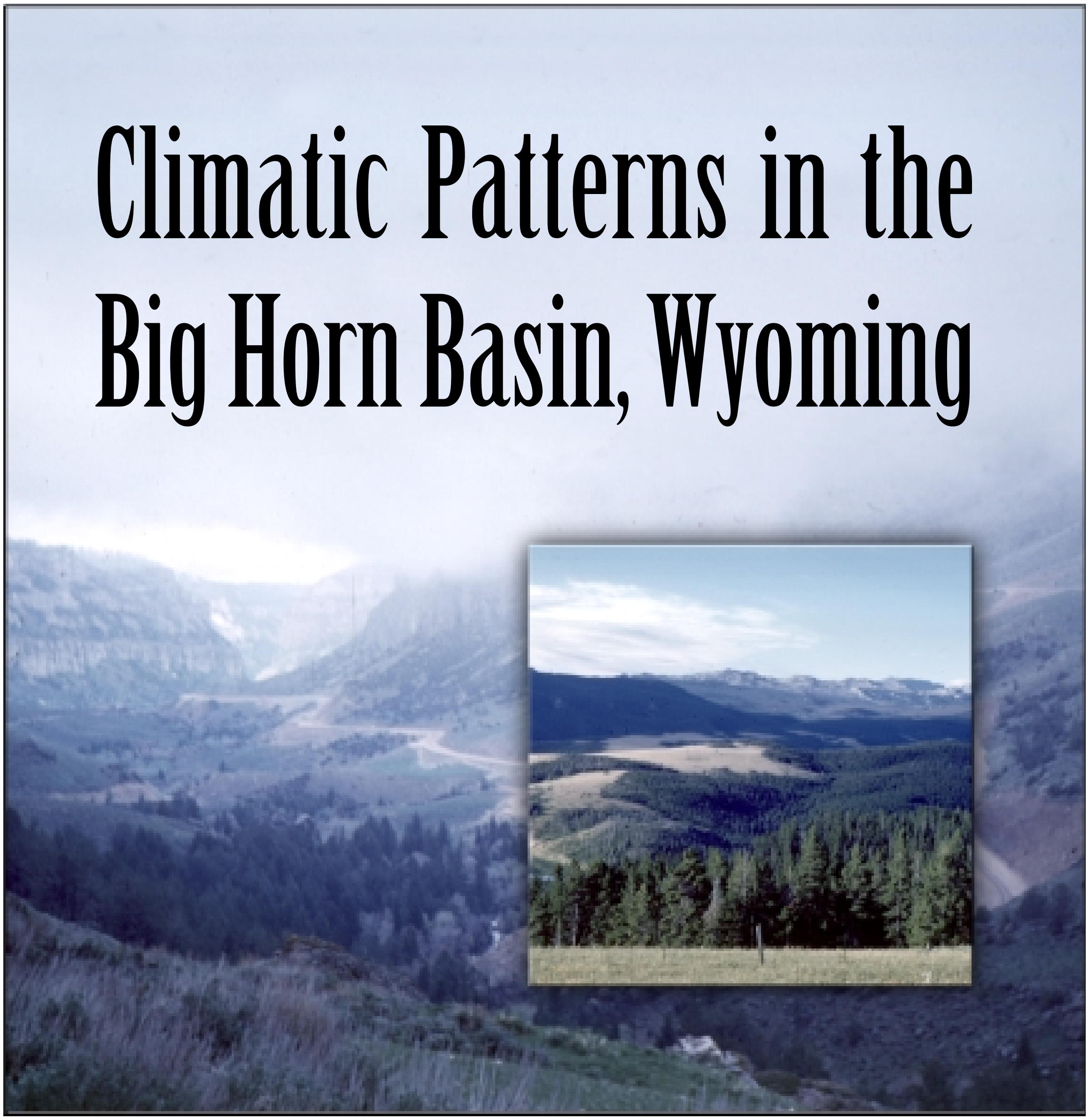
Climatic Patterns in the Big Horn Basin, Wyoming



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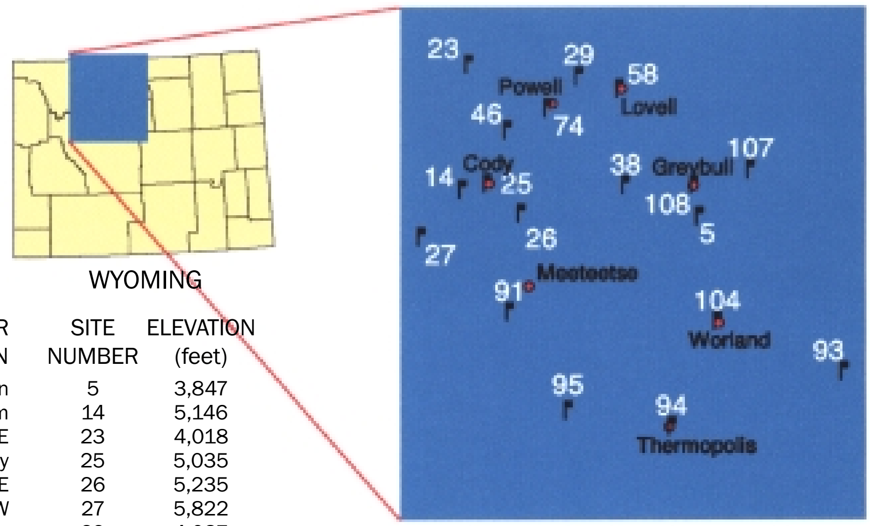
The Big Horn Basin is one of Wyoming's major agricultural regions. However, production agriculture is generally unsuitable at higher elevations in the Big Horn Basin because of cold temperatures and short growing seasons. Lower elevation sites have higher temperatures and more growing degree-days. To enhance the economy and sustainable agriculture of the Big Horn Basin, research addressing new or alternative high yielding and profitable cropping systems would be extremely useful. When evaluating alternatives to diversify Big Horn Basin agriculture, the first step is to identify crops that can be grown in the area. Because of the influence of temperature, precipitation, frost-free days, and growing degree-days on crop growth, data on climatic variables in the Big Horn Basin are needed to predict which crops might be suitable.

