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WATER AVAILABLE FOR RUNOFF
FOR 4 TO 15 DAYS DURATION
IN THE SNAKE RIVER BASIN IN IDAHO

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ABSTRACT. Through adaptation of the National Weather Service River Forecast System (NWSRFS) Snow Accumulation and Ablation model, this study estimates the frequency of water available for runoff (WAR) from snowmelt and precipitation over the agricultural areas of Idaho's Snake River Basin.

The report outlines the adaptation, testing, and use of the NWSRFS model, presents maps of 4- and 15-day WAR values at return periods of 2 and 100 years, and discusses seasonal variation of WAR and differences between WAR-frequency and precipitation-frequency values.

1. INTRODUCTION

Precipitation-frequency studies and publications are available which depict the amount of precipitation likely to occur at various durations and return periods (Yarnell 1935; U.S. Weather Bureau 1953, revised 1955, 1954a; Hershfield 1961; Miller 1964; Miller, et al. 1973). Such information is used for planning and design of hydrologic structures and for flood evaluation reports. This use of precipitation-frequency values assumes that the precipitation is immediately available for runoff or infiltration. There are, however, areas where a significant amount of the annual precipitation falls as snow which accumulates into a snowpack. At some later time this stored water is released for runoff. This release will occur during warmer weather and may or may not be accompanied by precipitation. Depending upon the climatological regime, this period could come as one or more thaws during the winter, or the snowpack could continue to increase until spring. In either case, over a period of a few days, the melting snow could release greater amounts of water than any single precipitation event during the year. Since hydrologic structures must be designed to handle runoff no matter what the source, frequency of precipitation alone is inadequate for design purposes where melting snow releases water at a rate exceeding precipitation on a scale significant to the structure.

Soil Conservation Service engineers found that in certain parts of southern Idaho, comparison of runoff and stream flow with precipitation-frequency values indicated the precipitation-frequency values were too low. To investigate this problem, a project was undertaken to quantify the water release from a snowpack, combine this with rainfall, and through use of frequency analysis determine how much liquid water is available for runoff (WAR) for 4- to 15-day durations and return periods of 2 to 100 years. The analysis ends with water at the ground surface. Varying infiltration rates due to soil type and conditions are an important part of the total problem but are excluded from this meteorological study.

1.1 Study Area

The area of the study is the agricultural land of the Snake River Basin (fig. 1), i.e., the basin south of a smoothed 6,000-ft contour west of about 115°W blending into a 7,000-ft contour east of about 115°W. The western boundary is the Oregon-Idaho border except for a small portion of southwestern Idaho southwest of the 6,000-ft contour that is excluded. The eastern border and most of the southern border of the study area coincide with the State border. Small portions of the study area are not drained by the Snake River, i.e., extreme southeastern Idaho which drains toward the Great Basin.

1.2 Data

No long-record data series of water release from a snowpack exist. Climatological data are available for a network of stations (Environmental Data Service 1948-72) that include daily maximum and minimum temperatures and daily precipitation. Depth of new snow and snow on the ground is recorded on the observation form by many observers, either intermittently or daily. These data are included on the archive tapes described later but are published in Climatological Data for only selected stations. At two stations (Boise and Pocatello) in the study area there are published data on water equivalent of snow on the ground but this variable is not reported each day. Daily temperature and precipitation data for a network of stations covering a wide variety of orography over a long period of record were the main input for this study. These data were applied to a model described in chapter 2.

2. NATIONAL WEATHER SERVICE RIVER FORECAST SYSTEM (NWSRFS) SNOW ACCUMULATION AND ABLATION MODEL

The National Weather Service (NWS) has developed a model for snow accumulation and meltoff (Anderson 1973) for use in its river forecasting service. This model uses basin averages of 6-hr temperature and precipitation values as its major input to estimate the accumulation and melting of snow. Of less importance to the working of the model are parameters of wind movement and atmospheric pressure. The model is calibrated to a given area through determination of two "melt factors" which are an expression of heat exchange at the air-snow interface. The <u>melt factor</u> is used when air temperature exceeds a critical value and there is no rain, and is an expression of how much melting will occur per unit of temperature excess above freezing for the basin. The <u>negative melt factor</u> is an expression of heat exchange for

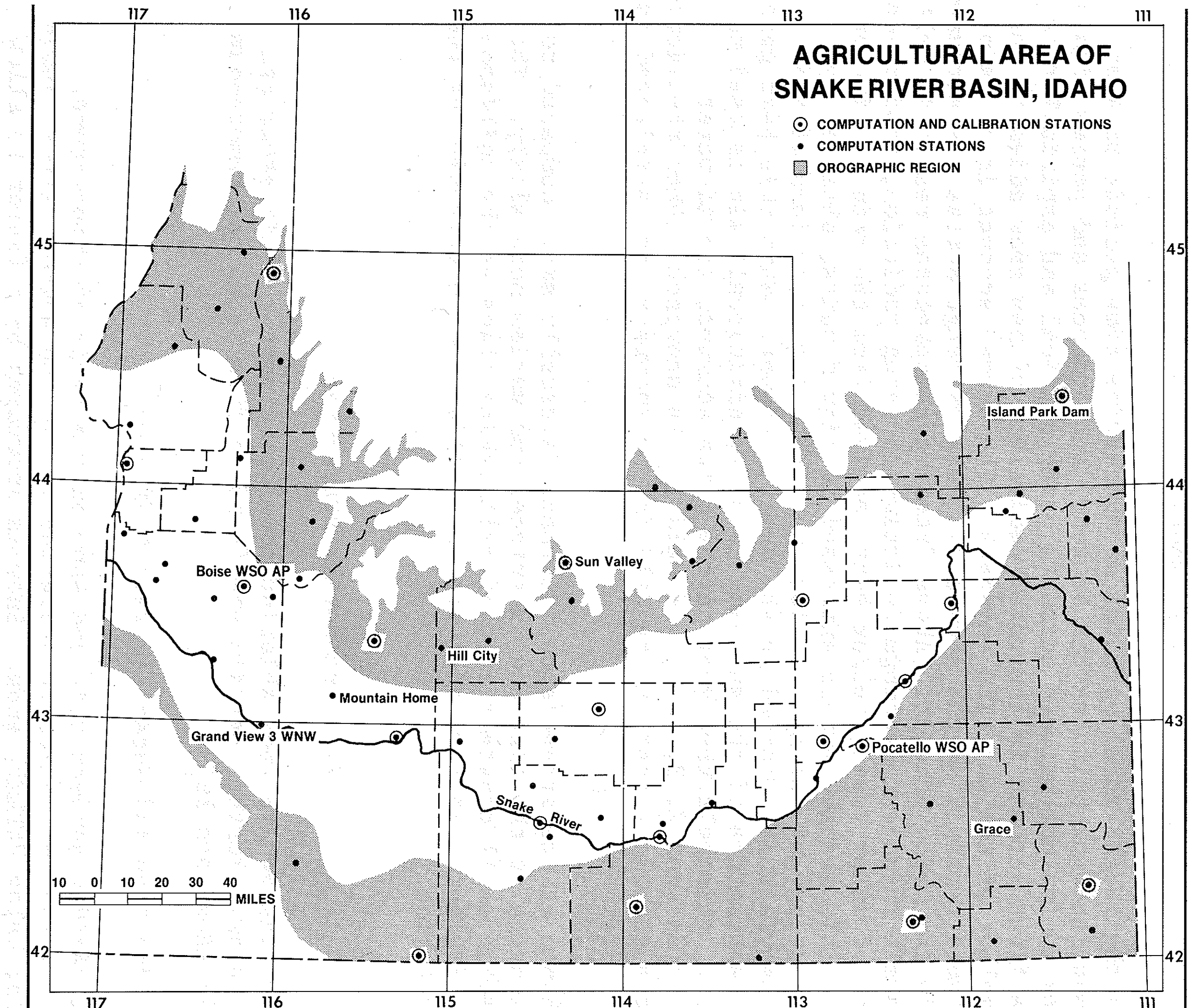

Figure 1.--Map of study area showing stations used and regions referred to in text.

the accounting of heat storage within the snowpack when air temperature is below the critical value. Both factors vary seasonally from a minimum on December 21 to a maximum on June 21, varying with a sine function between these dates. The melt factors implicitly contain long- and short-wave radiation terms. Units of melt factor are inches of water per °F per unit time.

2.1 Model

Basically the NWSRFS model operates on successive time periods to keep five accounts (account balances can be zero) and produces and passes liquid water or its equivalent between accounts using physical and empirical relations. The first account is the water equivalent of new snow added to the water equivalent of the existing snowpack. The second account is of rain added to liquid retained in the snowpack. Heat exchange across the air/snow interface is the third account. Above freezing temperatures result in melt. During rainfall this heat exchange is estimated using radiation, conduction, condensation of water vapor, and/or heat received from the rain falling on a snowpack. This energy term is expressed in liquid units, obtained by dividing the energy by the heat of fusion. The net gain or loss of heat within the snowpack is recorded in the fourth account. When this heat gain raises the temperature of the snowpack to 32°F, additional gain is used to produce melt. This melt then goes to the fifth account, liquid water received from account 2, 3, or 4, and held in the snowpack. When the liquid water exceeds the limit that can be held in the snowpack, it is released as runoff.

Heat exchange at the ground/snow interface is usually small compared to the heat exchange at the air/snow interface, and varies more slowly. The model assumes a small constant rate of melt taking place at the soil/snow interface. Neglected in the model are sublimation and interception of the snow by vegetation.

2.2 Accounting Procedures

Features of the NWSRFS snow ablation model pertinent to this study are summarized below. Further details are found in NOAA Technical Memorandum NWS HYDRO-17 (Anderson 1973).

Account 1 - New Snow and Water Equivalent of Snow

The model decides between rain and snow on the basis of temperature. The critical value for making this distinction is the symbol PXTEMP; above PXTEMP, rain; below PXTEMP, snow. Snow is increased by a factor to allow for precipitation gage deficiency in catching snowfall. The new precipitation measurement, if snow, is added to the water equivalent of the snowpack.

Account 2 - Rain Added to a Snowpack

Rainfall on a snowpack is added to the liquid water held in the snowpack and the new total passed to account 5, while rainfall on bare ground is considered immediately available for runoff.

Account 3 - Heat Exchange at the Air/Snow Interface

The model assumes that melt can occur at the snow surface when the air temperature of the base period is above 32°F. During periods with no rain, this heat exchange is expressed as the product of 1) the melt factor and 2) air temperature minus 32°F. The melt factor for a given day is derived by the sine function and is expressed in inches of water per °F per unit time. The resulting number is in inches of water per base period and is passed to account 5.

During rainfall the model makes 4 assumptions as follows: 1) solar radiation is zero; 2) incoming long wave radiation equals black body radiation at the ambient air temperatures; 3) snow surface temperature is 32°F; 4) dew point and temperature of the rainwater equals the ambient air temperature. The energy balance of the melting snowpack is expressed as:

$$M = Q_n + Q_e + Q_h + Q_{P_x} , \qquad (1)$$

where M is the amount of melt. (The "melt factor" is not used during rainfall.)

Q_n is the net heat transfer by radiation. It is (air temperature (°K)^4 minus (snow surface temperature (273°K)^4 times the Stefan-Boltzmann constant. This figure divided by the heat of fusion converts the result to inches of water.

Q_e is the latent heat transfer due to condensation and has three factors. The first factor is the latent heat of melt plus the condensation that would result when the air was cooled by the extraction of this heat to cause melting. The second factor is a wind factor. The third factor is the difference in vapor pressure of the ambient air and of the snow surface (at 32°F) in inches Hg.

The model assumes that the eddy transfer coefficients for heat and vapor are equal. The sensible transfer, Q_h, is obtained from Q_e from the Bowen ratio concept. The Bowen ratio, Q_h/Q_e, is assumed to equal a psychrometric constant times the difference between air and snow surface temperatures divided by the difference between ambient air vapor pressure and vapor pressure at temperature of the snow surface. (The snow surface temperature is held at 32°F during rain.) The psychometric constant contains unit conversions and also depends upon atmospheric pressure.

