VOLUME FORECASTS USING THE SSARR MODEL IN A ZONE MODE[a]

653-79

By
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Introduction

Variation of precipitation and snowfall with topography was recognized by early investigators, many of whom suggested elevation as a component of a rigorous solution of the analysis of the runoff from mountain watersheds. Lee (10) and Henry (8) discussed these effects early in this century, and Church (3), Stall (18), Himmel (9), and Daniels (6) presented Western Snow Conference papers in the 1940's with particular reference to snowfall and elevation relationship. In some early papers the snowpack was analyzed by area zones or via a snow profile to arrive at a snow variable for a correlation-type water supply forecast procedure. Attempts at using snow-elevation relations in early deterministic models were made by Wilson (23), Linsley (11), Solo (16), and Summersett (19).

The Cooperative Snow Investigations of the late 1940's and 1950's investigated many of the basic relationships which were combined by Rockwood to develop an operational snowpack depletion model which simulated detailed hydrographs from ablation of mountain snowpacks. The Streamflow Synthesis and Reservoir Regulation (SSARR) Model was implemented in 1958 and refined in 1962 to include a complete rainfall runoff model (14). That this model had the capacity of analyzing snow in a watershed in various elevation zones or other homogenious bands was demonstrated by Rockwood (15) and Pierson (12).

The "New Direction of Water Supply Forecasting" which Tarble presented to the Snow Conference in 1971 stressed model simulation (20). Since 1970 numerous investigators have reported on models of various complexity to simulate mountain snowfall runoff. Anderson (1) developed a snow accumulation and ablation model which treats the watershed snow-covered area as a single area but suggested the need of considering elevation in mountainous areas. This model is part of the National Weather Service River Forecast System (NWSRFS). Carroll (4) proposed a method of weighting Snow Water Equivalent (SWE) measurements into a single area model operation. Numerous investigators discussed models which account for snow conditions by elevation band at the Workshop on Modeling of Snow Cover Runoff in 1978 (24).

The development of a practical operational version of the SSARR which could simulate the snow accumulation and depletion from a watershed by analyzing numerous elevation bands or zones had to await the availability of adequate computer power and sophisticated file management procedures. The Corps of Engineers' North Pacific Division and the River Forecast Center of the National Weather Service are now in the final phases of development of such an operational model. This paper used a study version of the program to investigate the relationship of model zone SWE to observed SWE at snow courses as they affect volume forecasting.

Model Computations

The zone or band mode of the SSARR is designed to be a modular part of the existing forecast system. Runoffs computed for all zones are combined and routed through the present SSARR three levels of storage (17).

The model employs independent accounting of precipitation, SWE, soil moisture, evapotranspiration, and other watershed quantities in up to 20 elevation zones. Zone precipitation is computed on the basis of a fixed precipitation-elevation relationship. Character of falling precipitation as either snow or rain is dependent on the zone temperature determined by: (1) a fixed lapse rate of one input temperature, or (2) a computed lapse rate if more than one temperature is input. During the study reported in this paper, a fixed lapse rate was used.

At any given computation time each zone is assumed to be either completely snow-covered or bare. The various relationships to simulate evapotranspiration, soil moisture, interception and cold content, liquid water storage, ground melt and snowmelt, are similar to those described in Snow Hydrology (5) and employed by Anderson (1).

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Test Watershed

The initial testing of the study version of the model during its development is being done on the watershed of the Clearwater River above Orofino, Idaho (drainage area 5,580 square miles). The basin is divided into ten unequal zones as shown in Figure 1, with the assumed precipitation-elevation relation. The initial selection of precipitation and temperature stations is shown on Figure 2. The simulation is accomplished using six-hour compute periods with temperature and precipitation produced by NWSRFS's MAP and MAT routines.

Reconstitutions were performed on the years 1965 through 1975. Simulation is continuous for the entire 11 years, with only temperature and precipitation as input and with no reference to observed flow or SWE data. The accumulated monthly deviation of the simulation from the observed runoff was the primary criteria for optimizing the model coefficients.

It must be emphasized that no reference was made to the existing snow course data or snow cover information during the optimization process. In this way the correspondence of the computed and observed SWE becomes an additional measure of the validity of the model's basic functions.

Test Results

Comparison of the simulated monthly runoff and the observed is shown on Figure 3. The correlation coefficient is a 0.981 with standard deviation of the errors equal to 0.444 inch. Although detailed fit of the hydrograph was not the primary optimization criteria in this study, the hydrograph simulation is quite encouraging. Figure 4 shows the hydrographs for 1965 and 1967 for the April-September period. The first year (1965) is the poorest fit of the 11 years, and 1967 is among the better fits.

Total April-September volumes and the model simulations are shown in Figure 5. Average error of the relation is 1.22 inches with a standard deviation of the departures of 1.50 inches.

As stated above, no reference was made to the observed snow cover or SWE available in the basin. There are 19 snow courses in and surrounding the watershed. The computed zone SWE on dates when snow courses were measured was plotted against the observed SWE at each course. Typical plots are shown on Figures 6 and 7.

Combined Use of Model and Observed SWE

Correlations such as shown on Figure 6 suggest that observed SWE can be used to refine the SWE computed by the temperature and precipitation model.