Estimating precipitation and other climatic variables at unmonitored sites is a fundamental problem, primarily because weather station locations are spread out in Wyoming (Hevesi et al., 1992). Since weather stations exist at discrete locations, climatic parameters recorded at these sites are used to estimate conditions throughout an entire area. Many methods are available to estimate climatic variables for the unmeasured locations (Martinez-Cob, 1995). Tabious and Salas (1985) suggested that in a topographically homogeneous area, geostatistical approaches can be used to estimate climatic variables throughout a region (Ashraf et al., 1997).

Objectives of this study were to determine the relationship between climatic variables and elevation and to develop continuous climatic data layers for the Big Horn Basin. Continuous climatic layers can be used within a geographic information system (GIS) to model areas where alternative crop production may be pursued. Using linear regression methods, researchers can evaluate the relationship of climatic values and elevation, further validating areas suitable for production of new or alternative agricultural crops.

Materials and Methods

The Big Horn Basin study area is approximately 1,900,000 acres (or approximately 3,000 square miles) and includes the major Wyoming cities of Cody, Powell, Lovell, Greybull, Worland, and Thermopolis. Elevation of weather stations in the Big Horn Basin study area ranged from 3,780 feet in Greybull to 6,420 feet at Sunshine (Western Region Climate Center, 1998). The region is bordered on the west by the Absaroka Mountain Range and by the Big Horn Mountains on the east. Relatively low elevation of agricultural lands in the basin, in comparison to the rest of the state, results in this area having 90 to 120 frost-free days (Western Regional Climate Center, 1998). The Big Horn Basin is broadly classified as a desert because less than 10 inches of precipitation per year occur in many parts of the region (Martner, 1986). Basins on the leeward side of mountains are often dry because of descending air from the adjacent mountains. The motion of descending air inhibits condensation and results in low amounts of precipitation (Martner, 1986). This area is, however, one of the most productive agricultural regions in Wyoming due to irrigation supplied by Buffalo Bill Reservoir built in 1905 (Churchill, 1984). Martner (1986) further classified the Big Horn Basin with the following attributes: 30 to 50 days per year above 90 degrees Fahrenheit,



WEATHER STATION	SITE NUMBER	ELEVATION (feet)
Basin	5	3,847
Buffalo Bill Dam	14	5,146
Clark 3 NE	23	4,018
Cody	25	5,035
Cody 12 SE	26	5,235
Cody 21 SW	27	5,822
Deaver	29	4,087
Emblem	38	4,438
Greybull	108	3,780
Heart Mountain	46	4,776
Lovell	58	3,828
Powell Field Station	74	4,356
Shell	107	4,218
Sunshine 2 ENE	91	6,420
Ten Sleep 16 SSE	93	4,667
Thermopolis	94	4,297
Thermopolis 25 WNW	95	5,684
Worland FAA AP	104	4,159

Figure 1. Location of area used for climatic analysis in the Big Horn Basin, Wyoming. Table lists station identification and elevation (Western Region Climate Center, 1998).

the length of the growing season supports many crops, and a frost-free season of up to four months. Portions of the Big Horn Basin receive less than 6 inches of precipitation per year (40 percent of which occurs in the summer months).

Eighteen weather stations in the Big Horn Basin (Figure 1) have collected weather data for 30 years or more (Western Regional Climate Center, 1998). Climatic variables used in this study were related to environmental traits that are important for crop growth. Variables selected were used to determine if new or alternative crops could be grown in the Big Horn Basin, and all parameters selected have an impact on the growth of agricultural crops.

To understand relationships between elevation and climatic variables, linear regression was performed on 31 variables recorded at Big Horn Basin weather stations. Linear regression was useful in predicting the response of the variables to elevation. The correlations (R^2 values) provide a summary of the strength of the relationship between each climatic variable and elevation (Table 1), with values closer to 1.0 indicating the models are more accurate.

To provide information about climatic conditions thoughout the Big Horn Basin, geostatistical analysis was used to produce continuous data layers representing 31 different variables, many of which may be important to plant growth. First, model type

Table 1. Linear model parameters* for elevation (feet) and climate variables (precipitation = inches; temperature = degrees Fahrenheit; frost-free period = days) in the Big Horn Basin. Models were developed utilizing data from 15 to 18 (N) of the weather stations that provided the best correlation (R^2) for the particular climatic variable evaluated.

