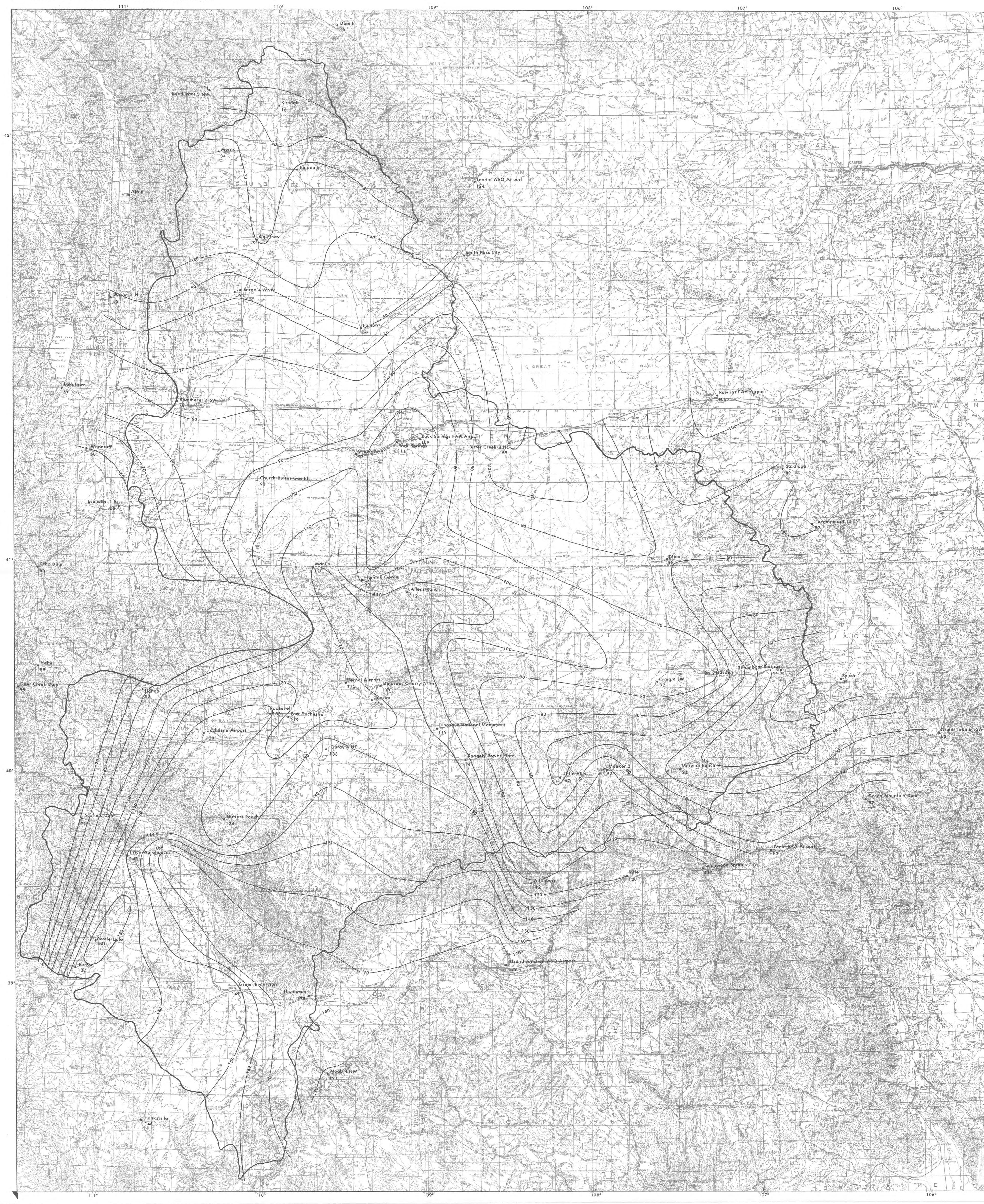
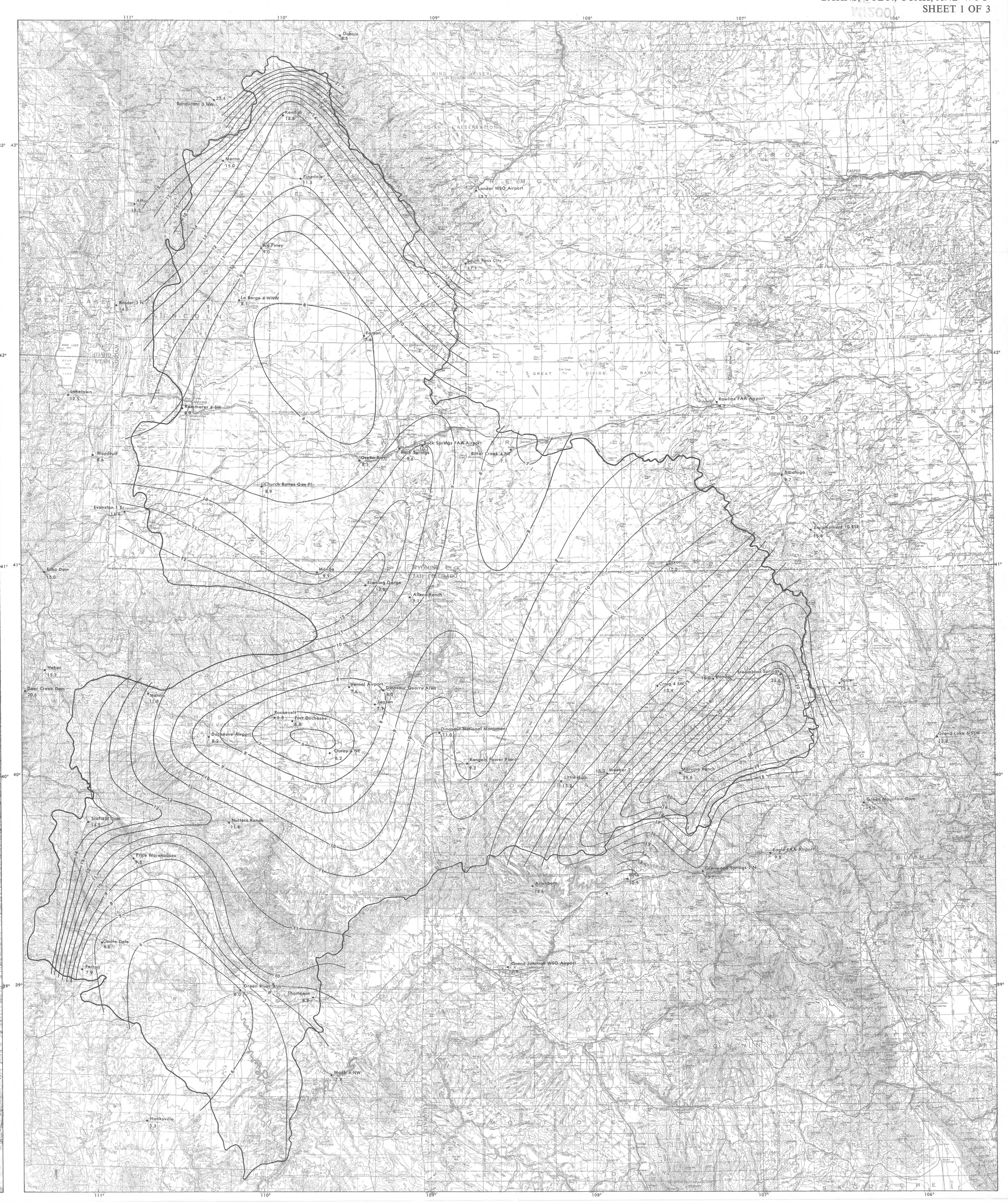
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES MAP MF-1212
GREEN, YAMPA, AND WHITE RIVER DRAINAGE
BASINS, COLO., UTAH, AND WYO
SHEET 1 OF 3