Q_{P_x} is the heat transferred by rainwater. It is the product of 1) precipitation amount, 2) the difference between the rain temperature (assumed to equal ambient air temperature) and 32°F (snow surface temperature), and 3) the specific heat of water expressed as equivalent inches of melt. Melt computed through application of these relations is added to the water content of the snowpack and is passed to account 5.

Account 4 - Heat Storage Within the Snowpack

The snowpack gains or loses heat depending on whether the air is warmer or colder than the snowpack. This accounting is done through use of an antecedent temperature index. The index is calculated by adding to the preceding index the difference between the present air temperature and the preceding index times a scale parameter between 0.0 and 1.0. Physically this says that the temperature of the surface layer of the snowpack changes with differences in ambient air and snowpack temperatures but not at a rate of 1:1. In this account, 1) the antecedent temperature index cannot exceed 32°F and 2) when more than 0.4 in. of water equivalent of new snowfall occurs in 12 hours, the index is set to the temperature of the new snow. The antecedent temperature index is then used to keep account of the heat storage within the snowpack. The negative melt factor times 1) the difference between air temperature and 2) the antecedent temperature index equals the change in heat storage. When the total heat storage becomes positive, the excess heat is converted to melt, the water content of this melt is passed to account 5, and account 4 reverts to zero.

Account 5 - Liquid Water Held in the Snowpack

A snowpack holds water until it becomes saturated. Beyond this limit, the excess water is released and is available for runoff. Account 5 keeps track of the liquid water passed to it from the previous accounts and releases any water in excess of the snowpack holding capacity. The maximum holding capacity is defined as a percentage of the total water content of the snowpack.

2.3 Adaptation of the Model

As adapted to the present study, the NWSRFS model uses point observed data (as opposed to basin averages) of daily maximum and minimum temperature and precipitation as principal inputs. The computation period is 12 hr.

The temperature for the 12-hr daytime period is 0.75 (maximum temperature) plus 0.25 (minimum temperature). The night 12-hr temperature is 0.75 (minimum temperature) plus 0.25 (maximum temperature). These formulas give full weight to each observation.

Precipitation for each 12-hr period is assumed to be half the observed 24-hr precipitation. Division of the 24-hr precipitation into two equal parts was examined for diurnal bias. Using Climatography of the United States No. 82 - 10, "Summary of Hourly Observations for Boise, Idaho" (1951-60) (U.S. Weather Bureau 1963), the diurnal pattern of precipitation for October through May was determined in two ways. Occurrences of measurable precipitation were tabulated by hours of the day. Precipitation amounts were also summed by hours. Cooperative weather observers (whose observations make up the bulk of the input for this study) normally make their daily observation at either 8 a.m. or 6 p.m. Accordingly, 8 a.m. and 8 p.m., and 6 a.m. and 6 p.m., were used in dividing 24-hr precipitation into daytime and nighttime halves. Hourly precipitation and total depth of precipitation were summed within each of these four 12-hr periods. Differences in both number of occurrences and amount of precipitation were less than 10 percent between "day" and "night." This is not considered sufficient to materially affect the outcome of the study.

Our adaptation defines the snow season as the period October through May, and simulation runs begin on October 1. Although this is an overly long winter season for the Snake River plains, nearby upland stations may have snow in October, and the snowpack in many areas lasts well into May.

Constants and parameters used in the various accounts are defined as follows: In account 1, PXTEMP (the index for determining whether precipitation was rain or snow) was assigned the value 33°F and precipitation observations designated as snow were increased by 20 percent to allow for gage deficiency in catching snowfall. Account 3 used the mean monthly wind speed from the nearest NWS station having a published wind record for that month. The atmospheric pressure was based upon the elevation of the station and was held constant for that station's computation. In account 4, the scale factor 0.5 was used throughout our study to adjust the antecedent temperature index. For account 5, the maximum holding capacity for water within the snowpack varied from 2 percent of the total water of snowpacks averaging over 60 in. in depth to 20 percent in snowpacks averaging less than 8 in. (table 1). These parameters are based on material in chapter 5 of NOAA Technical Memorandum NWS HYDRO-17 and discussions with the author.

Table 1.--Average depth of snowpack vs. maximum liquid water holding capacity of snowpack (MLWHC,%)

Depth of snowpack (in.)	MLWHC
< 8	20% of water equivalent of snowpack
≥ 8 <18	15%
≥ 18 <40	10%
≥ 40 <60	5%
≥ 60	2%

2.4 Calibration of Model

The suggested method of calibrating the NWSRFS Snow Accumulation and Ablation Model begins with the selection of initial values for the snow parameters discussed above. Using the selected values, the calibration process involves a trial-and-error variation of the two melt factors until the simulated results approach observed results. The calibration method is much the same whether using the NWSRFS model directly or our adaptation of it. The preferred "observed result" for calibration would be stream discharge at the outlet of a basin. Since such series of data could be found for basins within the study area the calibration was made to observed snow depth.

For this study 19 stations (table 2) having published daily maximum and minimum temperatures, precipitation, and snow on the ground were selected as test stations (fig. 1). These stations represent all geographical sections of the study area and have a wide variety of elevations and terrain. For each station 8 to 10 of the heaviest snowfall seasons were selected. The aim of the calibrating process was to simulate a time profile of water equivalent of snow on the ground similar to the observed time profile of depth of snow on the ground and to have both curves reach zero within a few days (fig. 2). In judging the similarity of the profiles, subjective consideration was given to the ripening of the snowpack as the season progressed by expecting depth of snow on the ground to decrease at a somewhat faster pace than water equivalent of snow. Also used for verification of the model output were observations of observed water equivalent of snow on the ground (a very limited sample) and published (U.S. Soil Conservation Service 1965) snow course data from courses near some of the 19 stations.

At each of the 19 stations the calibration process involved presenting the model with "first guess" estimates of melt factors and trial-and-error adjustment of the melt factor estimates until the model-simulated curve of water equivalent of snow on the ground was closest to the observed depth from the snow-on-the-ground curve during the test seasons. In the calibrating process, three values are presented to the model: 1) the maximum melt factor (MF_{max}, applies to June 21); 2) the minimum melt factor (MF_{min}, applies to December 21); and 3) the maximum negative melt factor, (NMF_{max}, applies to June 21). The minimum negative melt factor (NMF_{min}) is computed as follows:

$$NMF_{min} = \frac{MF_{min}}{MF_{max}} \times NMF_{max} \qquad (2)$$

Daily variation in melt factors follows a sine curve between days of maximum and minimum values. As illustrated by Anderson's figures 5-7 and 5-8, the most conservative of the calibrating factors is the negative melt factor. In the present study, after some experimentation, the maximum negative melt factor was set at 0.020 in./12-hr °F for all stations. This reduced the calibrating process to adjustment of the maximum and minimum melt factors

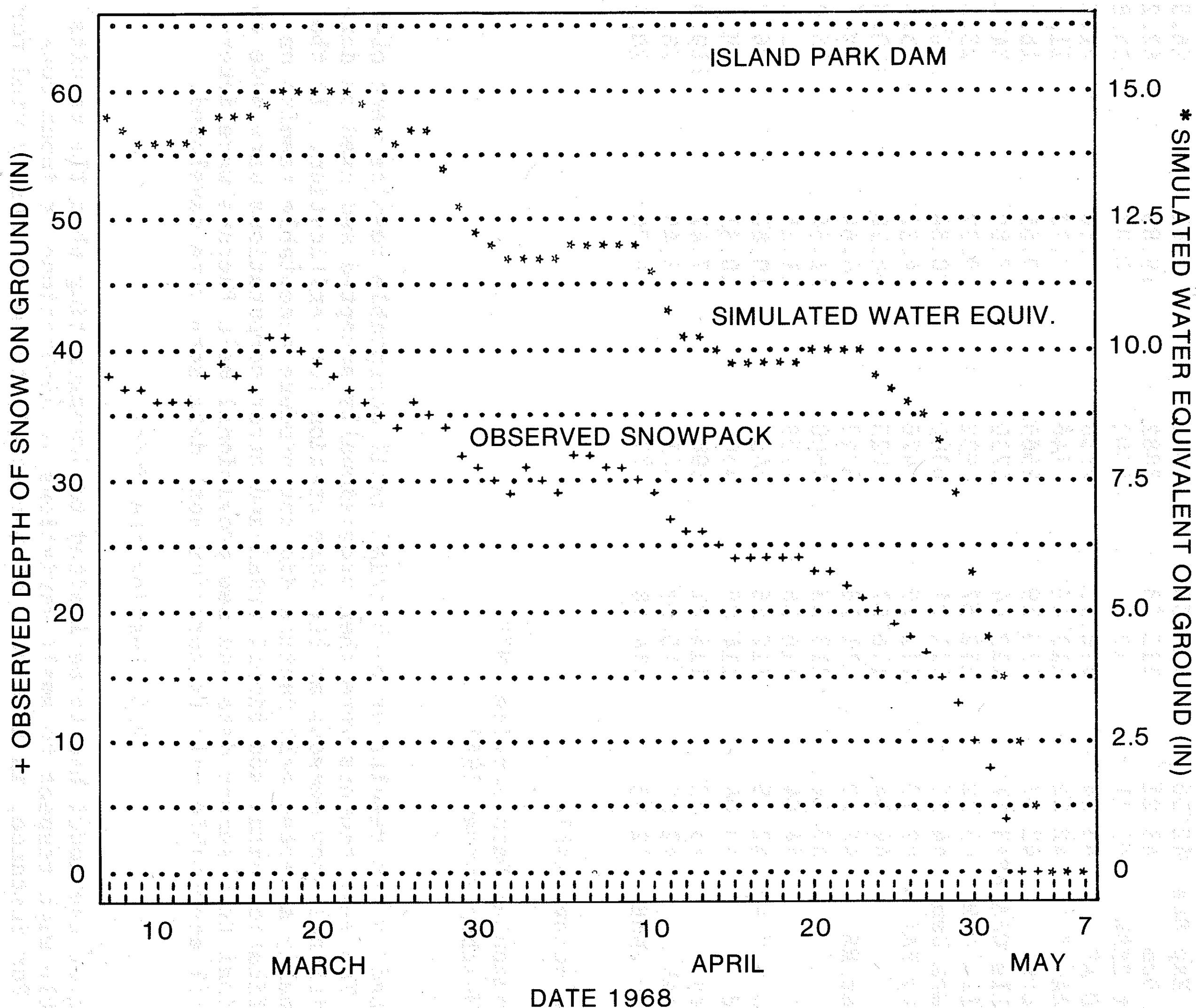

Figure 2.--Profile of simulated water equivalent of snow on the ground vs. observed snow depth.

Table 2.--Data on stations used to calibrate NWSRFS model

Station	Latitude deg & min N	Longitude deg & min W	Elevation (ft)	Normal Annual Precipitation (1) (in.)	Mean (2) Snowfall (in.)
Aberdeen Exp Sta	42 56	112 50	4405	8.61	26.5
Anderson Dam	43 21	115 28	3882	19.89	62.2
Blackfoot 2SSW	43 11	112 21	4503	10.87	34.8
Boise WSO AP	43 34	116 13	2838	11.50	21.2
Burley FAA AP	42 32	113 46	4146	9.73	21.4
Glenns Ferry	42 57	115 19	2569	9.65	18.2
Idaho Falls CAA AP	43 31	112 04	4730	8.89	34.5
Idaho Falls 46W	43 32	112 57	4932	8.72	25.3
Island Park Dam	44 25	111 24	6300	30.84	196.1
Malad City FAA AP	42 10	112 19	4476	14.32	43.6
McCall	44 54	116 07	5025	28.18	130.8
Montpelier RS	42 19	111 18	5943	14.64	M
Oakley	42 14	113 53	4600	11.54	26.0
Payette	44 04	116 56	2159	11.15	23.2
Pocatello WSO AP	42 55	112 36	4454	10.80	36.2
Richfield	43 04	114 09	4306	10.81	M
Sun Valley	43 42	114 21	5980	17.47	119.5
Three Creek	42 05	115 09	5410	13.49	78.7
Twin Falls 2NNE	42 35	114 28	3770	9.20	20.5

M - No value available

1) Environmental Data Service 1973
2) U.S. Weather Bureau 1964

as dictated by the results of each trial until acceptable results were obtained. The melt factors were then provisionally accepted and used on data from additional snow seasons at the same station for verification. If the provisionally accepted melt factors did not produce acceptable results on the verification data, additional trial-and-error computations were made on the original test season data and new provisional melt factors were determined until acceptable melt factors for both data sets were developed.