Climatic Variable	N	Slope	Intercept	R^2
Annual precipitation	15	0.0032	-6.18	0.93
Summer precipitation	18	0.0022	-3.46	0.82
May minimum temperature	18	-0.0027	52.0	0.52
May mean temperature	18	-0.0036	70.0	0.86
May maximum temperature	17	-0.0042	87.1	0.86
June minimum temperature	16	-0.0030	61.2	0.73
June mean temperature	18	-0.0039	80.8	0.88
June maximum temperature	17	-0.0041	97.2	0.83
Number of days in June exceeding 90°F	17	-0.0028	17.2	0.75
July minimum temperature	17	-0.0036	68.7	0.74
July mean temperature	18	-0.0038	86.5	0.82
July maximum temperature	17	-0.0039	103.8	0.77
Number of days in July exceeding 90°F	17	-0.0063	40.1	0.75
August minimum temperature	17	-0.0029	63.7	0.64
August mean temperature	18	-0.0034	83.1	0.82
August maximum temperature	18	-0.0039	102.7	0.83
Number of days in August exceeding 90°F	17	-0.0061	37.7	0.77
September minimum temperature	17	-0.0024	51.6	0.48
September mean temperature	16	-0.0026	68.7	0.78
September maximum temperature	17	-0.0031	86.7	0.79
Summer mean temperature	18	-0.0037	83.5	0.86
Shortest frost-free (32°F) period	17	-0.0206	176.3	0.64
90% chance of frost-free period (32°F)	16	-0.0191	181.0	0.62
80% chance of frost-free period (32°F)	17	-0.0216	201.5	0.72
Shortest frost-free (28°F) period	16	-0.0192	193.5	0.48
90% chance of frost-free period (28°F)	15	-0.0184	203.1	0.61
80% chance of frost-free period (28°F)	15	-0.0132	192.5	0.54
Growing degree-days (base 40°F)	18	-0.2835	3194.0	0.85
Growing degree-days (base 45°F)	18	-0.2749	2747.0	0.83
Growing degree-days (base 50°F)	18	-0.2516	2246.0	0.84
Growing degree-days (base 55°F)	18	-0.2185	1740.0	0.84

*Models can be used to predict the climatic variable based on elevation:
climatic variable = [slope x elevation] + intercept
for example: annual precipitation at 5,000 feet would equal [0.0032 x 5,000] - 6.18 = 9.82 inches

was determined for each climatic variable using geostatistics (Kravchenko et al, 1996). The model parameters were selected based on the data from the 18 weather stations and were used to estimate values for the climatic variable at unsampled locations throughout the study area.

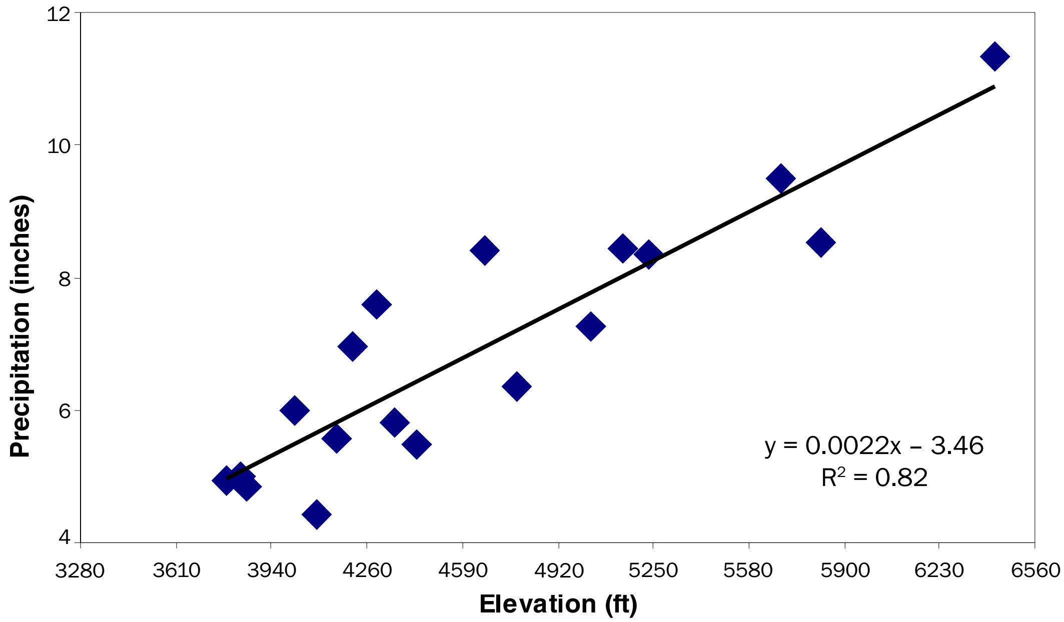
Results and Discussion

Elevation has a direct influence on climate conditions. Dirks and Martner (1982) reported that northwestern Wyoming has an annual cooling rate (adiabatic lapse rate) of 5.4 degrees Fahrenheit per 1,000 feet increase in elevation. In the Big Horn Basin, adiabatic lapse rate ranges between 3.9 and 4.1 degrees Fahrenheit for maximum monthly temperature in May through August. Due to Wyoming's high topographic relief, temperatures across the state vary widely (Knight, 1994). In addition, Linacre (1992) found that daily temperature ranges depended on properties such as elevation, cloud cover, and humidity. Weather stations in the study area do not have a record of these variables, with the exception of elevation, because there are only four first-order weather stations recording such detailed climatic data in Wyoming (Pochup, 1999, personal communication). First-order weather stations record wind speed, humidity, cloud cover, temperatures, precipitation, and evapotranspiration every three hours. Other weather stations in the state record only temperature and precipitation data.

