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**Major Vegetation Types, Climatological Data, and
Solar Radiation Calculations for Colorado's Brush Creek Valley**

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MAJOR VEGETATION TYPES, CLIMATOLOGICAL DATA,
AND SOLAR RADIATION CALCULATIONS FOR COLORADO'S
BRUSH CREEK VALLEY

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April 1987

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SUMMARY

The vegetation and climate of the Brush Creek valley were investigated to support a study on the energy budget of the overlying atmosphere.

Vegetation in the Brush Creek valley varies significantly among the major valley surfaces. The valley floor contains predominantly tall sagebrush, with a narrow riparian zone along the perennial stream. Scattered deciduous trees (boxelder and cottonwood) along the lower reaches of the stream increase in density and height as one goes farther up the valley. Secondary vegetation in the sagebrush community includes rabbitbrush and greasewood. Soil moisture increases going up the valley. Eight kilometers up the valley are several western wheatgrass meadows surrounded by boxelder and cottonwood trees. The valley floor becomes narrower with distance up the valley, until, at 10 to 12 km, the valley becomes essentially v-shaped. The lowest 2 km of the valley floor is under cultivation.

The west sidewall of the valley has primarily sagebrush at the valley floor margin, but the slope itself contains a dense cover of serviceberry and mountain mahogany.

The east sidewall contains primarily shadscale on the upper slope and sagebrush on the lower slope, with a few scattered greasewood, sagebrush, juniper, and pinyon pine. The sagebrush and greasewood are generally smaller than those on the valley floor. About 75% of the barren rock area in the valley is on the east sidewall. Erosion is advanced on this sidewall relative to the western sidewall.

The ridge tops are covered with sagebrush in denser stands than on the valley floor. However, individual sagebrush plants are smaller. Aspen and evergreen trees are especially predominant in shallow north-facing declivities on the broad, relatively flat, ridge tops.

These characteristics of valley vegetation were verified in a short site survey on October 3, 1984, in a small area of the valley. Climatological data and solar radiation calculations for the Brush Creek valley are provided as appendices to the report.

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INTRODUCTION

In September and October of 1984, a large meteorological field experiment was conducted in Colorado's Brush Creek valley by the U.S. Department of Energy's Atmospheric Studies in Complex Terrain (ASCOT) program. A preliminary experiment had been conducted in the same valley in July and August of 1982. The 1984 experiment (Gudiksen, Dickerson and Yamada 1984) had as one of its goals the investigation of the energy budget of the Brush Creek valley atmosphere. Because the energy budget of the valley atmosphere is known to be strongly affected by the characteristics of the underlying surface (i.e., the valley floor and sidewalls), investigation of the vegetative cover in the valley is appropriate.

The vegetative cover can be broken down into vegetation types, which are groupings of plants frequently found together in response to environmental conditions. The vegetation types can indicate the surface microclimate, specifically evapotranspiration, the ground heat flux, and the radiation characteristics of the surface. In the semiarid Brush Creek valley the vegetation types are especially useful, since the local distribution of plant species depends strongly on the availability of soil moisture. The microclimate and vegetation types are also used as baseline data in mathematical models attempting to simulate the surface energy budget.

In this report we present information on the vegetative cover, climate, and solar radiation for the Brush Creek valley. A brief vegetative survey was made on October 3, 1984, to identify the vegetation types in the lowest 8 km of the valley; the reader is cautioned that this included only a small part of the Brush Creek valley. The intent was to identify the principal vegetation types, with no attempt to use available scientific sampling techniques to determine accurate relative frequencies of the vegetation types. Nevertheless, the site survey has allowed us to identify the major species of vegetation, and to make reasonably accurate differentiations of both major vegetation types on valley surfaces (the valley floor, two sidewalls, and ridgetops) and the relative abundance of major vegetation types on each surface.

Further, the experience of one of the authors (Lambeth) in the region and, specifically, in the Brush Creek valley, enabled us to comment on the distribution of species in other parts of the valley.