2.5 Testing the Model

Testing of the model had to be limited to demonstrating that the results were stable with respect to small variations in assumptions or input constants. For instance, in account 3 of the model, the mean monthly wind for the nearest NWS station was used in the computations. To test this parameter, 22 station-seasons of data were used (8 seasons from each of 2 stations and 6 seasons from a third station). The data were then rerun letting the station winds and months occur at random (station A for January of some year might have station C's wind from October of another year). For each of the

22 station-seasons, the difference between maximum seasonal N-day WAR values computed with the 2 wind factors was expressed as a percentage of the N-day WAR value computed using the adopted wind factor. The average of these differences was less than 3 percent at durations of 1, 4, 7, 10, and 15 days (table 3). At durations greater than 4 days the largest differences were less than 10 percent.

Table 3.--Comparison of maximum seasonal WAR values computed using average monthly wind from the nearest NWS station and using randomly selected wind values (22 station-seasons)

Duration (days)	1	4	7	10	15
Maximum difference (%)	11	19	9	6	8
Mean difference (%)	3	3	2	1	2

The same set of test data was used to examine differences in the scale parameter used in account 4 to adjust ambient air temperature and snowpack temperature differences for computing the antecedent temperature index. The value adopted for this scale parameter was 0.5. The test data set was also run using a scale parameter of 0.4 and 0.6. As shown in table 4, mean differences were only a few percent and at durations of more than 4 days, the maximum difference was less than 10 percent.

Table 4.--Differences in maximum seasonal WAR values between a scale parameter in account 4 of 0.5 used in this study, compared with 0.4 and 0.6

Duration (days)		1	4	7	10	15
Scale parameter = 0.40	max (%)	12	12	9	9	7
	mean (%)	2	3	4	3	3
Scale parameter = 0.60	max (%)	12	8	9	8	5
	mean (%)	1	3	3	3	3

Sensitivity of the model to changes in the melt factors was tested. The computations for Grace Power House and Hill City were compared using the adopted minimum (Dec. 21) and maximum (June 21) melt factors of 0.02 and 0.05 and the adopted melt factors ± 0.01 in./°F./12 hr. Using the methods described in chapter 3, the 2- and 100-yr return period WAR for durations of 1, 4, 7, 10, and 15 days were computed using the same data series but with the three different melt factors. As shown for the 10-day duration (fig. 3) the resulting WAR frequencies at the 100-yr return period vary by only 5 to 10% compared with variations in melt factor of 20 to 50%.

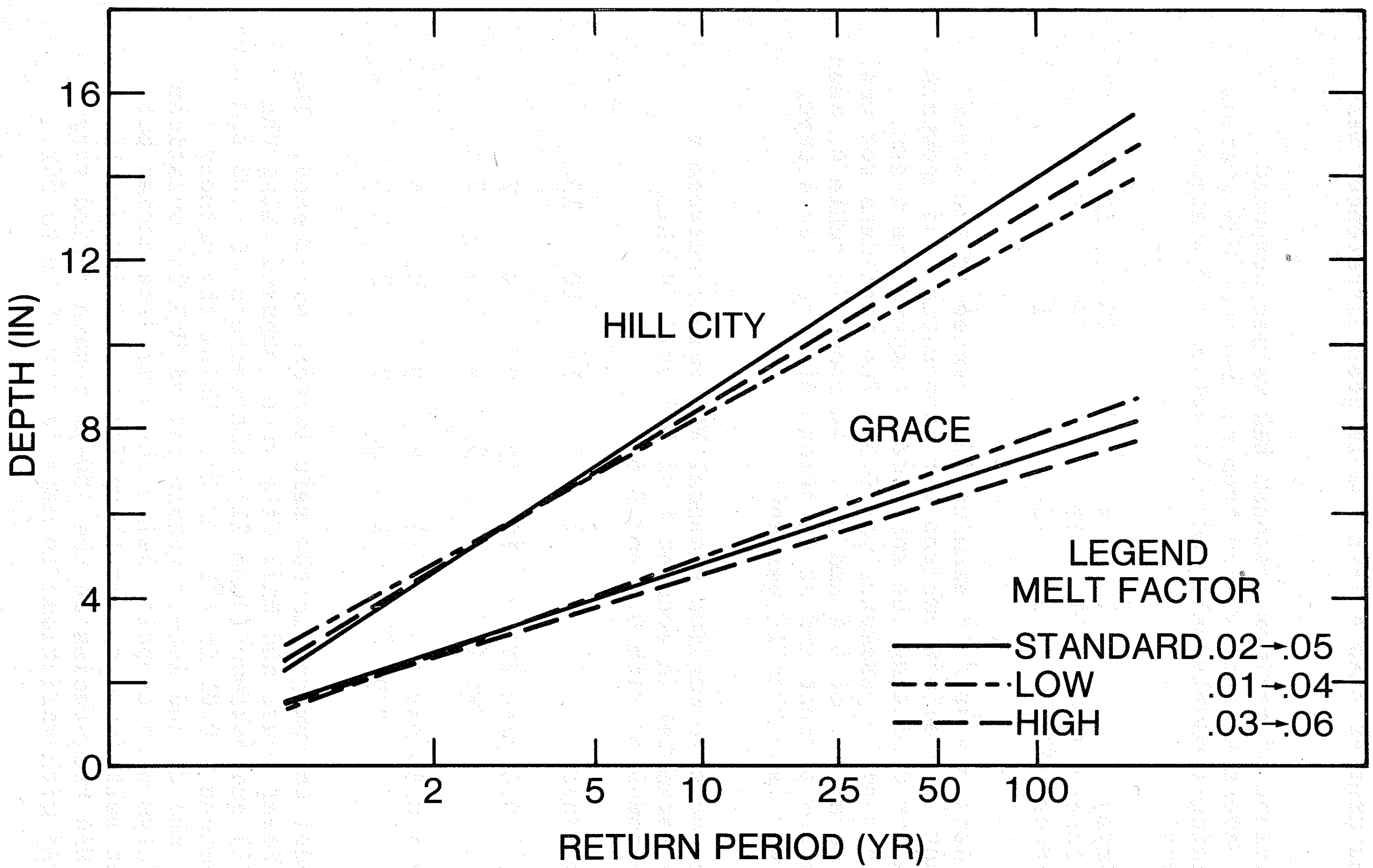

Figure 3.--Comparison of frequency curves using different melt factors for Grace and Hill City.

3. APPLICATION OF MODEL

Calibration of the NWSRFS model is a time consuming process. Therefore, steps were taken to determine whether the calibration parameters from the 19 test stations could be manipulated to provide the parameters needed for other stations within the study area by relating to readily available physiographic and climatological parameters such as elevation and mean seasonal precipitation. Figure 4 is typical of the resulting plots in its lack of definitive correlation and this approach was not further pursued.

3.1 Development of Melt Factor Map

The maximum and minimum factors for the 19 test stations were plotted on maps of the study area and isolines of melt factors were drawn by interpolation (fig. 5). Melt factors were read from the maps by interpolation for several stations not included in the test station list but for which observations of depth of snow on the ground were available. Data for these stations were analyzed through the model and comparisons were made between 1) profiles of water equivalent of snowpack and depth of snow on the ground, and 2) dates both profiles reach zero. These comparisons showed that observed snow depth corresponded with computed water equivalent as subjectively judged at the original 19 stations, thus verifying the interpolation.

3.2 Data Sources

Magnetic tapes containing daily observations for the period 1948 through 1972 (24 October-through-May seasons) for all stations in Idaho were purchased from the National Climatic Center, Asheville, N.C. The data were in the O/H format (NOAA Technical Memorandum NWS HYDRO-14 1972). The inventory of the data on the tapes was searched to find all stations within the study area with at least 15 seasons of record. This search located 72 stations (fig. 1) including the 19 test stations.

3.3 Computation of WAR

The computer program used to calibrate and test the NWSRFS Snow Accumulation and Ablation model was used to simulate the buildup and meltoff of the snowpack and compute WAR values for each of the 72 stations. The observed data were read from the tapes for each season and the model made the necessary decisions and computations and computed the WAR for each 12-hr period. Two 12-hr periods were combined into daily values ending at observation time.

The program was run year 'round so that it extracted any maximum water-year precipitation events that occurred during June through September. Snow computations were not attempted for June to September even though snow was occasionally reported.

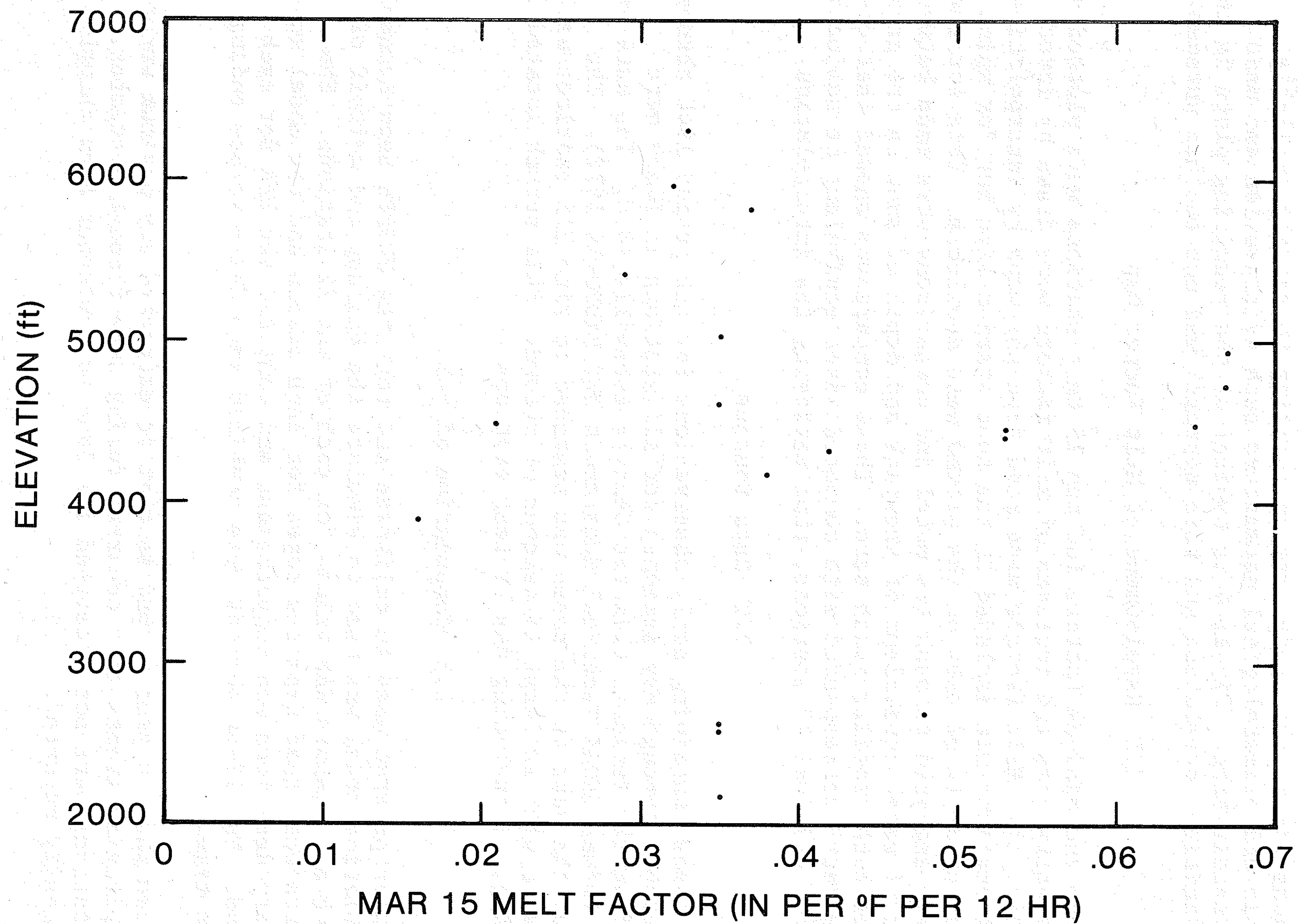

Figure 4.--Example of noncorrelation of melt factors and physiographic parameters.

