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# PREDICTING TEMPERATURE AND PRECIPITATION AT UNGAGED SITES IN THE UPPER GREEN RIVER BASIN

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## 1. INTRODUCTION

A method for estimating monthly irrigation requirements was needed for the Upper Green River Basin of Wyoming to properly size proposed reservoirs. Monthly irrigation requirements are equal to monthly crop evapotranspiration, less monthly precipitation. The simplest and most commonly used method in the western United States to estimate monthly evapotranspiration is the Soil Conservation Service version of the Blaney-Criddle method (SCS, 1967). This method requires only mean monthly temperature to estimate monthly evapotranspiration. Thus, mean monthly precipitation and temperature for the growing season are the minimum climatic measurements necessary to determine evapotranspiration rates and subsequent irrigation requirements.

Historic measurements of temperature and precipitation were limited in the Upper Green River Basin which comprises some 38,800 square km. Long-term data were available from twelve National Weather Service stations. Therefore, a practical, theoretically correct method was needed to estimate monthly temperature and precipitation, respectively, at ungaged sites in the Basin.

## 2. SITE DESCRIPTION

The Upper Green River Basin of Wyoming contains the headwaters of the Green River, one of four major tributaries to the Colorado River. The Basin is approximately 225 km long, 177 km across, and is surrounded by imposing mountain ranges to the south, west, and north. Pacific air masses deposit the majority of precipitation in the surrounding mountains. Consequently, the Basin is considered semiarid.

## 3. METHODS

Historical temperature and precipitation data were obtained from twelve National Weather Service stations having 16 to 64 years of daily data. Monthly means were calculated for each year of record and then averaged to provide monthly normals.

Three methods for estimating monthly temperature and precipitation normals at ungaged sites in the Basin were developed. The first method used the isohyetal method of spatial interpolation to estimate monthly normals at ungaged sites. The second method used regression models to estimate monthly normals using the physiographic characteristics of the site. The third method, the combined approach, combined regression modeling with spatial interpolation.

Spatial interpolation techniques, in general, describe the relationship of the station values as a function of spatial location only. The isohyetal method estimated between-station values by assuming linear variation in temperature or precipitation between stations. A computer contour program, obtained from the National Center for Atmospheric Research in Boulder, Colorado, was used to develop isohyetal maps of the spatially interpolated observed station normals. The computer program formed triangles between all of the grid coordinates and linearly interpolated values along each side of the triangle. Contour lines connecting points of like values were drawn.

Both seasonal and monthly regression models to predict average monthly temperature and precipitation based on the physiographic characteristics of the site were developed. Those physiographic characteristics identified by the literature as having the potential to influence temperature or precipitation and which could be measured for each National Weather Service station without going into the field, e.g., using public documents, were included in a stepwise regression program. The characteristics were: latitude, longitude, spot elevation, average elevation, exposure, distance to the western divide, slope, and aspect.

These physiographic characteristics were defined as follows. Latitude and longitude values were transformed to a coordinate system of grid values because longitude and latitude values are not linear. Spot elevation was equal to the exact elevation of the station site. Average elevation was the average of the elevation at the eight compass points at a distance of 2.41 km from the station. Exposure was the number of degrees in a circle of eight km radius centered on the station in which there is no land higher than 305 m above the station. Distance to the western divide was the distance from the station location to the highest point on the mountain range forming the western divide of the Upper Green River Basin. Slope was measured as the change in elevation across a three mile distance in the direction of drainage. Aspect was defined as the direction of drainage coded in octants.

Average biweekly incoming solar radiation values at the top of the atmosphere for the months of interest were obtained from the literature. LaGrange polynomials were used to numerically integrate the extraterrestrial solar radiation values to obtain average mid-months values. These values were lagged one month and also included in the stepwise regression analysis.

Selection of significant variables by the stepwise procedure was based on an evaluation of the $R^2$ value for each regression equation and the t-ratio for each regression variable. An equation with a high $R^2$ and few significant variables was preferred. Once the significant variables were selected, multiple regression analysis was run using a weighted least squares regression. The weights were equal to the number of years of record at each station or the inverse of the population variance for that station.

Both seasonal and monthly regression models were developed for both temperature and precipitation. A flexible seasonal regression model was developed for temperature only. A flexible seasonal regression model uses month-specific variables, which are only significant for specific months within the seasonal model, to improve the predictive capabilities of the model for a particular month.

The regression models were evaluated in three ways. First, the statistical properties of the models, or aptness of the models, were evaluated. Second, the predictive capabilities of the models, e.g., $R^2$ values, were evaluated. Finally, the models were evaluated for their ease of use and physical meaningfulness.

The combined approach required two steps. First, the regression model was used to estimate the monthly normal for a point in the Basin. Next, spatial interpolation was used to construct isohyetals of the regression residual values. The residual value corresponding to the specified point in the Basin was added to the value predicted by the regression model for that point. The sum represented a more theoretically correct estimated normal as it combined both spatial and physiographic influences.

The regression models and combined approach were used to estimate monthly temperature and precipitation normals at selected grid points in the Basin. The grid system was established by overlaying an X,Y coordinate system and replacing longitude and latitude values with X,Y coordinates. Isohyetal maps of monthly normals estimated with the regression models and combined approach, respectively, were also constructed.

## 4. RESULTS AND DISCUSSION

Spatial interpolation of observed normals was based on only ten points. Two of the National Weather Service stations had to be eliminated from the contour routine to achieve good triangulation, e.g., equilateral triangles, between all stations. This small number of points for a 38,800 square km area may be insufficient to describe the spatial relationships between stations. Furthermore, many studies have found that climatic variables do not vary linearly, particularly in physiographically heterogeneous environments. Thus the isohyetal method of spatial interpolation may not be appropriate for estimating normals at ungaged sites.

