Atmospheric environment in a southwestern Montana mountain valley
by Steven Matthew Ottenbreit

A professional paper submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in SOILS
Montana State University

Abstract:
A climatological study of Big Sky, Montana, was made from April 1970 to June 1973. This is a resort area located near Lone Mountain on the West Fork of the West Gallatin River in southwestern Montana.

The Meadow Village area of Big Sky is located on the floor of a narrow mountain valley. Mobile measurements of temperature in Gallatin Canyon and thermograph data from a mountainside near Meadow Village were combined to show that cold air pools in the area at night and inversions extending to a height of 500 to 700 feet above the valley floor are. common. However, inversions rarely persist through the day. Phenological studies reaffirmed the presence of cold air at night in the valley and indicated a thermal belt midway up the mountainside. Turf species that will survive at Meadow Village are limited by the cold nighttime temperatures. Winds at Meadow Village are typically slow and erratic during the afternoon and calm (though exhibiting a downcanyon direction) at night. Wind measurements in the cirque of Lone Mountain near the ski area suggest that the area is windy much of the time with severe winds occurring on occasion.

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Signature Steven M Ottenbreit

Date May 21, 1974

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by

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ABSTRACT

A climatological study of Big Sky, Montana, was made from April 1970 to June 1973. This is a resort area located near Lone Mountain on the West Fork of the West Gallatin River in southwestern Montana. The Meadow Village area of Big Sky is located on the floor of a narrow mountain valley. Mobile measurements of temperature in Gallatin Canyon and thermograph data from a mountainside near Meadow Village were combined to show that cold air pools in the area at night and inversions extending to a height of 500 to 700 feet above the valley floor are common. However, inversions rarely persist through the day. Phenological studies reaffirmed the presence of cold air at night in the valley and indicated a thermal belt midway up the mountainside. Turf species that will survive at Meadow Village are limited by the cold nighttime temperatures. Winds at Meadow Village are typically slow and erratic during the afternoon and calm (though exhibiting a downcanyon direction) at night. Wind measurements in the cirque of Lone Mountain near the ski area suggest that the area is windy much of the time with severe winds occurring on occasion.

INTRODUCTION

In February of 1970, Chet Huntley announced plans to begin construction of a year-round recreational complex. This complex, referred to as "Big Sky", was to be located near Lone Mountain on the West Fork of the West Gallatin River. Initial plans included development of two population centers, Meadow Village and Mountain Village. The total resident population of these two villages was not to exceed 10,000. Projected summer activities included boating, tennis, golf, swimming, fishing, and horseback riding. Winter activities proposed were skiing (both downhill and cross country) and ice skating. Hunting and pack trips were planned for the fall. Most of these activities would be undertaken by non-residents as well as residents.

The proposed recreational complex was to be built on land designated as a semi-primitive area. An investigative team, funded by the National Science Foundation, was formed at Montana State University to study the impact of the Big Sky Complex on this area. It was hoped that guidelines for the development of future recreational projects could be made from this study. The MSU investigative team had three major objectives. The first of these objectives was to identify, describe and analyze the impact of the Big Sky complex on the local recreational area. Another objective was to present the data in a form that would be understandable and useful to potential "users". The third objective was to maximize the transferability and application of the findings to other recreational area developments.

In keeping with these objectives a climatological study of the Big Sky area was undertaken. Meteorological factors affecting air pollution were investigated. For a given pollution source, the concentration of pollutants in the atmosphere depends primarily on two factors, the vertical variation of temperature and the direction and strength of the wind (Neiburger, 1969). Climatological information can be used at the study area as an input for planning water requirements for turf species, housing design and location, time suitable for construction, and times for various recreational activities. A knowledge of climate of two areas is a factor that should be considered in transferability of many types of data regarding animal and plant life, soils, water quality, and types of recreation.

The primary purpose of this climatological study was to measure weather data in the Big Sky area and to present it in a useful form. Meteorological parameters that were measured included temperature, solar radiation, and wind direction. Phenological data were also gathered to aid in site comparisons.