A--Length of growing season (days)



B--Mean annual precipitation (inches)

INTRODUCTION

The study area of this report (fig. 1) is defined as the drainage basins of the Green, Yampa, and White Rivers. The Uinta Mountains of northeastern Utah are excluded because of the lack of sufficient reliable and representative climatological records and because of the unlikelihood of surface-mining within these mountains.

Much of the study area lies within arid or semiarid climate regions with insufficient precipitation to sustain dense vegetation growth (Critchfield, 1966). The annual rate of potential evapotranspiration (loss of water into the atmosphere through the combined processes of surface evaporation and plant transpiration) exceeds the annual rate of precipitation in this area. Consequently, the potential growing season, as defined on the basis of temperature, is truncated by drought-induced dormancy of vegetation.

This report shows the variability of climatic elements within the study area and provides estimates of the irrigation water requirement for plant species used in the revegetation of surface-mined areas. Rehabilitation and the control of surface erosion necessitates timely revegetation, which can be achieved most efficiently if the entire potential growing season is utilized. We feel that irrigation could be practiced only for the first few years to produce better than normal conditions and enhance the probability of successful revegetation. Following this initial period, supplemental moisture can be reduced and eventually eliminated as the vegetation adjusts to natural climate conditions.

We used detailed climatic information, such as growing-season length, precipitation characteristics, and consumptive water use by revegetation plant species, to estimate the magnitude of water deficiency and irrigation water requirement. Consumptive water use is a term commonly used synonymously with evapotranspiration. It was necessary to assemble as much detailed climatic information as possible in order to make the estimates. On-site data would be best, but they were rarely available. Maps based on available records provided a reasonably accurate portrayal of climatic conditions during the past 15 years in the study area.

Sixty-four climate stations were selected on the basis of length and completeness of record for the data base of this report. Two time intervals were considered, 1958-1977 and 1963-1977. The shorter period was selected because more stations had a 15-year record than had a 20-year record, thus yielding a better spatial coverage of the basin (fig. 1); and a more complete set of data could be developed for each station.

The dates of last spring frost and first autumn frost were obtained for each station during the 1963-1977 period from the U.S. National Oceanic and Atmospheric Administration (1963-1977). Mean dates and growing seasons were determined for each station (map A). (The term "mean" can be used interchangeably with "average".) Infrequently, a critical date was missing from the record; and in these cases, the record was synthesized by transposing the datum for this date from a nearby station. Appropriate transfers were made in consultation with U.S. Geological Survey personnel having long-term experience in the study area.

