WEATHER BUREAU
Western Region

Salt Lake City, Utah
February 1968

Objective Minimum Temperature Forecasting for Helena, Montana

D. E. OLSEN

Technical Memorandum WBTM WR-27

U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

WESTERN REGION TECHNICAL MEMORANDA

The Technical Memorandum series provide an informal medium for the documentation and quick dissemination of results not appropriate, or not yet ready, for formal publication in the standard journals. The series are used to report on work in progress, to describe technical procedures and practices, or to report to a limited audience. These Technical Memoranda will report on investigations devoted primarily to Regional and local problems of interest mainly to Western Region personnel, and hence will not be widely distributed.

These Memoranda are available from the Western Region Headquarters at the following address: Weather Bureau Western Region Headquarters, Attention SSD, P. O. Box 11188, Federal Building, Salt Lake City, Utah 84111.

The Western Region subseries of ESSA Technical Memoranda, beginning with No. 24, are available also from the Clearinghouse for Federal Scientific and Technical Information, U. S. Department of Commerce, Sills Building, Port Royal Road, Springfield, Virginia 22151. Price $3.00.

Western Region Technical Memoranda:

No. 1 Some Notes on Probability Forecasting. Edward D. Diemer. (Out of print.) September 1965.
No. 2 Climatological Precipitation Probabilities. Compiled by Lucianne Miller. December 1965.
No. 3 Western Region Pre- and Post-FP-3 Program. Edward D. Diemer. March 1966.
No. 4 Use of Meteorological Satellite Data. March 1966.
No. 5* Station Descriptions of Local Effects on Synoptic Weather Patterns. Philip Williams. April 1966.
No. 6 Improvement of Forecast Wording and Format. C. L. Glenn. May 1966.
No. 7 Final Report on Precipitation Probability Test Programs. Edward D. Diemer. May 1966.
No. 8 Interpreting the RAREP. Herbert P. Benner. May 1966. (Revised Jan. 1967.)
No. 9 A Collection of Papers Related to the 1966 NMC Primitive-Equation Model. June 1966.
No. 10 Sonic Boom. Loren Crow (6th Weather Wing, USAF, Pamphlet). June 1966.
No. 11 Some Electrical Processes in the Atmosphere. J. Latham. June 1966.
No. 12 A Comparison of Fog Incidence at Missoula, Montana, with Surrounding Locations. Richard A. Dightman. August 1966.
No. 13 A Collection of Technical Attachments on the 1966 NMC Primitive-Equation Model. Leonard W. Snellman. August 1966.
No. 14 Applications of Net Radiometer Measurements to Short-Range Fog and Stratus Forecasting at Los Angeles. Frederick Thomas. September 1966.
No. 15 The Use of the Mean as an Estimate of "Normal" Precipitation in an Arid Region. Paul C. Kangieser. November 1966.
No. 16 Some Notes on Acclimatization in Man. Edited by Leonard W. Snellman. November 1966.
No. 17 A Digitalized Summary of Radar Echoes Within 100 Miles of Sacramento, California. J. A. Youngberg and L. B. Overaas. December 1966.
No. 18 Limitations of Selected Meteorological Data. December 1966.
No. 19 A Grid Method for Estimating Precipitation Amounts by Using the WSR-57 Radar. R. Granger. December 1966.
No. 20 Transmitting Radar Echo Locations to Local Fire Control Agencies for Lightning Fire Detection. Robert R. Peterson. March 1967.
No. 21 An Objective Aid for Forecasting the End of East Winds in the Columbia Gorge. D. John Coparanis. April 1967.
No. 22 Derivation of Radar Horizons in Mountainous Terrain. Roger G. Pappas. April 1967.
No. 23 "K" Chart Application to Thunderstorm Forecasts Over the Western United States. Richard E. Hambidge. May 1967.

*Revised November 1967.