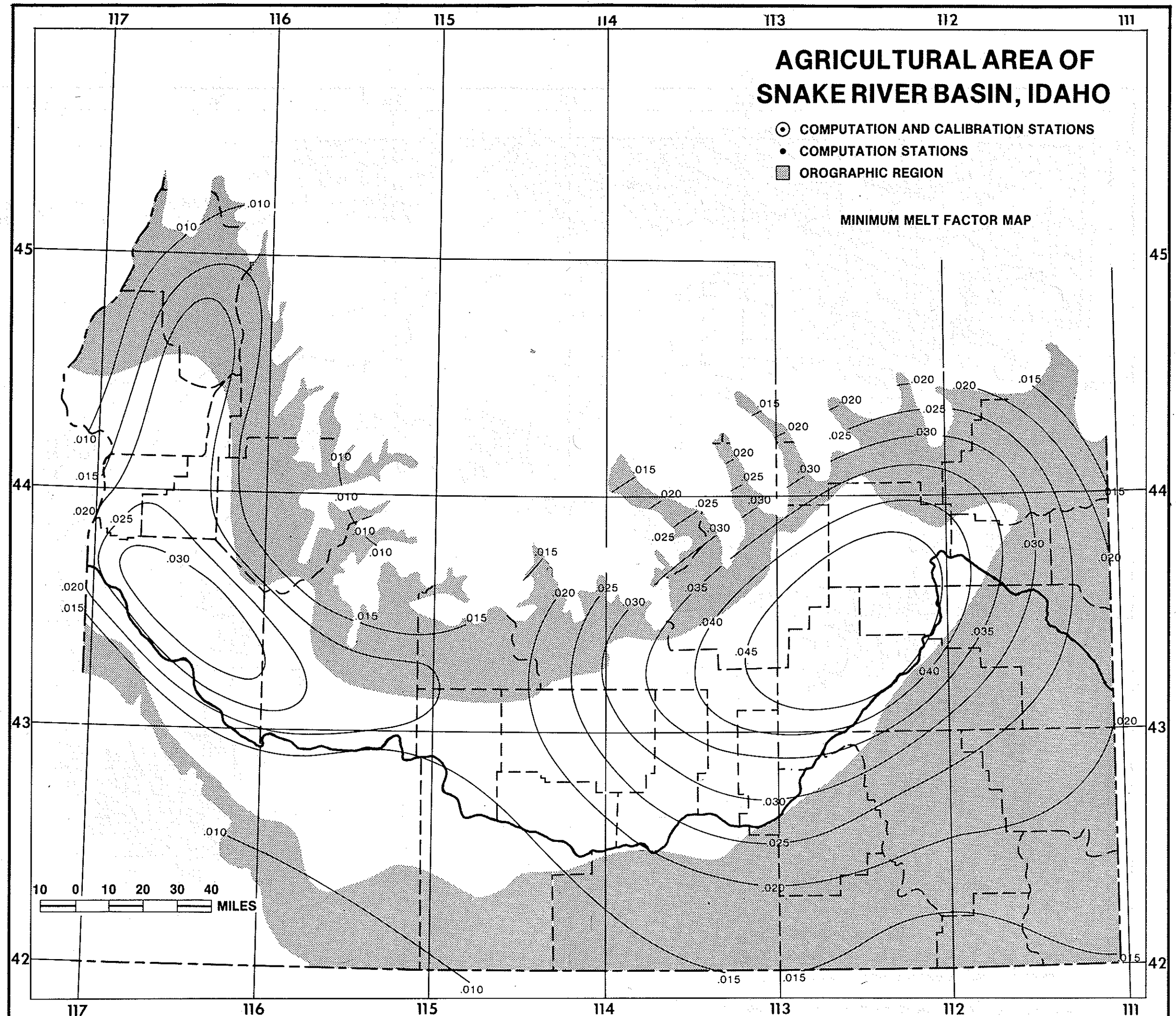

Figure 5a.--Adopted melt factor maps.

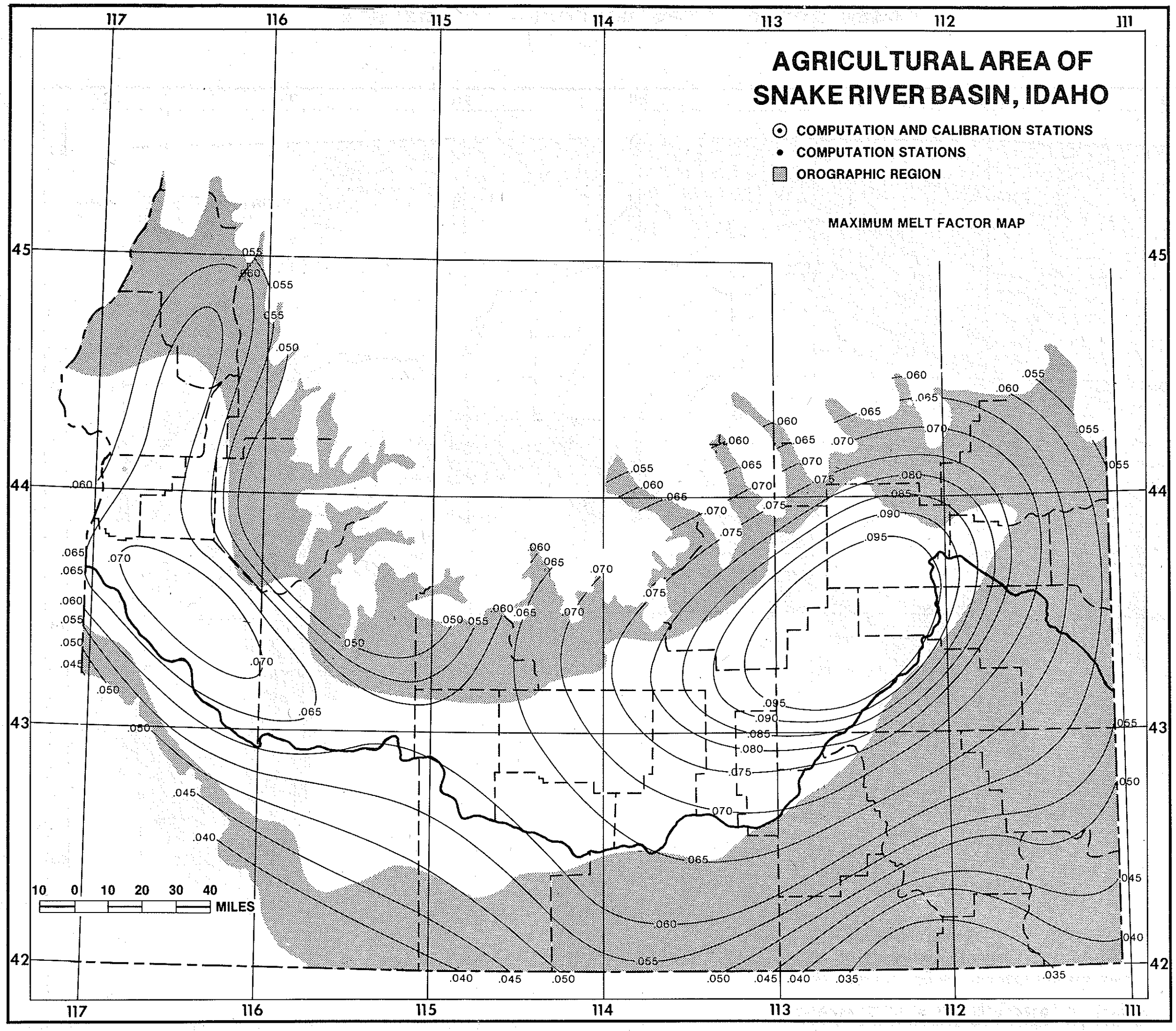

Figure 5b. Adopted melt factor maps.

3.4 Statistical Analysis

The computer program computed WAR values for each day of the year. Overlapping summations were also kept for durations of 2 to 15 days. For each year, beginning on October 1 and for each duration 1 through 15 days, the program selected 1) the maximum seasonal value of WAR for October to May, 2) the maximum water-year precipitation event regardless of form of precipitation or season of occurrence, and 3) the larger of the previous two values. Once the program completed analysis of all data for a station, it fitted a Fisher-Tippett Type I curve to each of the three data series using the Gumbel fitting technique (Gumbel 1958). This distribution has been used in previous precipitation frequency studies (Hershfield 1961; Miller 1964; Miller et al. 1973) and its adequacy discussed by Hershfield and Kohler (1960). Its use in this study facilitates comparison of results with those of previous studies. Although this computation was made for each of the three data series, the values used for the map analysis was the maximum annual value regardless of the source of the water (series 3 mentioned above). The other two series served for comparison. (See chapter 5, Discussion.)

It is generally accepted that with maximum rainfall events the annual series and partial-duration series differ. Two or more large precipitation events can occur in one year, with one or more of them being greater than the maximum event in another year. However, in mountainous areas of Idaho the data series which was formed of winter or spring snowmelt with or without additional precipitation does not have this capability. The maximum seasonal value of snowmelt with or without additional precipitation occurs only during the melt season. Especially at longer durations, it is unlikely that a maximum event will be followed by either more snow buildup or cessation of melting with a second or third large event occurring in the same season. In the mountains of Idaho the annual series and partial-duration series are the same.

In the nonorographic areas of the Snake River Plains, on the other hand, a snowpack can be melted during a winter rain, build up again, and be melted again during another rain. It is, therefore, concluded that the WAR data series would lend itself to partial-duration analysis in the lower elevations of the study area but would not be appropriate in the mountains. The maps presented with this study represent values from the annual series. For users needing partial-duration values in the Snake River Plains the factors listed in table 5 should be applied to convert from annual series to partial-duration series.

4. DEVELOPMENT OF WAR-FREQUENCY MAPS AND INTERPOLATION DIAGRAMS

4.1 Duration and Return Period Specification

The NWSRFS Snow Accumulation and Ablation model was developed for operational purposes. For this study the model was adapted to use climatological data rather than real time observations. This adaptation used maximum and

Table 5.--Empirical factors for converting annual series to partial-duration series

Return period	Conversion factor
2-yr	1.13
5-yr	1.04
10-yr	1.01
25-yr	1.00
50-yr	1.00
100-yr	1.00

minimum observed temperatures to compute an approximation of the average temperature over a 12-hr period. Daily 24-hr precipitation was divided equally between two 12-hr periods. Approximations in lieu of wind movement and atmospheric pressure were also introduced into the adaptation. Each of the approximations introduced is considered reasonable and makes the best possible use of the climatological data available.

In any use of approximations, the assumption is made that the errors introduced by their use are randomly distributed about the true value. While these errors introduce a positive error in computations for one data set, the error will be of opposite sign in computations using another set. Therefore, computations made over a number of data sets will approach a true value when summed.

In the present study it was decided that a duration of 4 days (8 computations of 12-hr duration) would be sufficient to allow the various approximations and assumptions to cancel out and produce a true result. The maximum duration analyzed is 15 days. Return periods of interest range from 2 to 100 years. Thus maps of 2-yr 4-day, 100-yr 4-day, 2-yr 15-day, and 100-yr 15-day envelope all durations and return periods of interest.