Mean monthly temperature data were obtained for each station from the U.S. Department of Commerce, National Climatic Center, Asheville, North Carolina. This information was used in estimating consumptive water use. Infrequently, a monthly entry was missing from the record. In such cases the available data for a particular month were averaged. For example, if April's temperature was missing for 1963, the mean April temperature for 1964-1977 was inserted into the record. Growing season precipitation, consumptive water use, F-factor, and irrigation water requirement analyses are based on the reconstructed record.

Monthly precipitation totals were also obtained from the National Climatic Center. Data for each of the 15 years (1963-1977) were used in the calculation of annual means (map B). The mean precipitation was computed for each month during the same period (1963-1977) of record (graphs). Where a monthly entry was missing, the record was reconstructed using the method described for temperature.

EXPLANATION AND USE OF STANDARD DEVIATION
AND STANDARD ERROR OF THE MEAN

Statistical data of annual precipitation for each station used in this report are shown in table 3; growing season precipitation data are shown in table 4. Although the mean ($\bar{x}$), maximum, minimum, and range are easily understood, the standard deviation (σ) and standard error of the mean (S.E.) may require explanation. The standard deviation is a measure of variability of the items in the data set about the mean. In this case, the larger the standard deviation, the more variable is the precipitation from year to year (table 3), or from growing season to growing season (table 4). For example, of the stations used in this report, Bondurant 3NW, Wyoming, experiences the greatest variability in annual precipitation (σ = 5.5); while Nutters Ranch, Utah, experiences the greatest variability in growing season precipitation (σ = 3.4).

The mean and standard deviations of monthly precipitation for each station are shown in table 2. In this case, the greatest variability in monthly precipitation, based on the entire year, occurs at Lander WSO AP, Wyoming (σ = .720); and the greatest variability in monthly precipitation, based only on the growing season, occurs at Afton, Wyoming (σ = .787). The most even distribution (least variation from month the month), based on the entire year, occurs at Grand Junction WSO AP, Colorado (σ = .157); and the most even distribution, based only on the growing season, occurs at Merna, Wyoming (σ = .028).

Statistical inferences can be made using the standard deviation. A complete discussion is beyond the scope of this report and can be found in most elementary statistics texts. However, one use can be demonstrated. The precipitation received in any year at a particular station is very unlikely (2.25 percent of the time, or, one year in 43) to be less than the number of inches determined by the value of the mean minus two standard deviations ($\bar{x}$ - 2σ). For example, Altenbern, Colorado, is likely to receive less than 9.2 inches of precipitation [9.2 = 14.6 - (2 x 2.7)] only once in 43 years. By the same token, it is equally unlikely that a station will receive more precipitation than that determined by the mean plus two standard deviations ($\bar{x}$ = 2σ). For example, it is unlikely that Altenbern, Colorado, will receive more than 20.0 inches of precipitation in any one year. Of course, the rare year has to occur some time. This procedure is based on probabilities determined over long periods of time. Altenbern, Colorado, received 21.8 inches of precipitation in 1965. This prodecure can be used to evaluate growing season precipitation as well.

If a small number of years is selected to represent a longer period, there is likely to be a difference between the mean determined by the sample and that which would have been determined by the entire population of years, sometimes called the true mean. The standard error of the mean shows how much discrepancy is likely between the sample mean and the true mean. It is unlikely that the true mean will differ from the sample mean by more than two standard errors. For example, using the information provided in table 3, the true mean of annual precipitation for Altenbern, Colorado, is likely to be between 13.2 and 16.0 inches [$\bar{x}$ ± (2 S.E.)]. The range in which the true mean lies can be determined for any station and for either year or only the growing season using this procedure.

LENGTH OF GROWING SEASON

The growing season is generally considered to be the period of time during which atmospheric temperatures favor plant growth. More specific definitions are elusive because plant species making up the community in a given locale possess varying degrees of frost hardiness and also because the critical temperatures for a particular species remain a subject of debate. The growing season utilized in this report is actually the frost-free period extending from the mean date of last spring frost to the mean date of the first autumn frost. According the Critchfield, (1966. p. 276), the frost-free period is commonly taken to be the growing season at a particular place. The U.S. Soil Conservation Service, (1970, p. 8) uses the frost-free period in making seasonal consumptive-water-use estimates for the purpose of computing irrigation water requirements. The so-defined growing season was extended to the beginning of the first month and the end of the last month in the calculation of growing-season precipitation, and the accompanying graphs reflect this extension.

The mean, maximum, and minimum growing season lengths for each station used in this report are shown in table 1. Moab 4NW, Utah, has the longest growing season, averaging 191 days. Bondurant 3NW, Wyoming, has the shortest growing season, averaging only 11 days between frosts. The variation from year to year in growing-season length at a particular station can be evaluated by comparing the maximum, minimum, and mean growing-season lengths for that station.

Map A shows the spatial variation in mean growing-season length for the study area. The isochronal lines on this map, connecting points of equal growing-season length, were determined by the average values shown in table 1. A general pattern is discernible wherein the shortest average growing seasons occur in the northern part of the study area with the duration of the frost-free period increasing toward the southern part. The longest growing seasons recorded within the basin occur in the southwestern part.

Explanation of the variation in growing-season length requires detailed investigation of several possible controls. There exists a significant statistical relation (r = -0.77) between growing-season length and elevation in this study area. Average growing season may be estimated using the following equation:

$$Y = 281.473 - 0.0304X \qquad (1)$$

S_{xy} = 25.60 days

where: Y = average growing-season length, in days

X = elevation above sea level, in feet.