A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum WR-27

OBJECTIVE MINIMUM-TEMPERATURE FORECASTING FOR HELENA, MONTANA

David E. Olsen
Meteorologist
WBAS, Helena, Montana

WESTERN REGION
TECHNICAL MEMORANDUM NO. 27

SALT LAKE CITY, UTAH
FEBRUARY 1968

TABLE OF CONTENTS

LIST OF FIGURES

OBJECTIVE MINIMUM-TEMPERATURE FORECASTING FOR HELENA, MONTANA

I. INTRODUCTION

During a clear night when the surface wind is almost calm, the main factors involved in nocturnal cooling are long-wave radiation from the atmosphere and ground, and length of night (principally the latter). The purpose of this paper is to determine a simple formula for forecasting minimum temperatures on such nights, using the above parameters.

II. DEVELOPMENT OF AN EMPIRICAL EQUATION FOR NIGHTTIME RADIATIONAL COOLING

The rate of cooling under clear skies and calm surface wind is determined approximately by a complex relationship between air temperature, dewpoint, and ground temperature. The total decrease is proportional to the length of the night. Other investigators have found these variables to be related to the minimum temperature and their physical justification can be found in Brunt's [1] classical formula for the drop in temperature from evening to the minimum the following morning. Therefore, the minimum temperature during a particular night can be estimated by some relationship between air temperature, dewpoint and length of the night. In this paper, air temperature will be represented by the maximum afternoon temperature. Average dewpoint near 1500 MST will be used.

For easier computation an empirical equation was developed near June 21, the day when length-of-night contribution is least. Ten clear, almost calm nights were selected from June 16-26 periods, 1961 to 1966 (see Appendix). The most accurate empirical equation solved by trial and error was:

(1) $T_{MIN.} = 3.98\ T_{MAX.}^{1/2}\ T_{DP}^{1/4}$ (temperatures in °K to avoid working with zero).

The general equation can be written,

(2) $T_{MIN.} = Q\ T_{MAX.}^{1/2}\ T_{DP}^{1/4}$

where Q is a number incorporating length of night, ground temperature and any other influences such as drainage winds.

III. LENGTH-OF-NIGHT INFLUENCE

Assuming length of night to be a sinusoidal function of time of year, the value of 3.98 in equation (1) must decrease with departure from June 21. Figure 1 shows the relative importance of length of night at various times of the year.

To develop an expression for the length-of-night term, it was necessary to find values of Q on the sine curve in Figure 1. This was done by substituting in equation (2) known maximum, dewpoint and minimum temperatures at two other selected times of the year. If the length-of-night influence is truly a sine curve, values of Q can be easily computed at any time of year. Twenty clear, almost calm nights were selected near September 21 and March 21 in the years 1961-1966. The average value of Q was 3.92. Since March 21 and September 21 are in the middle of the sine curve, the least value would then be approximately 3.86 near December 21. Percentage difference between Q near March 21 or September 21 and Q at June 21 or December 21 is 1.5 per cent. With this information, an expression for the length-of-night term becomes,

$$(3) \quad [1 + .015 \text{ SIN } (\frac{\pi}{180}(\text{DATE-MAR } 21))°]$$

(in this study one year has 360 days).

The entire empirical equation is finally,

$$(4) \quad \text{Tmin}=3.92 \ \text{Tmax}^{1/2} . T_{\text{D.P.}}^{1/4} [1 + .015 \text{ SIN } (\frac{\pi}{180} (\text{DATE-MAR } 21))°]$$

Instead of solving equation (4) each time, a nomogram was constructed as shown in Figure 2. Mathematically, the minimum temperature lines are curved. However, they can be drawn as straight lines with sufficient accuracy within the range of maximum and dewpoint temperatures indicated on this nomogram. An example of the nomogram's use follows:

> given a maximum temperature of 70°F. and a 1500MST dewpoint of 30°F. on October 15, the intersection of the two temperatures gives a forecast of 273°K. This would be a predicted temperature if the day were March 21 or September 21. The ordinate value of 273°K is then found on the left side of the nomogram, and by following along a horizontal line to the abscissa date of October 15, the minimum temperature is forecast to be 30°F.