Values for intermediate durations or return periods can be determined through use of nomograms and equations as detailed in section 4.3.

4.2 Map Analysis

The topography of the study area includes a region of gentle slopes and a mountainous region where elevation changes sharply over short distances. Slope and elevation changes are considered major factors in precipitation distribution, and the expected variation of precipitation in the mountains is greater than revealed by the observations. This is especially true since stations tend to be far apart in such areas. Therefore, methods were sought for estimating interstation WAR patterns in the mountains (fig. 1), i.e., terrain above about 4,000 ft elevation to the west of 116°W and above 5,000 ft to the east of 116°W.

In this orographic region, regression equations were developed for each of the 4 maps. Independent variables considered in the regression process were elevation, effective elevation (mean elevation within x miles of the station), normal annual and seasonal precipitation, distance and direction to the Snake River (i.e., the lowest elevation from which moist air could flow), and latitude/longitude.

Correlation of the individual independent variables with 2-yr, 4-day, and 15-day WAR values showed normal seasonal precipitation and annual precipitation, not orographic parameters, to be the best predictors. Normal seasonal precipitation correlated to the WAR values explained less than 1 percent more variance than did normal annual precipitation. Since maps of normal seasonal precipitation are not available for Idaho, the additional fraction of a percent of explained variance was not considered worth the effort needed to develop them. The two variables chosen by the computer program explained over 85 percent of the variance and in both cases the third variable explained less than 1 percent more of the variance. The resulting equations are shown in table 6. At the 2-yr return period, equations for both the 4- and 15-day durations used normal annual precipitation and a latitudinal factor. Realistically, centers of maximum WAR should follow normal annual precipitation more closely than would precipitation-frequency values. In Idaho winter is the season of greatest precipitation. High WAR values would be associated with the accumulation of the precipitation, especially at higher elevations, and its release at some later time. The latitudinal factor expresses not only a geographical increase but also the fact that a southwesterly air flow causes more precipitation on slopes exposed to winds from that direction. Table 6 also lists the equations developed to estimate 100-yr values at both 4- and 15-day durations for this region.

In the nonorographic region (fig. 1) station data were deemed sufficient to define the pattern of WAR frequency values at the 2-yr return period. The period of record is several times the return period and changes in the pattern of frequencies are systematic and gradual enough to be depicted by the station network. At the 100-yr return period, a regression equation was derived (table 6) as an aid in interpolating between stations.

The WAR isolines were drawn using the computed station values and interstation estimates from the regression equations. Such estimates were computed on a 5-min latitude/longitude grid. Normal annual precipitation values for the grid points were read from a 1:500,000 scale copy of Mean Annual Precipitation, 1930-57, State of Idaho map prepared by U.S. Weather Bureau River Forecast Center, Portland, Oreg., and published in cooperation with the Soil Conservation Service, USDA, March 1965. The isolines of WAR were established on the 2-yr return period maps and the 4-day and 15-day were considered about equally definitive. Station data were drawn for unless substantial reason could be found for discounting them. At the 100-yr return period, station data were given less weight when ratios between the station 2-yr and 100-yr values appeared to conflict with the ratios at neighboring stations.

Table 6.--Equations used to estimate interstation WAR values

Orographic regions

$Y_1 = -0.239 + 0.131\ (X_1) + 0.189\ (X_2)$

r = 0.94   SE = 0.352 $\overline{Y}$ = 2.60   SE/$\overline{Y}$ = 0.135   N = 35

$Y_2 = 1.930 + 0.317\ (X_1) + 0.367\ (X_2)$

r = 0.93   SE = 0.916 $\overline{Y}$ = 4.68   SE/$\overline{Y}$ = 0.196   N = 34

$Y_3 = -.268 + 5.706\ (Y_1) - 1.021\ (Y_2) - 0.201\ (X_1)$

r = 0.96   SE = 0.703 $\overline{Y}$ = 6.53   SE/$\overline{Y}$ = 0.108   N = 34

$Y_4 = 1.038 - 0.818\ (Y_1) + 1.447\ (X_2) + 0.809\ (X_3)$

r = 0.96   SE = 1.445 $\overline{Y}$ = 11.82   SE/$\overline{Y}$ = 0.122   N = 34

Nonorographic

$Y_3 = 1.605 + 3.923\ (Y_1) - 0.235\ (X_1) - 0.396\ (X_2)$

r = 0.97   SE = 0.264 $\overline{Y}$ = 4.08   SE/$\overline{Y}$ = 0.065   N = 38

$Y_4 = -0.676 - 1.101\ (Y_1) + 0.873\ (Y_3) + 2.035\ (Y_2)$

r = 0.96   SE = 0.633 $\overline{Y}$ = 6.18   SE/$\overline{Y}$ = 0.102   N = 37

where

Y_1 = 2-yr 4-day estimate of WAR (in.)

Y_2 = 2-yr 15-day estimate

Y_3 = 100-yr 4-day estimate

Y_4 = 100-yr 15-day estimate

X_1 = Normal annual precipitation (in.)

X_2 = Station latitude - 40° (in decimals)

Once the isolines were drawn, WAR values from each of the four maps were read on a 5-min by 5-min latitude/longitude grid. Ratios were computed for 100-yr 15-day/2-yr 15-day, 100-yr 15-day/100-yr 4-day, 100-yr 4-day/2-yr 4-day, and 2-yr 15-day/2-yr 4-day data. These ratios were plotted on maps and analyzed as a check on the intra-map fitting for both compliance with the data and a smooth pattern of transition. The final maps are presented in figures 6 to 9.

4.3 Interpolation for Other Durations and Return Periods

Interpolation between 4 and 15 days and extrapolation to 3-day duration is done through use of figure 10. This figure is independent of location and return period.

For the development of figure 10, the station data were divided by return period and geographical location into four data sets. The geographical division was between those stations located in the orographic and nonorographic regions (fig. 1). The return period division was between data for the 2-yr and the 100-yr return periods. The data at each station were scaled so that the 4-day value was at zero and the 15-day value was at 1.00. All other durations were expressed in terms of this new scale. Means were computed for each duration for each of the four data sets. For each duration the differences between the values from the four data sets were small and randomly distributed (i.e., 2-yr not consistently larger or smaller than 100-yr, orographic not consistently larger or smaller than nonorographic). One diagram covers both regions and all return periods.

Although the section Duration and Return Period Specification presents the argument that 8 computations of 12-hr duration (4 calendar days) is necessary to approach true values, durations from 3 to 15 days were used in the development of figure 10. Some users need values for as short a duration as possible and therefore extrapolation to 3 days was permitted although some loss of confidence results. The duration diagram (fig. 10) is presented without numbers on the ordinate scale. This is for user convenience since the scale is linear and the user can insert values appropriate for the data of interest. Numerical solution of the diagram is presented in table 7.

Table 8 presents a numerical solution for the return period diagram (fig. 11). Figure 11 is based on the Gumbel method of fitting the Fisher-Tippett Type I distribution. Both the equations and the diagram for return period computations use annual series data (which is depicted on the maps).

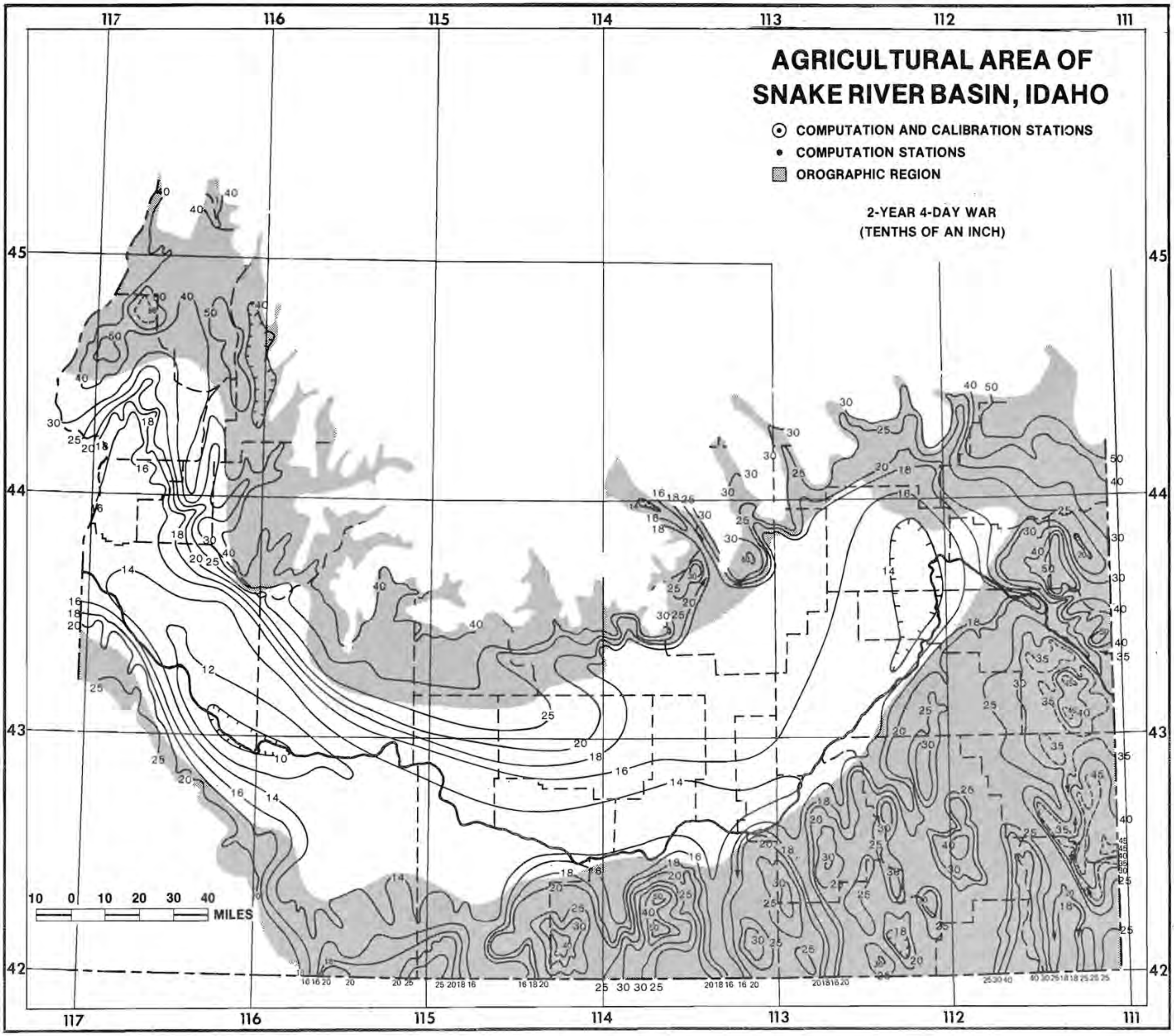

Figure 6.--2-yr 4-day WAR frequency map.