The large standard error of the estimate (S_{xy} = 25.60 days) accompanying this equation indicates that there are factors other than elevation affecting growing season length. Local terrain characteristics are probably important; however, it is beyond the scope of this research to develop a comprehensive growing season model.

PRECIPITATION

The amount of precipitation received in a particular region can be expressed in a variety of ways. Means annual totals are commonly computed and used as representative statistics of regional climate. For example, the Environmental Studies Board of the National Academy of Sciences and National Academy of Engineering, (1974) seems to base their appraisals of rehabilitation potential on these values. Mean annual totals provide only the crudest estimate of available moisture for plant growth; the distribution of precipitation during the growing season is of paramount importance. Packer, (1974) uses precipitation zones, based on mean annual precipitation and its seasonal distribution, in an evaluation of rehabilitation potential of surface-mined lands in the northern Great Plains. Mean growing-season-precipitation totals may disguise periods of low precipitation within the growing season.

Precipitation is a complex element of climate and must be examined in detail to gain a useful understanding of its characteristics. Annual, seasonal, or monthly precipitation totals are indices of effective precipitation, that is, precipitation remaining after some runoff and deep percolation.

The mean monthly precipitation for stations in the study area is shown in table 2. The data used to compute these values were also used in computing the annual and growing-season precipitation characteristics (tables 3 and 4).

The variation of mean annual precipitation in the study area is shown by the data in table 3. Bondurant 3NW, Wyoming, receives an average of 23.4 inches annually; Hanksville, Utah, receives 5.3 inches. Thus, there is more than a four-fold difference between stations within this study area. The standard deviation (σ) indicates the variability of annual precipitation from year to year for a particular station; and the standard error of mean (S.E.) indicates the range within which the true mean probably lies, as explained in the earlier section.

Map B shows a general pattern in the distribution of mean annual precipitation. Precipitation tends to be least in the central part of the basin and increases toward the periphery, suggesting an orographic control.

The data in table 4 shows the variation in mean growing-season precipitation in the study area. Glenwood Springs 1N, Colorado, receives an average of 7.1 inches; Kendall, Wyoming, only 0.9 inches during its very brief growing season. There is more than a seven-fold difference between some stations in this region during the growing season. The standard deviation indicates the variation of growing-season precipitation from year to year for a particular station. The standard error of mean indicates the range within which the true growing-season precipitation mean probably lies.

Map C shows the distribution of mean growing-season precipitation in the study area. The amount of growing-season precipitation tends to be highest in the southern part of the basin and decreases in rather systematic fashion toward the northern part.

The importance of growing-season precipitation and the problem associated with using annual statistics is illustrated by several stations in this study area. For example, at Hayden, Colorado, the average annual precipitation is 16.0 inches; however, only 5.4 inches are received during the 94-day growing (table 4). On the basis of the annual statistics, one might conclude that there is plenty of moisture for revegetation (Environmental Studies Board of NAS and NAE, 1974, p. 2); although, in fact, only one-third of the annual amount is received during the growing season.

Table 2 and the graphs associated with map B show the distribution of mean monthly precipitation for the year. Annual precipitation is distributed rather evenly throughout the year for many stations in the southern part of the basin with the stations in the northern part showing a tendency for a peak during the spring. April, May, and June tend to comprise a period of higher monthly precipitation totals, while the minimum amounts usually occur during the winter months.

The mean monthly precipitation and the standard deviation of the mean based on the entire year are shown in table 2 for each station. Generally, stations having relatively low mean monthly precipitation and relatively low annual totals have relatively low standard deviations (lesser variability from month to month), and stations having relatively high mean monthly precipitation and relatively high annual totals have relatively high standard deviations (greater variability from month to month). There is no consistent temporal pattern in precipitation which produces the larger standard deviations. Some stations receive the larger proportion of the annual total during winter; other stations receive the larger proportion of the annual total during the spring.

As earlier described, the larger the standard deviation, the more variable the precipitation from month to month during the year. The greatest variability in monthly precipitation for the station records examined occurs at Lander WSO AP, Wyoming; and the most even distribution (least montnly variability) at Grand Junction WSO AP, Colorado.

Mean monthly precipitation and the standard deviation of the mean based only on the growing season for each station is also shown in table 2. Many stations in the study area receive the largest proportion of growing-season precipitation in the beginning of the frost-free period. At Roosevelt, Utah, approximately 55 percent of the growing-season precipitation is received in May and June with the remaining 45 percent evenly distributed over the remaining three months of the growing season.

The data in table 2 show that there is some tendency for stations averaging greater amounts of monthly precipitation during the growing season to have larger standard deviations. Frequently, these stations have a rather short, three-month growing season with one of those months receiving a substantial proportion of the growing-season total. The larger the standard deviation, the greater the variability of precipitation from month to month during the growing season. The greatest variability in monthly precipitation during the growing season for the station records examined occurs at Afton, Wyoming, which averages 2.47 inches in June and 1.03 inches in July. The most even distributions of growing-season precipitation (least monthly variability during the growing season and hence lowest standard deviations) are at Spicer, Colorado (.064), and Merna, Wyoming (.028); these stations have very short frost-free periods.