IV. SNOW CONTRIBUTION

Since snow is common from fall into spring, snow cover correction formulas were developed. The contribution of snow cover will vary with its thermal conductivity which in turn varies approximately with its density. The density varies so greatly with air and ground temperature and age of the snow that only a rough estimate of the contribution can be developed. This development was based on 75 clear fall and winter nights from 1950 to 1960, using differences between predicted temperatures from equation (4) and observed minimums with various types and depths of snow on the ground. For greater accuracy, snow cover in Helena has been classified under the following definitions, which apply up to the time the minimum temperature forecast is made:

<u>Fresh</u>	Snow fallen while temperature was below 32°F. with the snow ending about 18 hours or less before the occurrence of the following morning's minimum temperature.
<u>Dry</u>	Fresh snow that has settled, but with maximum daily temperatures remaining below 32°F.
<u>Crusty</u>	Dry snow which has experienced at least one daily maximum air temperature above freezing followed by at least one daily maximum air temperature below freezing.
<u>Wet</u>	Snow which has fallen while the air temperature was above freezing or dry snow with daily maximum air temperatures above freezing.
<u>Wet Ground</u>	Damp ground caused by melting snow. The maximum air temperature will be above freezing with the snow depth ranging from a trace to near one inch prior to the occurrence of a minimum.

Using the above snow definitions, the following empirical equations were developed. (The letter "d" is the depth of the snow in inches).

(5) Fresh $\Delta\ T\ F^\circ = -6\sqrt{d}$

(6) Dry $\Delta\ T\ F^\circ = -4\sqrt{d}$

(7) Crusty $\Delta\ T\ F^\circ = -2\sqrt{d}$

(8) Wet $\Delta\ T\ F^\circ = \sqrt{d}$

(9) Wet Ground $\Delta\ T\ F^\circ = +6$

V. VERIFICATION

To verify equation (4) 250 random clear nights selected from all months during the period 1950 to 1966 were tested. Skies were clear to threetenths opaque cloud cover. More cloudiness was allowed until about 2100MST and again after 0700MST for some of the nights. The wind had to average under five knots from midnight until 0700MST on each night in order for the data to be used.

An attempt was made to distribute the days evenly throughout all months of the year, However, this was not possible since, on the average, cloudiness and wind allow only about three nights out of each January to be tested, while approximately 10 August days can be tested. Roughly 90 per cent of the days tested were during April through November.

Evaluation of errors in the 250 test cases demonstrated the necessity for some adjustment of the sine curve in Figure 2. Predictions during July and August were generally too low and predictions during April and May were too high. Figure 2, therefore, has some adjustment of the sine curve built in so as to refine predictions during these two months.

After this adjustment in the sine curve, the average error for the 250 days was 2.1°F. The cumulative frequency distribution of errors is shown in Table 1.

TABLE 1

Absolute Error in F°	0-1	≤2	≤3	≤4	≤5
Percentage of Days	43	68	80	92	96

The largest error was 8°F., which occurred in three of the 250 cases.

To further test equation (4), 76 random clear nights during 1965 and 1966 were selected, including cases from all months, to compete with four Helena forecasters and persistence. The forecasters were severely handicapped by only having the maximum afternoon temperatures 15MST dew dewpoint, and assurance that all 76 nights were clear and the winds averaged under five knots. The forecasters were also allowed average temperature tables for Helena. The average errors and cumulative frequency distributions are shown in Table 2.

TABLE 2

	0-1 F°	2 F°	3 F°	4 F°	5 F°	F° Average	F° Greatest
Equat. (4)	36%	63%	75%	86%	90%	2.2	6
Forecaster	23%	39%	53%	65%	76%	3.9	18
Persist.	35%	53%	62%	72%	78%	3.3	10

Verification with snow on the ground is questionable because of the subjectivity of the snow definitions. To ensure independent data, 50 clear nights during the fall and winter months from 1960-1965 and 1942-1949* were tested. The average error was 2.6°F., with a range of zero to 9°F. Table 3 shows the cumulative frequency distribution.

TABLE 3

Absolute Error in F°	0-1	≤2	≤3	≤4	≤5
Percentage of Days	33	44	61	83	92

VI. CONCLUSIONS

An objective method of forecasting minimum temperatures on clear nights for Helena, Montana, has been developed. Corrections are applied for snow cover and wet ground. Verification on an independent data sample indicates the objective method to be superior to subjective forecasts.