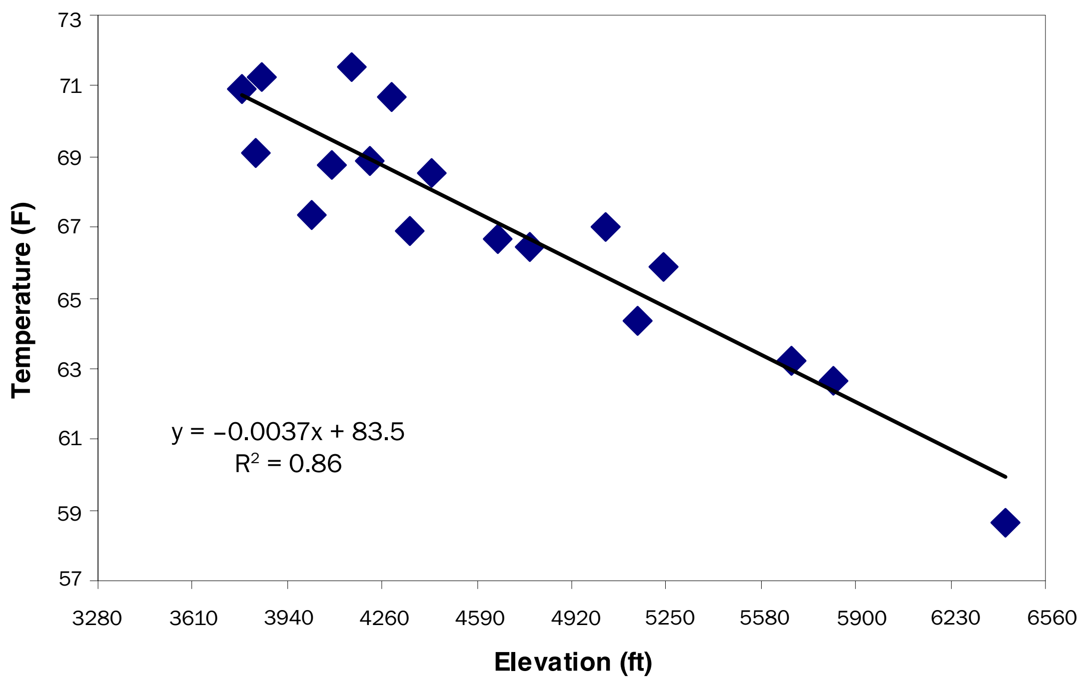
Environmental variables in the Big Horn Basin were plotted against elevation to determine linear regression model parameters and correlation factors (Table 1). Weisberg (1985) suggested that in some instances, outlying cases may be discarded and labeled as not representative of the process under study because factors such as site exposure, distance to windbreaks, albedo of ground, and height above ground can greatly affect measurements taken from regional weather stations. Harrison (1994) also stated that "...small differences in site exposure can result in very different impressions of the rate of change in temperature with elevation." Using this rationale, selected "outlier" sites were excluded. For example, after examining outliers in the climatic data from the Big Horn Basin, 19 of 31 different climatic variables required a reduced number of weather stations for developing linear regression models that best described the available data.

Linear regression models were developed using data from 15 to 18 of the weather stations that provided the best fit (R^2) for climatic data variables (Table 1), with Site 14 the most often excluded. Estelle (1999, personal communication) confirmed that Site 14 at Buffalo Bill Dam is at the bottom of an east to west canyon within a protected environment. This site does not receive as much sunlight due to its location; therefore, Site 14 was considered an outlier and taken out of several linear regression models because it did not follow the same trends as sites at similar elevations. After Site 14 was removed, the correlation (R^2) improved for many of the climatic variables.

Figure 2 illustrates the relationship between elevation and two climatic variables: summer precipitation and summer temperature. Table 1 summarizes the model parameters (slope, intercept, and R^2 values) for the linear regression analysis of each climatic variable versus elevation. High



(a) Summer (June, July, and August) precipitation in the Big Horn Basin.



(b) Summer (June, July, and August) temperature in the Big Horn Basin.

Figure 2. Linear regression graphs illustrating elevation versus (a) summer precipitation and (b) summer temperature in the Big Horn Basin, Wyoming.

correlation coefficients were obtained for most climatic variables when outliers were excluded.

Annual precipitation (5.4 to 14.8 inches) correlated with elevation reasonably well (R^2 = 0.69). However, when Sites 93, 94, and 107 were taken out of analysis, R^2 increased to 0.93 (Table 1). These sites are close to the Big Horn Mountains in the east. Climatic conditions at these sites may be a product of a windward effect in which water vapors in the air condense as they start to rise up a mountain slope. Summer precipitation (4.3 to 11.1 inches) was highly correlated with elevation (R^2 = 0.82).