TOPOGRAPHY AND CLIMATE

Brush Creek (Figure 1) is a 25-km-long tributary of Roan Creek, 55 km north-northeast of Grand Junction, Colorado. The Brush Creek valley drains part of the Roan Plateau south of the Piceance Basin. The valley runs from northwest to southeast, is 650 m deep at its lower end, has sidewalls with slopes of 30 to 40°, and has a valley floor that falls 14 m per km. A succession of short box canyons (especially on the valley's east side), are the only tributaries to Brush Creek (Figure 2).

Brush Creek valley has a semiarid, continental climate with low precipitation, low relative humidity, large temperature variations, and high evaporation. The Altenbern ranch, located in the Roan Creek valley near the mouth of Brush Creek at an elevation of 1734 m (5690 ft), reports temperature and precipitation data to the National Weather Service. Examples of the weather reporting forms for September and October 1984 are presented in Appendix A, and a summary of the climate record for the 1947-1980 period of record is given in Appendix B. Figure 3 shows the monthly mean temperatures and precipitation at this site for the entire period of record. The monthly mean maximum temperature ranged from 1.6°C (34.9°F) in January to 32.0°C (89.6°F) in July, and the monthly mean minimum temperature ranged from -13.2°C (8.3°F) in January to 10.4°C (50.7°F) in July. The annual average precipitation was 394 mm (15.5 in.), with August contributing the highest mean monthly amount of 43 mm (1.7 in.). Snow covered the ground an average of 50% of the days from November through March each year.

The ratio of the extraterrestrial solar radiation to the average solar radiation reaching the earth's surface for Grand Junction, Colorado, is shown in Figure 4. This ratio, commonly called the clearness index, is closely correlated with mean cloud cover. Grand Junction is cloudy in midwinter as Pacific air masses bring abundant cloud cover and moisture to the mountains and western valleys. As summer arrives and moist air masses become a rarity,

FIGURE 1. Topographic Map of the Lowest 10 km of Colorado's Brush Creek Valley and its Confluence with Roan Creek Valley

FIGURE 2. View Looking up the Brush Creek Valley, Made With a Digital Topographic Model of the Valley and a Grid Interval of 100 ft

FIGURE 3. Monthly Mean Temperatures and Precipitation from 1947 to 1980, Altenbern Ranch, Colorado. In the upper part of the figure, the mean monthly, mean maximum, and mean minimum temperatures are indicated. In the lower part of the figure, precipitation is indicated by a solid line and snow cover is indicated by a dashed line.

FIGURE 4. Monthly Clearness Index Values for Grand Junction, Colorado

Grand Junction has the highest clearness indices in Colorado. The clearness index values given in Figure 4 for Grand Junction are indicative of those expected in the Brush Creek area.

As mentioned above, solar radiation has a strong influence on the distribution of vegetation in the semiarid Brush Creek valley. Appendix C

presents extraterrestrial solar radiation for a variety of slope inclination and azimuth angles. These theoretical curves, calculated with Whiteman and Allwine's (1986) solar model, can be used to estimate the solar influence on the microclimates of the major topographic surfaces in the valley.

THE MAJOR VEGETATION TYPES

A field survey of the major vegetation types was accomplished on October 3, 1984, and aerial photographs of the vegetation in the Brush Creek valley were taken on September 20, 1984. The different species of vegetation are listed in the following section, along with remarks on their distribution and relative abundance. Sites PNL, WPL, W, E, and R [energy budget sites established by Fritschen et al. (1985)] have been used in this report as reference points (see Figure 1).

VALLEY FLOOR

The floor of the Brush Creek valley is grazed by cattle and sheep in the summer. Vegetation on the valley floor consists primarily of big sagebrush; black greasewood, rabbitbrush, and grasses are secondary in importance. Fritschen et al. (1985) found sagebrush as the primary vegetation type and bunchgrass as the secondary vegetation type at Site PNL (Figure 1) on the valley floor. The 0.8- to 1.5-m-tall sagebrush provided 30% of the canopy cover, while the 0.20-m-tall bunchgrass provided 5% of the canopy cover. The remaining 65% was composed of bare soil and small shale rocks. Fritschen et al.'s estimates of the percent cover of different vegetation types were made subjectively by an experienced observer; the vegetation heights were determined by measurement. Figure 5 is a photograph of the PNL site.