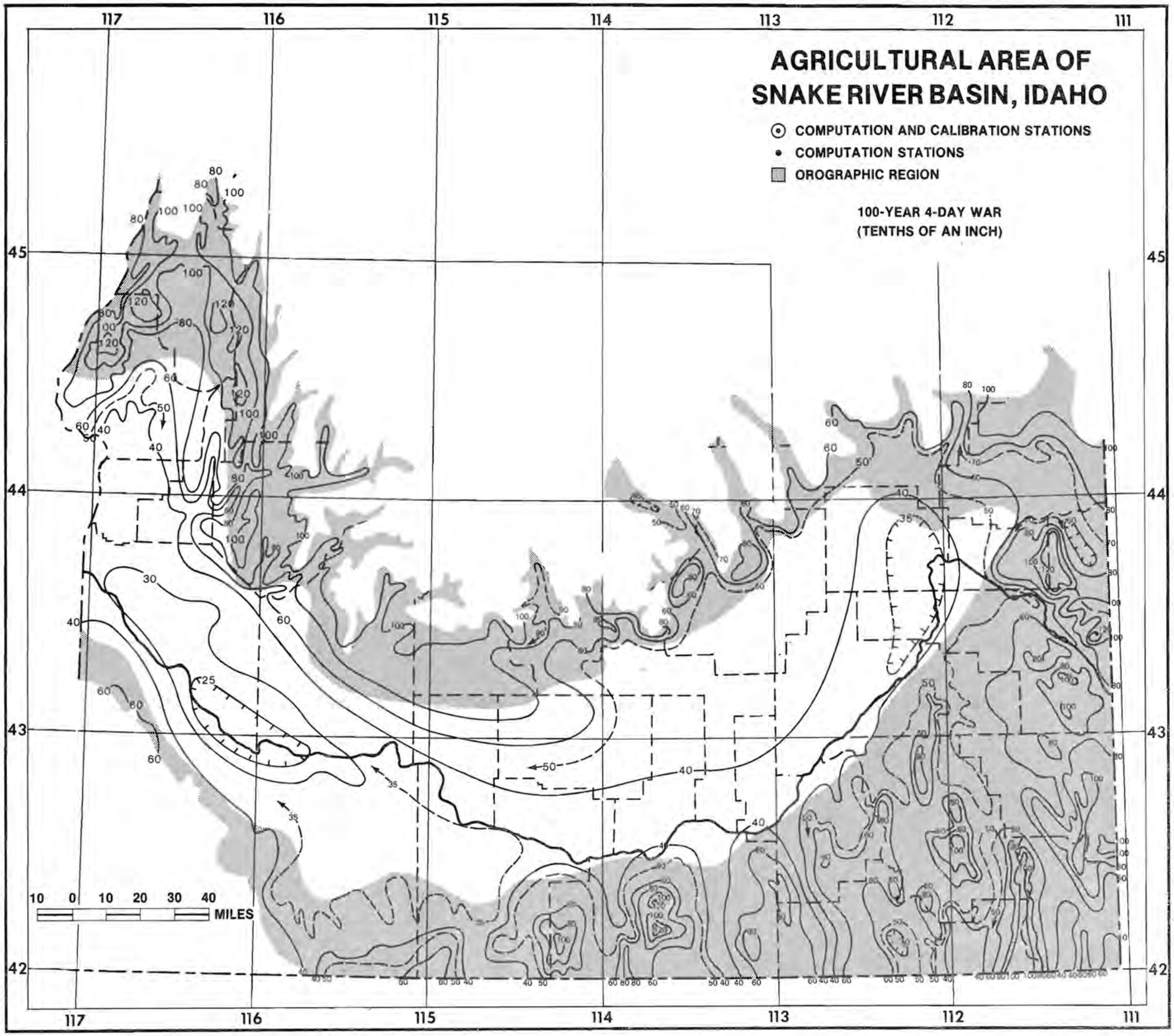

Figure 7.--100-yr 4-day WAR frequency map.

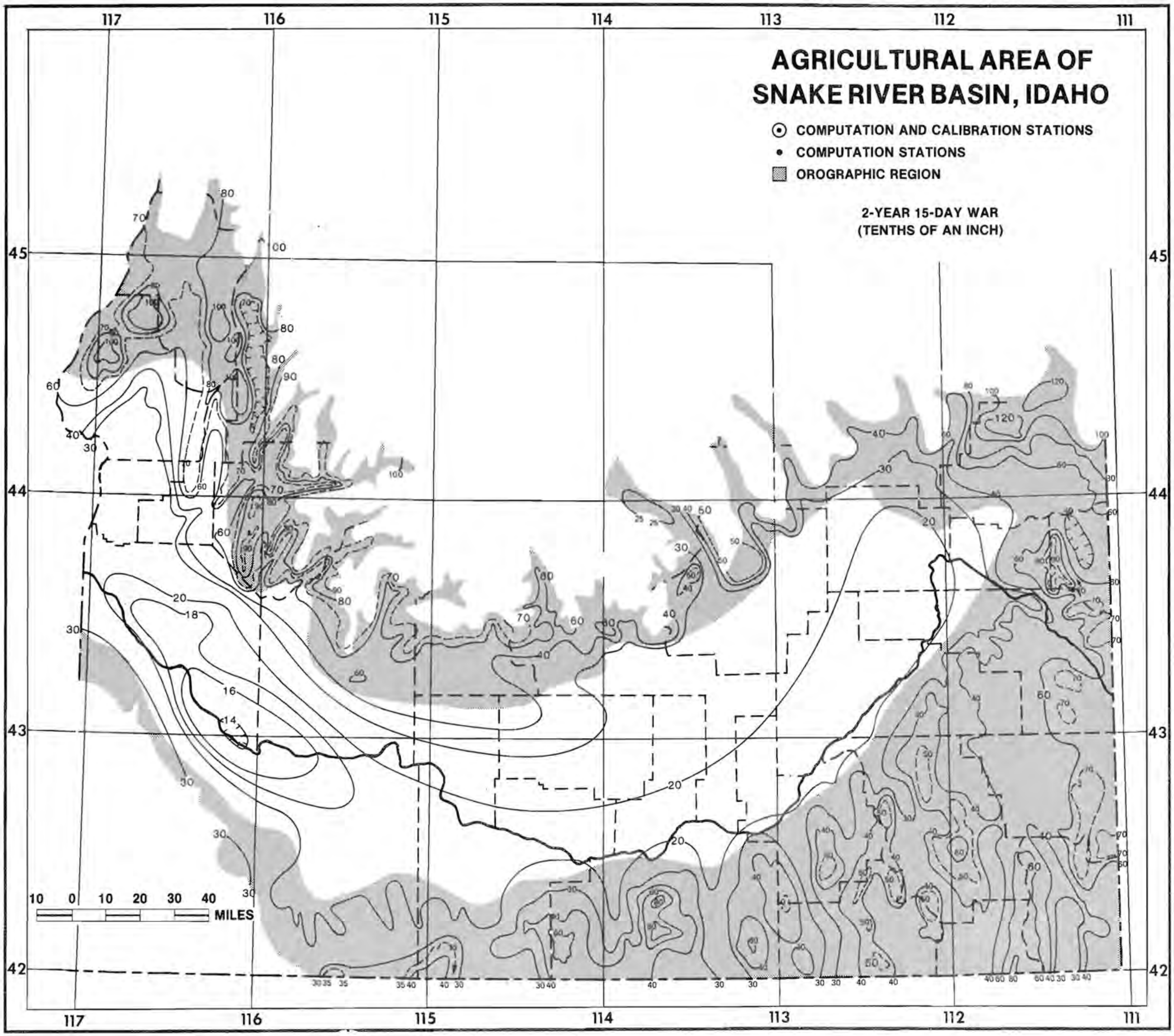

Figure 8.--2-yr 15-day WAR frequency map.

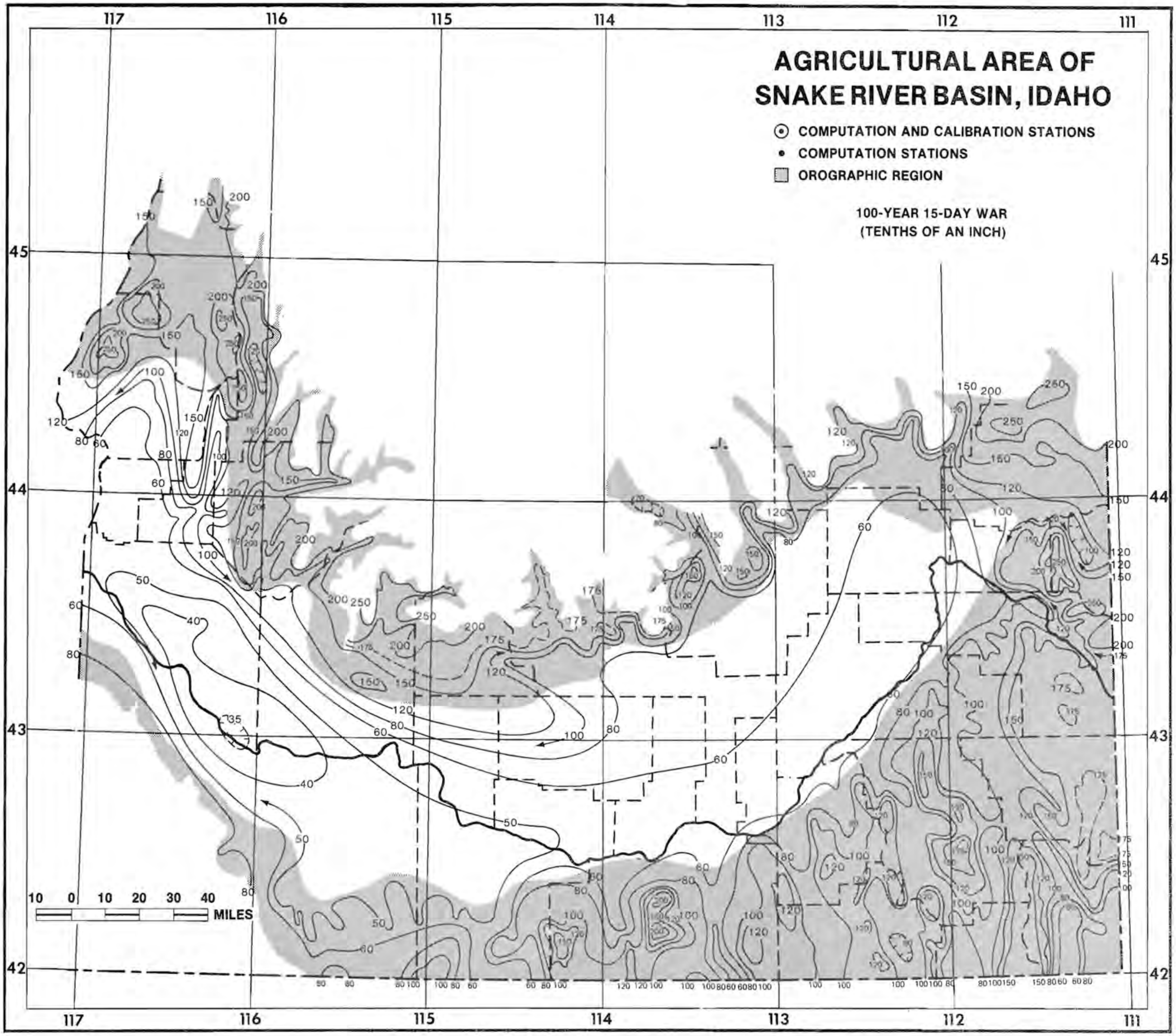

Figure 9.--100-yr 15-day WAR frequency map.