Three regression models which estimated monthly temperature normals for the months April through October were developed using the physiographic characteristics of the site. The models included a flexible seasonal model, a standard seasonal model, and individual monthly models. The flexible seasonal model was easier to computerize than the individual monthly models, while still providing acceptable predictive capabilities. Monthly $R^2$ values for the flexible seasonal model varied between 0.83 and 0.91. The significant physiographic characteristics were: lagged mid-month incoming solar radiation, latitude, distance to the western divide, exposure, and elevation. The three temperature regression models are given in Table 1.

Only monthly regression models, and then only for the months June through September, could be developed to estimate monthly precipitation normals due to the variability of precipitation patterns between stations and between months in the Basin. The $R^2$ values for the monthly precipitation models varied between 0.54 and 0.61. The significant physiographic characteristics were: elevation, exposure, and latitude. The monthly precipitation regression models are given in Table 2.

The combined approach was developed to optimize the advantages of regression modeling and spatial interpolation. The estimated monthly normals formed by the combined approach incorporated the influences of both physiographic site characteristics and the spatial location of the data. Therefore, the resulting values would theoretically be a more accurate estimate of the true normals.

To evaluate the predictive capabilities of these methods, predicted values should be compared to observed monthly normals at sites not used in the development of the methods. Thirty years of record would be necessary at additional sites within the Basin for this comparison, but these sites were not available. Thus, an analysis of variance test was conducted to determine whether a significant difference existed between the monthly normals estimated with each method. Monthly temperature normals estimated with each method were found to be significantly different, except for the month of June. The combined approach was the most theoretically correct method for estimating monthly temperature normals and was, therefore, recommended for use in the Basin. No significant difference existed between the monthly precipitation normals estimated with each method. The easiest method, spatial interpolation of observed normals, was recommended for use in the Basin.

The estimated temperature and precipitation normals can be applied to a variety of hydrological and meteorological studies, as well as, to certain range management studies. Possible applications include estimating crop consumptive use and irrigation requirements, development of plant growth models, species selection for range improvement or mined land reclamation, and evaluation of average soil moisture storage capacity.

Table 1. Temperature regression models

| Model | Regression Equation* | $R^2$ |
|---|---|---|
| Seasonal | T = -21.46 + 4.03 Solar + 0.353 Lat + 0.0173 WDiv | ** |
| Flexible | | |
| Apr | T = -14.41 + 3.69 Solar - 0.342 Lat + 0.0079 WDiv - 1.17 Expos | 0.88 |
| May | T = -14.41 + 3.69 Solar - 0.342 Lat + 0.0079 WDiv - 1.17 Expos + 0.026 Elev | 0.88 |
| Jun | T = -14.41 + 3.69 Solar - 0.342 Lat + 0.0079 WDiv - 1.17 Expos | 0.83 |
| Jul | T = -14.41 + 3.69 Solar - 0.342 Lat + 0.0259 WDiv - 1.17 Expos | 0.86 |
| Aug | T = -14.41 + 3.69 Solar - 0.342 Lat + 0.0225 WDiv - 1.17 Expos | 0.86 |
| Sep | T = -14.41 + 3.69 Solar - 0.342 Lat + 0.0079 WDiv - 1.17 Expos | 0.91 |
| Oct | T = -14.41 + 3.69 Solar - 0.342 Lat + 0.0079 WDiv - 1.17 Expos | 0.86 |
| Monthly | | |
| Apr | T = 21.83 - 0.245 Lat - 8.20 Elev | 0.92 |
| May | T = 24.78 - 0.243 Lat - 0.583 Expos - 5.87 Elev | |
| Jun | T = 31.83 - 0.268 Lat - 0.628 Expos - 6.86 Elev | 0.89 |
| Jul | T = 22.39 - 0.366 Lat + 0.020 WDiv - 0.950 Expos | 0.91 |
| Aug | T = 18.28 - 0.405 Lat + 0.019 WDiv | 0.86 |
| Sep | T = 16.50 - 0.376 Lat + 0.012 WDiv - 0.911 Expos | 0.92 |
| Oct | T = 12.22 - 0.359 Lat - 1.178 Expos | 0.85 |

*Temp = Monthly temperature (°C).
Solar = Solar radiation received at the top of the atmosphere (ly per day/100).
Lat = Latitude of the station (degrees/100).
WDiv = Distance to the western drainage divide (km).
Expos = Exposure of area surrounding the station (degrees/100).
Elev = Elevation of the station (km).

**$R^2$ values for the seasonal model were: Apr = 0.77; May = 0.63; June = 0.56; July = 0.69; August = 0.75; September = 0.82; and October = 0.73.

Table 2. Monthly precipitation regression models

| Month | Regression Equation* | $R^2$ |
|---|---|---|
| Jun | Prec = -5.59 + 4.142 Elev | 0.59 |
| Jul | Prec = -3.28 + 2.358 Elev + 0.030 Lat | 0.61 |
| Aug | Prec = -3.15 + 3.825 Elev + 0.483 WDiv | 0.54 |
| Sep | Prec = -1.73 + 2.950 Elev - 0.401 WDiv | 0.56 |

*Prec = Monthly precipitation (cm).
Elev = Elevation of the station (km).
Lat = Latitude of the station (degrees/100).
WDiv = Distance to the western drainage divide (km).