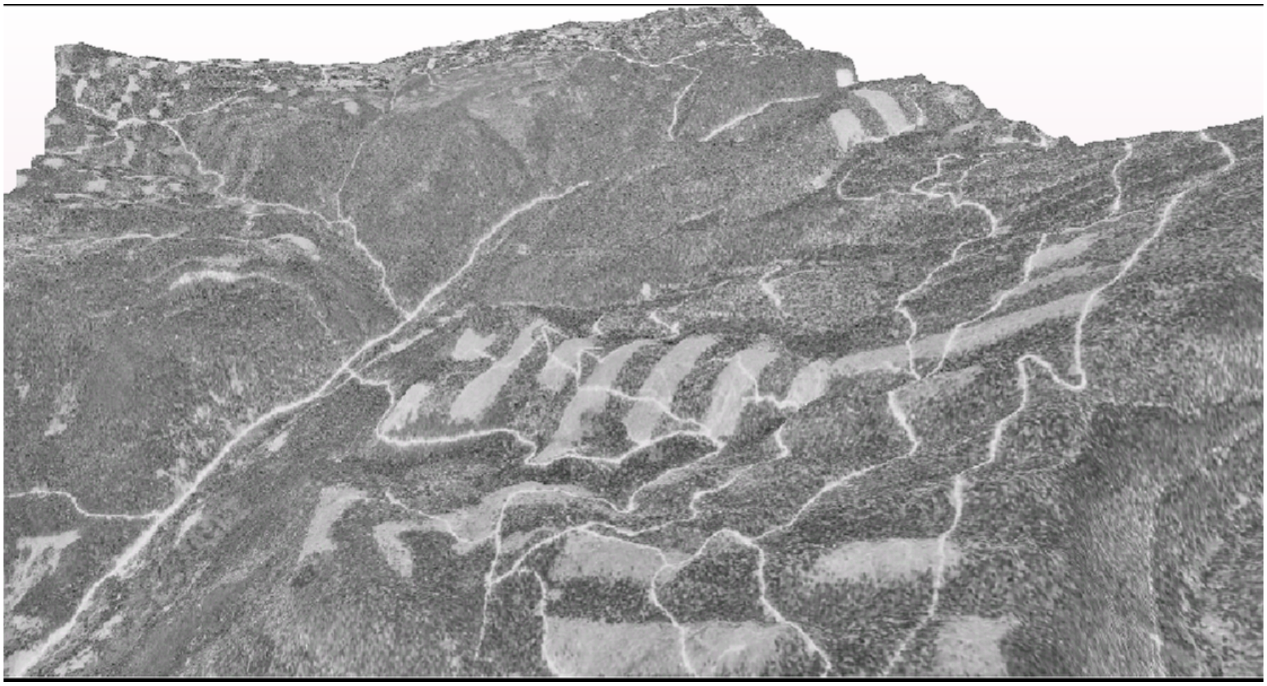
A-3 Surface geology map of drainage basins in Brush Creek area.



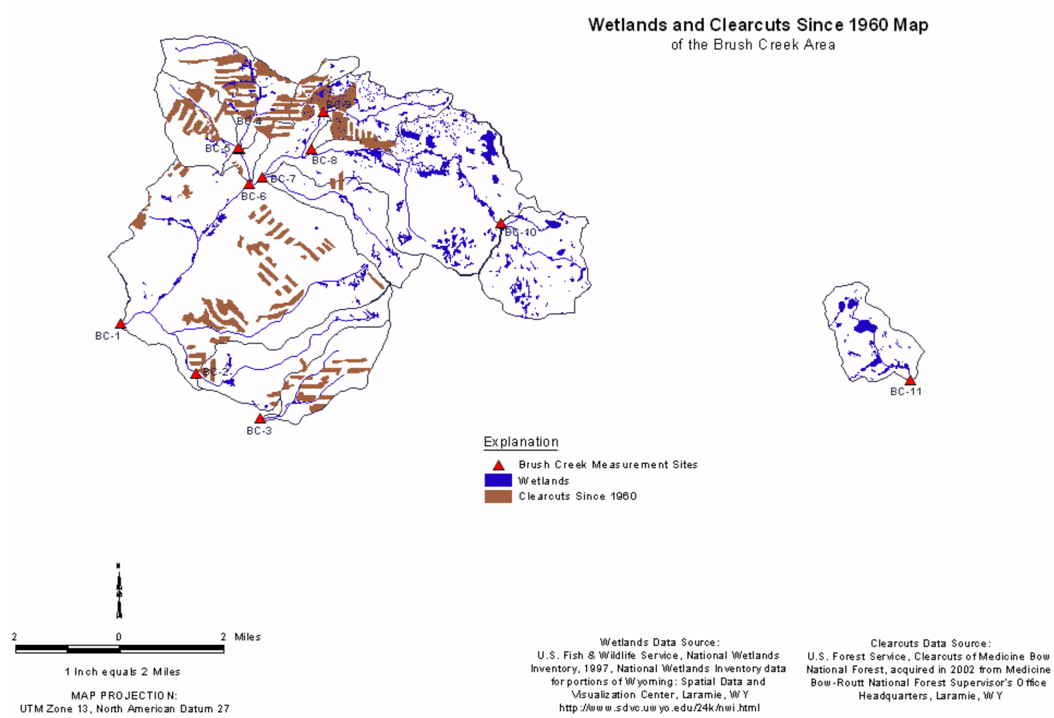
A-4 Soils map of drainage basins in Brush Creek area.



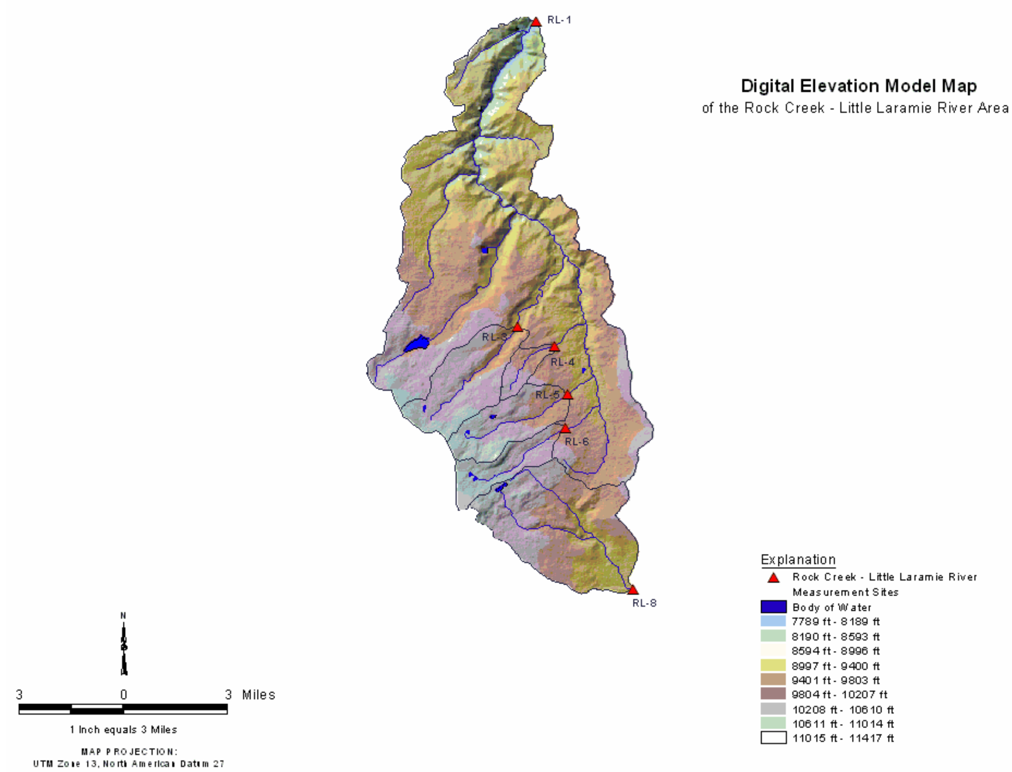
A-5 Land cover map of drainage basins in Brush Creek area.



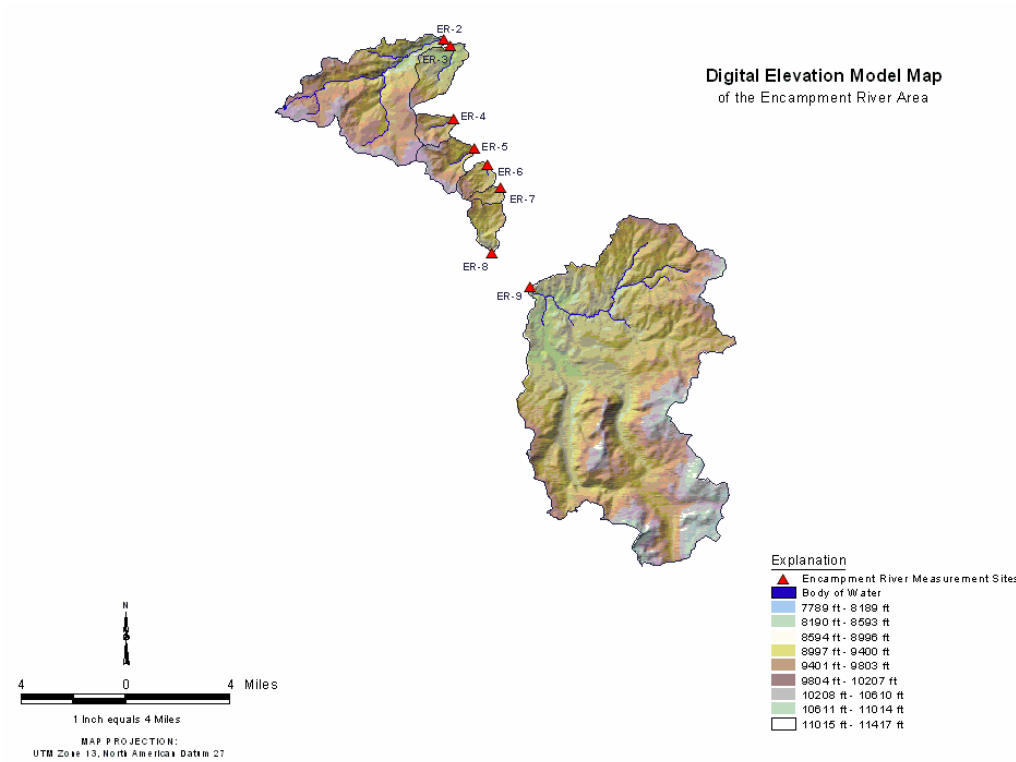
A-6 Aerial photograph of clearcuts in Brush Creek area.