Complete explanation for the spatial distribution of precipitation characteristics in any area requires the detailed investigation of several possible controls and is beyond the scope of this report. An attempt was made to establish a statistical relation between precipitation characteristics and elevation.

There is a significant relation between elevation and mean annual precipitation ($\underline{r}$ = 0.44) in this area. The following equation shows the nature of this relation:

$$Y = -.15559 + 0.00184X \qquad (2)$$

S_{xy} = 3.79 inches

where: Y = mean annual precipitation, in inches

X = elevation, in feet, above mean sea level.

There was not a statisically significant relation between elevation and mean growing-season precipitation. It appears that summer precipitation of the convectional type may mitigate the effect of topography and elevation. The correlation coefficients ($\underline{r}$) and standard error of the estimates (S_{xy}) indicate that there are other, probably local, factors influencing the distribution of climatic characteristics in the study area.

CONSUMPTIVE WATER USE

The significance of precipitation in the revegetation of surface-mined lands lies in its relation to consumptive water use. Effective precipitation can be regarded as the moisture input into the system of vegetative growth and development. Consumptive water use can be regarded as the moisture output resulting from evaporation from the soil surface and from use of water by plants, some of which is used in building plant tissue but most of which is transpired into the atmosphere as water vapor. If precipitation exceeds consumptive water use, moisture probably will not be a limiting factor in plant growth. If precipitation is less than the consumptive-water-use requirement, moisture deficiency will affect vegetative development.

The consumptive-water-use requirement is the amount of water needed by a particular plant species or community in order to sustain vigorous growth during the growing season. If a non-limiting water supply is assumed, this term may be used synonymously with potential evapotranspiration because it includes the water which would be transpired by plants, used in building plant tissue, and lost into the atmosphere through evaporation from adjacent soil surfaces.

Several methods are available for estimating consumptive water use. The modified Blaney-Criddle method [U.S. Soil Conservation Service, 1970; computer program TR21-V3 (western version)] was used in this study because it provides reasonably accurate results when locally calibrated (Burman, Rechard, and Munari, 1975) and the data input requirements are readily available.

Many environmental factors effect the rate and amount of water used by vegetation. Blaney and Criddle (U.S. Soil Conservation Service, 1970, p. 6) have shown that consumptive water use varies with temperature, length of day, and available moisture. The product of mean monthly temperature (t) and possible monthly percentage of daytime hours of the year (p) yields a monthly consumptive-use factor (f). Crop consumptive water use varies with this factor when an ample water supply is available.

Expressed mathematically, u = kf where:

u = monthly consumptive use of the particular crop, in inches;

k = empirical consumptive-use crop coefficient for a month (varies by crop), and

f = monthly consumptive-use factor where $f = \frac{tp}{100}$.

Mean monthly temperature data must be obtained from meteorological observation. The possible percentage of daytime hours of the year can be estimated from tables based on the latitude of a particular site.

Monthly consumptive-water-use factors can be summed for a given period to provide a growing-season consumptive-use factor (F), or, mathematically, $F = \Sigma f$. A growing-season consumptive-use crop coefficient (K) can be applied to (F) to produce an estimate of growing-season consumptive water use (U), or, mathematically, U = KF. Alternatively, of course, U can be determined by summing monthly consumptive-use values (u).

Map D shows the variability of growing-season consumptive-use factor (F) throughout the study area. Moab, Utah (41.57 inches), and Thompson, Utah (37.85 inches), the latter actually within the delimited study area, have the highest consumptive-use factors; Bondurant, Wyoming (2.12 inches), and Kendall, Wyoming (2.95 inches), the latter again within the delimited study area, have the lowest values. These values may be considered the potential for consumptive water use irrespective of vegetation type; the range for the basin is 34.90 inches. The lowest (F) values occur in the northern part of the study area with relatively low values also occurring in the eastern part. The lower values tend to occur at higher elevations and areas experiencing short growing-seasons. In both cases, the low consumptive-use factor values are a reflection of temperature regime. The highest (F) values occur in the southwestern part of the study area. Higher temperatures and longer growing seasons characterize this area.

The values on map D can be converted to estimates of growing-season consumptive water use (U) through the application of the appropriate growing-season consumptive-use crop coefficient (table 5). The U.S. Soil Conservation Service can assist in the selection of the best value for a particular crop in a particular area. For example, if the best growing-season crop coefficient at Altenbern, Colorado, for alfalfa is 0.85 and the growing-season consumptive-use factor (F) is 23.11, then the consumptive water use for the vigorous growth of alfalfa at this locale averages 19.64 inches per growing-season. This value can be compared to the total growing-season precipitation to determine the existence of moisture deficiency for alfalfa. This method provides only a crude estimate of moisture deficiency. A more precise estimating procedure, using a growing-season water budget, is given by the U.S. Soil conservation Service (1970). (See the following section on irrigation water requirement for a more detailed discussion of this method.)

