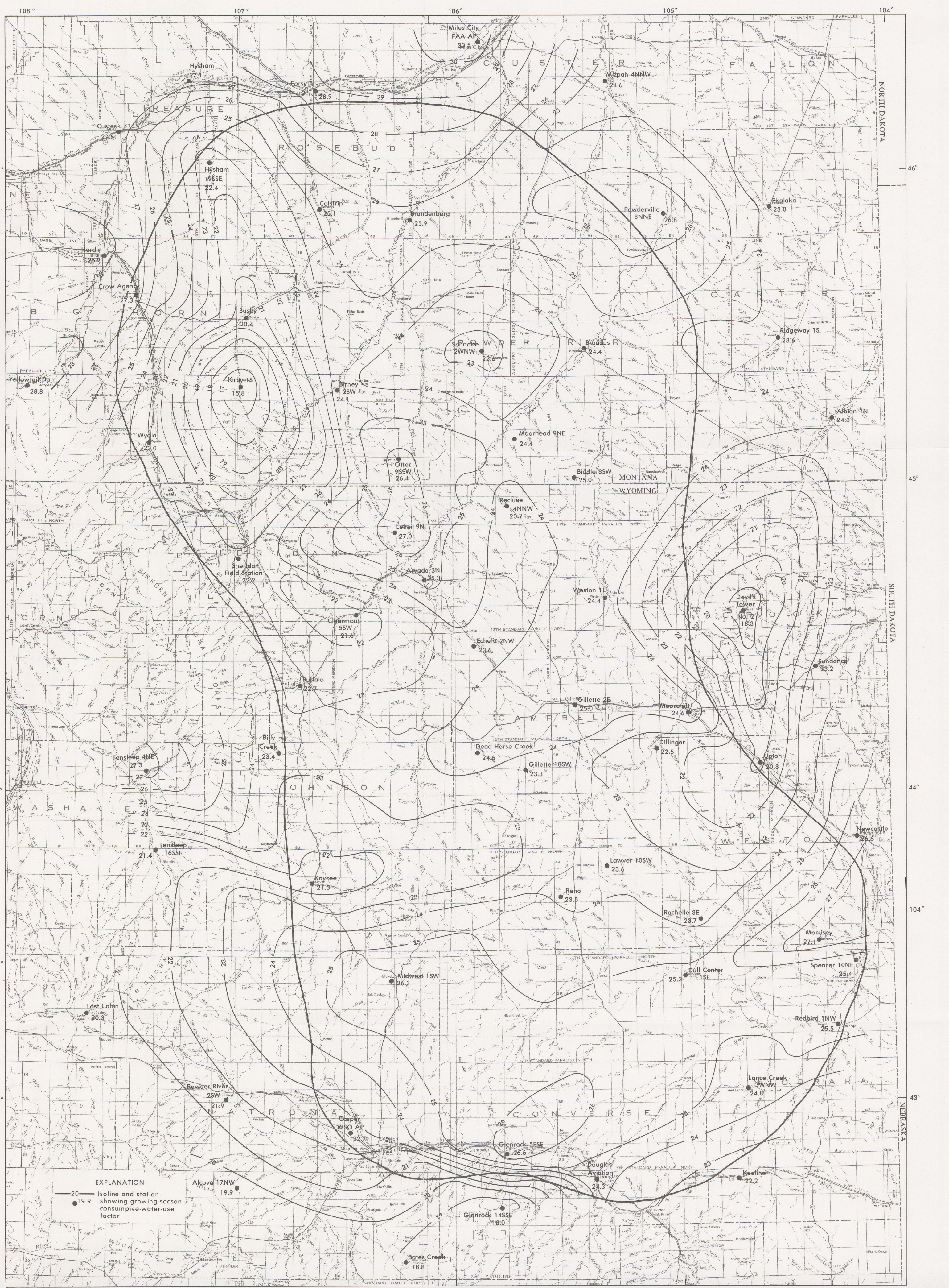