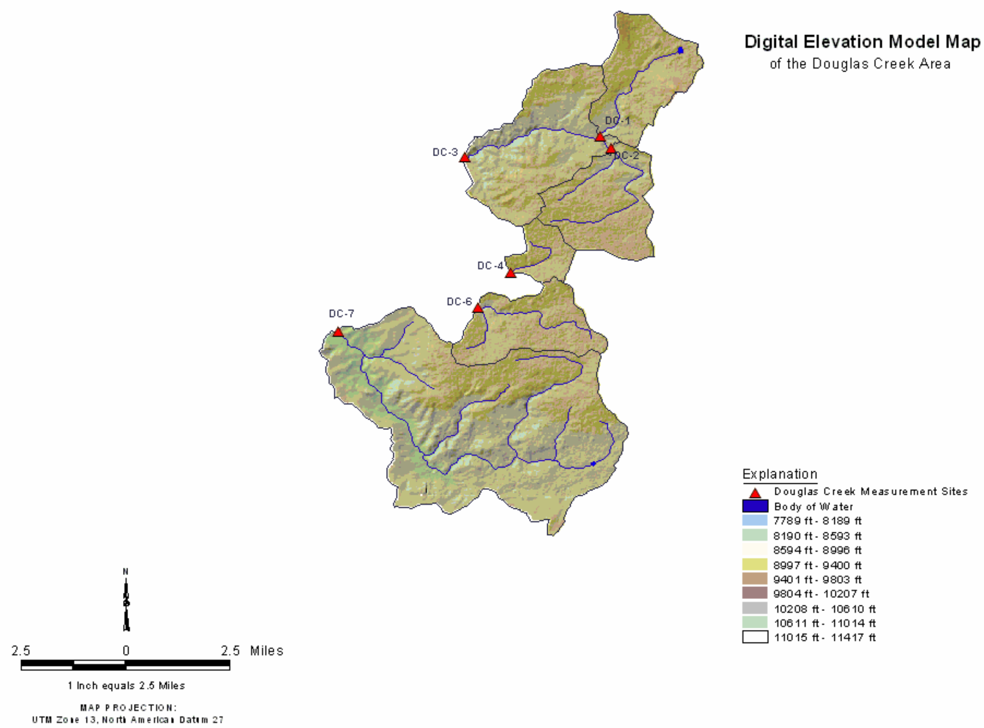
A-7 Clearcuts, group selection, and wetlands in drainage basins.



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

Combining modern and paleo-climate data to enhance drought prediction and response

Basic Information

Title:	Combining modern and paleo-climate data to enhance drought prediction and response
Project Number:	2002WY4B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Drought, None, None
Descriptors:	
Principal Investigators:	Stephen Jackson, Kenneth Gerow, Stephen Gray

Publication

1. Gray, S. T., J. L. Betancourt, C. L. Fastie, and S. T. Jackson, 2003. Patterns and sources of multidecadal oscillations in drought-sensitive tree-ring records from the central and southern Rocky Mountains, Geophys. Res. Lett., 30(6), 1316, doi:10.1029/2002GL016154.
2. Gray, S.T. 2003. Long-term Climate Variability and its Implications for Ecosystems and Natural Resource Management in the Central Rocky Mountains. Ph.D. Dissertation, Botany, A&S College, University of Wyoming, Laramie.
3. Gray, S.T., S.T. Jackson, and J.L. Betancourt. 2002. Tree-ring based reconstructions of precipitation variability in northeastern Utah. Proceedings of the 2003 Pacific Region Climate Workshop (PACLIM), Pacific Grove, California. http://tenaya.ucsd.edu/~dettinge/PACLIM/Abstracts_PACLIM03.pdf
4. Gray, S.T., S.T. Jackson, and C.L. Fastie. 2001. Use of Paleoclimate Proxy Data to Enhance Drought Planning and Response. Proceedings of the 2002 Pacific Region Climate Workshop (PACLIM), Pacific Grove, California. http://tenaya.ucsd.edu/~dettinge/PACLIM/agenda02.pdf
5. Gray, S.T. C.L. Fastie, S.T. Jackson, J.L. Betancourt and K. Taylor. 2001. 1000 year drought records from tree-rings in the Bighorn Basin, Wyoming. Proceedings of the 2001 Annual Meeting of the Ecological Society of America, Madison, Wisconsin http://abstracts.allenpress.com/esa-cgi/document.cgi?YEAR=2001&ID=28695

Problem and Research Objectives:

The State of Wyoming spent more time during the 20th Century under severe drought conditions (Palmer Drought Severity Index <-3) than any other state except Colorado (McKee et al. 1993; NOAA 1990). In fact, half of Wyoming's major river basins experienced severe drought conditions for more than 15% of the time from 1895-1995 (WGA 1996; NDMC 2000), accounting for millions of dollars in damage to crops, livestock, and wildlife along with diminished tourism and wildfires (WGA 1996).

A clear need exists for assessing potential drought impacts, developing contingency plans, and identifying inception of meteorological droughts. However, the drought record of the past 100-130 years is inadequate for implementation of these tasks. A more complete and realistic appraisal of Wyoming drought requires assessment over a much longer period, spanning several centuries. Sole dependence on the past century's record in assessing drought susceptibility and impact is analogous to a physician's relying only on the past five years of a patient's medical history, which may not include earlier events diagnostic of susceptibility to disease, allergy, or infection. In the case of drought, symptoms of susceptibility to severe and prolonged events, possibly far worse than those experienced during the past century, can only be observed by examining the records of previous centuries. Those records are available in tree-ring archives for many regions of Wyoming. Tree-rings are an excellent source of drought proxy data because of their long duration (centuries to millennia) and high (at least annual) temporal resolution (Fritts 1976). Furthermore, tree-rings have been used with great success in documenting droughts throughout North America (Cook et al. 1995) and to reconstruct the relationship between droughts and circulation indices (Stahle et al. 1998). By developing a network of tree-ring records from western Wyoming, we are providing a detailed reconstruction of drought events spanning the last 500 to 1000 years that can be used to enhance our understanding of extreme climate events in this state and the Rocky Mountain West as a whole.

Methodology:

This project centered on the development of a network of tree-ring sites selected to provide 600-1,000+ year reconstructions of regional droughts in western Wyoming, and the use of those records to improve methods of drought prediction.

Study Area: This study focuses on western Wyoming, specifically the Clark's Fork, Shoshone, Bighorn, Wind, and Green River drainages. Tree-ring sites along the edges of the Bighorn Basin and in the Flaming Gorge area of SW Wyoming and NE Utah form the core of our network.

Field Techniques: Tree-rings are useful for drought reconstructions when water availability becomes critically limiting and persists for long enough that the growth of many trees over a wide area is affected (Fritts 1976). At lower elevations, growth is most often limited by precipitation. Therefore, we have selected a network of sites at lower tree line for drought reconstructions. Our work shows that limber pine (*Pinus flexilis*), Douglas-fir (*Psuedotsuga menziesii*), ponderosa pine (*Pinus ponderosa*) and pinyon pine (*Pinus edulis*) are the most appropriate species for drought reconstructions in the study region. These species are found on dry sites throughout the area and reach sufficient age to produce 600-1,000+ year climate reconstructions. Over the course of this project we sampled over 600 trees, including dead snags and sub-fossil wood, at 13 sites throughout the study area.

Dating and Measurement of Cores: In the laboratory, we dried, mounted, and progressively sanded all cores to at least 400 grit (Cook and Kairiukstis 1990, Grissino-Meyer 1996), and assigned exact dates to each ring using standard cross-dating methods (Stokes and Smiley 1968, Swetnam et al. 1985). We then measured all rings from the dated series to the nearest 0.001 mm using a computer-based optical measuring device.

Reconstructing Droughts from Tree Growth: We used correlation analysis to compare modern meteorological records with tree-ring widths produced during the same time period (Fritts 1976). Monthly or seasonal climate variables with the highest correlation coefficients are then chosen for reconstruction. Response functions, a type of statistical equation describing the relationship between climate and growth, were then developed (Fritts 1991). After using subsets of the data to verify the climate/growth relationship, a new transfer function is developed which provides reconstructed climate values by substituting ring widths in the equation.

Investigating the relationship between drought and large-scale circulation patterns: We used methods developed by Hirschboeck et al. (1996), Woodhouse (1997), and Cayan et al. (1999) to determine the relationship between circulation indices (CI) and drought in western Wyoming. Using more extensive networks of tree ring sites obtained from the International Tree Ring Data Bank (www.ngdc.noaa.gov/paleo/treering.html), we repeated these analyses for the entire central and southern Rocky Mountain regions. Briefly, we compared the occurrence of both modern and paleo droughts with independent CI records using a combination of regression-based and event-based techniques. Using the regression-based approach, we looked for correlations between droughts recorded in the instrumental record and CIs for the same time period. We then used event-based analysis, a technique that looks for coincidence between unusual climatic events, to determine if extreme CI values correspond with regional droughts. Since the instrumental record has several important limitations, we repeat these analyses using data from our tree-ring sites.

Principal Findings and Significance:

During the course of this project, we completed sampling and analysis of tree-ring sites throughout the study area. In total, we have sampled trees at 13 sites. Seven sites are in the Bighorn Basin portion of the study area, making this one of the densest climate reconstruction networks in the Rocky Mountain region. To date, key findings from the project include:

1. Drought events in our long-term tree ring records are often longer and more severe than any droughts observed in the instrumental record of the past 120 years. Therefore, modern droughts do not represent the scope of events we should expect and plan for.
2. Statistical analyses of our long-term drought records show that dry events often occur at more-or-less regular intervals. In particular, droughts often return at

both 30 and 50-year cycles throughout much of the study area. However, these oscillations are not stable through the entire proxy record, and should not be over-emphasized in predictive models of drought.

3. Drought conditions in western Wyoming are often highly persistent. In the Southwestern U.S., 2-3 years of drought are often followed by several years of normal to wet conditions. In Wyoming, however, dry years are much more likely to be followed by additional dry years, with drought cycles often extending over 10 or more years. The 20th Century has been somewhat unusual in that this persistence has been dampened. A return to the high-persistence mode of the previous several centuries would lead to droughts of far greater duration than those experienced in recent decades.
4. Droughts in western Wyoming show a strong link to circulation patterns in the northern and tropical Pacific. However, the strength and sign of these correlations may vary over time. More specifically, the relationship between precipitation variability and ENSO (El Nino-Southern Oscillation) varies throughout western Wyoming and much of the central Rockies.
5. Circulation anomalies in the Gulf of Mexico and Northern Atlantic may lead to rare but severe and long-duration drought events that affect the entire Rocky Mountain Region from Montana to the Mexican Border. Evidence from western Wyoming and our expanded network of tree-ring sites in the Rocky Mountain Region also suggest that variations in Atlantic Basin sea surface temperatures can modulate the influence of Pacific phenomena (i.e. ENSO) on the climate of Western North America.

