SIMULATING RUNOFF TO THE HUNGRY HORSE RESERVOIR OF WESTERN MONTANA

By

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Introduction

The Branch of Power Supply, of the Bonneville Power Administration, schedules the power operation of 26 dams in the Federal Columbia River Power System. Streamflow is one of the major variables in the models used to schedule the generation of this large hydropower system. Improved streamflow forecasting procedures would not only lead to more accurate forecasts of unregulated streamflow but also to more efficient scheduling of water releases from storage reservoirs and run of the river ponds. Streamflow and other inputs to the scheduling process are developed cooperatively by the Columbia River Forecasting Service (CRFS) composed of the National Weather Service, Bonneville Power Administration, and U. S. Army Corps of Engineers. The Streamflow Synthesis and Reservoir Regulation Model (SSARR) (1,2) is the basic forecasting model of the CRFS. This model has not been reconstituted for a sequence of years (tuned) on an annual basis for a major basin east of the Cascade Mountains with a large snowmelt component. One goal of the CRFS is to develop runoff coefficients for all major drainages in the Columbia River Basin that pertain to the annual runoff regime and to use this model to predict daily streamflow and perhaps the volume runoff on a seasonal basis. This report describes recent work by the BPA unit of the CRFS directed toward the achievement of this goal.

Modifications to the SSARR Model

We modified the Basin Model portion of the SSARR version described in reference 1 with the intent of improving its performance during the fall and winter seasons and to better account for the accumulation and depletion of the snow pack.

Daily Lapse Rate of Temperatures

In the Basin Model a lapse rate of temperature that varies daily was considered more realistic than a set lapse rate for the season. For this calculation a 10,000-foot free air temperature was determined by extrapolation from known temperatures at the 700 millibar and 850 millibar constant pressure levels. Temperatures of these levels were determined from grid point upper air data on magnetic tapes obtained from the National Center for Atmospheric Research. A lapse rate of temperature was then determined by subtracting this 10,000-foot temperature from a maximum temperature station in the basin. This difference was then divided by the difference in elevation of the two measurements. This daily lapse rate takes into account the variable freezing level and defines elevation zones of snow accumulation and depletion.

Zonal Division

In an effort to improve the accounting of the snow pack, the basin was divided into 10 zones of equal area instead of treating the basin as one zone with a snow depletion curve as is done in the current operational forecasting SSARR model. In the model, each zone is either snow-covered or snow-free. The 35^0 F. level is calculated by using the maximum daily air temperature at a climatological station in the basin and the daily lapse rate determined from upper air data. All zones above the 35° F. level accumulate snow and all zones below deplete snow cover.

Orographic Effect

An orographic precipitation effect was chosen for the model which distributes precipitation as a function of elevation. This function (figure 1), designed to give the best results, increases the weighted precipitation up to 7,000 feet elevation and decreases it above that elevation. A possible reason for the shape of the distributing function could

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be based on the concept of a moist parcel of air cooling and increasing in volume as it rises causing the parcel to approach its dew point temperature and maximum rainfall. Above this point, the rainfall diminishes due to reduced moisture content. We realize the flat portion of the function between 4200 and 6000 feet looks questionable but this curve is experimental and subject to modification.

Daily Evapotranspiration Index (ETI)

A daily evapotranspiration index for each zone was defined as in reference 2 as the difference between the temperature in each zone and 35° F. multiplied by the monthly average wind velocity in the basin. This value was then multiplied by a constant, .00629, which took into account atmospheric pressure. We also assumed that the ETI=0 if a zone is snow covered, or if the temperature in a zone is less than 35° F. The ETI is one of the factors in the Soil Moisture Index calculation which defines the proportion of direct run-off associated with rain or snow melt.

Daily Melt Rate

A daily melt rate determined from a curve (figure 2) of accumulated degree-days (°F) vs. melt rate (inches/accumulated degree-day) was employed for each zone. In this way the melt rate fluctuates in every zone with any sequence of warm or cold weather with 35° F. used as the base temperature for snow melt. The accumulated degree-days will decrease for temperatures less than 350 F. This change in the basic SSARR logic improved the models skill at simulating the seasonal hydrograph. It allows one to determine a certain threshold for melt to start based on degree-days. This procedure tends to account for the ripening of the snow pack.

The Hungry Horse Basin

The Hungry Horse drainage, located on the South Fork of the Flathead River in western Montana, was chosen as one of the initial basins for modeling the annual stream-flow and snow pack regimes because of its importance to the Federal Columbia River Power System. The Hungry Horse Basin comprises an area of 1660 square miles with an average annual runoff of 2,239,000 acre feet. The Hungry Horse hydroelectric project is second only to the Dworshak project on the Clearwater River in at site hydroelectric potential energy per unit of water. It also plays a major role in controlling floods on the South Fork of Flathead River and at downstream points.