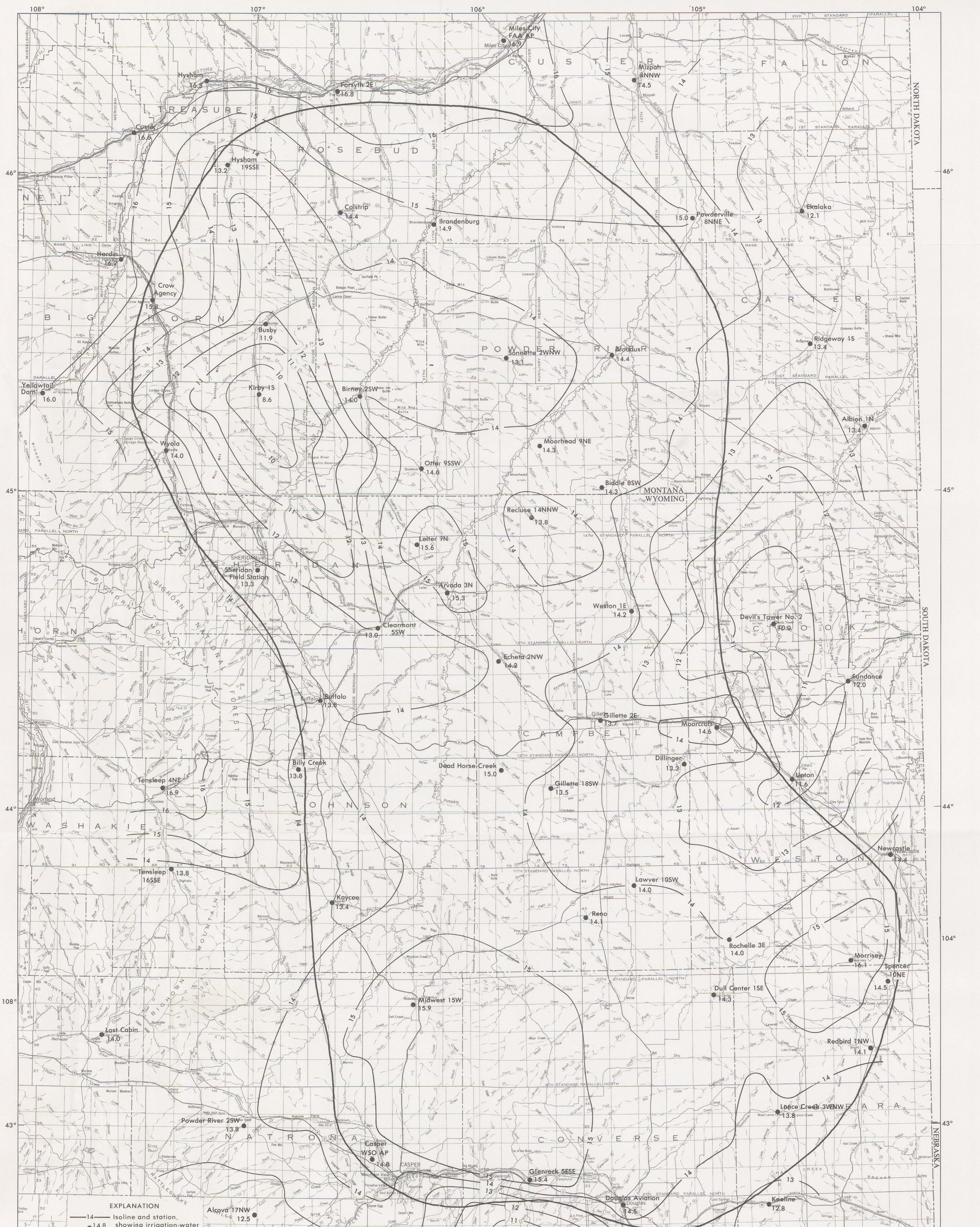