While the data derived from our study has already contributed to our understanding of drought in Wyoming and much of Western North America, this research will also play a key role in future work. Our tree-ring records are being used as input for models designed to study the frequency, duration and distribution of drought conditions throughout North America (Ed Cook, Lahmont Doherty Earth Observatory). Our tree-ring records for southwestern Wyoming and northeastern Utah will also play a key role in efforts to understand water resource issues in the Upper Colorado River Basin (Connie Woodhouse, NOAA).

The Wyoming Climate Atlas

Basic Information

Title:	The Wyoming Climate Atlas
Project Number:	2002WY5B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	1
Research Category:	None
Focus Category:	Management and Planning, None, None
Descriptors:	None
Principal Investigators:	Jan Curtis

Publication

Problem and Research Objectives:

It has nearly two decades since the last Wyoming State Climate Atlas was produced. During this period, the development and marketing of natural resources in Wyoming has accelerated in order to meet the rapidly increasing demands nationally and internationally. New Federal environmental regulations and interstate litigation over water usage and rights have also prompted the requirement for a new climate atlas. Additionally, since tourism and recreation are important economic revenue sources for the state, a new atlas that focuses on this market can only enhance the image of Wyoming.

Having completed about half of this project, it has become increasingly evident that since Martner (1986) original climate atlas, the state's climate has not changed markedly. This observation is both surprising and yet expected. With all the news and scientific research focused on observed and modeled global warming, one would expect that Wyoming was not exempted from this overall trend. Yet, as a rural state, the climate record has not been contaminated through urban heat island effects or land use changes. However since Martner landmark work, numerous weather stations have been added to the state's inventory, thus providing a higher level of depiction of various weather elements. Combined with more sophisticated merging of modeled data and graphical depictions, a new climate atlas will supplement Martner's atlas. The current three plus years of statewide drought has refocused the need for accurate and timely climate data for a wide spectrum of users. Additionally, recent research now suggests that climate changes have been very rapid over a period of years and decades then over centuries and millennia. This recognition of abrupt changes in the past reinforces concerns about the potential for significant impacts of anthropogenic climate change.

The objective of this study is to provide a data resource that will enable its users to answer the question as to how best do societies and ecosystems maintain resilience and adaptability under various climates and climate change scenario? Specific objectives include: (1) employing relational data base techniques to compile the massive quantity of data, (2) using the newest software to develop user friendly and maximum utility graphics, (3) focusing on general statewide climatology, regional (i.e., water basin or county level) and city data statistics, and (4) relating climate trends to drought and flood frequencies. With a detailed source of climate data in the form of this atlas and accompanied CD, researchers will have ready access to this important resource that should assist with their research. City planners will enhance public relations by providing the latest climate data and graphics to their informational brochures. Engineers will have a better assessment for building more efficient buildings (i.e., maximizing solar and wind power).

Methodology:

This atlas is intended to be provided in several formats to serve researchers, business, agriculture, tourists, and industry. As a hard copy book, this atlas will contain many figures and maps, some in color, as an overview of specific weather elements.

Depending on the user, additional data in the form of text, tables and graphs can be acquired from an accompanied CD. Eventually, through an internet map server, customized climate products are envisioned. This longer term project will build on the existing database from this atlas. This living document is expected to be updated on a routine bases with little if any manual input since there are multiple data sources available via the internet.

Much of Martner's descriptive work on climate governing factors, evaporation, and air quality has not changed significantly. However, additional data and statistics on severe weather, wind, precipitation frequency and intensity, and drought will be greatly expanded. New sections on lightning (figure 1), renewable energy sources (solar and wind), and agriculture (climate optimalization for plant types) are being added since technology has advanced and data availability has increased considerably in these areas.

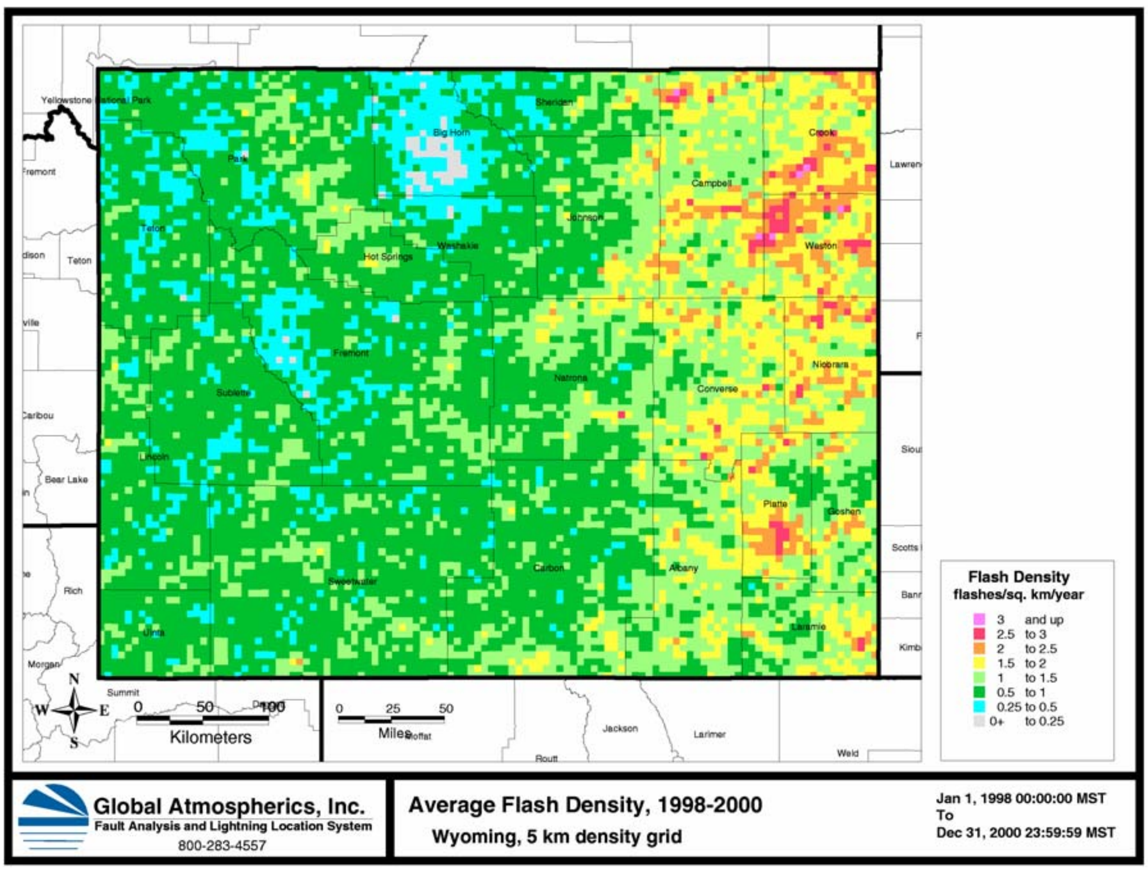


Figure 1 - Annual cloud to ground lightning frequency per sq. km resolution from 1998-2000.

The methodology employed in this study examines climate trends and specific weather parameters and relates them to user requirements. For example, a supplier of clothing for the coal-bed methane industry needs to know the frequency when the humidity is below

20 percent in order to purchase clothing that will not cause static sparking. The obvious consequence of this requires a detailed analysis.

Principle Findings and Significance:

Many possibilities for additional research exist with this concise yet expanded climate atlas. Since climatology is truly interdisciplinary by its very nature and bridges the social and physical sciences, this atlas will serve as a common reference tool across the widest cross section of academia and the general public. For example, since the start of this study, on-going research by university graduate students on tree-ring correlation to ancient droughts over the Big Horn Mountains has been conducted (Gray, 2003). This may have far reaching implication for future occurrences of multi-decadal droughts over the western US. Potential research into climate modification using cloud seeding to suppress the expansion of drought might benefit from the data contained in this state's climate atlas as well.

Student Support:

During the entire period of this study, biology major, Candice Hudson, a senior at the University of Wyoming has provided technical assistance in the compilation of the climate data that will be used in the new Wyoming Climate Atlas. She has taken digital data and created Arc View maps of numerous weather elements. Additional, she has taken large data sets and through the use of EXCEL, has developed informative charts. Candice's work has inspired her to further her studies in the Environmental Natural Resources field at the University of Wyoming.

References:

Gray, S. T., J. L. Betancourt, C. L. Fastie, and S. T. Jackson, 2003. Patterns and sources of multidecadal oscillations in drought-sensitive tree-ring records from the central and southern Rocky Mountains, Geophys. Res. Lett., 30(6), 1316, doi:10.1029/2002GL016154, 2003.

Martner, B.E., 1986. Wyoming Climate Atlas, University of Nebraska Press, pp. 432.

Real-time monitoring of E.Coli contamination in Wyoming

Basic Information

Title:	Real-time monitoring of E.Coli contamination in Wyoming
Project Number:	2002WY6B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	1
Research Category:	None
Focus Category:	Water Quality, None, None
Descriptors:	None
Principal Investigators:	Paul E. Johnson

Publication

1. Johnson, P.E. 2002. Biodetection with flow cytometry: better, faster, cheaper, Biodetection Technologies, Knowledge Press, Brookline, Massachusetts, Volume 1: 71-83.

Problem and Research Objectives:

The state of Wyoming supports 108,767 miles of rivers and streams and 325,048 acres of lakes (USEPA website). The Clean Water Act (CWA) requires states to designate uses for surface waters such as these and monitor the quality of the water in support of its use. Under section 305(b) of the CWA, Wyoming is required to include the results of these water assessments in biennial reports submitted to the United States Environmental Protection Agency (USEPA). Fecal coliform contamination is one water quality standard tested and included in these reports. Fecal coliform monitoring is an indicator of the sanitary quality of the water and can determine the extent of fecal contamination in the water from warm-blooded animals. Fecal contamination is important from a public standpoint when the surface water's designated use includes contact recreation such as beach use, boating, or swimming (USEPA report, 1986).