Minimum, mean, and maximum temperatures for May, June, July, August, and September were evaluated as they directly affect crop production. Minimum temperatures (31.6 to 56.5 degrees Fahrenheit) generally occur just before dawn of each day, maximum daily temperatures typically occur in late afternoon, and mean temperatures are the average of maximum and minimum temperatures (Pochup, 1999). Minimum temperatures, excluding outliers (Sites 14, 91, or 93), resulted in coefficients of determination no greater than 0.74 (Table 1). Martner (1986) reported little relation in minimum temperatures and elevation due to geographic variability in topography and wind patterns.

Mean temperatures for all months evaluated (46.2 to 73.2 degrees Fahrenheit) resulted in R^2 values above 0.80 with the exception of September. September mean temperatures, with exclusion of Sites 14 and 94, resulted in a correlation of 0.78. In the Big Horn Basin, the first winter freeze usually occurs in early to mid-September in low lying areas. A low correlation (R^2 = 0.48) found for September could be attributed to different years having warmer or cooler months at the end of the growing season. Summer (June, July, and August) mean temperature (58.6 to 70.3 degrees Fahrenheit) versus elevation was highly correlated (R^2 = 0.86) with elevation.

Maximum temperatures (61 to 90.7 degrees Fahrenheit) were also moderately correlated (R^2 = 0.62 to 0.78) to elevation using all 18 weather stations. May, June, July, and August correlation values increased substantially (R^2 = 0.77 to 0.86) once Site 14 was taken out of the analysis. September maximum temperatures (67.8 to 78.8 degrees Fahrenheit) within the study area are variable for the same reason as September minimum temperatures; however, removal of Site 94 resulted in a correlation of 0.79.

The number of summer days with temperatures exceeding 90 degrees Fahrenheit (0 to 18 days each month) is important for growth and production of certain crops. Temperatures above this range can seriously damage or even kill some crops. Correlation between this climatic variable and all station elevations ranged from 0.72 to 0.74; excluding Site 14 had only a minor effect on the resulting correlation (R^2 = 0.75 to 0.77).

The study area's frost-free period was determined using both 32 degrees Fahrenheit (37 to 136 days) and 28 degrees Fahrenheit (51 to 172 days) as freezing temperatures because certain crops, such as alfalfa, have higher frost tolerance. For each of these temperatures, the shortest recorded frost-free period, using either 80 or

90 percent chance of frost-free period, was evaluated so agriculturalists could identify areas most suitable for a crop in terms of length of frost-free period.

While most correlations exceeded 0.5 when climatic variables were compared to elevation, variables pertaining to the frost-free period were more weakly correlated than other variables. This is probably due to variability in the first and last freezing dates from year to year. When outliers were taken out of linear regression, R^2 values did not increase above 0.72 (Table 1). Results indicate the frost-free period is linearly related to elevation, although the relationship is not as strong as with other climatic variables.

Growing degree-days are an accumulation of daily heat units over time. This is a standard formula that can be tailored to specific crops having optimal base temperatures for growth. The growing degree-day variable (474 to 2,167 growing degree-days with variable base temperatures) correlated well with elevation, with all correlations above 0.80 (Table 1).

Continuous Data Layers

Geostatistical analysis was performed using data from all 18 weather stations for the 31 climatic variables. Geostatistics relies upon points with known data to estimate areas without data. All information from the 18 weather stations was needed for analysis of climatic variables to provide general information for the Big Horn Basin. A greater number of sites would have increased the accuracy of analysis.

Figures 3 through 7 illustrate continuous data layers for precipitation, minimum and