Base from U. S. Geological Survey. Monttana, 1:500,000, 1966, and Wyoming, 1:500,000, 1967 Compileed in 1976

D--Growing-season consumptive-water-use factor

Base from U. S. Geological Survey. Monttana, 1:500,000, 1966, and Wyoming, 1:500,000, 1967 Compileed in 1976

E--Consumptive water use by natural vegetation



Base from U. S. Geological Survey. Montana, 1:500,000, 1966, and Wyoming, 1:500,000, 1967 Compiled in 1976

F--Irrigation-water requirement for natural vegetation

CONSUMPTIVE WATER USE

The significance of precipitation in the revegetation of surface-mined lands lies in its relationship 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. This term is used synonymously with potential evapotranspiration because it includes the water which would be transpired by plants, used in the building of plant tissue, and lost into the atmosphere through evaporation from adjacent soil surfaces, if an adequate supply were available. The rate of transpiration and evaporation are affected by environmental conditions.

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 and others, 1975) and the data input requirements are readily available.

Many environmental factors affect the rate and amount of water used by vegetation. Blaney and Criddle 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 meterological observation. The possible monthly 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) values throughout the Powder River Basin. Miles City, Mont., showed the highest consumptive-use factor of 30.48 inches, Kirby 1S the lowest of 15.79 inches. These values may be considered the potential for consumptive water use irrespective of vegetation type, so the range for the basin is 14.69 inches. Examination of the values for consumptive use at the selected stations reveals only poorly developed patterns; relatively low values tend to occur in the southwestern part of the basin and relatively high values along the northwestern perimeter.

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 area. For example, if the best growing-season crop coefficient at Albion 1N for alfalfa is 0.85 and the growing-season consumptive-use factor (F) is 24.31, then the consumptive water use for the vigorous growth of alfalfa at this locale averages 20.66 inches per year. 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 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 natural vegetation. Monthly crop coefficients for alfalfa or pasture grasses are sometimes used in the absence of coefficients for natural species. Burman, Rechard, and Munari (1975) recommend local calibration of crop coefficients to improve the accuracy of the method. Potential evapotranspiration data provided by W. K. Lauenroth, Natural Resources Ecology Laboratory, Colorado State University, allowed the computation of monthly crop coefficients for natural vegetation. These data were collected in northeastern Colorado on the Pawnee site of the United States/International Biological Project Grassland Biome, a site climatically and botanically similar to the Powder River Basin. The natural vegetation of the study plots consists of blue grama grass (Bouteloua gracilis), fringed sagewort (Artemisia frigida), scarlet globe mallow (Sphaeralcea coccinea), plains prickly pear (Opuntia polyacantha), broom snakeweed (Gutierrezia sarothrae), and needleleaf sedge (Carex eleocharis). Lauenroth and Sims (1976) discuss in detail their method of determining potential evapotranspiration at this location.

Map E shows the consumptive water use by natural vegetation during the growing season (U). These values were determined by summing monthly consumptive-use values (u) for each station. Miles City, Mont., showed the highest consumptive water use, 26.76 inches, Kirby 1S, Mont., the lowest, 15.02 inches; thus, the range for the basin is 11.74 inches.

The pattern of values for consumptive use by natural vegetation at the stations is rather poorly developed. In the southwestern part of the basin, vegetation tends to consume relatively less moisture; in the northwestern part, relatively more.

Variations in the amount of water consumed by natural vegetation principally reflect variations in mean monthly temperature and length of the growing season. Consumptive use by natural vegetation is the product of mean monthly temperature (t) and possible monthly percentage of daytime hours of the year (p) adjusted by the monthly crop coefficient. Comparing the northernmost station, Miles City, Mont., and the southernmost station, Bates Creek, Wyo., the mean difference in possible monthly percentage of daytime hours of the year (p) during the growing season is 0.2 percent. Miles City has a mean monthly temperature during the growing season of 62°F; Bates Creek, 57°F. The monthly crop coefficients are the same for each station.

IRRIGATION WATER REQUIREMENT

The Blainey-Criddle method also 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 (potential evapotranspiration) 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.

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 provided by Robert Tresler, Conservation Agronomist, U.S. Soil Conservation Service, Casper, Wyo. (oral communi., April 8, 1976).

Map F shows the mean irrigation water requirement for natural vegetation during the growing season in the Powder River Basin. Miles City, Mont., and Ten Sleep 4NE, Wyo., have the highest requirement, 16.9 inches each; Kirby, Mont., the lowest, 8.6 inches. Thus, the range in irrigation water requirement for the basin is 8.3 inches.

An irrigation water requirement of nearly 17 inches may appear excessive; however, it is the aggregate requirement for the entire growing season at these stations. The length of the growing season at Miles City averages 140 days. The average weekly irrigation water requirement is 0.85 inches and the average daily requirement 0.12 inches.

Examination of the values for irrigation water requirements at the selected stations reveals that highest values tend to occur along the northwestern perimeter of the basin. Requirements tend to vary more in the western part than in the eastern. The water requirement in the southern half of the basin tends to be uniform, most stations having a water deficit of approximately 14 inches.

This pattern of irrigation water requirements results from a composite of growing-season precipitation and consumptive water use. The latter parameter probably exerts greater influence on the pattern of irrigation water requirement because of the larger magnitude of values. Miles City and Kirby, Mont., have the highest and lowest values of consumptive- water-use requirement respectively.

CLIMATE AND REHABILITATION POTENTIAL

The primary consideration in the reclamation of surface-mined lands is control of erosion (Holliday, 1975). Erosion is most readily controlled through the early re-establishment of vegetative cover following 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 and other types of planting 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 the semiarid climate of the Powder River Basin, 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 water deficiency and directly related to the amount of water available for plant growth.