Two or three courses were selected which best index the simulated snowpack for each zone. In operations these correlations provide a means of computing model zone "observed" SWE. Profiles of observed and computed zone SWE can be computed and compared for any measurement date (Figure 8). A compromise profile can be determined which will then be the basis for computation of the expected future runoff hydrograph. Future runoff volumes can be computed on the basis of ESP techniques as described by Twedt (21)(22), or by simple use of stochastic values.

Standard correlation type water supply forecast procedures generally depend primarily on end-of-March measurements. Comparison on this date of computed and observed zone SWE produces a correlation coefficient of 0.983 and a standard deviation of errors of 2.12 inches.

Figure 5 shows a comparison of the "water supply relation" using model SWE and observed SWE. Careful inspection will reveal that a combination of the two factors will improve the performance. A snow profile which compromises 30 percent toward the observed SWE decreases the standard deviation of the error from 1.50 inches to 1.40 inches and reduces the average error from 1.22 to 1.02 inches.

Model-SWE Relationships

Excellent correlations exist between the zone SWE in each of the upper three zones with SWE at each of six or seven courses. Any two of these provide an excellent means to estimate the SWE in the upper four zones. The quality of the correlations and the number of available courses deteriorates drastically for the lower zones. The relationship between the SWE observed on courses and computed in the lower zones is reasonable and consistent during the accumulation season but generally breaks down in the depletion periods. Generally, the lower zone SWE relates well, if at all, with only one or two courses. The traditional criteria for the selection of snow course sites which weight the existence of a snowpack at the time of the maximum watershed SWE helps to explain this phenomenon.

At many middle and lower elevation courses the regression coefficient for the accumulation phase is significantly different from the depletion period. When this is true for courses at the same elevation, the difference is most probably related to the exposure.

The excellence and validity of the correlations of zone and observed SWE suggests a potential to employ modeling to assist in evaluation of the quality and character of existing snow courses with a minimum period of record. Correlation or double mass plot techniques usually require periods of record in the order of 10-15 years before meaningful conclusions can be demonstrated. By comparison of frequent measurements over a 3- or 4-year period with model computations, the climate of the course and the effect on the accumulation and oblation can be adequately established.

In this basin there is an oversupply of courses which are adequate indexes of the SWE in the upper zones. Conversely, there are a minimum of courses which are good indexes of both the accumulation and depletion in the lower zones. Because of the seasonal difference in behavior of lower courses, we can expect each course to index a smaller portion of its area.

Therefore, to obtain an adequate index to lower zone SWE, we have two alternatives: (1) more discriminant analysis of the course data, or (2) increase the number of courses at these levels. The first choice is of course easiest and most cost-effective, and its prospect for success is enhanced by daily records such as provided by SNOTEL stations. It appears that a combination of these alternatives is necessary and that some increase of the lower level courses is justified.

Considering the economics of snow course measurement, it seems reasonable to consider combined use of a snow model and a reduced number of high-elevation courses, and an increase in carefully sited lower courses. These lower courses are less costly to maintain and measure, yet they have very high information content when used in combination with a zone band model.

Summary and Conclusions

It is evident from the results of this study that a zone model operating on temperature and precipitation alone, optimized to runoff volumes, also produces reasonable estimates of snow accumulations. Thereby, the model becomes a useful tool for water supply forecasting which can provide forecasts with accuracy comparable to correlation techniques. In addition, the model can produce more frequent and detailed advisories on runoff.

The use of snow course and snow pillow data to supplement the model does improve forecasts significantly. This is particularly true if observed SWE is available on a more frequent schedule. Weighting of model and observed SWE on the basis of SWE profiles is a viable technique for incorporation of SWE into zone model.

In the lower elevations of this study watershed there is a shortage of SWE measurements to index the highly variable conditions of accumulation and ablation in the ephemeral snow zone. However, there are many courses which provide adequate indexes to the higher zone SWE. It may be prudent to examine the distribution of courses in the watershed.

An auxiliary benefit of a model is that, when needed, missing snow course records can be computed and course records can be extended back in time. With the assistance of the model, new snow courses can be evaluated sooner, with two or three years of record.

The "snow climatology" of an area can be established in the most cost-effective manner by use of a model and a relatively few permanent snow courses and a group of courses which are moved after a short record period.

Future Developments

Continuing development on the SSARR zone model will include:

(1) Extend study to include 1976-79 data so as to strengthen statistical basis for the conclusions.
(2) In cooperation with Soil Conservation and the Corps of Engineers, test the model on a variety of basins to establish an adequate experience base and confidence in the methodology.
(3) Test variable lapse rate provision.
(4) Improve the ground melt function to employ an index of soil moisture rather than season.
(5) Code a version of the SSARR model which can be used operationally for both water supply-ESP purposes and daily river forecasting.
(6) Code automatic use of observed SWE data to prepare and compare SWE profiles and to adjust model computed zone SWE quantities.