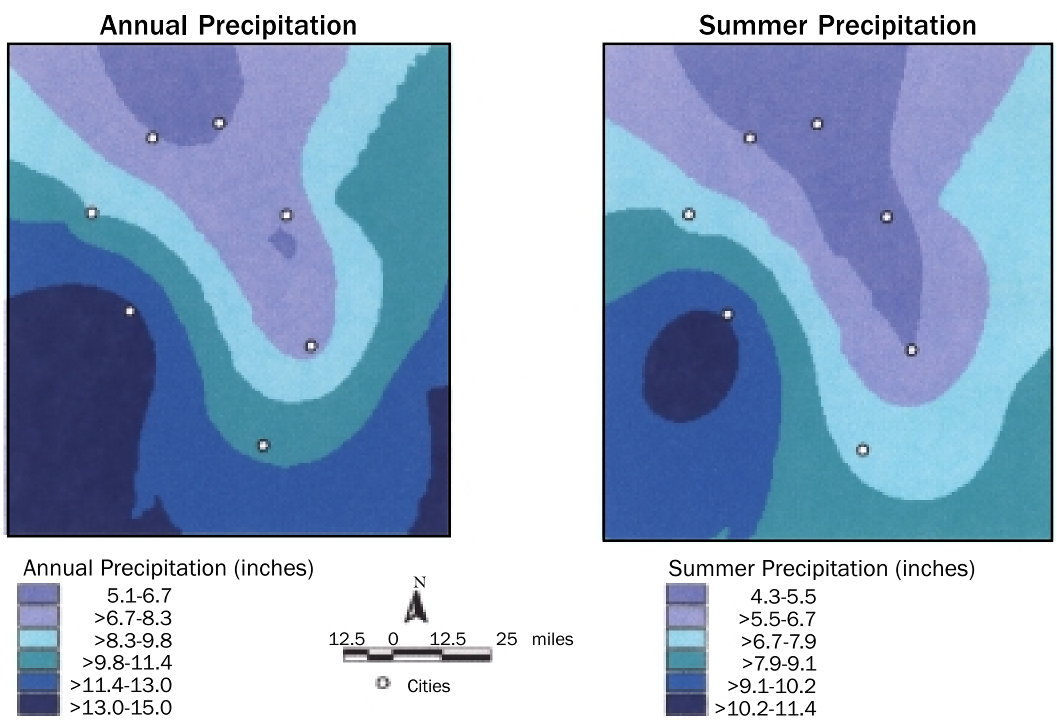


Figure 3. Precipitation patterns derived from geostatistical analysis in the Big Horn Basin, Wyoming. See Figure 1 for city identification. Note differences in increments used in the figures.

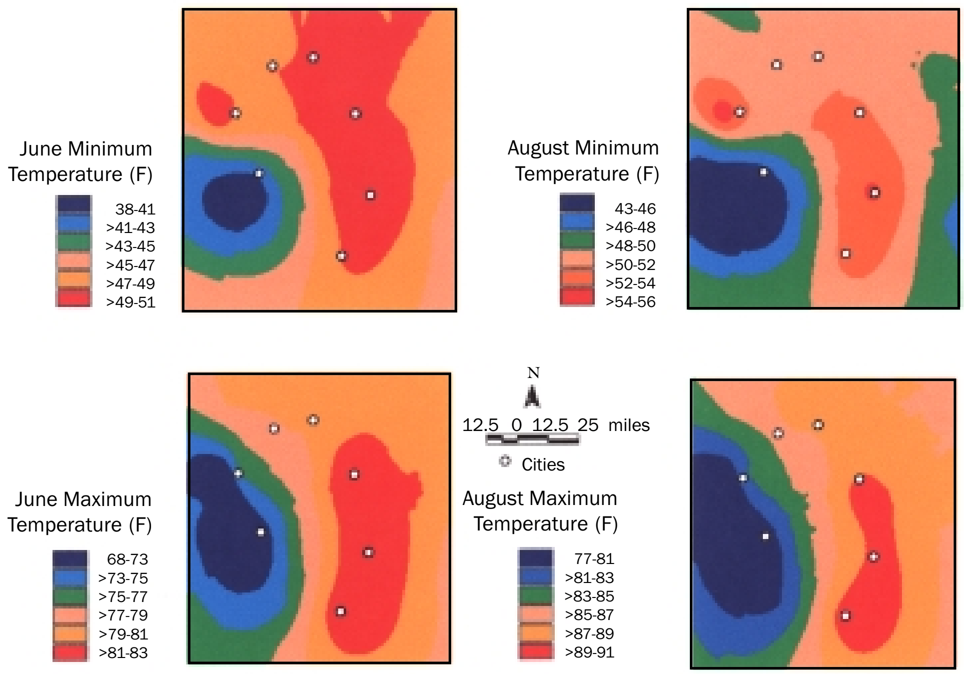


Figure 4. Minimum (nighttime) and maximum (daytime) temperatures for June and August derived from geostatistical analysis for the Big Horn Basin, Wyoming. See Figure 1 for city identification. Note differences in increments used in the figures.

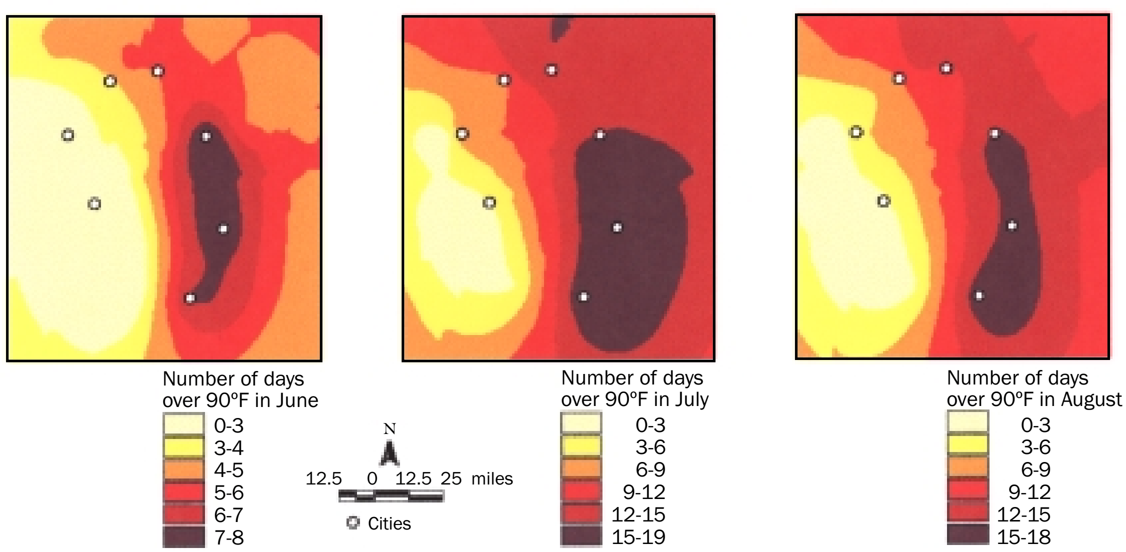


Figure 5. Number of days over 90°F in June, July, and August derived from geostatistical analysis for the Big Horn Basin, Wyoming. See Figure 1 for city identification. Note differences in increments used for the figures.