Where temperature is the limiting factor for plant growth, one might expect that there is a direct relationship between growing-season length and vegetal productivity; as growing-season length increases, vegetal productivity increases. Whereas temperature manipulation over any extended area to increase growing-season length is difficult, the moisture problem may be more easily managed through irrigation. Therefore, it appears reasonable to conclude that areas with longer growing seasons possess greater rehabilitation potential than areas with shorter growing seasons. On this basis, the northern part of the Powder River Basin seems to have greater potential for rehabilitation than the southeastern part, provided that water is made available. Water deficiencies, however, may be of greater magnitude in areas of longer growing season, other things being equal, because of the 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 this study area because a small proportion of the total is typically lost due to runoff and the remainder is stored in the soil. Additionally, the models for estimating effective precipitation from total precipitation data, discussed previously, are rather complicated and their discussion may result in more confusion than clarity.

The amount of moisture required varies with plant type. However, the Environmental Studies Board of the National Academy of Science and National Academy of Engineering (1974) suggests that areas receiving 10 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 rehabilitation failure, that is, the likelihood of a year with less than 10 inches of precipitation. Table 6 provides a summary of these evaluations. Of the 63 stations used in this report, 33 are likely to receive less than 10 inches of precipitation at least once in 20 years. Of these, 15 are likely to receive less than 10 inches of precipitation at least once every 10 years, and 9 are likely to receive less than 10 inches at least once every 5 years. The stations omitted from table 6 are likely to experience precipitation failure less than 5 percent of the time (less frequently than one year in twenty, perhaps only as often as one year in 30).

Based on the above information, surface-mined areas in the Montana part of the basin probably can be revegetated with only infrequent failure necessitating additional treatment. Rehabilitation efforts in the southern and western part of the basin have a higher probability of failure, once every five years in some places, and repeated treatment will be required. That an area may possess a higher probability of failure in revegetation does not mean that rehabilitation is 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 relationship between growing-season precipitation and rehabilitation potential; as growing-season precipitation increases, rehabilitation potential increases. The data contained in table 4 and map C suggest that revegetation will experience least difficulty in the eastern part and greatest difficulty in the southwestern part of the basin.

Table 5.--Seasonal consumptive-use crop coefficients in the Powder River Basin

Range of values results from regional variation. Selected from U.S. Soil Conservation Service (1967)

Crop	Consumptive-use crop coefficient (K)
Alfalfa--------------------	0.80-0.90
Corn (maize)---------------	0.75-0.85
Grains, small--------------	0.75-0.85
Grains, sorghums-----------	0.70-0.80
Deciduous orchard crops----	0.60-0.70
Grass, pasture-------------	0.75-0.85
Ladino whiteclover---------	0.80-0.85
Soybeans-------------------	0.65-0.70
Sugar beets----------------	0.65-0.75
Truck crops, small---------	0.60-0.70

Table 6.--Rainfall reliability at stations in the Powder River Basin
[Stations not listed are not likely to fail to receive less than 10 inches of annual precipitation within any 20-year period]

Station	Likelihood of less than 10 inches of annual precipitation: Once in 5 years	Once in 10 years	Once in 20 years
MONTANA			
Biddle 8SW------------	-----	-----	X
Broadus---------------	-----	-----	X
Custer----------------	-----	X	-----
Forsyth 2E------------	-----	-----	X
Mizpah 4NNW-----------	-----	X	-----
Powderville 8NNE------	-----	X	-----
Ridgeway 1S-----------	-----	-----	X
WYOMING			
Alcova 17NW-----------	X	-----	-----
Arvada 3N-------------	-----	X	-----
Bates Creek-----------	-----	-----	X
Billy Creek-----------	X	-----	-----
Buffalo---------------	-----	X	-----
Casper WSO AP---------	-----	X	-----
Dead Horse Creek------	X	-----	-----
Douglas Aviation------	X	-----	-----
Dull Center 1SE-------	-----	X	-----
Glenrock 5ESE---------	-----	X	-----
Kaycee----------------	-----	X	-----
Keeline---------------	-----	-----	X
Lance Creek 3WNW------	-----	-----	X
Lawver 10SW-----------	-----	-----	X
Lost Cabin------------	X	-----	-----
Midwest 1SW-----------	-----	-----	X
Moorcroft-------------	X	-----	-----
Morrisey--------------	X	-----	-----
Powder River 2SW------	X	-----	-----
Recluse 14NNW---------	-----	X	-----
Reno------------------	X	-----	-----
Rochelle 3E-----------	-----	X	-----
Spencer 10NE----------	-----	X	-----
Ten Sleep 4NE---------	-----	X	-----
Ten Sleep 16SSE-------	-----	X	-----
Weston 1E-------------	-----	X	-----