VII. ACKNOWLEDGMENT

Appreciation is expressed to the MIC and Staff, Helena WBAS, and to Western Region Headquarters Scientific Services Division for valuable assistance and suggestions.

VIII. REFERENCES

[1] D. Brunt, Physical and Dynamical Meteorology, Cambridge University Press, London, 2nd Ed., 1939, pp. 136-142.

*Prior to 1949 dewpoints were observed only every six hours, so dewpoints used in this paper for data from 1942-1948 are interpolated from the 1100-1800MST observations.

IX. APPENDIX

Derivation of Equation (1) and (2). The value of Q in equation (2) is the key for solving the exponential values of 1/2 and 1/4. To demonstrate, equation (2) is rewritten,

$$Q = \frac{T_{MIN}}{T_{MAX}^{\ x}\ T_{DP}^{\ y}}$$ where x and y are now

the unknown exponential values.

Different values of x and y with known temperatures will, of course, yield different values of Q in most instances. But if ten different nights near the same date (say June 21) are chosen where nocturnal radiation plays the important role in determining the following morning's minimum temperature, Q will be nearly the same for all these nights. Therefore, different values of x and y were tried on these ten nights until the value of Q became almost the same for each night. Trial and error showed x=1/2 and y=1/4 to be the most convenient and accurate values found. Listed below are sample computations for three of these nights near June 21 in the years 1961, 1965 and 1966.

Date	Maximum °K	15MST Dewpoint °K	Minimum °K	Q
6/25/66	295	274	279	3.98
6/27/65	293	271.5	277	3.97
6/16/61	307	274	286	4.00

The average value of Q for the ten nights was 3.98 with extremes of 4.00 and 3.96.