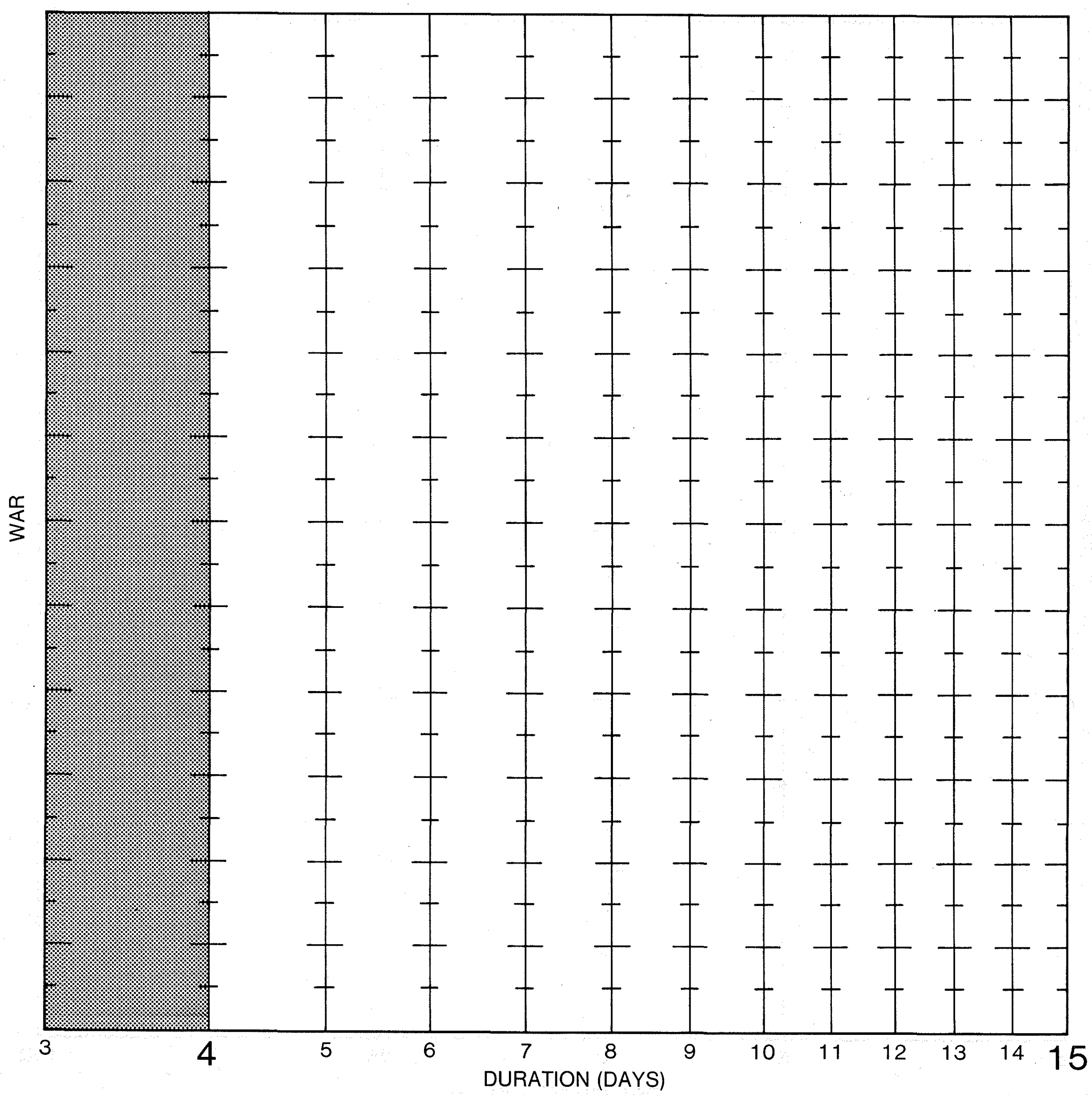

Figure 10.--Duration interpolation diagram.

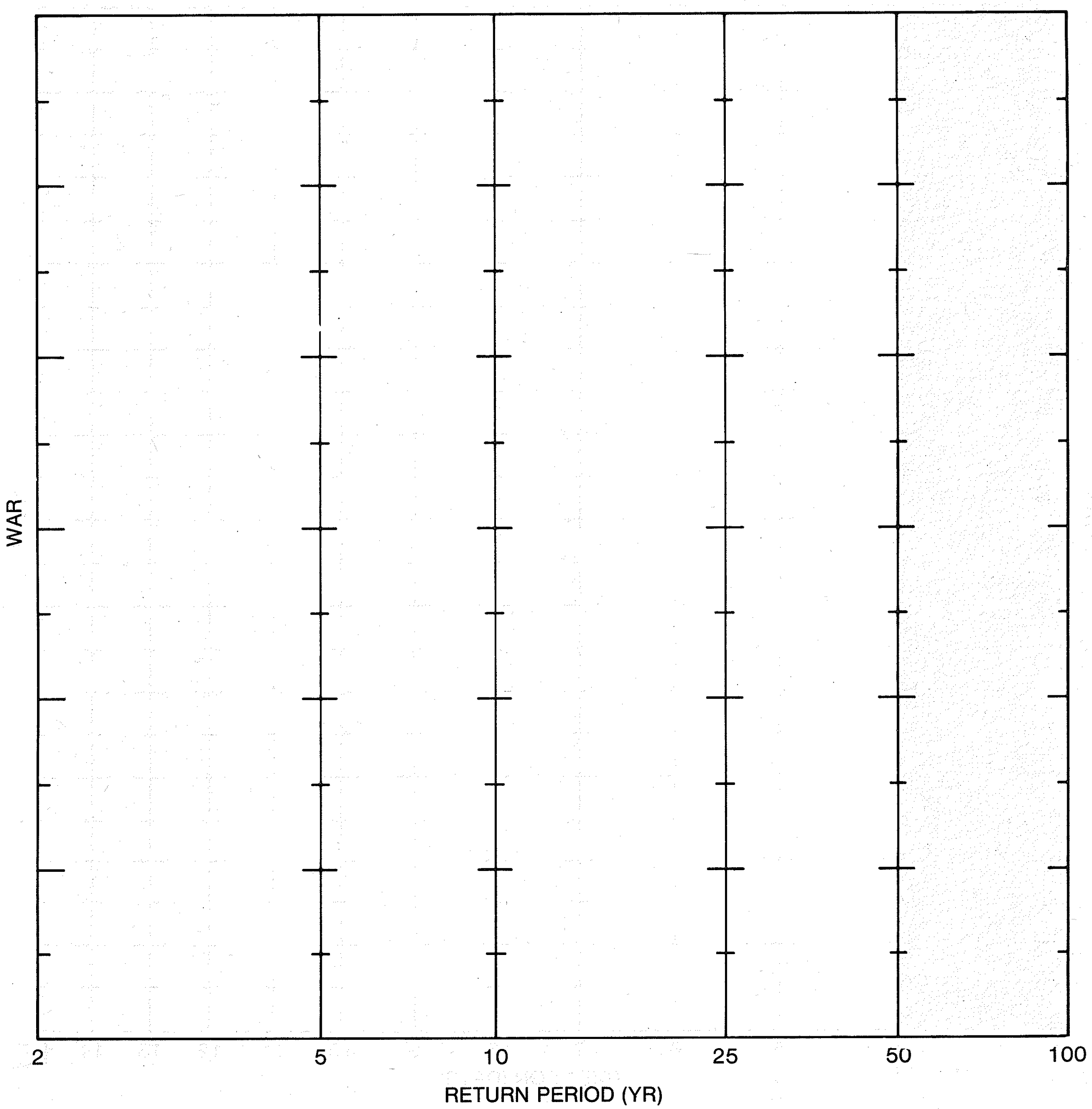

Figure 11.--Return period interpolation diagram.

5. DISCUSSION

5.1 Comparison of 10-day WAR Frequency with 10-day Precipitation Frequency

5.1.1 Computation of Precipitation and WAR Values for 10 Days

WB Technical Paper No. 49 (Miller 1964) outlines a method of using 2-yr 24-hr and 2-yr 1-hr precipitation-frequency and latitude to estimate 2-yr 10-day precipitation-frequency. The method involves use of figure 6 in that publication. This figure was digitized for computer processing and 2-yr 10-day precipitation-frequency values were estimated using the 2-yr 24-hr and 2-yr 1-hr values from NOAA Atlas 2 (Miller et al. 1973). The next step was to estimate 100-yr values. In TP-49, the 100-yr 10-day map was obtained through application of a geographically varying ratio to the 2-yr 10-day map. The same ratio was used in this study to convert 2-yr to 100-yr 10-day values. Two-yr and 100-yr 10-day WAR values were computed by the procedure of this study, namely using the 4- and 15-day maps (figs. 6 to 9) and the numerical solution of the interpolation diagram (table 6).

5.1.2 Comparison

At the 2-yr return period over most of the Snake River Plains section, WAR values are 1.15 to 1.33 times the precipitation-frequency values except for an area of slightly lower ratios near Grand View and Mountain Home where WAR values are about equal to precipitation-frequency. At the 100-yr return period, WAR values along the Snake River Plains are 150 to 200 percent of precipitation-frequency with about 125 percent in the lowest areas. At the other extreme, in the northeast corner of the study area, WAR frequency values are 300 to over 350 percent of the precipitation-frequency at the 2-yr and 100-yr return period. In most mountain areas the WAR frequencies are 200 percent or more of the precipitation-frequency. The pattern of WAR isolines follows normal annual precipitation isolines rather closely so that the highest WAR values fall on or near the tops of mountain ridges. This is logical since the heavy snowpack accumulates on mountain tops because of 1) lower temperature meaning more snow than rain, and 2) higher frequency of precipitation. Highest precipitation-frequency tends to occur somewhat below mountain ridges with the distance downslope a function of ridge height, slope, and exposure. Thus mountain ridges would be expected to have the greatest difference between precipitation-frequency and WAR-frequency.

In chapter 3, the section on Statistical Analysis mentions that a data series of maximum annual water-year precipitation values was analyzed. Comparison of 15-day WAR values with 15-day values from the precipitation series shows WAR values exceeding precipitation by about 5 to 10 percent along the Snake River and its immediate environs. The ratio WAR/precipitation only increases to 125 to 175 percent in most mountain locations and over 250 percent in the northeast corner of the area. Although most of the samples show higher ratios at the 100-yr return period, this is not true at all data points. At the 4-day duration the ratio WAR/precipitation is about the same (as the 15-day ratio) along the river plains but tends to be somewhat less than the ratio for 15-day duration in mountainous areas.

Table 7.--Numerical solution relating N-day X-yr WAR value to 4-day and 15-day X-yr values

3-day	= 1.193	(4-day)	-0.193	(15-day)
5-day	= 0.864	(4-day)	+0.136	(15-day)
6-day	= 0.742	(4-day)	+0.258	(15-day)
7-day	= 0.632	(4-day)	+0.368	(15-day)
8-day	= 0.532	(4-day)	+0.468	(15-day)
9-day	= 0.440	(4-day)	+0.560	(15-day)
10-day	= 0.355	(4-day)	+0.645	(15-day)
11-day	= 0.276	(4-day)	+0.724	(15-day)
12-day	= 0.202	(4-day)	+0.798	(15-day)
13-day	= 0.132	(4-day)	+0.868	(15-day)
14-day	= 0.065	(4-day)	+0.935	(15-day)

Table 8.--Return period interpolation equations

5-yr	= 0.2677	(100-yr)	+0.7323	(2-yr)
10-yr	= 0.4450	(100-yr)	+0.5550	(2-yr)
25-yr	= 0.6689	(100-yr)	+0.3311	(2-yr)
50-yr	= 0.8351	(100-yr)	+0.1649	(2-yr)

5.2 Seasonality of WAR

Figures 12 and 13 show the ending dates of the three largest 4-day and 15-day WAR events at each station during 22 years, simulated WAR, and observed precipitation during the N-day period.

The 4-day duration (fig. 12) values in December 1964 appear at 38 stations (more than half the 72 stations used) which are spread throughout the study area. The same month gave large 15-day values (fig. 13) at several stations in the south-central portion of the study area. The large WAR values for this month were mostly due to heavy rain with little snowmelt except at higher elevations.

Climatological Data, Idaho (Environmental Data Service 1948-72) has a writeup on the excessive rain during this month. This period illustrates how extensive winter rains can cause runoff over a large part of the Snake River basin.