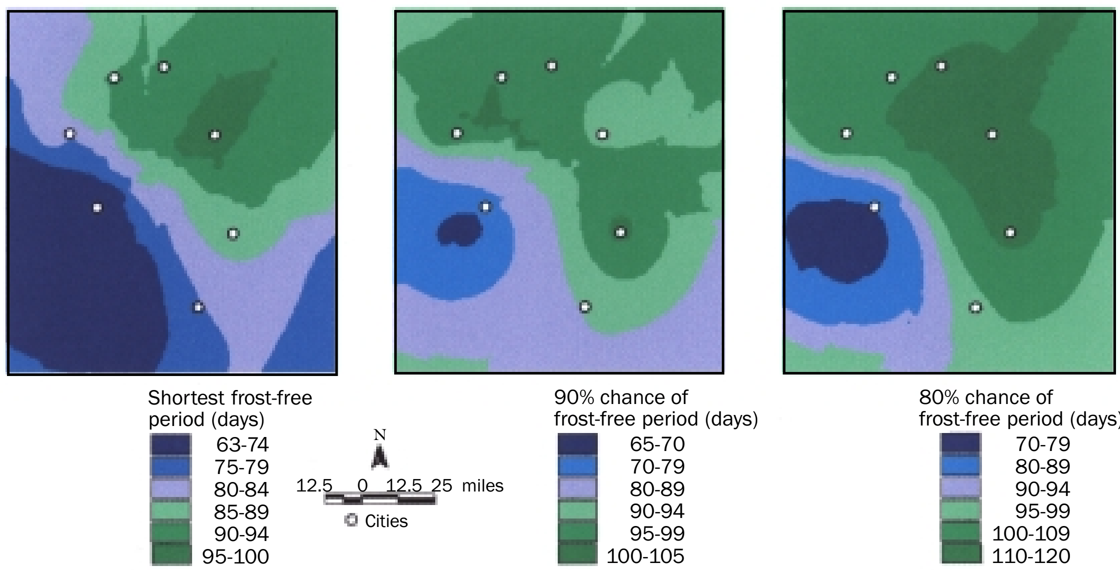


Figure 6. Frost-free (32°F) period derived from geostatistical analysis for the Big Horn Basin, Wyoming. See Figure 1 for city identification. Note differences in increments used in the figures.