Wyoming's 2002 305(b) report to USEPA included a 303(d) list of the State's surface waters with water quality impairments not allowing those reaches to support their designated use(s). Reasons for impairments include metal contamination from copper, selenium, cadmium and silver, excess siltation, high phosphate and chloride levels, high pH, habitat degradation, oil deposits, and fecal contamination. Of the 45 water reaches included in the list, 22 are for fecal coliform exceedences, with all having contact recreation designated uses. This illustrates that fecal contamination of surface waters is an important issue for the State of Wyoming.

This project is developing and proving the concept of an economical system capable of real-time detection of individual *E. coli* in surface waters in Wyoming, including streams, rivers, and lakes, in order to quantify fecal coliform contamination. Our goal is a detection limit of < 5 *E. coli* cells per 100 ml of water in 15 minutes of analysis time, with a minimum detection efficiency of 50% and a false detection rate of < 1%. We are proving the concept of a low-cost, portable testing system that screens water in the field. This system will also support a more economical testing regime than any currently in use, allowing for more frequent and comprehensive water monitoring, thus minimizing human pathogen exposure, e.g. in contact recreation. This proof of concept allows for the design and fabrication of a remote monitoring system that will automatically screen water in real time. Alternative methods necessitate the shipping of bulk water samples or concentrates to laboratories and labor-intensive screening technologies, which may include bulk water concentration, incubation, and culturing. These factors combine to impede overall routine monitoring for fecal coliforms in the field and preclude widespread, routine screening of surface waters.

Based on USGS Year I funding (in partnership with the Wyoming Water Development Commission), we developed and tested a low-cost, portable, highly sensitive, self-contained single cell detection system for *E. coli* in surface waters, which will greatly exceed the current testing procedures in both speed and reliability. Project objectives are**:** 1) low-cost detection of *E. coli* in Wyoming surface waters, 2) allows rapid (<<1hour) enumeration of *E. coli* concentration, 3) sensitive, will allow for enumeration of concentrations < 5 cell/100 ml with minimal number of false positive detections, 4) portable for field monitoring, 5) simple to use, does not require substantial training, and 6) development of proof of concept for remote monitoring.

Methodology:

The innovative technique employed in this research has the potential to detect foodborne and waterborne pathogens in real time at the level of a single bacterium in a volume of air or water through the use of specific fluorescent antibodies. The resulting fluorescence is detected with a CCD imager using a novel integration scheme called Fountain Flow (FF). Our system is called the Wyoming Biodetection System or WBS.

Our proprietary and patented (pending) WBS is based on immunofluorescence identification:

- An antibody specific to the cell species of interest is labeled with a fluorescent molecule or fluorochrome.
- The labeled antibody is mixed in solution with the cell species of interest. The antibodies attach to specific sites on the cells (antigens).
- The cells are passed in a stream of liquid toward a low-cost laser diode, which illuminates the fluorochromes causing them to fluoresce at a different wavelength.
- A low-cost CCD (charge coupled device) 2-D detector detects a burst of fluorescence emission each time a marked cell is illuminated by the laser diode while passing in front of the detector.
- The number of marked cells is then counted via computer. Antibodies can be chosen that are highly specific to the cells of interest.

In our current USGS/NSF-funded research, an operational CCD/FF apparatus was assembled and used to demonstrate the practical and economic feasibility of real time detection of *E. coli* to image and count (via computer) individual microorganisms. **The NSF-funded research focuses on detection of *E. coli* O157:H7 in ground beef, while the USGS-funded research involves detection of *E. coli* in Wyoming surface waters.** This device enabled the flow cytometry feasibility demonstrations to date and established the suitability of the FF cytometer to ***effectively detect single pathogenic microorganisms*.** Emphasis is placed on signal-to-noise enhancement. This allows for multicolor detection providing enhanced reliability using several markers. In this detection system, fluid is transported through a hole that is large enough (2-mm dia.) to prevent clogging. Our imaging technique allows automated measurement of individual cells while they transit this flow cell.

In Fountain Flow a sample of fluorescently-labeled bacteria suspended in a transparent or translucent aqueous solution flows up a tube toward imaging optics, where sample particles can be imaged onto a CCD camera and counted or measured photometrically. The imaging optics include, with a single color instrument, a filter isolating the wavelength(s) of fluorescent emission. The ideal situation occurs when a particle flowing up the flow tube is imaged in the same pixel(s).

Principal Findings and Significance:

Our US Geological Survey Year I proposal outlined the following five goals: 1) optimize fluorescent labeling of *E. coli*, 2) perform laboratory measurements on quantified *E. coli* samples to determine the detection efficiency and sensitivity of the monitoring system, 3) test methods of removing background detritus, 4) test methods of counting quantified samples of *E. coli* in a background matrix, and 5) enumerate *E. coli* in stream and lake water samples using both our proposed method and the standard method currently recommended by the USEPA. Progress toward these goals is listed below.

FLUORESCENT LABELING

The fluorescent labeling of *E. coli* was the first goal accomplished. A protocol was designed using an R-phycoerythrin (R-PE) labeled antibody to *E. coli* K12, the benign test microorganisms used in our preliminary research. The antigen/antibody reaction was optimized to ensure fluorescent emission strong enough to be detected with the system with as little waste of unattached antibody as possible. This optimization can be scaled up or down according to sample size.

E. COLI DETECTION METHOD AND EFFICIENCY OF FF

In order to determine the efficiency of the Fountain Flow (FF) technique, comparisons were made between FF and Whipple-grid counting. For FF, samples of fixed *E. coli* K12 were labeled with propidium iodide dye and flowed through the FF system at 2.2 ml/hr. A 13-mW 475-nm laser diode was used to illuminate the stained bacteria at an illumination angle of 45 degrees. The exposure time of the CCD imaging the flow was 400 ms. Multiple frames were recorded and software used to quantify the detections made. The original overnights of the *E. coli* K12 were dilution-plated and counted with a Whipple grid to obtain the total number of cells in the sample. This number was compared with the number of cells counted by our system, the Wyoming Biodetection System or WBS. Efficiencies of ~50% are obtained with cells and ~90% when comparisons are made with hemocytometer counts of microbeads, even when the microbeads are fainter than cells. This discrepancy is largely due to cell clumping, which doesn't significantly affect our Whipple-grid results, but has a large effect on FF counts. Typically, one ml of flowing liquid produces 900 images. This large amount of data necessitates counting in real time so that data archiving is not necessary. Detection efficiency is computed by comparing the counts from the WBS with the Whipple-grid counting method or by the mTEC filtration method (described in the next section).

FILTERING BACKGROUND DETRITUS

The USEPA introduced the mTEC enumeration method for *E. coli* in 1986. This method is currently employed by the USGS Water Resource Office in Cheyenne, WY and was demonstrated to us by USGS staff hydrologist Melanie Clark in a visit to our site. This membrane filter method provides a direct count of *E. coli* in water, based on the development of colonies that grow on the surface of the membrane filter. We first established that filtration through a 10-µm filter was necessary to remove any autofluorescing material from the water sample. We then used the mTEC method to test the efficiency of bacteria recovery after this initial filtration. An overnight culture of *E.*

coli K12 was diluted by a factor of 10 using Crow Creek Reservoir (Wyoming) water as the diluent. (Because it is non-pathogenic, K12 was used in the preliminary research.) Crow Creek water simulates water samples that will be collected in the field, which contain sand, other dirt particles, and a small percentage of organic material. Fifteen ml of the sample was vacuum filtered through a 10-µm filter to remove debris, and then subsequently filtered through a 0.45-µm filter to separate bacteria from the solute. The 0.45-µm filter was then placed onto the surface of an mTEC agar plate. A second 15 ml sample, the control, was filtered only through the 0.45-µm filter. This 0.45-µm filter was also placed onto an mTec agar plate. Both plates were incubated at 35.2^{o}C for two hours and then at 44.5^{o}C for 22 hours. The colonies were enumerated the next day. Tween 80 was added to some samples to attempt to increase the recovery fraction. Similarly, sonication was also applied to some samples. **Results from spiked Crow**

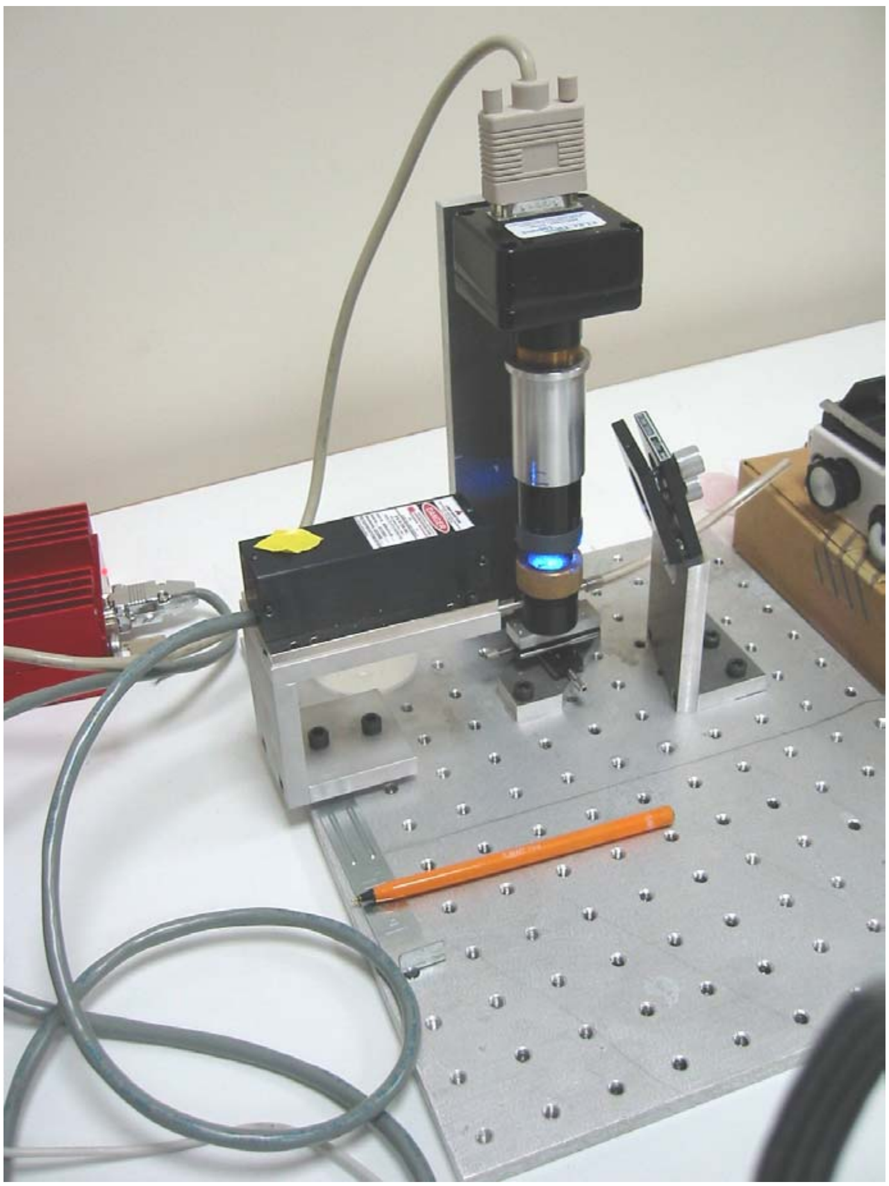


Figure 1. *The Wyoming Biodetection System with a 475 nm solid-state 13-mW laser.*

Creek Reservoir water are summarized with the following mean bacteria separation efficiencies: 1) 62% (±5%) with no surfactant, 2) 33% (±2.5%) in a 2% Tween 80 solution, and 3) 33% in 2% Tween 80 following 10 minutes of sonication.