EXPERIMENTAL PROCEDURE

Temperature Analysis

Most of the climatological study was centered on deriving accurate temperature information for Big Sky area. Temperature records prior to this study were available only for short periods of time at several locations around the area. A thermograph, mounted in a standard weather shelter, was placed in the valley floor near the center of the Meadow Village area in April 1970. The thermograph was moved at the end of May 1971 because of construction at Meadow Village. The new site is about 100 feet higher and one mile west-southwest of the original site. Due to the difference in elevation of the two sites, minimum temperature would be expected to be about 2°F higher at the new site (MacHattie, 1970) because of the temperature inversion situation that normally exists at night in the Meadow Village area. Mobile measurements made in 1970 and 1971 indicate that maximum temperatures are about the same at both sites and that minimum temperatures average about 2°F higher at the new site. Minimum temperatures recorded at the old site were corrected by 2°F so the data would be compatable with measurements made at the new site. By the end of the study there were three years of data available for Meadow Village (April 1970-April 1973).

Data from Meadow Village station were compared with data from Bozeman for the same period in order to use the long-term record for Bozeman to correct for the bias of the short-term Meadow Village data. A maximum temperature probability graph (Figure 1) constructed by

J. M. Caprio of Montana State University was available for Bozeman based on the fifty-year period 1909-1958. A similar chart (Figure 4) was constructed for Meadow Village based on the graph for Bozeman. The difference in maximum temperature for the two sites was calculated on a daily basis. Monthly temperature differences were calculated by first averaging the daily temperature differences and then calculating running means of three monthly averages (i.e. the monthly temperature difference for February is equal to the average of the monthly differences for January, February, and March). A system of running means is frequently used to smooth data when the sample is relatively small and the variation is high. A maximum temperature probability curve for Bozeman at 14-day intervals according to the temperature difference between Meadow Village and Bozeman, for that period, is shown in Figure 3. The same procedure was used to derive a minimum temperature probability curve (Figure 5) for Meadow Village.

A thermograph (installed in a standard weather shelter) was operational in the Winter Village area from July 1971 through November 1972. The record was not continuous due to periods of inaccessibility. The record from Winter Village was compared to the Meadow Village record for the same period. The average difference in maximum temperatures between the two sites showed little seasonal variation. The Meadow Village maximum temperature probability chart can be used for Winter Village by changing the temperatures values according to the difference

between the two sites. The same procedure can be used to determine minimum temperature probabilities for Winter Village.

A network of thermographs and Six's maximum-minimum thermometers was installed on a steep ridge northeast of Meadow Village. This network was to provide information on the vertical temperature structure from Meadow Village to a height over 1,000 feet above the valley floor. The network consisted of fifteen stations spaced at approximately 100 foot elevation intervals (Table 1). Maximum-minimum thermometers, mounted in triangular shelters open on one side, were located at each of the stations and thermographs were installed in

Table 1. Heights of ridge temperature sites.

Ridge site numbers	Height from base (feet)
01	00
02	95
03	220
04	295
05	410
06	585
07	705
08	835
09	925
10	1070
11	1135
12	1225
13	1355
14	1420
15	1695

standard weather shelters at four of the stations (numbers 1, 5, 7, and 12) for continuous temperature records. The thermograph at Site #1

was moved to Site #3 on March 30, 1972. Table 1 gives the height of the ridge sites above Site #1 as determined by use of an altimeter. Table 2 gives the operational dates of the thermographs.

Table 2. Operational dates of ridge site thermographs.

Ridge site number	Date
01	March 30, 1972 - June 30, 1973
03	October 10, 1971 - March 30, 1972
05	March 23, 1972 - June 30, 1973
07	November 6, 1971 - June 30, 1973
12	September 8, 1971 - June 30, 1973

Warm and Cold Spots

A series of nighttime automobile drives were made between Bozeman and West Yellowstone to determine relative cold and warm spots along the road. The drives were all made on clear nights so that outgoing radiation would be high. Under these conditions, the cold spots should be areas where inversions are likely to form.