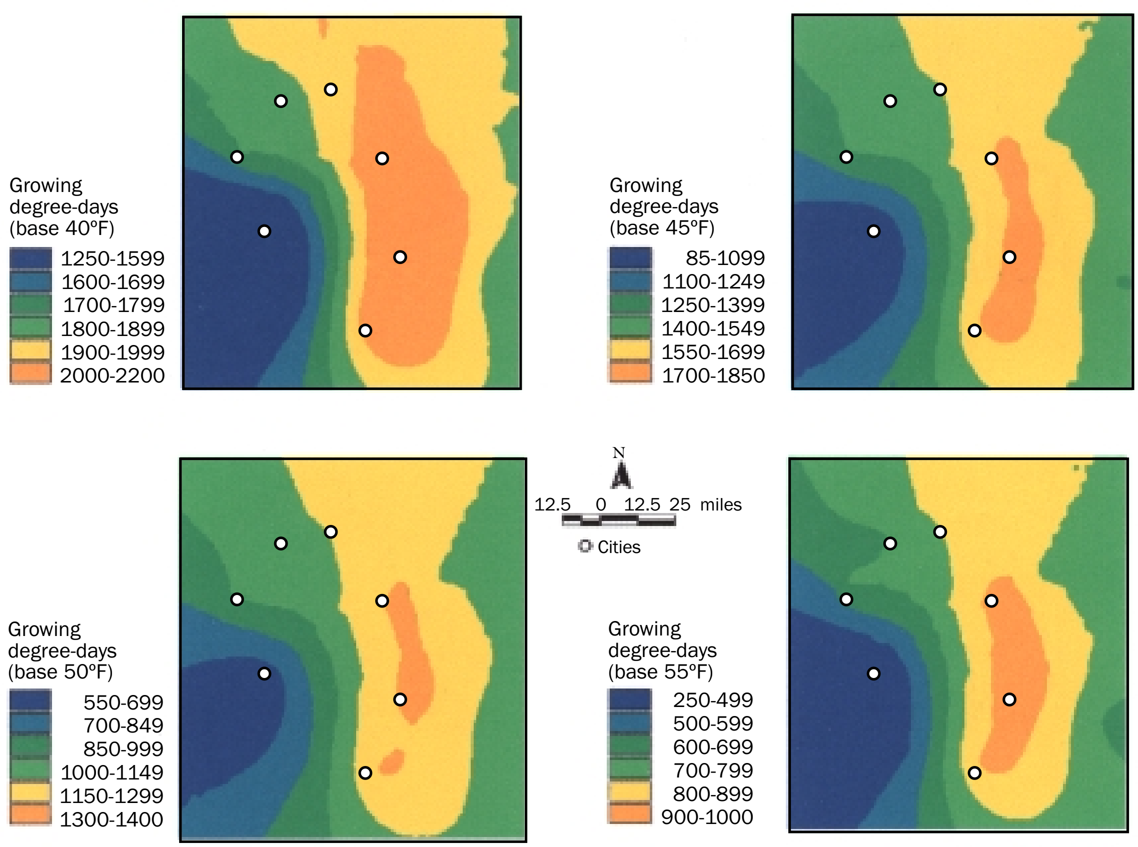


Figure 7. Growing degree-days derived from geostatistical analysis for the Big Horn Basin, Wyoming. See Figure 1 for city identification. Note differences in increments used in the figures.

maximum temperatures for June and August, number of days in the summer exceeding 90 degrees Fahrenheit, frost-free period (above 32 degrees Fahrenheit), and growing degree-days, respectively. These figures represent the finished product of the geostatistical analysis of weather station data and climatic variables. The Big Horn Basin consists of gently sloping topography that results in environmental gradients associated with elevation.

The data layers developed using geostatistics (Figures 3 to 7) illustrate climatic trends based upon elevation. The warmest, driest part of the region lies just east of the center of the Big Horn Basin and is lowest in elevation. Similarly, the southwestern portion of the study area has the greatest precipitation, generally the coldest temperatures, and highest elevation. Geostatistics enables the weather station data to be converted into continuous surfaces.

Conclusion

Linear regression modeling of climatic variables indicated that strong relationships exist between elevation and climatic variables such as precipitation, temperature, and growing degree-days. Correlations computed for climatic variables reinforce the idea that production agriculture is not suited for higher elevation areas in the Big Horn Basin because of cold temperatures and a shorter growing season. Lower elevation sites have higher temperatures, higher growing degree-days, and less precipitation. Geostatistical analysis performed for the basin provides climatic maps of 31 precipitation and temperature variables. These maps followed the same trends as the linear regression models; higher elevations are colder and wetter, while lower elevations are warmer and drier. These spatially-referenced maps depicting climate trends enable an initial estimate of temperature and precipitation for any location in the Big Horn Basin. Analysis of environmental traits in the study area will allow the preliminary identification of potential areas for new or alternative crop production, utilizing each crop's climatic requirements. These climatic layers were used to estimate if new or alternative crops might be suitable for growth in the Big Horn Basin of Wyoming (Young et al., 2000).

Acknowledgments

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References

Ashraf, M, J.C. Loftis, and K.G. Hubbard. 1997. "Application of geostatistics to evaluate partial weather station networks." *Agricultural and Forest Meterology* 84:255-271.

Churchill, B.G. 1984. *People Working Together: A 75th Anniversary Salute to Powell.* Custom Printing: Powell, WY.

Dirks, R.A. and B.E. Martner. 1982. "The climate of Yellowstone and Grand Teton National Parks." U.S. National Park Service, *Occasional Paper* 6.

Estelle, R., Data Acquisition Program Manager, National Weather Service. 1999. Personal communication, April 15.

Harrison, S.J. 1994. "Air temperature and elevation in the Ochil Hills, Scotland: problems with paired stations." *Weather* 49:209-215.

Hevesi, J.A., J.D. Istok, and A.L. Flint. 1992. "Precipitation estimation in mountainous terrain using multivariate geostatistics. Part 1: structural analysis." *Journal of Applied Meteorology* 31:661-676.

Knight, D.H. 1994. *Mountains and Plains: The Ecology of Wyoming Landscapes.* Yale University Press: New Haven and London.

Kravechenko, A., R. Zhang, and Y.K. Tung. 1996. "Estimation of mean annual precipitation in Wyoming using geostatistical analysis." p. 271-282. In: Morel-Seytoux, H.J. (ed.). *Proceedings of the 16th Annual American Geophysical Union Hydrology Days.* Hydrology Days Press: Atherton, CA.

Linacre, E. 1992. *Climate, Data and Resources: A Reference and Guide*. Routledge: London and New York.

Martinez-Cob, A. 1995. "Estimation of mean annual precipitation as affected by elevation using multivariate geostatistics." *Water Resources Management* 9:139-159.

Martner, B.E. 1986. *Wyoming Climate Atlas.* University of Nebraska Press: Lincoln, NE.

Pochup, L.O., Professor, Civil and Architectural Engineering. 1999. Personal communication, March 18.

Tabious III, G.Q. and J.D. Salas. 1985. "A comparative analysis of techniques for spatial interpolation of precipitation." *Water Resources Bulletin* 21:365-380.

Weisberg, S. 1985. *Applied Linear Regression – Second Edition.* John Wiley and Sons: Toronto.

Western Regional Climate Center. Wyoming climate summaries. Website. Viewed July 15, 1998. [www.wrcc.dri.edu/summary/climsmwy.html]

Young, J.A., G.F. Vance, L.C. Munn, B.M. Christensen, and M.S. Schaad. 2000. "GIS identification of potential alternative crops utilizing soil and climatic variables in the Bighorn Basin, Wyoming." *American Journal of Alternative Agriculture.* (In press)