In areas where alluvial fans sweep down onto the valley floor from the box canyon tributaries, we found that drainage paths in the alluvial fans supported invader species, such as mullein, that occupy frequently disturbed ground more readily than sagebrush.

The high soil moisture near perennial Brush Creek supports the growth of water-loving riparian species, including deciduous trees. Here we found primarily boxelder, cottonwood, and a few stands of locust. Shrubs, such as wild roses and chokecherries, also grew in profusion near the stream banks.

FIGURE 5. Sagebrush Vegetation Type at Valley Floor Site PNL

The lowest 2 km of the Brush Creek valley is cultivated, using water from Brush Creek for irrigation. An abandoned ranch house 7.5 km up the valley marks the location of several meadows where crops were formerly grown. These meadows are covered predominantly with western wheatgrass and are surrounded by boxelder, cottonwood, and a few locust trees. The WPL site (Figure 1) was located in one of these meadows. Fritschen et al. (1985) found that western wheatgrass of 0.25 m height provided 70% canopy cover at the WPL site. Alfalfa of 0.9 m height provided most of the remaining 30% cover. Smooth brome and sweet clover can also be found in the meadow. The vegetation at this site is shown in Figure 6. The valley floor becomes progressively narrower upstream, and deciduous trees (mostly cottonwood and boxelder) and shrubs become the predominant vegetation. The valley becomes essentially v-shaped, with no valley floor, 10 or 12 km from the mouth.

FIGURE 6. Cropland Vegetation Type at Valley Floor Site WPL With Instruments Used For Evaluating Energy Budget.

WEST SIDEWALL

The west sidewall of the Brush Creek valley faces northeast. Its inclination angle and exposure are such that the sidewall is in shadow or with only weak insolation during the afternoons for most of the year. This results in a relatively moist microclimate on the west sidewall, which supports a wide variety of shrubs. While sagebrush is the predominant vegetation on the western edge of the valley floor, serviceberry and mountain mahogany are predominant on the west sidewall. Mountain mahogany dominates the steeper, better drained shale slopes. These shrubs grow in rather dense stands on the west slope, and some parts are difficult to access because of the density of vegetation. However, livestock and game trails provide some entry into even the densest areas. Secondary vegetation includes sagebrush, Gambel oak, skunkbrush, snowberry, and Utah juniper.

In the shallow drainages on the ridgetops, and in major drainages coming down the west sidewall (especially on the north-facing slopes of such drainages), stands of Douglas fir and/or aspen are found. These stands extend only a short distance down the upper sidewall at the mouth of the valley, but extend (with the addition of white fir) down to the valley floor some 8 km farther up the valley. This extension of the stands to lower elevations as one goes farther up the valley is due to the moister microclimates

produced on this slope as the valley floor gains elevation and turns westward near its head. Thus, the "west" sidewall faces more to the north with increasing up-valley distance.

Observations on the west sidewall at the W site (Figure 1) made by Fritschen et al. (1985) found that mountain mahogany and serviceberry of 1.5 m average height made up 40% of the canopy cover. Grass of 0.4 m height made up 10% of the canopy cover; the remaining 50% was bare ground. Figure 7 shows the vegetation at Site W.

EAST SIDEWALL

The east sidewall, a southwest-facing slope, is exposed to a severe radiation climate. The sun's rays in afternoon fall directly on the slope, producing strong afternoon warming. The consequent cycle of daily freezing and thawing and the sparse vegetation are responsible for the strong erosional features on this slope. Consequently, the east sidewall has deeper box canyons and more marked alluvial features than the west sidewall. The east sidewall soil is rockier and drier, supporting more desert-like vegetation.