QUANTIFYING SAMPLES OF *E. COLI* IN VARIOUS BACKGROUND MATRICES

We have demonstrated successful recovery of *E. coli* spiked Crow Creek water. However, testing of different water sources is necessary to encompass the diversity of Wyoming's waters. It is anticipated that bacteria recovery will be different in waters containing other types of soil and detritus. For this it may be necessary to employ techniques other than simple filtration to recover adequate amounts of bacteria without background interference. Alternative techniques include: addition of surfactants, recovery of bacteria using immunomagnetic beads, and centrifugation or gravity separation. Immunomagnetic bead separation, based on using fluorescently tagged magnetic beads coated with an antibody specific for the target bacteria, shows promise. The beads are added to the sample, mixed for a determined period allowing for bacteria attachment to the antibody, and recovered through their magnetic properties. The beads are then placed into a transparent aqueous solution and flowed through the biodetection system. Water samples from various locations throughout the state will be taken and analyzed for bacteria recovery, testing the previously mentioned techniques to improve efficiency. Sampling will be coordinated with USGS sampling. These additional techniques are being explored in Year II.

ENUMERATION OF *E. COLI* IN STREAM AND LAKE WATERS

The latter part of Year II research will encompass end-to-end testing (filtration and FF) of various water sources in Wyoming using the WBS. Water samples from locations throughout the state will be taken and analyzed for endogenous bacteria. Results from the system will be compared with counts obtained from the mTec method currently employed by the USGS Water Resource Office in Cheyenne, WY. Sampling will be coordinated with USGS and results compared with theirs.

SUMMARY OF GOALS FOR YEAR II RESEARCH

In preliminary testing, our team has demonstrated success in proving the concept of the WBS. Bacteria labeling, recovery of bacteria from authentic Wyoming surface water, and enumeration efficiency of the WBS have all been successfully accomplished. Year II plans include: 1) developing techniques to efficiently recover *E. coli* bacteria from surface waters throughout the state, 2) end-to-end sampling of those waters to detect endogenous *E. coli,* and 3) comparison of results to with the current USEPA techniques to test the efficiency of the WBS.

Students Supported Through This Project:

During the last year, the P-I employed two undergraduate and two graduate students, in this research. The interaction among personnel of varying backgrounds (including microbiology, pharmacy, and physics) has provided a highly educational experience for everyone in research biodetection technology.

Drought prediction model development and dissemination in Wyoming

Basic Information

Title:	Drought prediction model development and dissemination in Wyoming
Project Number:	2002WY7B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	1
Research Category:	None
Focus Category:	Agriculture, Drought, Management and Planning
Descriptors:	None
Principal Investigators:	Michael A. Smith, Thomas L. Thurow, Philip A. Rosenlund

Publication

Problem and Research Objectives:

Timely, locally relevant, within year drought prediction tools for each major land resource area within Wyoming are not available. The few sites with existing data have not been developed or extent of their geographic relevance examined. The overall goal of this proposed research is to develop a timely, locally relevant, within year drought prediction tool for each major land resource area within Wyoming, focusing on the relationships of precipitation variables and annual forage production on rangeland by accomplishing the following objectives.

1. Cooperatively with CES and land management agencies, establish herbage yield and quality measurement sites representative of the predominant soils and precipitation pattern/amounts in major land resource areas in Wyoming and continue sampling the existing long-term forage production harvest site near Saratoga.

2. Locate and access existing annual forage production data from agency files within Wyoming.

3. Obtain and summarize relevant precipitation records for reporting stations nearest to vegetation sampling sites.

4. Analyze relationships of monthly and seasonal precipitation with annual peak standing crop forage yields and quality.

5. Provide cooperators with sampling and analysis tools for each to continue to strengthen predictive capabilities for their site.

6. Widely disseminate to the broad constituency of land managers and users in Wyoming, the most useful drought prediction methods resulting from this study.

Methodology:

Cooperating agencies will establish vegetation production sampling sites in different land resource areas in Wyoming near their weather site or existing weather recording stations. Existing sources of long term vegetation production/weather records will be sought, including those at Cheyenne from USDA-ARS-HPGRS. A 16 year record of productivity and weather data from a site near Saratoga will be continued.

Regression techniques will be used to determine the best seasonal or monthly weather variable for prediction of the upcoming growing season productivity. Multi-variate regression analysis and time series analysis will examine the precision of the predicted forage production associated with adding successive climatic inputs received during the year prior to cessation of plant growth. An analysis goal is to identify a weather variable existing early enough in the year for livestock producers to respond to predicted forage production by making relevant stocking level adjustments before financial hardship or resource damage are probable.

Results will be disseminated through the CES web site and county offices statewide. Other print and visual/audio media will also be used.

Principal Findings and Significance:

This is the end of the first year of a project approved for three years. A graduate assistant was recruited to conduct sampling and analysis duties. In the first year, six cooperator production sites were established including the following counties-cooperators, Converse-CES, Laramie-CES and HPGRS, Campbell-CES, Johnson-CES, Washakie-TNC, Sublette-CES. Five additional cooperator sites have been confirmed for this years sampling and analysis; Crook , Carbon, Platte, Washake, and Natrona. The site in Carbon County, maintained for 16 years jointly by UW and Saratoga Cons. Dist., was again sampled. In aggregate, these sites provide a geographic dispersion oriented toward east of the continental divide where effective precipitation for forage growth largely comes in spring. We assisted cooperators with aid in sampling and weighing materials as needed.

Preliminary analysis of data from Saratoga site (Figs. 1A-D and 2A-D) indicates as has previous treatments of this data, that winter precipitation is not an effective predictor of growing season productivity. Normal winter precipitation wets the upper few centimeters of the soil providing moisture for early growing species. Precipitation received in April produces the highest level of correlation with forage yields of the months/season tested. May and June precipitation are less effective predictors of growth but are valuable in extending the green season and maintaining higher forage quality. An end of April decision point for stocking decisions related to predicted forage production, is early enough in the year for economically effective decisions in most years.

The data from other sites in the state when examined in the context of the data from Saratoga (Fig. 3A-C), reveals that many of these sites responded to precipitation in 2002 similar to the long term responses. These tentative results imply that fewer long term sites around Wyoming may be needed to effectively inform producers and land managers of upcoming forage production.

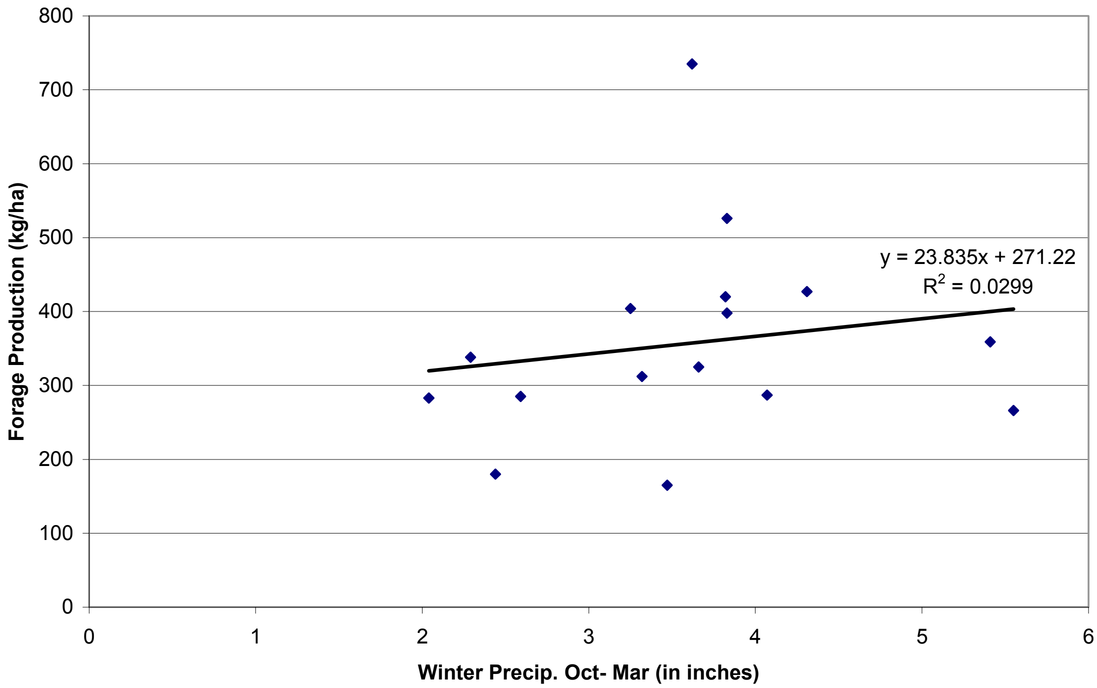


Figure 1A. Oct- Mar Precip vs. Forage Production for Check plots (no sage removed) 1987-2002