Acknowledgments

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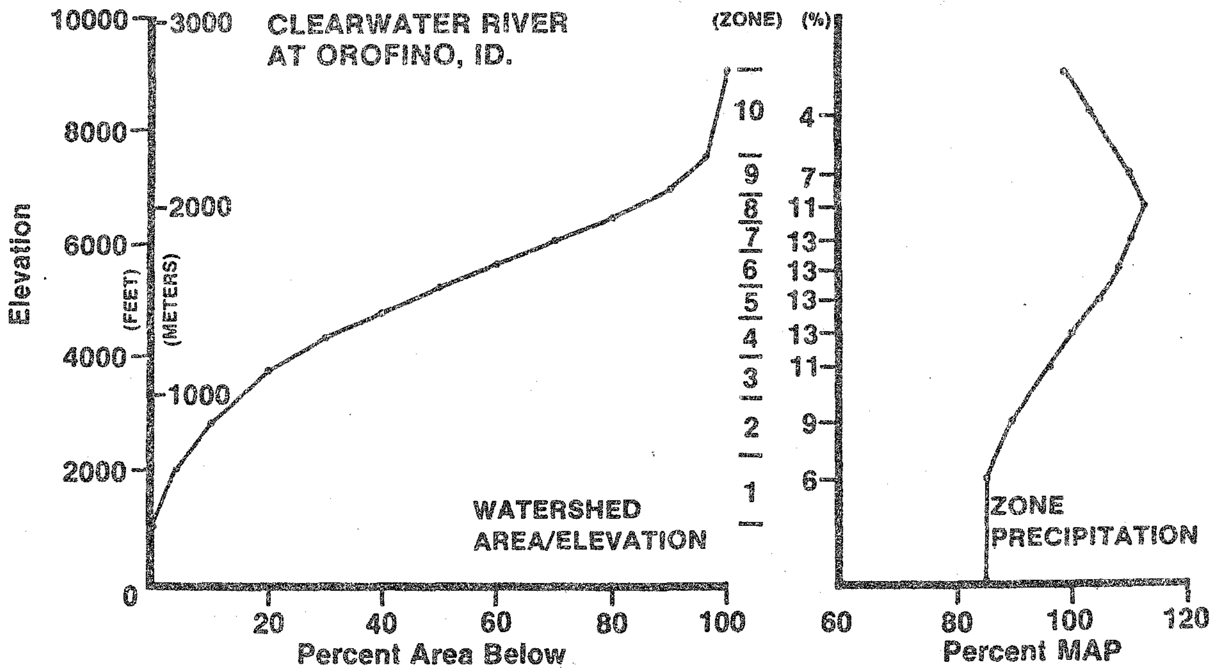
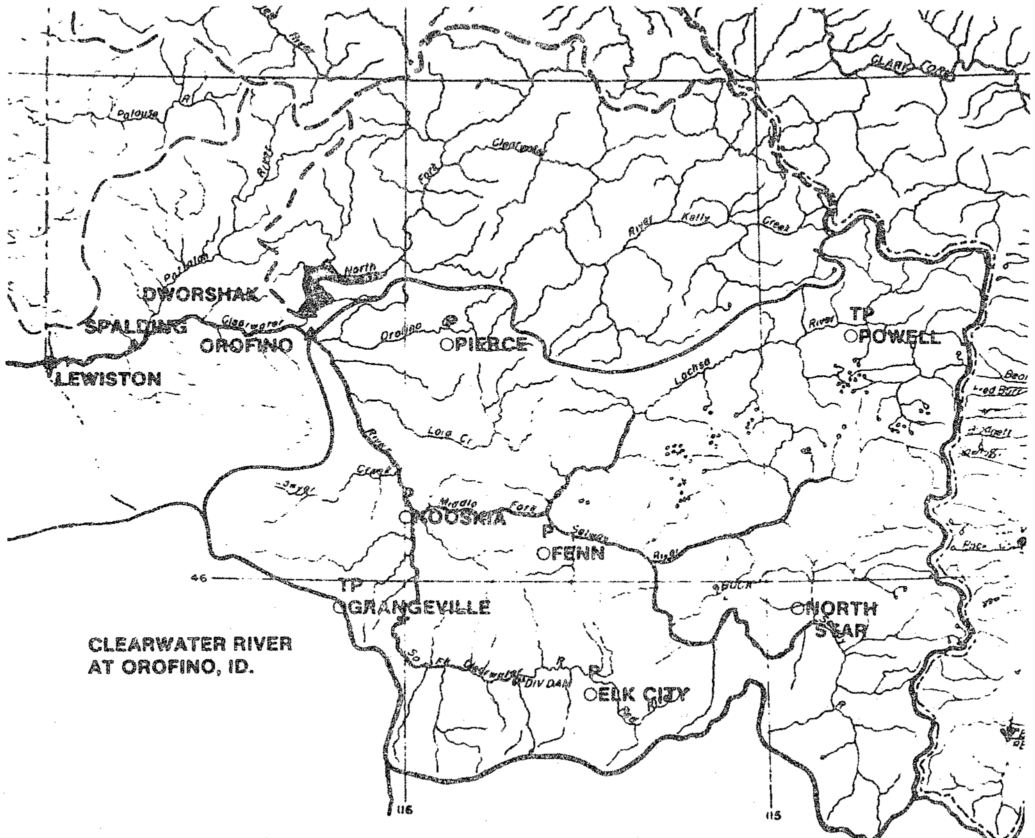