Widely scattered juniper and pinyon pine are found primarily on the lower slopes of the east sidewall. Scattered sagebrush is the predominant vegetation on the lower slope to 100 to 150 m above the valley floor, but shadscale becomes predominant higher on the slope. Greasewood is also present on the east sidewall, but is usually secondary in importance to shadscale and sagebrush.

The east sidewall at Site E (Figure 1) is pediment, with 0.4- to 1-m-high sagebrush making up 15% of the surface cover. The remainder is bare ground and shale rocks of various sizes (Fritschen et al. 1985). The vegetation at this site is shown in Figure 8.

FIGURE 7. Mountain Shrub Vegetation Type at West Sidewall Site W

FIGURE 8. Sagebrush Vegetation Type at East Sidewall Site E

RIDGETOPS

Since the valley drains a plateau, there is little difference in elevation between the ridgetops at the upper end of Brush Creek and the ridgetops at the lower end. The ridges on either side of the valley are not sharp, but broad and rolling. Steep cliffs mark the edge of the ridgetops. The increased amount of precipitation on the high elevation mesa results in a better cover of grasses than in the valley itself. Consequently, the mesa is summer range for sheep and cattle. The soil is relatively deep on the ridgetops, with a higher content of organic material and fewer rocks. The ridgetops are covered with a mosaic of serviceberry, snowberry, sagebrush, bunchgrasses, and aspen stands. Even over this relatively gentle terrain, slope and aspect determine available moisture, and thus the type of vegetation community.

The ridgetop site (Site R in Figure 1) described by Fritschen et al. (1985) had a 30% cover of 0.35- to 0.97-m high sagebrush, a 10% cover of 2.25-m high oakbrush, and a 60% cover of bare soil. Figure 9 shows the vegetation at this site.

FIGURE 9. Sagebrush Vegetation Type at Ridgetop Site R

SUMMARY OF VEGETATION TYPES

Figure 10 shows the topography of the lower 9 km of the Brush Creek valley. Figure 11 is a map showing the distribution of the vegetation types in the same area. The vegetation typing on Figure 11 was drawn from aerial photographs and the limited vegetation survey. Vegetation types found in the Brush Creek valley site survey are listed in Table 1. We have included the common and scientific names of major plant species occurring within each vegetation type, as well as a listing of the areal coverage of the individual vegetation types, determined by planimetry from Figure 11.

FIGURE 10. Topographic Map of the Lower Brush Creek Valley for Comparison With the Vegetation Types Shown in Figure 11

FIGURE 11. Vegetation Type Map of the Lower Brush Creek Valley.
Compare the vegetation distribution with the elevations and slopes in Figure 10

TABLE 1. Major Plant Species of Vegetation Types in the Lower Brush Creek Valley

Vegetation Type	Primary Location	Total Area in Valley (km ²)	Typical Species	
			Common Name	Scientific Name
Cropland	Valley floor	0.64	Alfalfa Western wheatgrass Smooth brome	<u>Medicago sativa</u> <u>Agropyron smithii</u> <u>Bromus inermis</u>
Riparian	Valley floor along stream	0.63	Narrowleaf cottonwood Boxelder New Mexico locust Common chokecherry Wild rose Skunkbrush	<u>Populus angustifolia</u> <u>Acer negundo</u> <u>Robinia neomexicana</u> <u>Prunus virginiana</u> <u>Rosa woodsii</u> <u>Rhus trilobata</u>
Sagebrush	Lower valley floor, benches of both side-walls, shallow valleys of ridgetops	4.29	Big sagebrush Black greasewood Western wheatgrass Bluebunch wheatgrass	<u>Artemisia tridentata</u> <u>Sarcobatus vermiculatus</u> <u>Agropyron smithii</u> <u>Agropyron spicatum</u>
Pinyon/Juniper	Lower end of valley, especially on the east sidewall	2.69	Utah juniper Colorado pinyon pine Galleta (grass) Goldenweed	<u>Juniperus osteosperma</u> <u>Pinus edulis</u> <u>Hilaria jamesii</u> <u>Haplopappus sp.</u>
Saltbush Desert	East sidewall	3.77	Shadscale Nuttall's (Gardner's) saltbrush Black Greasewood	<u>Atriplex confertifolia</u> <u>A. nuttallii</u> <u>Sarcobatus vermiculatus</u>
Mountain Shrub	Ridgetops, W sidewall, N-facing slopes of E sidewall, upper valley floor	27.09	Saskatoon service-berry Mountain mahogany Gambel oak Skunkbrush Mountain snowberry Big sagebrush	<u>Amelanchier alnifolia</u> <u>Cercocarpus montanus</u> <u>Quercus gambellii</u> <u>Rhus trilobata</u> <u>Symphoricarpos oreophilus</u> <u>Artemisia tridentata</u>
Tall Conifer	N-facing slopes, mostly on the west sidewall	2.69	Elk sedge Douglas fir White fir	<u>Carex geyeri</u> <u>Pseudotsuga menziesii</u> <u>Abies concolor</u>
Aspen	W ridgetop (Brush Mountain)	0.06	Quaking aspen Mountain snowberry	<u>Populus tremuloides</u> <u>Symphoricarpos oreophilus</u>
Barren	E sidewall, narrow strip on W sidewall, escarpment	2.95		
Total Area (km ²)		44.81		