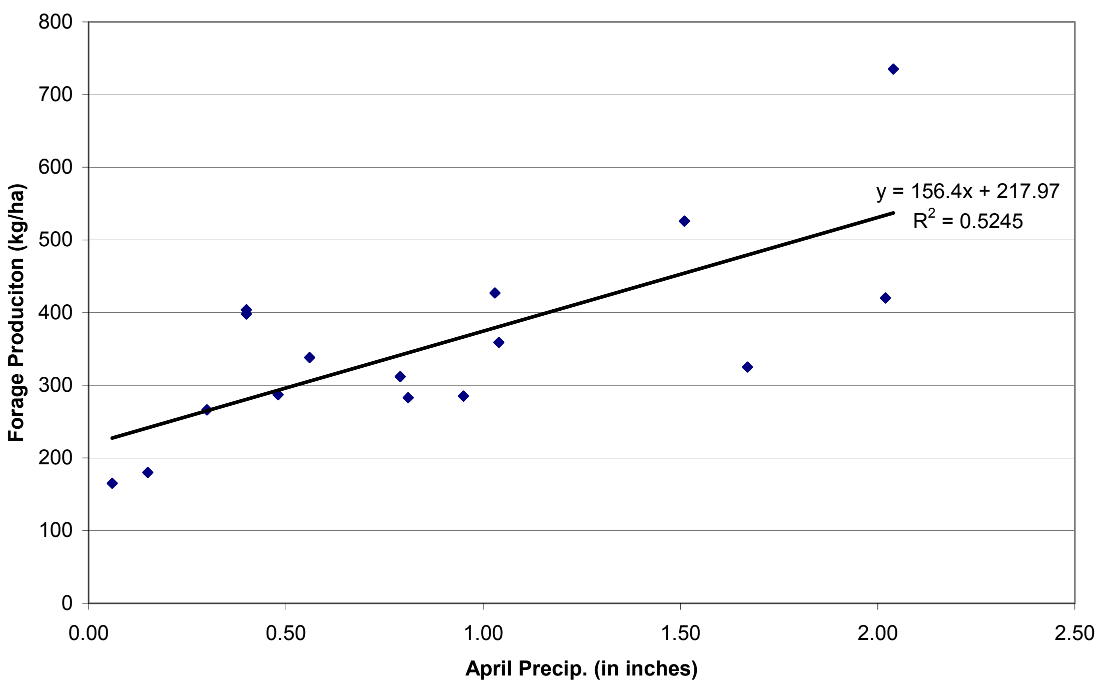


Figure 1B. April Precip. vs. Forage Produciton for Check Plots (no sage removed)1987-2002

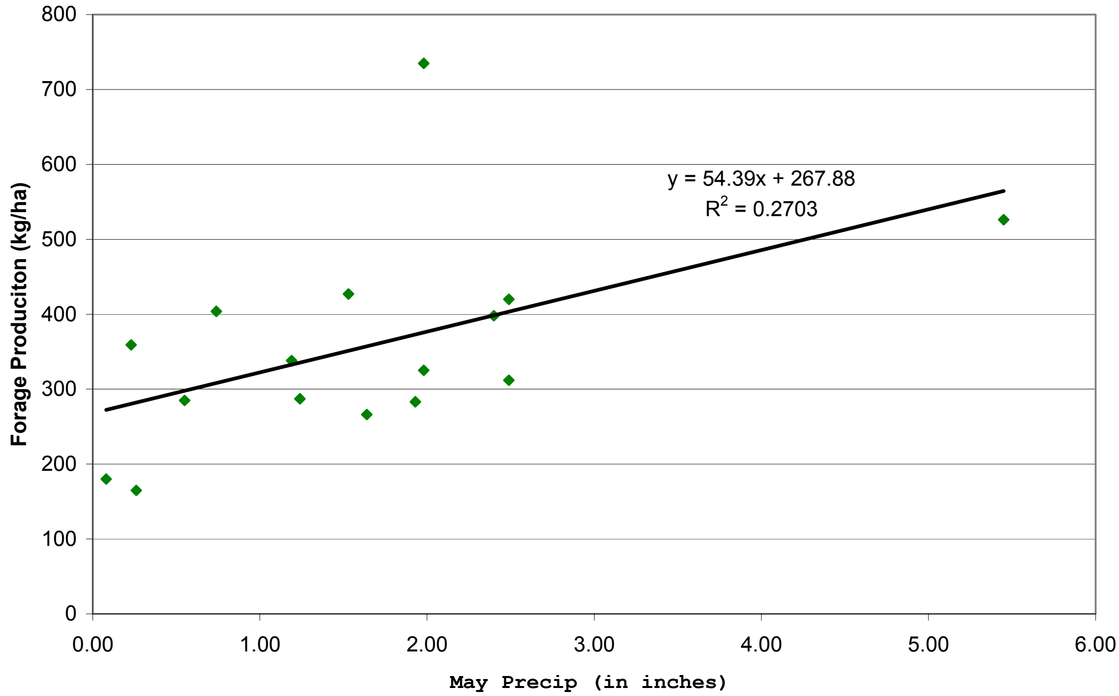


Figure 1C. May Precip. vs. Forage Production for Check Plots (no sage removed)1987-2002

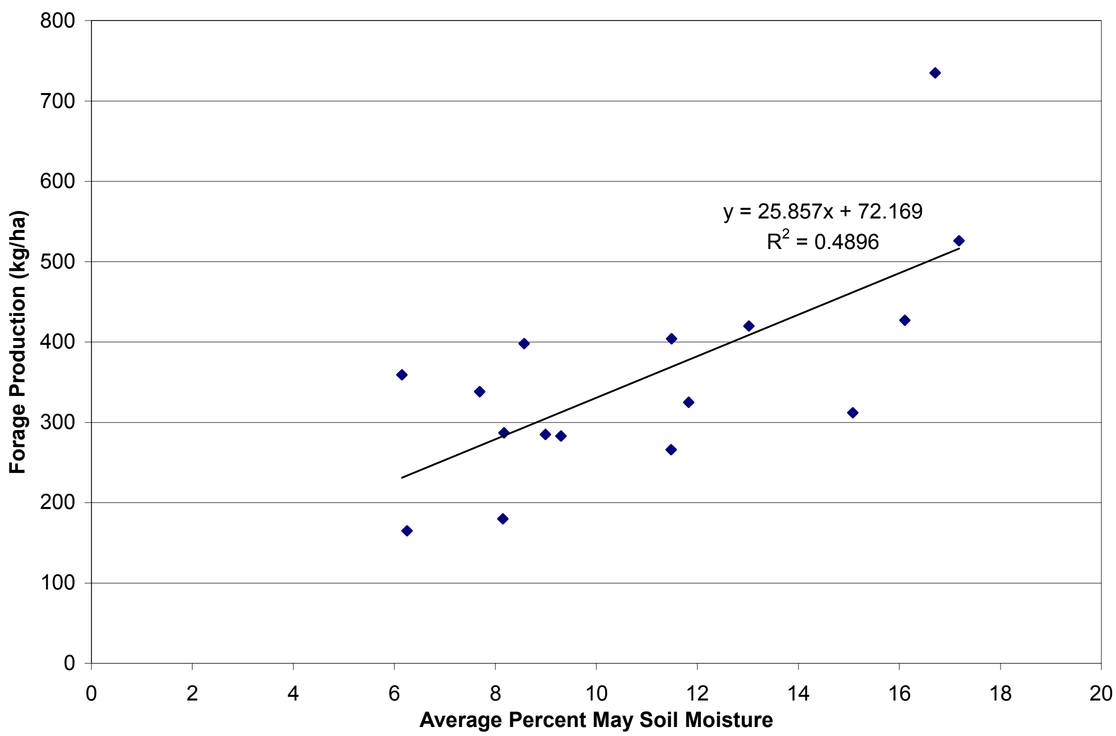


Figure 1D. May Percent Soil Moisture vs. Forage Production for Check Plots (no sage removed) 1987-2002

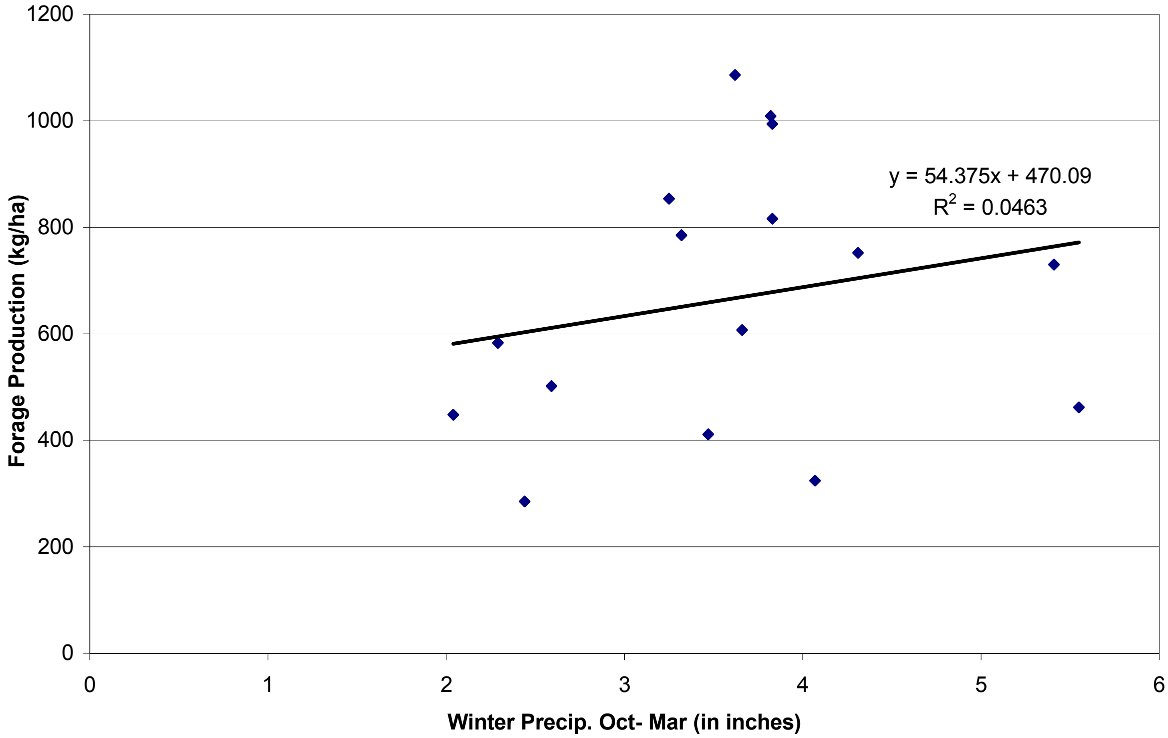


Figure 2A. Oct- Mar Precip. vs. Forage Production for Treated Plots (sage removed) 1987-2002