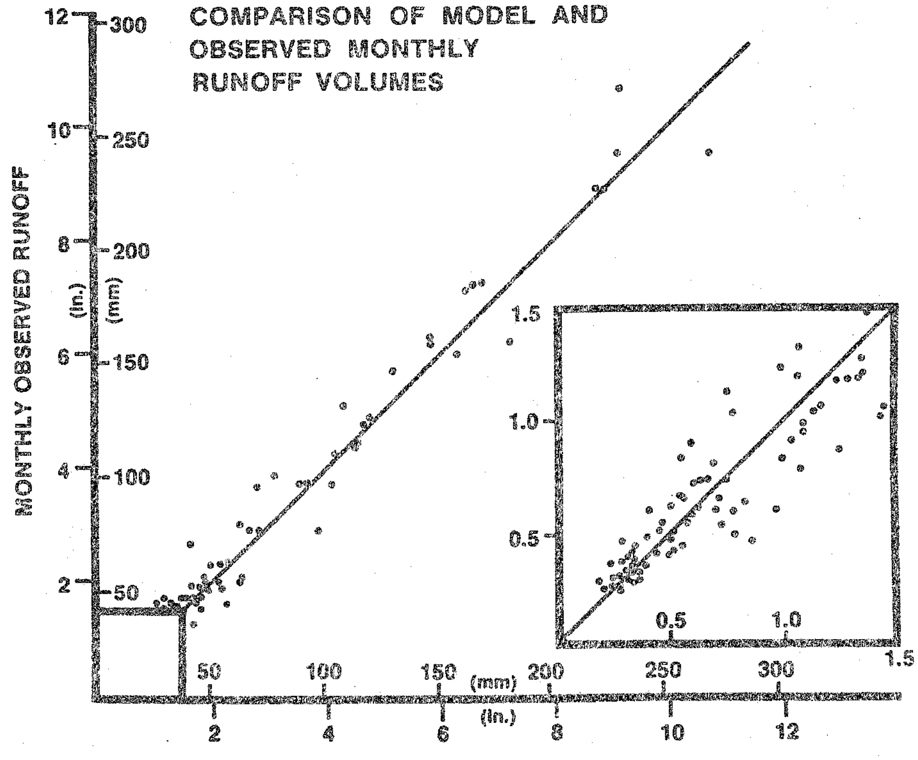
FIGURE 1

FIGURE 1



TEMPERATURE & PRECIPITATION STATIONS USED IN MODEL

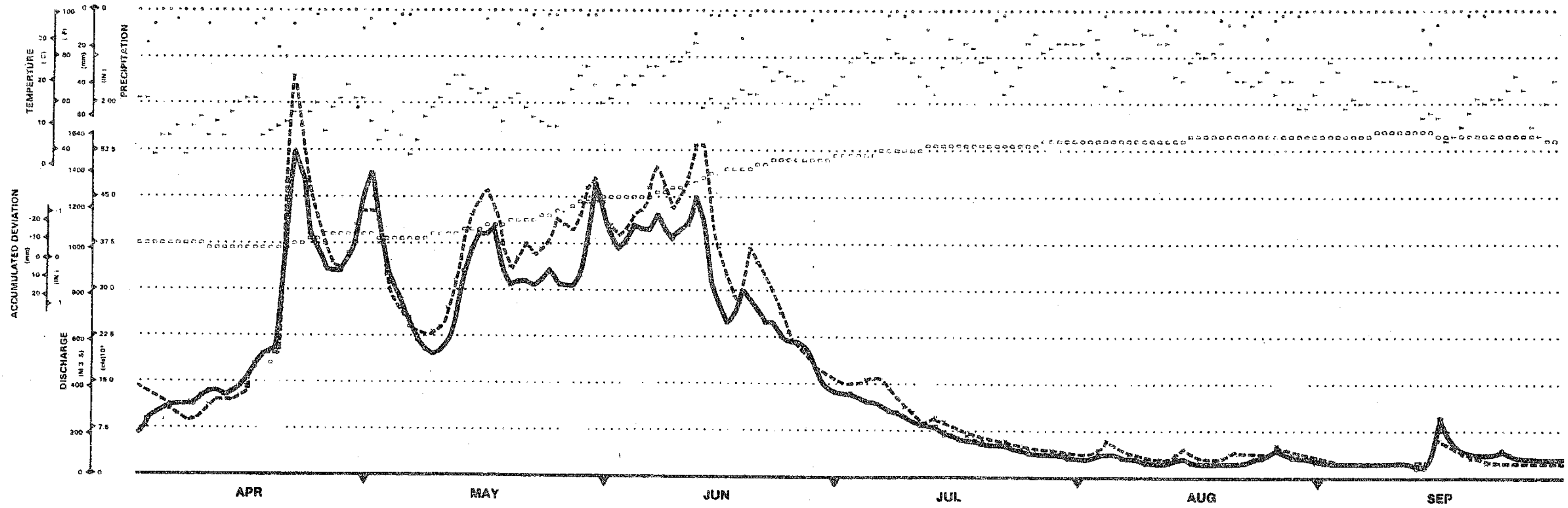
FIGURE 2



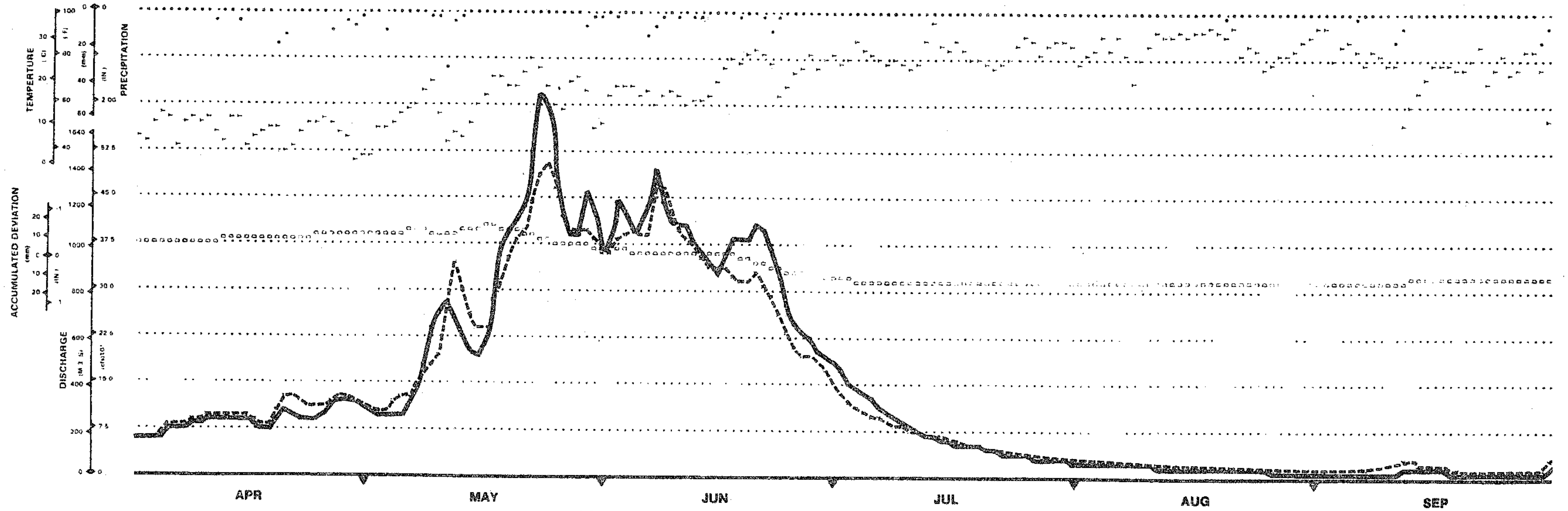
COMPUTED RUNOFF MONTHLY

FIGURE 3

FIGURE 4



COMPARISON OF OBSERVED AND COMPUTED HYDROGRAPH FOR 1965



COMPARISON OF OBSERVED AND COMPUTED HYDROGRAPH FOR 1967

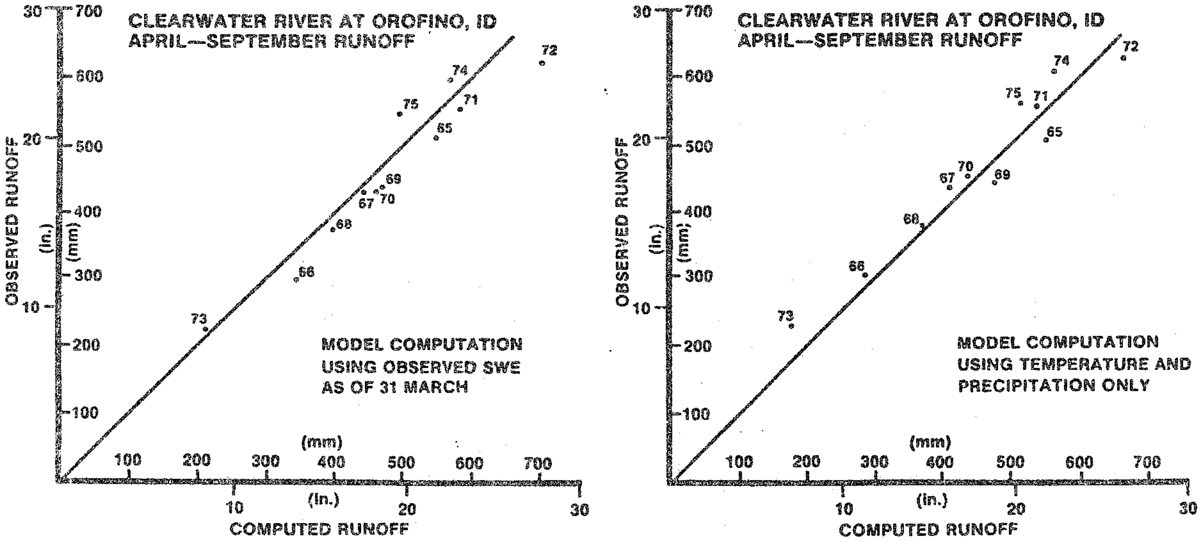


FIGURE 5

Comparison of Model and Snow Course Snow Water Equivalents

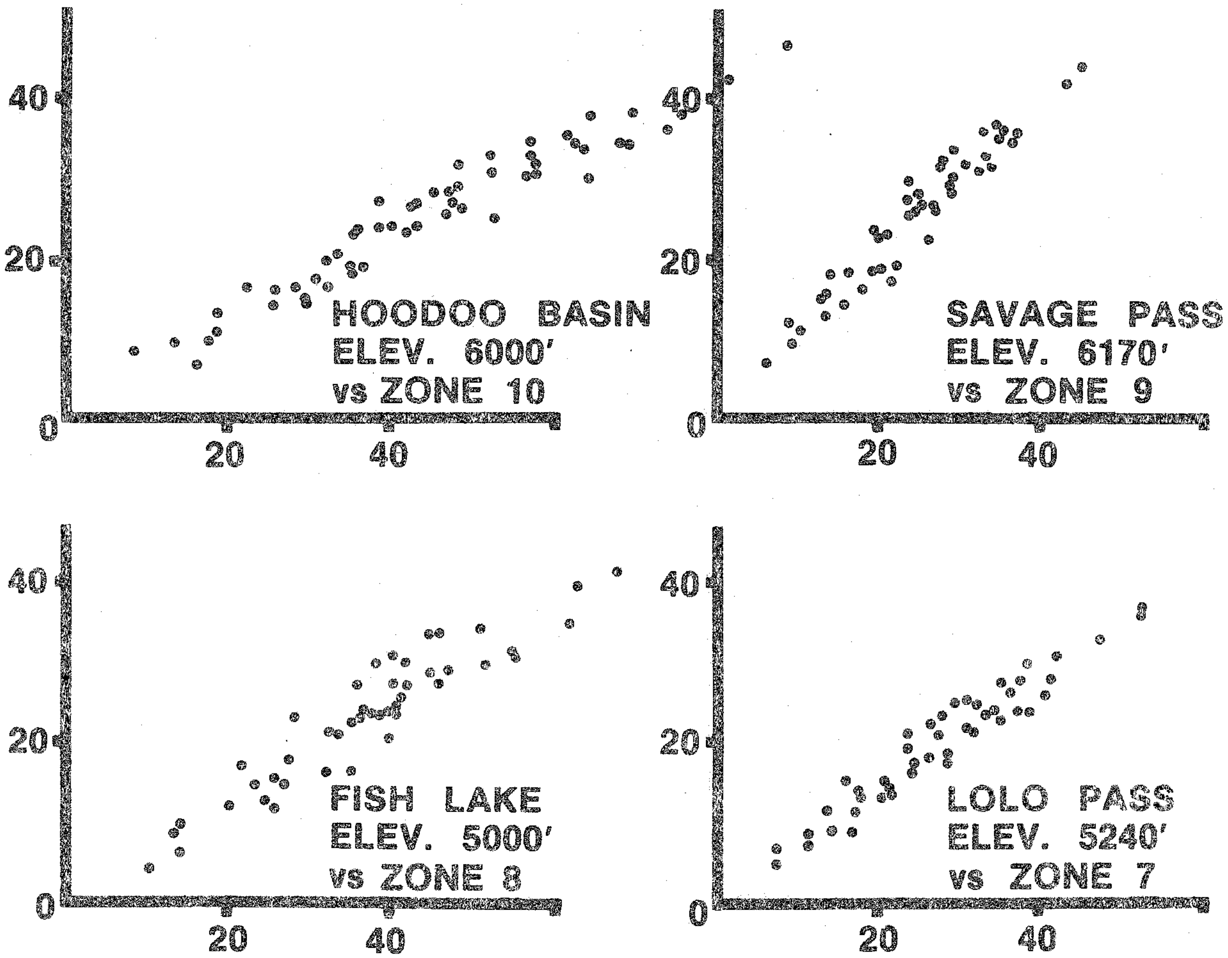


FIGURE 6

Comparison of Model and Snow Course Snow Water Equivalents

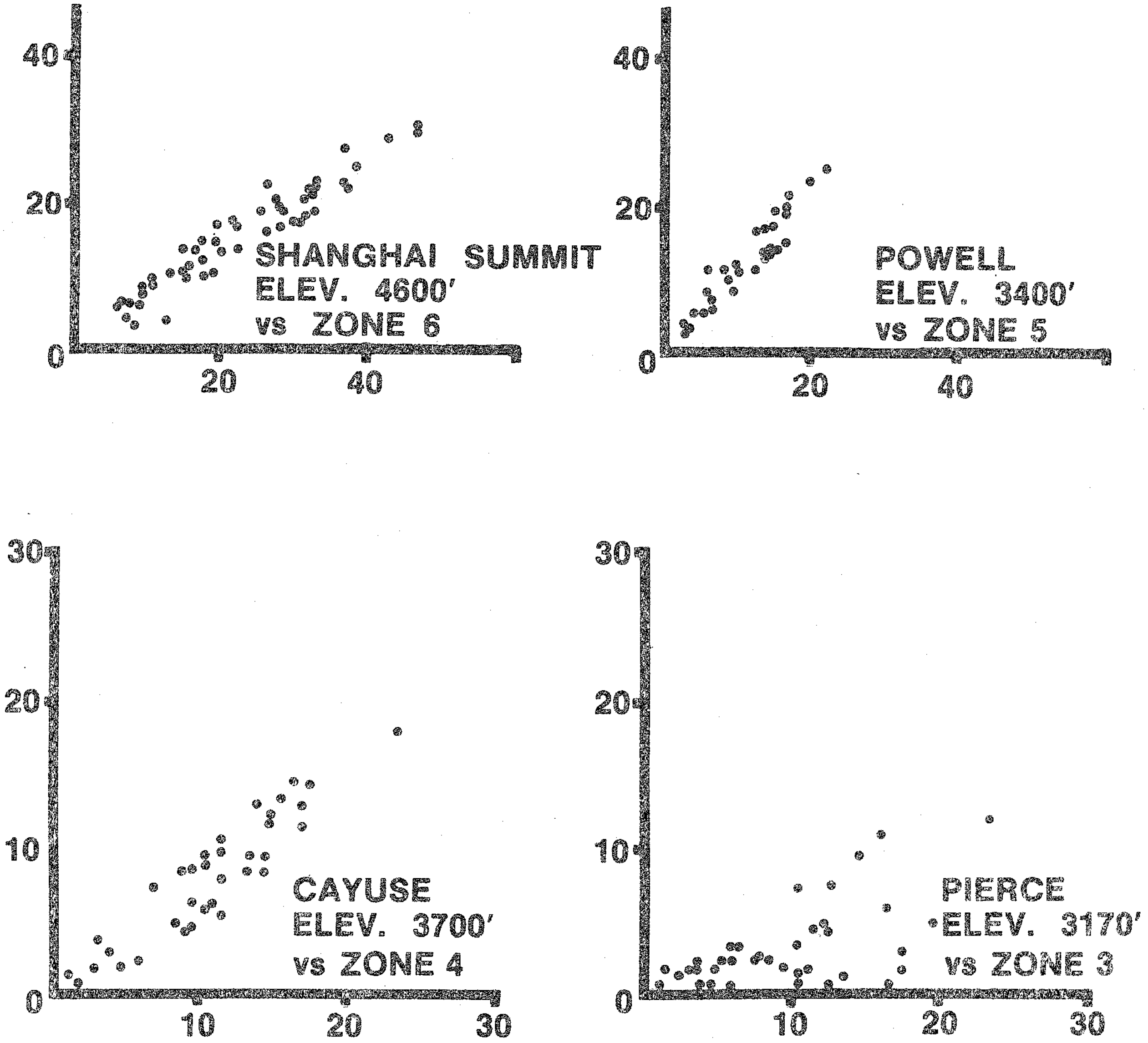


FIGURE 7

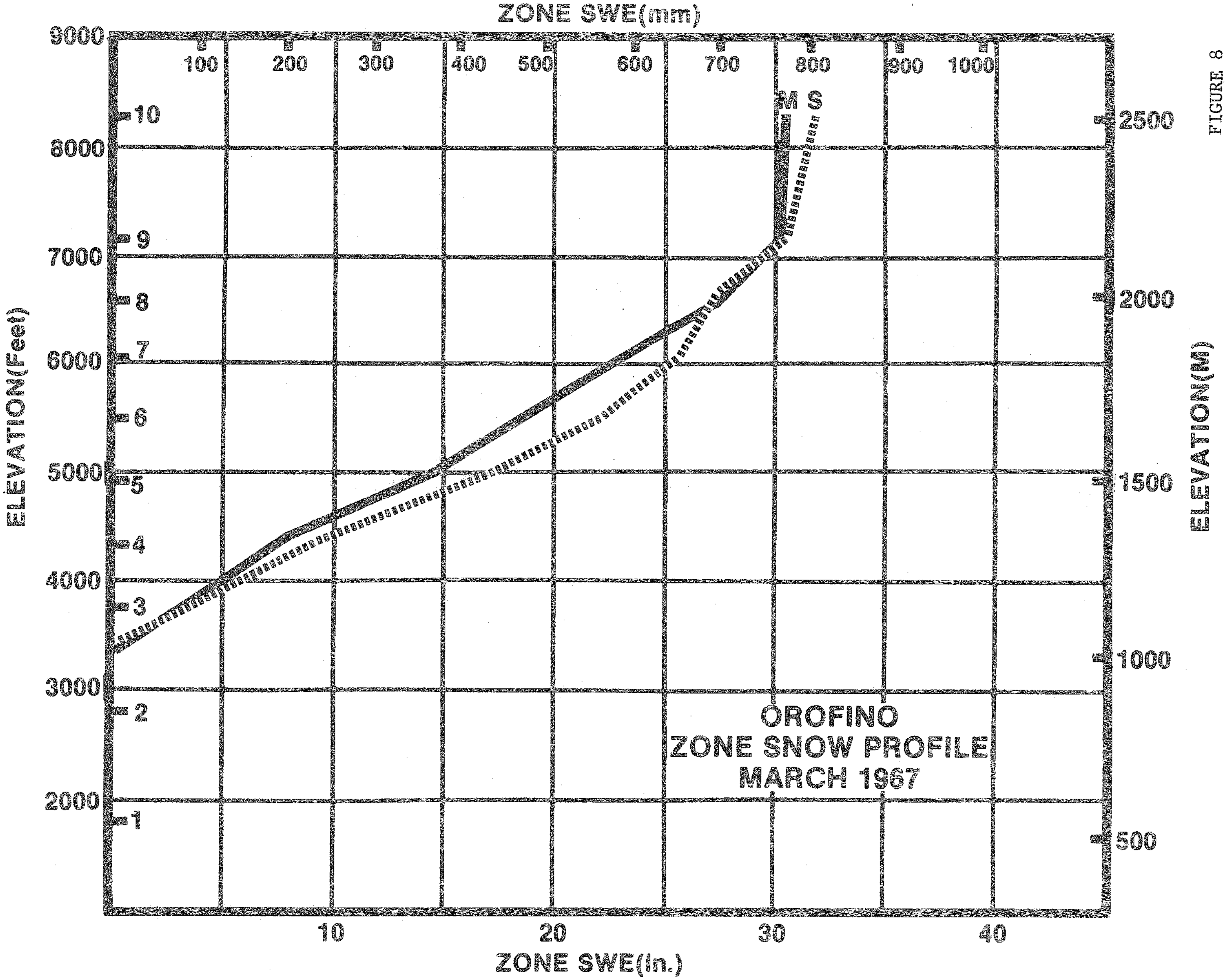

ZONE SWE(mm)
100
200
300
400
500
600
700
800
900
1000
M
S
9000
8000
7000
6000