REFERENCES

Gudiksen, P. H., M. H. Dickerson and T. Yamada. 1984. ASCOT FY-1984 Progress Report. ASCOT 84-6, Lawrence Livermore National Laboratory, Livermore, California.

Fritschen, L. J., J. R. Simpson, C. D. Whiteman and M. M. Orgill. 1985. Energy Balance Stations in a Deep Colorado Valley: ASCOT84. Preprints, 17th Conference on Agriculture and Forest Meteorology, May 1985, Phoenix, Arizona. Published by the American Meteorological Society, Boston, Massachusetts.

Whiteman, C. D. and K. J. Allwine. 1986. Extraterrestrial Solar Radiation on Inclined Surfaces. Environmental Software, 1, 164-169.

APPENDIX A

CLIMATE RECORD FORMS, SEPTEMBER AND OCTOBER, 1984

FIGURE A.2. Climate Record Form, October 1984, Altenbern Ranch, Colorado

APPENDIX B

CLIMATE SUMMARY, ALTENBERN RANCH, COLORADO

TABLE B1. Summary of Monthly Climatic Data for Altenbern, Colorado
for Years 1947-1980 (a)

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.
Monthly Mean Max. Temp (°F)	Ave.	34.9	42.5	50.9	61.6	72.2	82.9	89.6	85.5	77.1	65.9	49.9	38.3	62.6
	Max.	42.5	50.2	61.1	67.5	78.5	88.9	94.8	90.3	83.0	73.8	56.1	49.0	65.1
	Min.	26.7	35.9	44.1	54.9	66.9	75.8	86.3	77.8	70.0	55.0	42.0	28.9	60.3
	Yrs. Data	22	22	22	22	22	22	22	22	23	23	23	23	22
Monthly Mean Min. Temp (°F)	Ave.	8.3	15.6	21.9	29.4	37.1	43.6	50.7	48.4	40.2	31.0	21.2	11.8	29.9
	Max.	18.8	21.2	28.6	33.4	40.5	49.4	53.8	53.2	44.8	38.5	27.3	22.0	32.5
	Min.	-0.4	5.3	13.8	26.4	33.6	39.8	45.5	43.3	34.8	26.7	15.6	3.0	26.5
	Yrs. Data	22	22	22	22	22	22	22	22	23	23	23	23	22
Monthly Mean Ave. Temp (°F)	Ave.	21.6	29.1	36.5	45.5	54.7	63.2	70.1	67.0	58.7	48.5	35.6	25.1	46.3
	Max.	28.4	35.7	43.4	49.6	59.2	69.2	72.3	70.8	62.5	53.6	40.7	35.5	48.0
	Min.	14.4	21.2	29.0	40.7	51.4	58.8	67.4	62.8	52.5	42.5	28.8	16.0	44.2
	Yrs. Data	22	22	22	22	22	22	22	22	23	23	23	23	22
Degree Days (Base 65°F)	Ave.	1338.6	1009.1	878.0	578.3	312.7	95.0	2.0	27.5	191.1	505.4	875.6	1230.3	7055.2
	Max.	1563	1257	1108	722	418	180	8	93	371	690	1078	1512	7756
	Min.	1127	814	659	455	171	4	0	0	80	348	721	909	6468
	Yrs. Data	22	22	22	22	22	22	22	22	23	23	23	23	22
Number Days Max. Temp. ≥ 90°F	Ave.	0.0	0.0	0.0	0.0	0.0	6.8	16.9	8.7	1.1	0.0	0.0	0.0	33.6
	Max.	0	0	0	0	0	17	29	19	5	0	0	0	57
	Min.	0	0	0	0	0	0	7	0	0	0	0	0	14
	Yrs. Data	22	22	22	22	22	22	22	22	23	23	23	23	22
Number Days Max. Temp. ≤ 32°F	Ave.	11.4	2.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.1	7.8	24.0
	Max.	24	8	3	0	0	0	0	0	0	2	8	20	42
	Min.	0	0	0	0	0	0	0	0	0	0	0	0	5
	Yrs. Data	22	22	22	22	22	22	22	22	23	23	23	23	22