Another month which contributed large values at several stations for both durations was April 1965. Using Sun Valley as an example, the heavy precipitation of December 1964 started the buildup of a heavy snowpack that lasted through the winter. In early April there was still 1.5 ft of very ripe snow on the ground (estimated water equivalent about 12 in.). The 15-day WAR maximum value for that year was about 13.2 in. occurring on April 10-24. During this period 1.2 in. of precipitation was reported. The other 12 in. of water came from snowmelt as the mean daily maximum

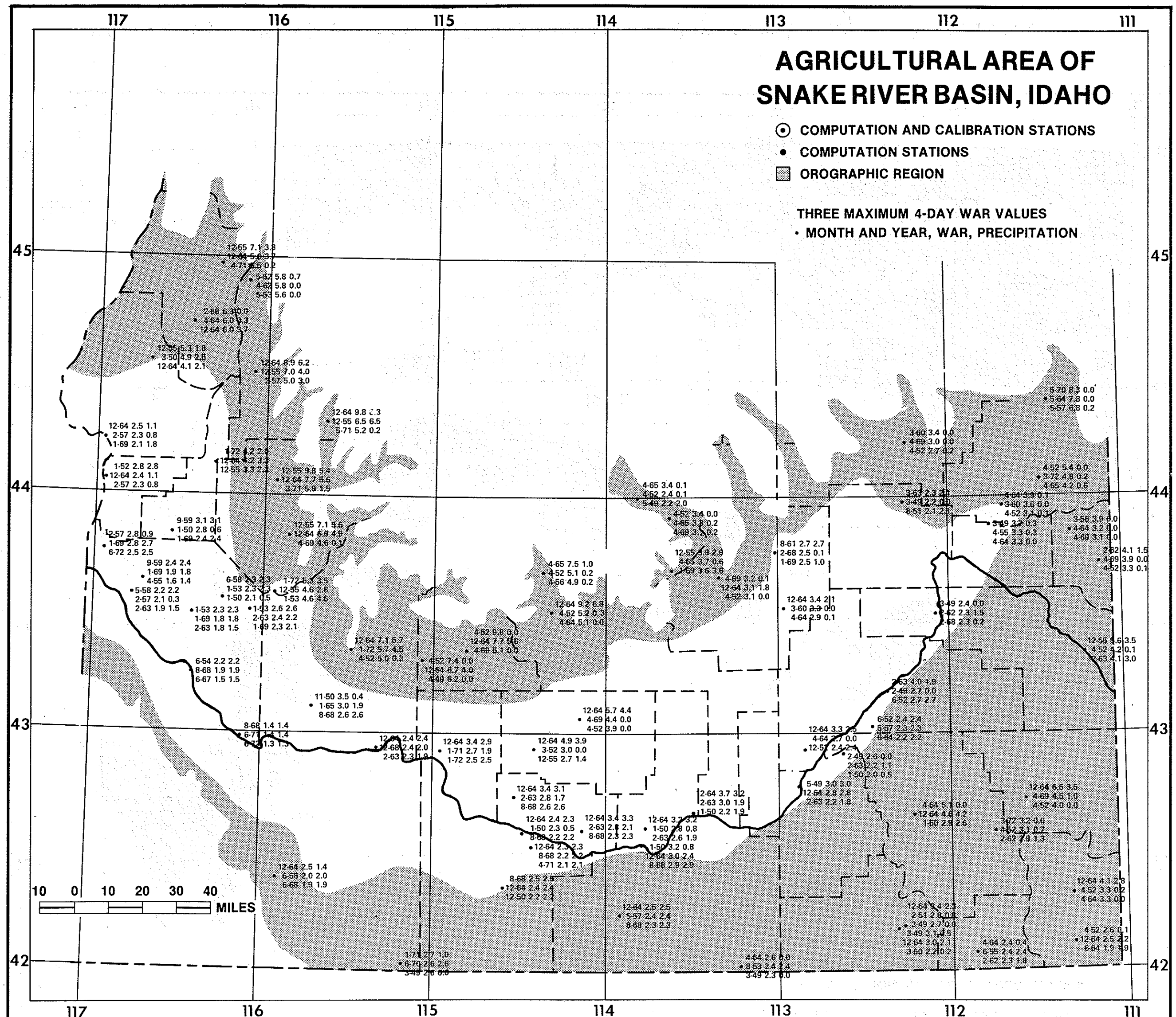

Figure 12.--Ending dates of 3 largest 4-day events at each station.

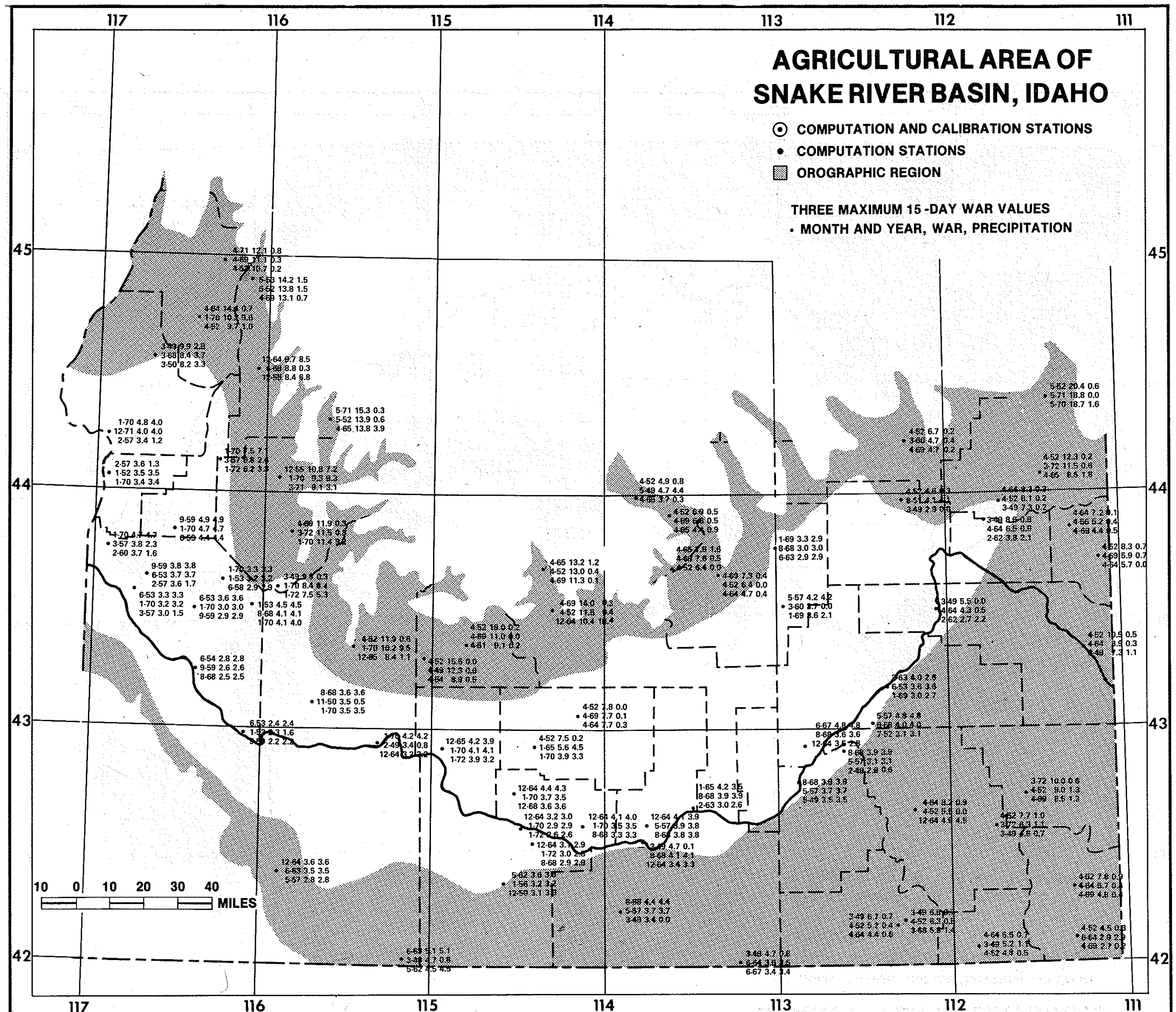

Figure 13.--Ending dates of 3 largest 15-day events at each station.

temperature for this period at Sun Valley was just over 51°F with mean minimum temperatures only going down to around 25°F. Figure 14 graphs the meteorological variables and model-simulated release of water from snowpack April 10-24, 1965, at Sun Valley. This is one illustration of the relative contribution of snowmelt and current precipitation to total WAR.

Figures 12 and 13 can also be used for indications of seasonality of large WAR values. In the northeastern corner of the study area, the largest values for both durations generally occur late March through May--the period when temperatures are getting warmer and the snow is melting rapidly. At the other extreme, western sections illustrate the importance of heavy winter rains and summer showers and thunderstorms. The maps show clearly that, except in the mountainous sections, large WAR values can occur during the winter, spring, or summer but not in the fall.

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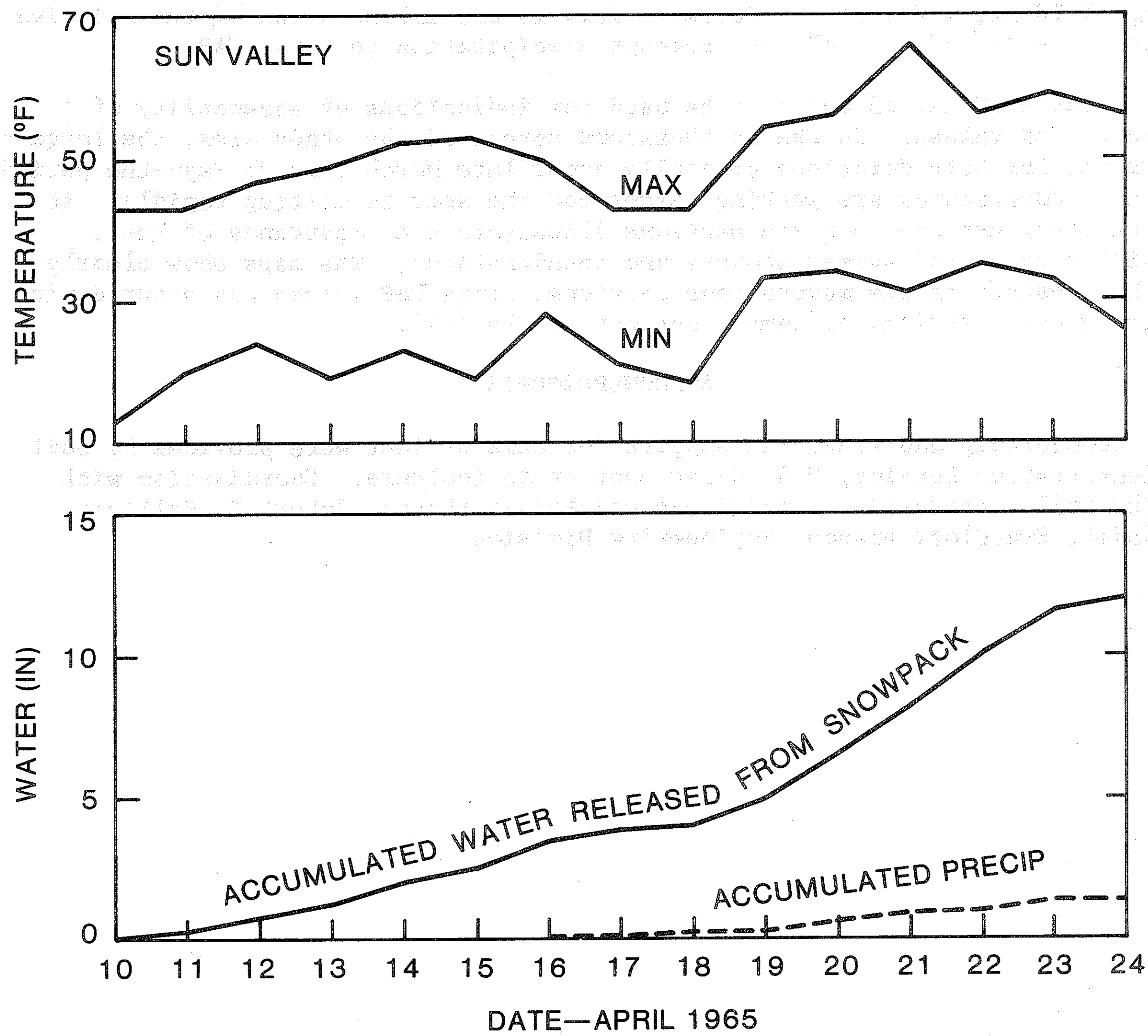

Figure 14.--Plot of meteorological elements during 15-day melt period at Sun Valley.

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