5000
4000
3000
2000
ELEVATION(Feet)
10
9
8
7
6
5
4
3
2
1
2500
2000
1500
1000
500
ELEVATION(M)
OROFINO
ZONE SNOW PROFILE
MARCH 1967
10
20
30
40
ZONE SWE(in.)

FIGURE 8

REFERENCES

1. Anderson, E., "NWS River Forecast System-Snow Accumulation and Oblation Model," NOAA Technical Memorandum HYDRO-17.
2. Anderson, E. A., "The Synthesis of Continuous Snowmelt Hydrographs on a Digital Computer," Stanford U. C. E. Technical Report No. 36, 1964.
3. Church, P. E., "Variability of Annual Snowfall," WSC 1941, TAGU, Part I-B, 1941, pp. 159-170.
4. Carroll, T. R., "A Procedure to Incorporate Snow Course Data into NWSRFS," Proceedings, Workshop/Meeting on Modeling of Snow Cover Runoff, U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N. H., 1978.
5. Snow Hydrology, North Pacific Division, U. S. Army Corps of Engineers, Portland, Oregon, 30 June 1956.
6. Daniels, G. E., "Area Distribution of Snow Cover in Relation to Weather and Terrain," WSC 1948, pp. 170-187.
7. Hannaford, J. F., Bush, R., Barsch, R. E., "The Development and Application of a Hydrologic Model as an Operational Tool," WSC 1970, pp. 7-15.
8. Henry, A. M., "Increase of Precipitation With The Altitude," MWR, Volume 47, 1919, pp. 33-41.
9. Himmel, J. M., "Variation in Depth of Precipitation and Water Equivalent of Snow on the Ground," WSC 1948, pp. 117-131.
10. Lee, C. H., "Precipitation and Elevation in the Sierra," MWR, Volume 39, 1911, pp. 1092-1099.
11. Linsley, R. K., "A Simple Procedure for Day to Day Forecasting of Runoff from Snow Melt," TAGU Volume 24, Part III, 1943, pp. 62-67.