The Blaney-Criddle method was developed for estimating irrigation water requirements of agricultural crops. Most of the crop coefficients available in the literature are of little use in estimating consumptive use for the types of vegetation used in surface mine rehabilitation. Monthly crop coefficients for alfalfa or pasture grasses are sometimes used in the absence of more appropriate coefficients. Burman, Rechard, and Munari (1975, p. 194) recommend local calibration of crop coefficients to improve the accuracy of the Blaney-Criddle method. Two strategies are possible for calculating crop coefficients which reflect the consumptive-use characteristics of the plant types used in rehabilitation, (1) use of consumptive-use measurements for rehabilitation species, or (2) use of consumptive-use measurements for natural vegetation. The latter strategy is based on the assumption that the most successful species to be used in rehabilitation will have consumptive-use characteristics similar to the species indigenous to the area. The crop coefficients used in this research were developed for Western wheatgrass (Agropyron smithii) by Wymore, Striffler and Berg (1973, p. C-2). A sample of several mining operations in this area showed that all included Western wheatgrass in the seed mixture used for rehabilitation.

Map E shows the consumptive water use by Western wheatgrass during the growing season (U). These values were determined by summing monthly consumptive-use values (u) for each station. Moab, Utah (31.5 inches), and Thompson, Utah (28.4 inches), the latter actually within the delimited study area, showed the highest consumptive water use; and Bondurant, Wyoming (1.5 inches), and Kendall, Wyoming (2.1 inches), the latter again within the delimited study area, showed the lowest; thus, the range for the study area is 26.3 inches.

The pattern of consumptive water use depicted on map E shows that the higher values occur in the southwestern part of the study area and the lower values occur in the northern and, to a lesser extent, eastern part. This again reflects the patterns of variation in growing-season length and overall temperature regime. For example, there is a rather steep gradient between Ferron, Wyo. (20.4 inches) and Scofield Dam (9.6 inches), Utah. The average growing season at Ferron is 132 days, while at Scofield Dan it extends for only 71 days (table 1); thus, there are an additional 61 days during which water can be consumed at Ferron. Examination of July and August mean montly temperature data for these two stations confirms the fact that Ferron is located in a warmer locale than Scofield Dam.

IRRIGATION WATER REQUIREMENT

The U.S. Soil Conservation Service method [1970, computer program TR21-V3 (western version)] was used to estimate mean irrigation water requirements. This procedure calculates a monthly water budget based on (1) effective precipitation received, (2) consumptive-water-use requirement of a particular plant species or community, and (3) storage of moisture in the soil. Monthly surpluses or deficits can be summed to arrive at a growing-season irrigation water requirement. There are very few available records of effective precipitation and it is necessary to estimate the part of the total that is effective. Discussion of the estimating procedure can be found in U.S. Soil Conservation Service (1970). The prodecure for estimating the consumptive-water-use requirement was explained in an earlier section.

The soil-moisture characteristics are incorporated into the procedure through the use of carryover soil moisture, normal net irrigation application, and pre-irrigation soil moisture. Carryover soil moisture is water stored in soils within the root zone during the winter at times when the vegetation is dormant, or before the crop is planted, and is available to help meet the consumptive water requirement of the vegetation. The normal net irrigation application is the amount of water applied at one irrigation and stored in the soil profile for plant use, and depends upon the capacity of the soil profile, at root-zone depth, to store readily available moisture. If the storage capacity is low and a storm of considerable magnitude occurs, a small percentage of the precipitation will be absorbed into the ground; most will be lost as runoff. Pre-irrigation soil moisture is the depth of water normally needed at the start of the growing season to fill the root-zone profile to field capacity. Values (in inches) for these three parameters can be obtained from U.S. Soil Conservation Service guidebooks for specific areas or from U.S. Soil Conservation Service personnel. The values used in this report were selected in consultation with Mr. Robert Tresler, Conservation Agronomist, S.C.S., Casper, Wyo. (oral commun., October 9, 1978).

Map F shows the mean irrigation-water requirement for Western wheatgrass in the study area. Moab, Utah (27.8 inches) and Thompson, Utah (24.6 inches), the latter actually within delimited study area, have the highest irrigation water requirements; Bondurant, Wyoming (0.3 inches), and Kendall, Wyoming (0.8 inches), the latter again within the delimited study area, show the least water deficiency to meet the needs of vegetation during their brief growing seasons. Thus, the irrigation water requirement for this study area is 23.8 inches.

An irrigation water requirement of 24 inches may appear excessive; however, it is the aggregate requirement for the entire growing season. The length of the growing season at Thompson, Utah, averages 178 days. The average weekly irrigation water requirement is 0.97 inches, and the average daily requirement is 0.14 inches.

Examination of irrigation water requirement values for the study area shows that the highest values tend to occur in the southwestern part of the study area; the lowest values tend to occur in the northern and eastern part. This pattern of irrigation water requirements is a composite of growing-season length, growing-season precipitation, and consumptive-water-use distributions.

CLIMATE AND REHABILITATION POTENTIAL

The primary consideration in the rehabilitation of surface-mined lands is control or erosion (Halliday, 1975, p. 1; Hodder, 1975, p. 91). Erosion is controlled through the early re-establishement of vegetative cover following surface disturbance. Consequently, an evaluation of rehabilitation potential requires consideration of the facility of revegetation.

The procedure for revegetation may include the preparation of seedbed, drilling or broadcasting of selected seed, application of fertilizers, and, perhaps, mulching the surface. Beyond this, successful revegetation requires adequate moisture to sustain plant growth. Moisture is most economically provided by natural precipitation falling during the growing season. However, in arid and semi-arid climates, as prevail in the study area, vegetation growth is limited by growing-season water deficiency. Several climate parameters influence the magnitude of water deficiency; hence revegetation facility, and rehabilitation potential. This discussion is based on the premise that rehabilitation potential is inversely related to the amount of water available for plant growth.