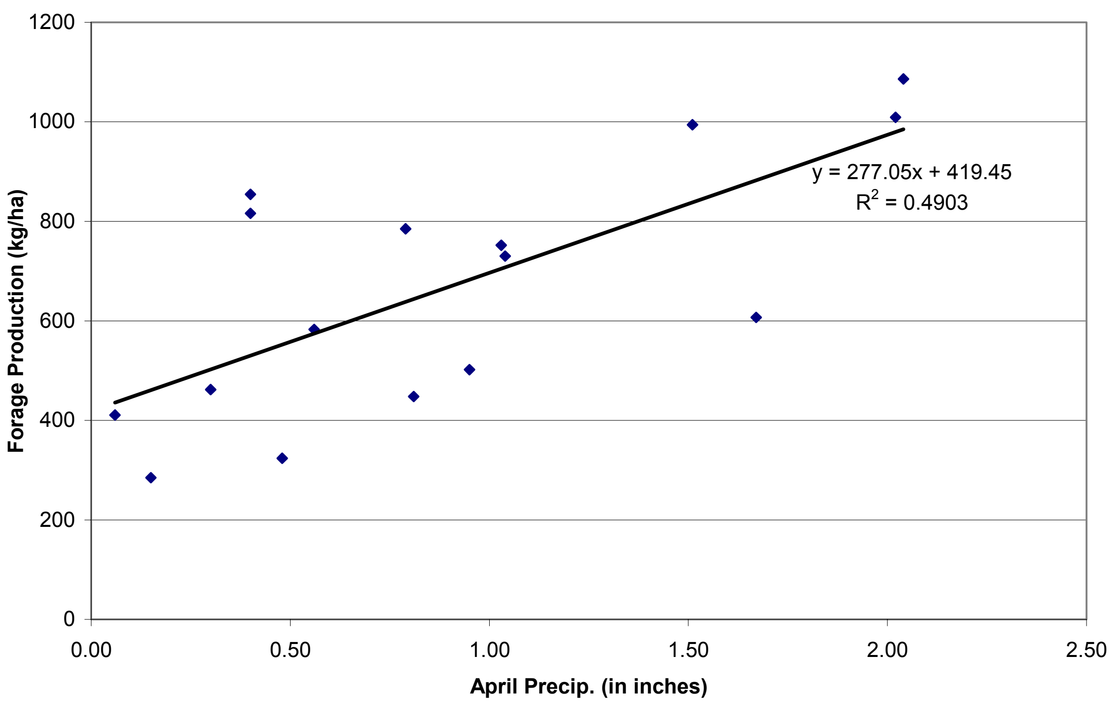


Figure 2B. April Precip. vs. Forage Production for Treated Plots (sage removed) 1987-2002

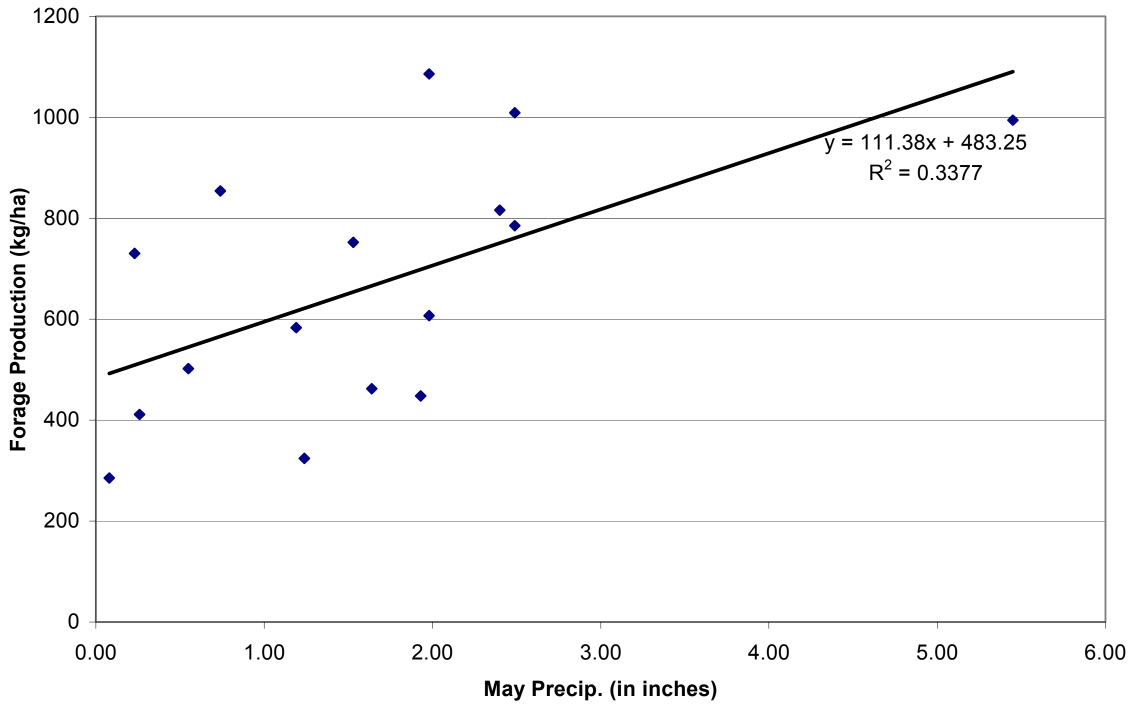


Figure 2C. May Precip. vs. Forage Production for Treated Plots (sage removed) 1987-2002

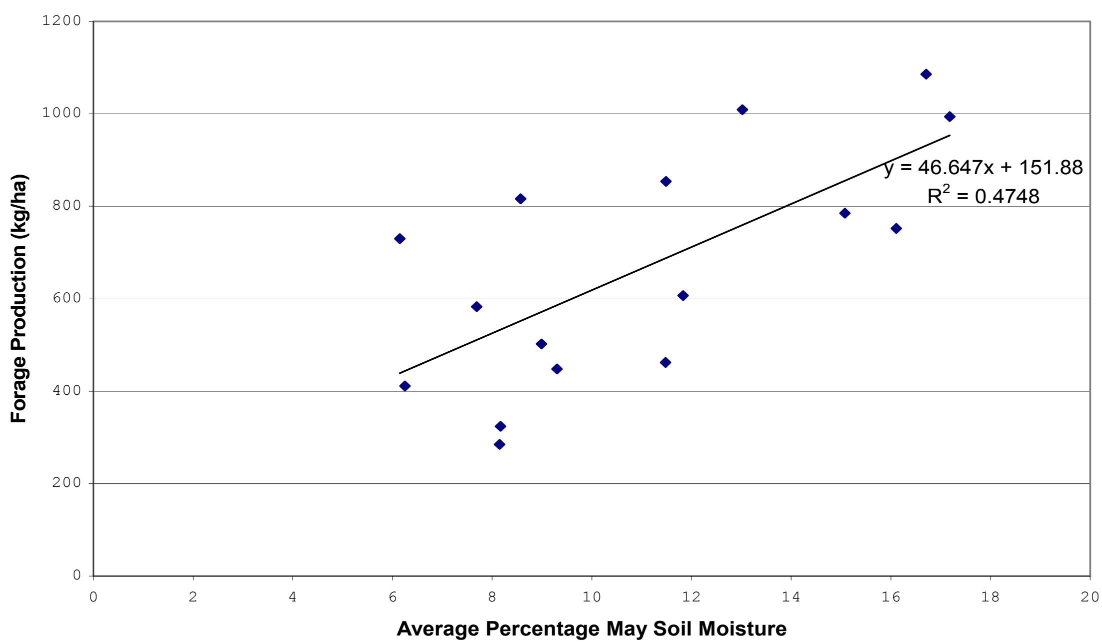


Figure 2D. May Percent Soil Moisture vs. Forage Production for Treated (sage removed) 1987-2002