Data contained in table 2 and map B show the mean monthly precipitation for each station. The May-June period of maximum precipitation, coupled with available snowmelt, should provide the moisture necessary for plant growth during the critical initial revegetation period of the growing season. However, more precipitation than that which can soak in results in surface runoff and erosion capable of removing the topsoil and washing seed into drainage channels. This scenario shows 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.

The period of low precipitation in July and August may cause problems in revegetation in some areas as this is also a period of maximum potential evapotranspiration. Irrigation during this period would result in better than normal moisture conditions and enhance the probability of successful revegetation.

The mean monthly precipitation values shown on table 2 are not particularly useful in evaluating rehabilitation potential in an area such as the Powder River Basin which experiences considerable variation from month to month. A single month may have a serious effect on revegetation if there is either so much precipitation that erosion and soil loss result, or so little precipitation that plants go into dormancy.

In general, the data in table 2 and map B suggest that the northern and eastern parts of the Powder River Basin will be the easiest to revegetate if mulch is applied to control erosion. Revegetation is likely to be most difficult in the southwestern part of the basin. These observations are based on precipitation characteristics alone. Better than normal conditions for revegetation can be obtained through irrigation during the months of July and August.

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 evaporation and plant-moisture requirements. The relationship between precipitation and water requirement (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 native vegetation or hybrid species suitable for revegetation of surface-mined lands. As these coefficients are developed, they can be used, together with those available for agricultural crops, to plan appropriate revegetation programs. 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 critical 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.

Map E shows the consumptive-water-use requirement for natural vegetation in the Powder River Basin. This type of information is useful in evaluating rehabilitation potential because the most successful species to use in revegetation likely will have consumptive-water-use requirements similar to the species indigenous to the area. Other things being equal, it appears reasonable to suggest an inverse relationship between rehabilitation potential and consumptive water use; as consumptive water use increases, rehabilitation potential decreases. There is no clearly discernible pattern to the distribution of consumptive use values on this map. Consequently, this climate element cannot be used to differentiate sub-areas of varying rehabilitation potential within the Powder River Basin.

As previously mentioned, irrigation during the period of low precipitation allows the use of the entire growing season for revegetation. This study provides estimates of growing-season irrigation-water requirement for natural vegetation in the Powder River Basin. Again, the use of natural vegetation water requirement assumes that the most successful species used in revegetation will have consumptive-water-use requirements similar to the species indigenous to the area.

Map F shows average irrigation water requirements for the Powder River Basin. It seems reasonable to suggest that, other factors being equal, successful revegetation and, hence, rehabilitation potential are inversely related to water deficiency or irrigation water requirement; 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. Again, it is difficult to identify a sub-areal pattern within the Powder River Basin. It appears that revegetation may be slightly more difficult in the southwestern part and northern edge of the basin. Generally, about 14 inches of supplemental water will be required to utilize the entire growing season for revegetation.

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 1967).

SUMMARY

Control of erosion is the primary goal in the rehabilitation of surface-mined lands (Holliday, 1975). 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 potential evapotranspiration. 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 in natural and revegetated areas, determine the magnitude of water deficiency.

Of the climate elements considered here, two seem most useful in evaluating rehabilitation potential: The irrigation-water requirement and the mean monthly precipitation (table 2 and graphs on map B). Irrigation-water requirement is a measure of water deficiency and, there appears to be an inverse relation between irrigation-water requirement and rehabilitation potential. Also, the computation of values includes consideration of precipitation, temperature (through potential evapotranspiration and growing-season length), and soil characteristics as they affect water availability for plant growth. 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, suggesting a need for irrigation. Mean annual precipitation appears to provide an insufficient basis for evaluating rehabilitation potential.

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 of 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 10 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 significant class interval is important. Is the rehabilitation potential of a sub-area with 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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SCALE 1:1 000 000

25 0 25 50 75 100 MILES

25 0 25 50 75 100 KILOMETRES

CLIMATE APPRAISAL MAPS OF THE REHABITITATION POTENTIAL OF STRIPPABLE COAL LANDS IN THE POWDER RIVER BASIN, WYOMING AND MONTANA

By
Terrence J. Toy and Brian E. Munson
1978

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