TABLE B1. (Contd)

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.
Number Days	Ave.	30.6	27.6	28.9	21.4	6.9	0.7	0.0	0.2	3.6	19.0	27.8	30.6	196.9
Min. Temp.	Max.	31	29	31	28	13	3	0	2	8	26	30	31	217
≤ 32°F	Min.	26	24	23	12	0	0	0	0	0	8	22	29	178
	Yrs. Data	22	22	22	22	22	22	22	22	23	23	23	23	22
Number Days	Ave.	8.0	2.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	4.5	15.5
Min. Temp	Max.	20	10	4	0	0	0	0	0	0	0	2	14	27
≤ 0°F	Min.	1	0	0	0	0	0	0	0	0	0	0	0	1
	Yrs. Data	22	22	22	22	22	22	22	22	23	23	23	22	21
Highest Temp.	Temp.	56	65	73	82	89	99	101	97	97	86	71	60	101
(°F)	Yrs. Data	22	22	22	22	22	22	22	22	23	23	23	23	22
Lowest Temp.	Temp.	-32	-20	-11	1	20	28	34	28	21	10	-7	-23	-32
(°F)	Yrs. Data	22	22	22	22	22	22	22	22	23	23	23	23	22
Monthly	Ave.	1.47	1.25	1.43	1.22	1.33	1.02	1.11	1.71	1.19	1.31	1.16	1.34	15.45
Precip.	Max.	4.04	3.86	3.55	2.80	3.65	3.45	2.73	4.01	4.75	4.02	3.13	4.80	27.78
(Inches)	Min.	0.00	0.00	0.07	0.47	0.00	0.00	0.24	0.09	0.00	0.00	0.03	0.14	10.21
	Yrs. Data	33	33	33	33	33	33	34	34	34	34	34	34	33
Greatest	Amount	1.45	1.20	0.82	0.78	0.96	1.32	1.32	1.55	1.46	1.35	1.07	1.66	1.66
Daily	Yrs. Data	33	33	33	33	33	33	33	33	33	33	33	33	33
Precip.														
(Inches)														
Monthly	Ave.	19.2	11.6	9.1	3.0	0.7	0.1	0.0	0.0	0.3	1.2	7.8	15.5	69.4
Snowfall	Max.	55.7	38.0	42.9	18.1	7.0	2.0	0.0	0.0	9.0	9.5	23.3	47.1	141.9
(Inches)	Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	26.7
	Yrs. Data	33	32	31	29	33	33	34	34	34	34	34	33	26

TABLE B1. (Contd)