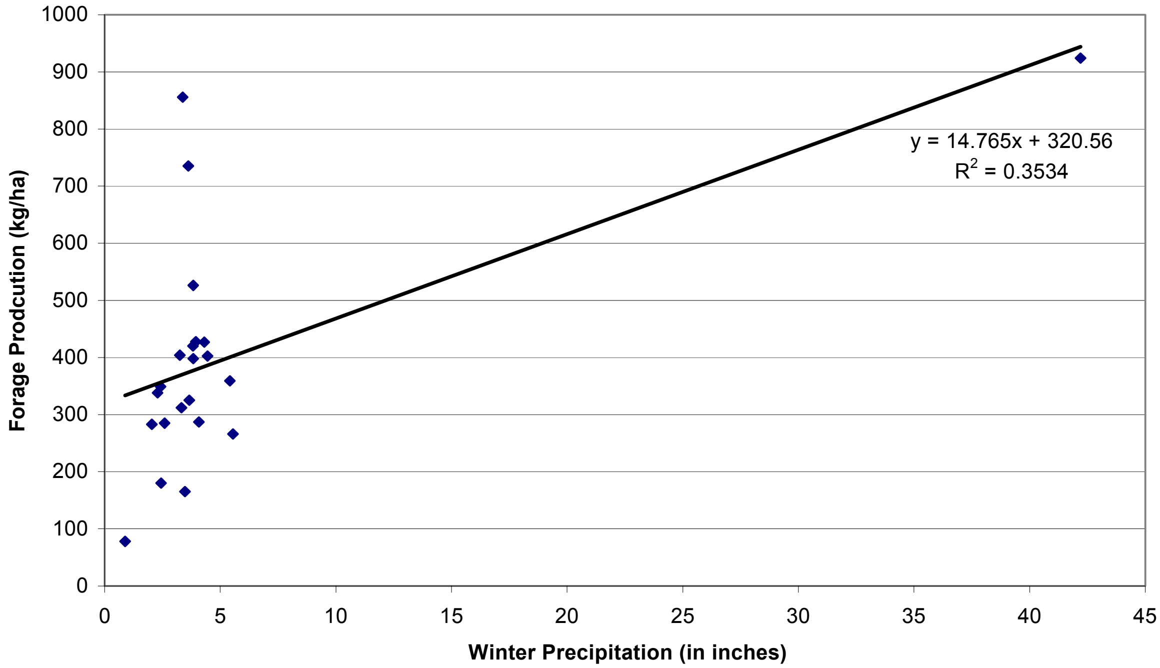


**Figure 3A. October- March vs. Forage Production -
Saratoga (1987-2002) and Statewide contributors data 2002**

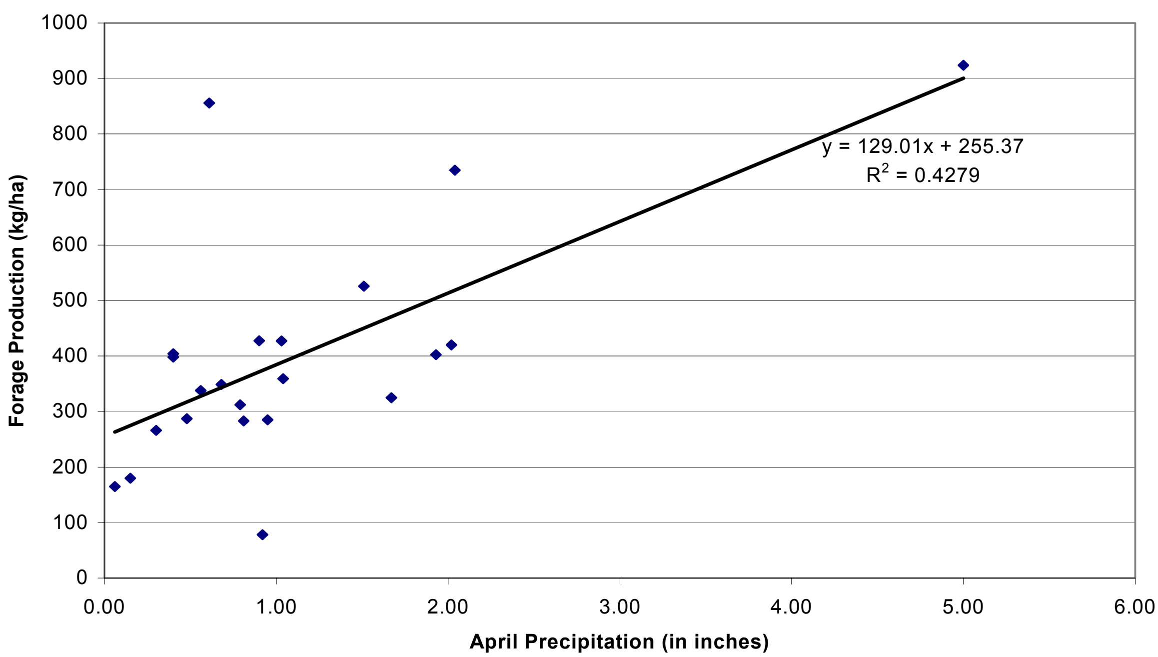


**Figure 3B. April Precip. vs. Forage Production-
Sartaoga (1987-2002) and Statewide contributors data (2002)**

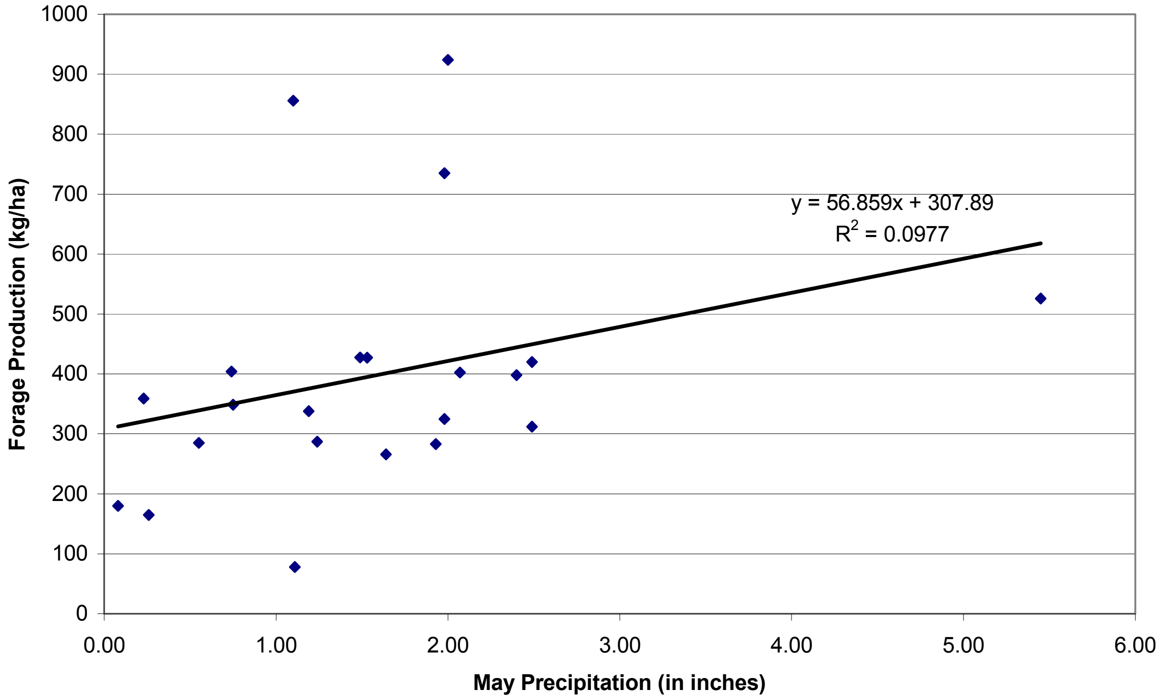


Figure 3C. May Precip. vs. Forage Production-
Saratoga (1987-2002) and Statewide contributors data 2002

Information Transfer Program

Product accessibility and dissemination for the Water Research Program at the University of Wyoming

Basic Information

Title:	Product accessibility and dissemination for the Water Research Program at the University of Wyoming
Project Number:	2002WY3B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	, None, None
Descriptors:	
Principal Investigators:	Jan Curtis, Larry O. Pochop

Publication

Problem and Objectives:

In the west, water is critical to survival. Data and information concerning this resource are very valuable. However, unless information developed from research is easily obtained, all of the effort and expense of collecting, analyzing, and reporting the information is of little use. Therefore, the objective of this project is to establish an efficient and effective way to disseminate the data and information developed by the Water Research Program (WRP).

Methodology:

Significant modifications of the approach for information dissemination have been implemented during FY02.

Water Resources Program Web Site: The Water Research Program's web site was transferred from the University of Wyoming Water Resources Data System (http://www.wrds.uwyo.edu/wwrp/wwrp.html) to the Civil and Architectural Engineering Department in the Engineering College and can be viewed at the following URL: http://wwweng.uwyo.edu/civil/research/wwrp/ The main reason for the move was to permit easily access to the Director for updating information. Considerable work was performed revising the site, with more planned. This site is used to disseminate information about the WRP, including posting of the Program's Section 104(b) Request for Proposals, contact information, listing of abstracts and program products, useful links, and announcements, such as the Announcement/Request for Proposals for the National Competitive Grant Program authorized by Section 104(g) of the Water Resources Research Act of 1984, as amended.

Report to Program's Priority and Selection Committee: A Priority and Selection Committee (P&S Committee) reviews and approves all proposals submitted to the USGS for consideration under the Wyoming Water Research Program. The P&S Committee is a group of Federal and State representatives which also prepares the Section 104(b) Request for Proposals each year. The P&S Committee has recognized the importance of information dissemination to the overall WRP. Since the P&S Committee represents seven agencies actively involved in water planning and management, they are well informed with respect to information needs. The Committee has requested reports at its summer 2003 from PIs of all projects completed to date.

Distribution of Information Through Water Resources Data System: The Water Resources Data System's (WRDS) Water Library collects and maintains publications on water, particularly Wyoming water issues. The Water Library is the single largest repository of water and climate data and information in the State of Wyoming. The Library provides physical and bibliographic access to various publications that have been produced by federal and state government agencies, student research and other sources. The Water Library exists to provide current and historical information on regional water issues, maintain and expand the Wyoming Water Bibliography on the Internet (a search-based catalog of the locations and holdings of regional water publications) and provide access to these publications. Patrons include students, faculty members, government employees and the public. Researchers with the WRP use the Water Library as a reference and historic data source. WRDS will house in the Water Library and on-line, to the extent possible, the data and information developed under the WRP which will further increase the viability of the Water Library's collection. This function will likely be performed on a no-cost basis to the WRP.

Principal Findings and Significance:

PIs of projects supported under the WRP often present information to various audiences without preparing formal publications which can be referenced. The following FY02 presentations have been reported to the Director.

Pochop, L.O., 2002. Wyoming's water research program, presentation at the Wyoming Water Association Education Seminar, Casper, WY, Oct.

Wilkerson, G. V., Lewis, B., and Konrad, S. K. (2003). Impact of DEM resolution on estimating hydrologic variables. Manuscript in preparation.

Wilkerson, G. V., Baxter, J. C., Johnson, J. (2000). GIS Erosion Potential Model for CBM Water Impacts. Paper presented at the 2000 Fall Geology Conference; Coalbed Methane in the Powder River Basin.

Wilkerson, G. V., Baxter, J. C., Johnson, J. H., and Konrad, S. K. (2003). A GIS model for assessing the impact of increased channel discharges on hydraulic geometry. Manuscript in preparation.

Wilkerson, G.V. (May 2003). Modeling CBM Surface Water Impacts Using Erosion Potential Modeler. Invited presentation to the State Water Forum, Cheyenne, WY.

Wilkerson, G.V. (Jan. 2003). Modeling CBM Surface Water Impacts Using Erosion Potential Modeler. Invited presentation to the Niobrara Conservation District and the U.S. Natural Resources Conservation Service, Lusk, WY.

Wilkerson, G.V. (2002). Modeling CBM Surface Water Impacts Using Erosion Potential Modeler. Invited presentation to the Department of Civil Engineering and the Department of Geology, University of Minnesota, Minneapolis, MN.

Wilkerson, G.V. (2002). Modeling CBM Surface Water Impacts Using Erosion Potential Modeler. Geological Society of America Annual Meeting, Denver, CO.

Wilkerson, G.V. (2002). GIS Model for Evaluating Coal Bed Methane Surface Water Discharges. Invited presentation to the Basin Advisory Group, Dayton, WY.

Wilkerson, G.V. (2002). GIS Model for Evaluating Coal Bed Methane Surface Water Discharges. Invited presentation to the Basin Advisory Group, Lusk, WY.

Wilkerson, G.V. (2002). GIS Model for Evaluating Coal Bed Methane Surface Water Discharges. Invited presentation to the Niobrara Conservation District, Lusk, WY.

Wilkerson, G.V. (Sept. 2002). Modeling CBM Surface Water Impacts Using Erosion Potential Modeler. Invited presentation at the CBM Water Management Conference, Jackson Hole, WY.

Wilkerson, G.V. (2001). GIS Erosion Potential Model for CBM Water Impacts. U.S. Geological survey NAWQA Liason Meeting.

Wilkerson, G. V., Baxter, J. C., Johnson, J., and Montgomery, J. (2000). Burger Draw Erosion Potential Mapping Project. Invited presentation at the August meeting of the Methane Operators Group in Casper, WY.

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	6	0	0	0	6
Masters	5	0	0	0	5
Ph.D.	1	0	0	0	1
Post-Doc.	1	0	0	0	1
Total	13	0	0	0	13

Notable Awards and Achievements

Publications from Prior Projects

None