FIGURE 2

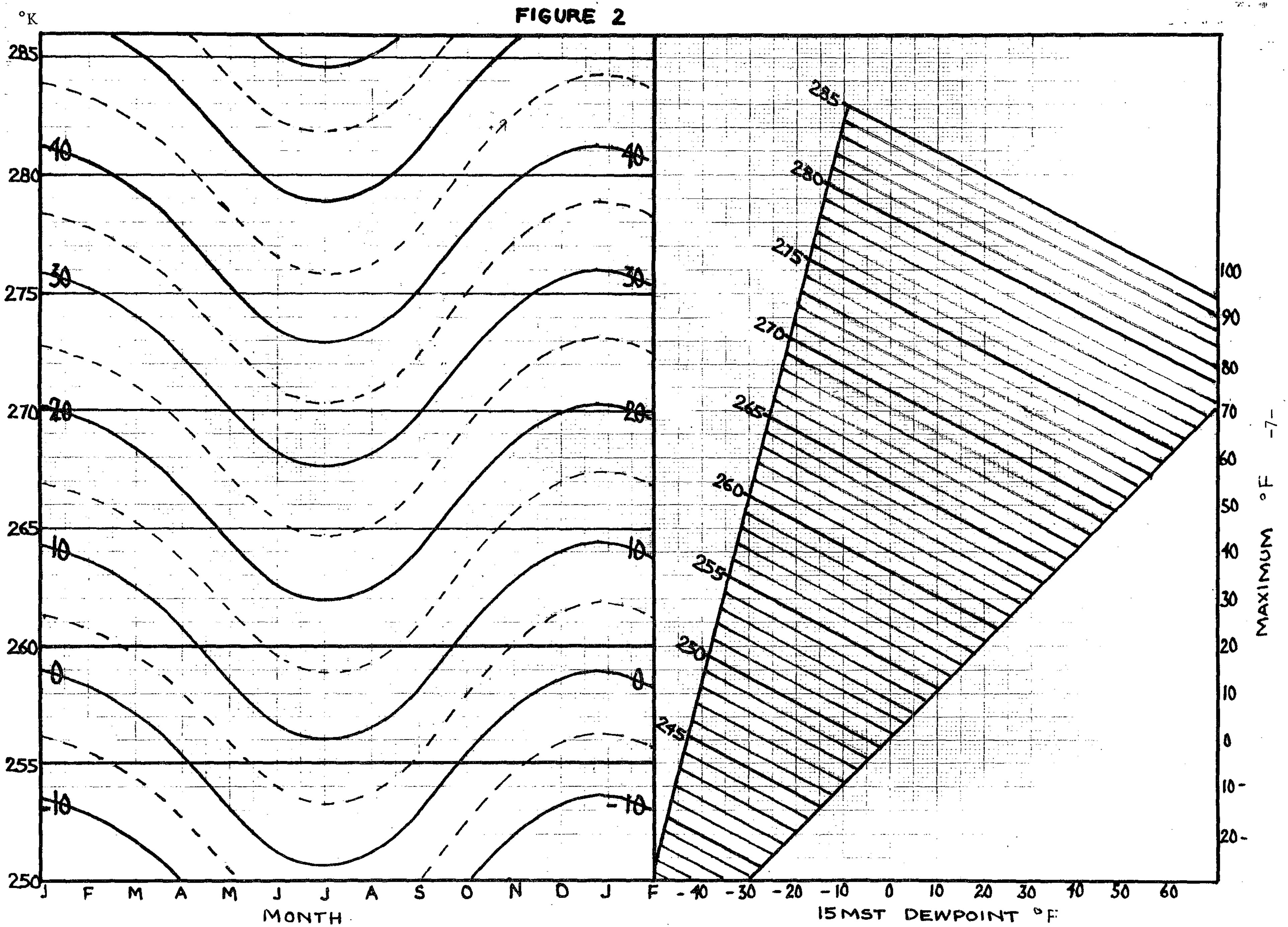

FIGURE 2 - Nomogram for forecasting minimum temperature at Helena, Montana, from 1500MST dewpoint temperature, previous day's maximum temperature, and day of year.

FIGURE 1

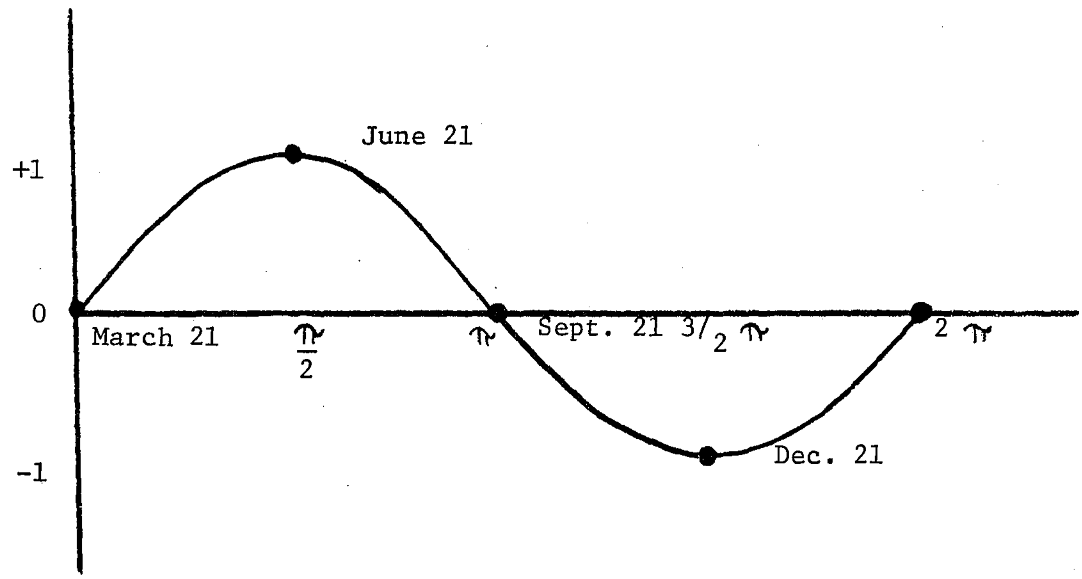

FIGURE 1 - Values of length-of-night term at different times of the year.

Western Region Technical Memoranda: (Continued)

No. 24 Historical and Climatological Study of Grinnell Glacier, Montana. Richard A. Dightman. July 1967.

No. 25 Verification of Operational Probability of Precipitation Forecasts, April 1966 - March 1967. W. W. Dickey. October 1967.

No. 26 A Study of Winds in the Lake Mead Recreation Area. R. P. Augulis. January 1968.