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.
Greatest Inches		71	71	54	6	2	0	0	0	3	8	10	32	
Depth of Yrs. Data		33	30	28	25	32	32	32	32	33	32	30	30	
Snow on Ground														
Number Days	Ave.	5.2	4.5	5.4	4.8	4.6	3.3	3.6	5.2	3.7	3.9	4.1	4.7	52.8
Precip. $\geq$ 0.1	Max.	14	11	15	12	14	11	8	12	10	9	11	13	105
Inches	Min.	0	0	0	1	0	0	0	1	0	0	0	0	33
	Yrs. Data	33	33	33	33	33	33	33	33	33	33	33	33	33
Number Days	Ave.	0.7	0.5	0.7	0.4	0.6	0.6	0.6	1.1	0.8	0.8	0.5	0.7	7.9
Precip. $\geq$ 0.5	Max.	3	3	3	2	4	5	3	4	4	4	2	4	32
Inches	Min.	0	0	0	0	0	0	0	0	0	0	0	0	2
	Yrs. Data	32	32	32	32	32	32	32	32	32	32	32	32	32
Number Days	Ave.	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.7
Precip. $\geq$ 1.0	Max.	1	1	0	0	0	1	1	1	1	1	1	1	4
Inches	Min.	0	0	0	0	0	0	0	0	0	0	0	0	0
	Yrs. Data	32	32	32	32	32	32	32	32	32	32	32	32	32
Number Days	Ave.	0.0	0.0	0.1	0.0	0.4	0.3	0.4	0.1	0.1	0.0	0.0	0.0	1.4
With Hail ^(b)	Max.	0	0	1	0	5	2	7	1	1	1	0	0	7
	Min.	0	0	0	0	0	0	0	0	0	0	0	0	0
	Yrs. Data	25	25	25	25	25	25	25	25	25	25	25	25	25
Number Days	Ave.	25.8	15.9	6.9	0.3	0.0	0.0	0.0	0.0	0.1	0.3	3.7	17.7	68.8
w/ Snow on	Max.	31	29	25	2	0	0	0	0	1	3	14	31	107
Ground ^(c)	Min.	0	0	0	0	0	0	0	0	0	0	0	0	36
	Yrs. Data	18	18	18	15	18	18	18	18	18	18	18	17	14

(a) Unpublished data summary generated by the Colorado Climate Center.

(b) Many weather stations do not record all hail occurrences. Therefore, these data may not be representative.

(c) $\geq$ 1 inch of snow on ground.

APPENDIX C

SOLAR RELATIONSHIPS

FIGURE C.1. Sunrise and Sunset Times for Brush Creek Valley, Colorado

FIGURE C.2. Extraterrestrial Solar Flux at Solar Noon on a Horizontal Surface at the Latitude and Longitude of the Brush Creek Valley. For reference, the solar constant ($1353 W m^{-2}$) is indicated.

FIGURE C.3. Daily Total Extraterrestrial Solar Radiation on South-Facing Slopes Having Different Inclination Angles at the Latitude and Longitude of the Brush Creek Valley, as a Function of Month

FIGURE C.4. Daily Total Extraterrestrial Solar Radiation on Vertical Walls of Different Orientation and on a Horizontal Surface at the Latitude and Longitude of the Brush Creek Valley, as a Function of Month

FIGURE C.5. Daily Total Extraterrestrial Solar Radiation on Southwest-Facing Slopes Having Different Inclination Angles at the Latitude and Longitude of the Brush Creek Valley, as a Function of Month

FIGURE C.6. Daily Total Extraterrestrial Solar Radiation on Northeast-Facing Slopes Having Different Inclination Angles at the Latitude and Longitude of the Brush Creek Valley, as a Function of Month

FIGURE C.7. Daily Total Extraterrestrial Solar Radiation on 30° Slopes Facing Southwest and Northeast at the Latitude and Longitude of the Brush Creek Valley, as a Function of Month

FIGURE C.8. X as a Function of Time of Year for Slopes of Different Inclination Angle, Where X is Defined According to the Following Formula:

$$X = \frac{\text{Daily Total Solar Radiation on NE-Facing Sidewall}}{\text{Daily Total Solar Radiation on SW-Facing Sidewall}} \times 100$$

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