Where temperature is the limiting factor for plant growth, one might expect a direct relation between growing-season length and vegetal productivity; as growing-season length increases, vegetal productivity increases. Temperature manipulation over any extended area to increase growing-season length is difficult, whereas the moisture problem can be more easily managed through irrigation. Therefore, it appears reasonable to conclude that areas with longer growing seasons possess a greater potential for rehabilitation than areas with shorter growing seasons, provided that moisture is made available. On this basis, it appears that some locales in the northern portion of the study area may experience difficulties in rehabilitation due to the rather brief frost-free period. This may also be true for some sites in northwestern Colorado at higher elevations. Water deficiencies, however, are likely to be of greater magnitude in areas of longer growing season, other things being equal, because of consumptive use by vegetation for a longer period of time.

The amount and temporal distribution of precipitation are important factors influencing the amount of moisture available for plant growth. Annual, seasonal, or monthly totals are useful indices of effective precipitation in arid and semiarid areas because a small proportion of the total is typically lost due to runoff (Branson, 1976, p. 193), and the remainder is stored in soil. The models for estimating effective precipitation from total precipitation data are rather complicated, and their discussion may result in more confusion than clarity. Further information concerning these models can be found in U.S. Soil Conservation Service (1970).

The amount of moisture required for growth varies with plant type. However, the Environmental Studies Board of the National Academy of Science and National Academy of Engineering (1974, p. 2) suggest that areas receiving ten inches or more of annual precipitation can be rehabilitated. Given the above estimate, the data presented in table 3 can be used to evaluate the likelihood of a year with less than ten inches of precipitation. Table 6 provides a summary of these evaluations.

Of the 64 stations used in this report, 51 are likely to receive less than ten inches of precipitation at least once in 20 years. Of these, 38 are likely to receive less than ten inches at least once in five years, and 31 are likely to receive less than ten inches at least 50 percent of the time (mean annual precipitation less than ten inches, table 3). The stations omitted from table 6 are likely to experience precipitation deficiencies less than five percent of the time (less than one year in 20, perhaps only as often as one year in 30).

Based on the above information, rehabilitation efforts relying on natural precipitation are likely to fail in any given year in much of the study area. Generally, it is only the stations located at higher elevations that will experience precipitation deficiencies less than five percent of the time. That an area may possess a high probability of receiving less than ten inches of precipitation does not mean that revegetation and rehabilitation are impossible. Obviously, there was some vegetation at the site prior to mining. It does mean that rehabilitation is likely to incur greater expense and require greater attention.

The distribution of annual precipitation throughout the year is of critical importance in evaluating rehabilitation potential. Plant growth is dependent upon precipitation received during the growing season. As moisture is typically the limiting factor in the revegetation of semiarid climate regions, it is reasonable to suggest that there is a direct relation between growing-season precipitation and rehabilitation potential; as growing-season precipitation increases, rehabilitation potential increases. Based on this criterion, the data contained in table 4 and map C suggest that revegetation will experience least difficulty in the southern part of the area and greater difficulty toward the northern parts.

Data contained in table 2 and the graphs accompanying map B show the mean monthly and yearly precipitation for each station. In the northern part of the study area, the April-June period of maximum precipitation, coupled with snowmelt in some locales, should provide sufficient moisture for plant growth during the critical initial period of revegetation. However, surface runoff and erosion, capable of removing topsoil and washing seed into the drainage channels, may occur if the amount of water available on the surface exceeds the amount which can infiltrate into the soil. This scenario illustrates the need to drill rather than broadcast seed, and the desirability of mulching the surface as a temporary measure toward soil stabilization. Mulching will have the added benefit of increasing infiltration and retarding evapotranspiration. As precipitation decreases in the later months of the growing season, drought, and its adverse effect on plant growth, will become more of a problem because evapotranspiration will increase due to higher air temperatures. Even those stations showing a rather even monthly distribution of annual precipitation are likely to experience water deficiencies later in the growing season. Irrigation during this period would result in better than normal moisture conditions and enhance the probability of successful revegetation.

The average mean monthly precipitation values shown in table 2 (last four columns) are not particularly useful in evaluating rehabilitation potential in the study area because of the considerable variation from month to month. A single month may have a serious effect on revegetation if there is either too much precipitation resulting in erosion and soil loss, or too little precipitation causing plants to go into dormancy.

In general, perusal of the precipitation characteristics of the study area suggests that the southern part will be the easiest to revegetate and the northern part the most difficult. Most areas will benefit from irrigation during the later months of the growing season.

Although growing-season precipitation characteristics provide a better basis for evaluating rehabilitation potential than annual characteristics, they do not provide complete answers. The ease and success of revegetation depends also on potential evapotranspiration and plant-moisture requirements. The relation between precipitation and consumptive-water-use requirement provides the most valid evaluation of the climate factor in rehabilitation potential. Crop coefficients for determining consumptive-water-use requirements have been developed for typically irrigated agricultural crops. With the exception of those discussed in an earlier section, they have not been developed for plant species suitable for revegetation of surface-mined lands. As these coefficients become available, they can be used, together with those available for agricultural crops, to plan appropriate revegetation programs for particular areas. Crop coefficients provide a basis for comparison for the selection of revegetation species and combinations. Because the consumptive-use factor (F) remains constant in any given area, consumptive water use varies with the coefficient of the crop type. For instance, alfalfa will require more moisture than grain sorghums (table 5). The difference in consumptive water use may be important in areas of frequent and severe water deficiency. Expansion of the crop coefficient list to include types frequently used in revegetation will make such comparisons more meaningful and add another consideration in seed selection, if permitted by the regulatory agency.