Station Selection

We tried a number of precipitation stations in our initial modeling work. We narrowed the selection by choosing climatological stations with annual precipitations close to the normal annual precipitation for the basin. This procedure yielded 3 stations: Summit, West Glacier, and Hungry Horse Dam. These three stations were shown to have consistent records by double mass curve analysis. Trial runs with various combinations of the precipitation from these stations showed the best results in terms of least squared errors were achieved by using Hungry Horse Dam alone with a weight of 1.41. The maximum temperature station chosen was also for Hungry Horse Project. The five years of climatic data used in this study were assembled from the large library of climatic data available on magnetic tape at the Bonneville Power Administration.

Simulations Results

The basin runoff was reconstituted on three water years of data: 1965, 1970, and 1971, and the coefficients thus derived were tested on two years of independent data: 1972 and 1973. The results of these reconstitutions are shown in Figure 3. You will note that the net errors in the dependent years were tolerably small with an average January-July net error of -29 ksfd indicating that the model simulations tended to produce too little runoff. Not shown in the Table is the monthly mean absolute error of the reconstitutions for independent years. This statistical measure of performance amounted to 19.4 ksfd on a monthly average basis indicating a daily average absolute error of about 650 cubic feet per second.

In applying this model to the independent data set, the coefficients adequately describe the total runoff that occurred in 1972. The model had a total error of +4 ksfd for the January-July period. On the other hand, during the extremely dry water year of 1973 the performance of the model deteriorated markedly with an average net error of +95 ksfd. For the two independent years the model yields a monthly mean absolute error of 24.0 ksfd for a daily average of 800 cfs which is slightly higher than for the dependent sample. The +95 ksfd net error in specification of the 1973 runoff was of about the same magnitude but of a different sign than the error resulting from use of statistical model operated by CRFS (3) with known weather input. The skill of the CRFS statistical model for forecasting the seasonal runoff is shown in Figure 4. The CRFS statistical model had a net error of -72 ksfd.

This demonstrates that neither the CRFS statistical model nor this version of the SSARR simulator is tuned to the dry water year runoff. The size of the model's error in 1973 demonstrates that additional adjustments to the basin coefficients need to be made to allow the model to fit the full range of runoff conditions and especially the dry years.

The correlation between the actual January-July runoff and the simulated runoff error is -0.90. The negative correlation indicates that the model simulates too much water in low runoff years and too little water in high runoff years. To correct this, a Soil Moisture Index (SMI) table will be tried in the simulations which will be modified by the addition of rainfall intensity as one of the arguments. This change will allow a higher SMI and therefore, more runoff in wet or high runoff years and maintain a lower SMI and lower runoff in dry or low runoff years. The three-dimensional SMI table is one of the current options of the SSARR.

Figure 5 is a plot of the actual and simulated runoff for the first independent water year, 1972. From the plot it can be seen that the simulated streamflows are fairly highly correlated with the actual streamflows. The beginning of the spring melts seem to be adequately modeled as does the general shape of the recession. Two rather large errors are noted. First is a large underestimation of the streamflows by the model which occurred just after the highest runoff, between June 12 and June 21. The early season error seems to balance out the error noted during the recession period. This error pattern seems to indicate that the snow pack is sufficient in the model. These two large errors probably indicate that either the upper air temperature is in error affecting the lapse rate and the amount of heat given to the upper zones, or that the base flow infiltration index needs improving.

The same error pattern was noted in the plot of data for the second independent water year, 1973. This is shown in Figure 6. The underestimation of the simulated stream-flows was noted from May 16 through May 21. This early season error seemed to be compensated for by an error of the opposite sign that started around the end of May. Apparently the under calculation of snow melt earlier in the season forced an over calculation of snow melt in the latter part. Again the simulated and actual hydrograph are fairly highly correlated. In fact, the correlation of the monthly averages of the actual and reconstituted stream-flows is 0.97 for the independent years. This compares with the correlation of 0.98 for the three years of the developmental sample.

It is important to note that some of the errors in the reconstitutions would be compensated for if this model was operating in the forecast mode. No attempt was made in this simulation to adjust the coefficient as the season progressed. As an example, a large part of the error made in the January-July runoff in 1973 would have been eliminated if the simulated flows during the early season have been reduced to the actual base flow values.

Utilization

Use in Assessment of Cloud Seeding Benefits

Besides forecasting daily inflows given the predicted weather sequence, the model has been used for other studies as well. A recent use was to estimate the runoff increase that might be expected from cloud seeding in the Hungry Horse Basin. To answer this question *we* took a 5-year sample of data and generated a snow pack in the model which was increased by 10 percent in the model during the months November through March, which was the cloud seeding period proposed for last year. We then allowed the actual weather in these years to operate on the snow pack. The resulting runoff from this increased snow pack was then compared to the simulated runoff produced without increasing the snow pack. The