Temperatures were measured by a thermistor probe mounted in front of the car and six feet above the highway. This height was considered sufficient to minimize the effect of heat from the car and the highway. Temperature readings were taken every 0.2 miles. A total of twelve runs were made between Bozeman and Big Sky, the last four of which continued on to West Yellowstone (see Table 7).

A baseline temperature was recorded at the Bozeman 6W Weather Service Climatological Station at the beginning of each drive. De-

viations of temperatures measured from the baseline temperature were calculated. The medians of these departures (2½ percent segments) were determined and are plotted in Figures 11 and 12. Distances were converted to a percentage basis to eliminate error due to differences in odometers. The total distance from Bozeman 6W to the Big Sky entrance is 35 miles and the distance from Big Sky to West Yellowstone is 45 miles.

Phenological Information

Zabeli honeysuckles (Lonicera korolkowii Stapf, var. zabelii (Rehd.) Rehder)) were planted at Big Sky to be used as climatological indicators. The two year old bare root plants were received in the spring of 1971 and planted in two-and-a-half gallon papier-mache pots. These were grown out-of-doors in Bozeman during the spring and summer of 1971. Later in the summer the plants, still in the papier-mache pots, were planted at Meadow Village, Winter Village, Lone Mountain, and each of the ridge sites except numbers 10, 13, and 15. The various phases of development were observed whenever possible for comparison purposes. Due to inaccessibility, observations at Lone Mountain and Winter Village were irregular.

Solar Radiation and Potential Evapotranspiration

A continuous recording drum type solarimeter was operational at the Meadow Village station from September 1971 through November 1972. There are small gaps in the record and a system of running means of three months was used to smooth the values. The constant for the solari-

meter was too low and was increased by 24% at the end of the period based on comparison with a Kipp pyranometer.

Potential evapotranspiration estimates were made by use of the Solar Thermal Unit method (Caprio, 1971).

Wind

Wind instrumentation consisting of Rustrak recorders, an anemometer, and a wind vane were installed at Meadow Village in August, 1971 and were in operation until their removal in May of 1973. Similar instrumentation was in operation on Andesite Mountain from January 3, 1972 to May 16, 1972 and in the Lone Mountain cirque from January 3, 1972 to February 16, 1972. The equipment was removed from Mount Andesite and Lone Mountain in August 1972. Part of this equipment was reinstalled at Winter Village and was operational there until May 1973.

Additional data for the fair-weather wind system were obtained by making five trips to Big Sky during June 1973 and taking wind speed measurements around the area with a hand anemometer and noting wind direction with a compass. Night measurements were made from 3:00-4:00 A.M. The approximate time of maximum development of a down canyon breeze is just before dawn, according to Geiger, 1965. Measurements during the day were made around noon. Wind speed charts from Meadow Village indicate that the highest wind speeds on a given day generally occur around noon and persist throughout the afternoon.

RESULTS

Temperature

The first step in the study was to compare the temperatures at Meadow Village to those at Bozeman. Figure 1 shows the probability (in percent chance) that the temperatures shown will be exceeded on a given day at Bozeman. For example, on April 15 there is a 60 percent chance that the maximum temperature will be 50°F or higher. Figure 2 is a similar graph for minimum temperatures at Bozeman. Table 3 gives the average monthly maximum and minimum temperature difference between Meadow Village and Bozeman. These values are graphed in Figure 3.

Table 3. Monthly temperature differences in °F. (Bozeman minus Meadow Village).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max. Temp.	3.8	4.3	5.4	6.1	6.7	6.7	7.1	6.3	5.9	5.6	5.3	4.7	5.7
Min. Temp.	6.2	6.9	8.0	8.6	9.8	11.7	12.8	11.9	10.1	8.1	7.1	5.9	8.9

The largest temperature differences between the two locations occur during July although the differences change little throughout the summer. The smallest temperature differences come during the winter months. Maximum and minimum temperature probability curves for Meadow Village are presented in Figures 4 and 5, respectively.

Comparison of temperature data at Winter Village and Meadow