12. Pierson, T., "Simulating Runoff to the Hungry Horse Reservoir of Western Montana," WSC 1974, pp. 96-101.
13. Pipes, A., Quick, M. C., Russell, S. O., "Simulating Snowmelt Hydrographs for the Frazer River System," WSC 1970, pp. 87-91.
14. Rockwood, D. M., "Program Description and Operating Instructions, SSARR," U. S. Army Technical Bulletin 22, 1964.
15. Rockwood, D., Anderson, J., "Simulation of Runoff from Rain-Snow Basin," WSC 1970, pp. 82-90.
16. Solo, J. V., "A Quantitative Forecast System of Runoff," WSC 1940, TAGU 1940, Part III-B, pp. 858-870.
17. Speers, D., Kuehl, D., Schermerhorn, V., "Development of the Operational Snow Band SSARR Model," Proceedings, Workshop/Meeting on Modeling of Snow Cover Runoff, U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N. H., 1978.
18. Stall, L. S., "Quantitative Method of Forecasting Runoff from Snow Surveys," WSC 1940, TAGU Part III-B, 1940, pp. 855-858.
19. Summersett, J., "Reproduction of Snowmelt Floods in the Boise Basin," WSC 1953, pp. 36-43.
20. Tarble, R., Burnash, R., "Directions in Water Supply Forecasting," WSC 1971, pp. 93-97.
21. Twedt, R., Burnash, R., Ferral, R., "Extended Streamflow Prediction During the California Drought," WSC 1978, pp. 92-96.
22. Twedt, R., Schaake, J., Peck, E., "NWS Extended Streamflow Prediction," WSC 1977.
23. Wilson, W. T., "Empirical Methods for Estimating Snow Melt Rates," WSC 1948, pp. 97-104.
24. Workshop/Meeting on Modeling Snow Cover Runoff, U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N. H., 1978.