Map E shows the consumptive-water-use requirement for Western wheatgrass in the study area. Other factors being equal, it appears reasonable to suggest an inverse relation between rehabilitation potential and consumptive water use; as consumptive water use increases, rehabilitation potential decreases. It appears, therefore, that the northern and eastern parts of the study area will be the easiest to rehabilitate; while the southwestern part will be the most difficult. Generally, the sites at higher elevations will be easier to rehabilitate than those at relatively lower elevations.

As previously mentioned, irrigation during the periods of low precipitation allows the use of the entire growing season for revegetation. Map F provides estimates of growing-season irrigation water requirements for Western wheatgrass throughout the study area. It seems reasonable to suggest that, other factors being equal, successful revegetation and hence rehabilitation potential are inversely related to water deficiency or as irrigation water requirement increases, rehabilitation potential decreases. This parameter is particularly useful in evaluating rehabilitation potential because it combines characteristics of climate, soil, and vegetation. From the information contained on map F, it appears that the southwestern part of the study area will be the most difficult to revegetate, while the northern and eastern parts will be the easiest.

It should be noted that a value on map F is actually a net irrigation requirement, or, the depth of irrigation water that must be delivered to the plant. No attempt has been made to adjust these figures for irrigation efficiency. Field irrigation efficiency may be estimated using applicable local irrigation guides or by referring to the U.S. Soil conservation Service personnel.

SUMMARY

Control of erosion is the primary goal in the rehabilitation of surface-mined lands (Halliday, 1975, p. 1; Hodder, 1975, p. 91). Revegetation of these areas is essential to erosion control. Because several elements of climate affect plant growth, they affect revegetation facility and, hence, rehabilitation potential.

The several climate elements examined in this report can be categorized into two groups: (1) characteristics of the temperature regime of the area, and (2) characteristics of the precipitation regime. Temperature characteristics determine the potential growing-season length and strongly influence the rate of consumptive water use. Precipitation characteristics control the amount of moisture potentially available for plant growth. The interaction of temperature, precipitation, and other elements, such as types of plants, determines the magnitude of water deficiency.

Of the climate elements considered here, three seem most useful in evaluating rehabilitation potential in the study area: (1) growing-season length, (2) irrigation water requirement, and (3) mean monthly precipitation. Each element may reveal climatic problems facing revegetation. The rather brief growing season found in the northern part of the study area and at higher elevations may prolong revegetation. It is virtually impossible to extend the frost-free period significantly. Irrigation water requirement is a measure of water deficiency, and there appears to be an inverse relation between irrigation water requirement and rehabilitation potential. Simply, as the extent of water deficiency increases, the difficulty of revegetation increases. The southwestern part of the study area experiences the greatest water deficiencies. Irrigation in this area would substantially enhance the probability of successful revegetation. Values of mean monthly precipitation can be examined to identify months during which precipitation characteristics may cause problems in rehabilitation. These problems may result from excessive precipitation, indicating the desirability of seed drilling and surface mulching, or from paucity of precipitation, indicating the need for irrigation.

The procedure for incorporating the irrigation-water requirement factor into a comprehensive rehabilitation-potential evaluation scheme requires additional study. Although the inclusion of this factor is logically valid, a central problem concerns interpretation values. The following questions highlight a number of aspects which must be dealt with:

If the goal is an absolute determination of rehabilitation potential for a particular area, can we conclude that an irrigation-water requirement of ten inches has twice the rehabilitation potential of a requirement of 20 inches, even if other things are equal?

If an evaluation of relative rehabilitation potential for sub-areas within a given region is the goal, then the question of class interval is important. Is the rehabilitation potential of a sub-area with a 14-inch irrigation-water requirement significantly less than a sub-area with a 12-inch requirement?

If the entire region has about the same irrigation-water requirement throughout, are we justified in excluding the factor; or should it be included, as a constant, to enhance the conceptual validity of our model?

At the present state of the art in evaluating rehabilitation potential, these questions are likely to require subjective decisions, as do other environmental factors in the evaluating procedure.

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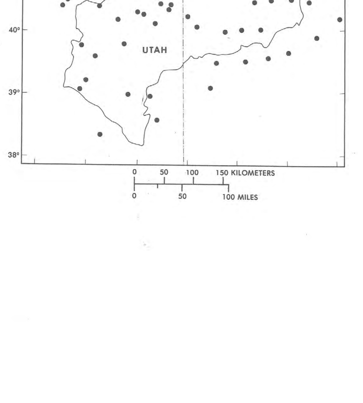

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A CLIMATIC APPRAISAL OF THE REHABILITATION POTENTIAL OF STRIPPABLE COAL LANDS IN THE GREEN, YAMPA, AND WHITE RIVER DRAINAGE BASINS, COLORADO, UTAH, AND WYOMING

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