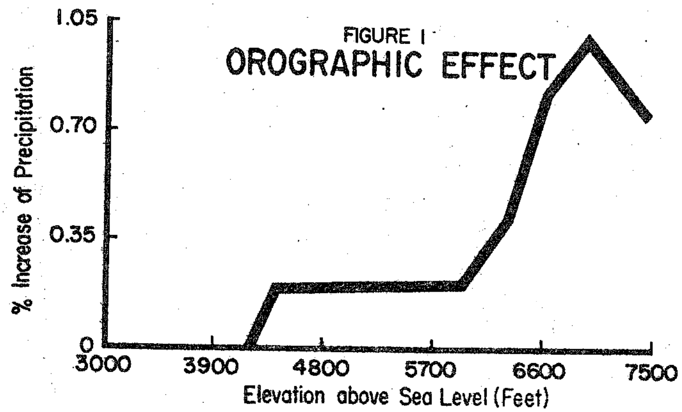


FIGURE 1
OROGRAPHIC EFFECT

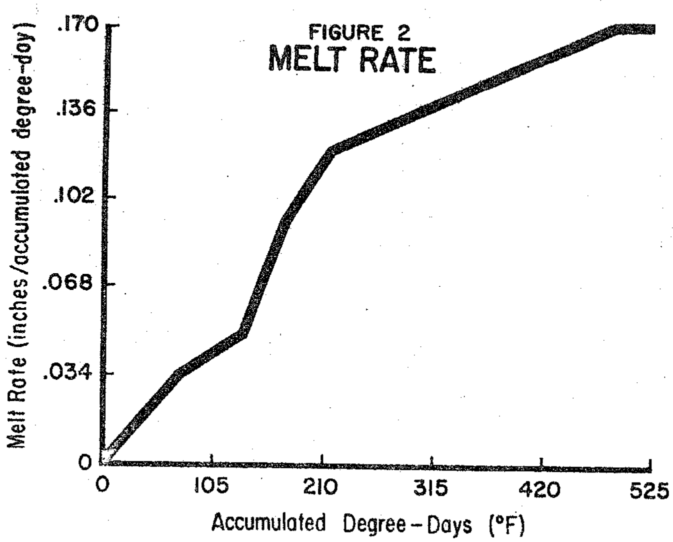


FIGURE 2
MELT RATE

MODEL ERRORS IN SIMULATION OF JANUARY – JULY RUNOFF (KSFD)

water year	actual runoff	simulated runoff	error	% error/actual
1965	1444	1409	–35	–2.4
1970	1143	1177	+34	+3.0
1971	1559	1473	–86	–5.5
1972	1510	1514	+4	+0.3
1973	771	866	+95	+12.3
MEAN	1285	1288	+3	+1.5
σ	330	269	69	

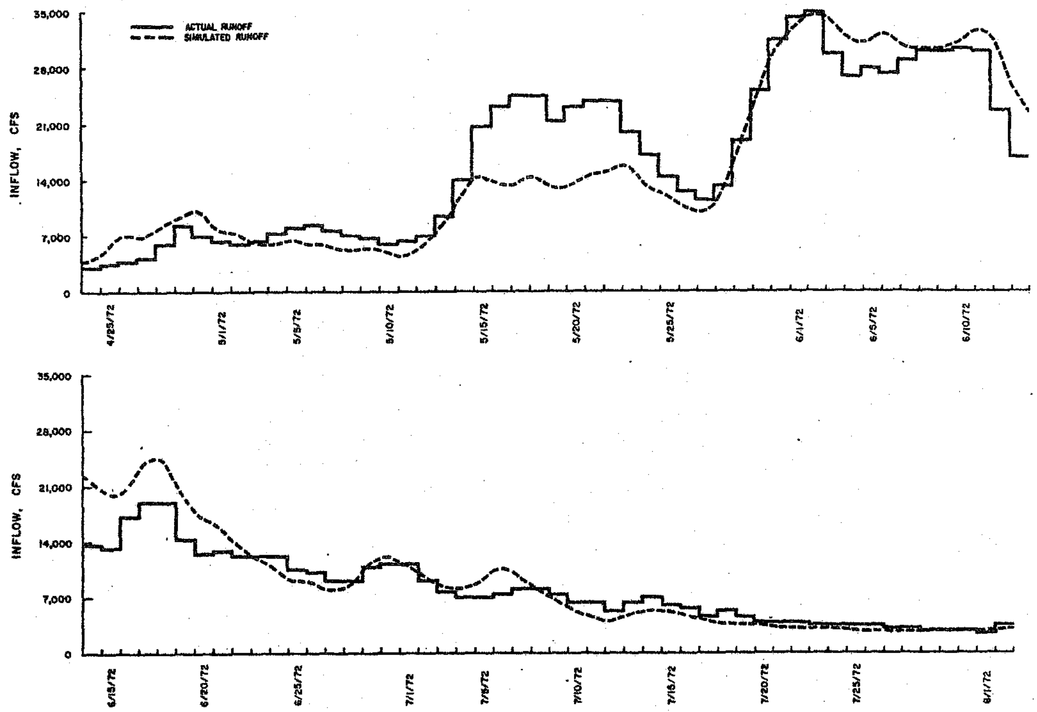
FIGURE 3

CRFS STATISTICAL MODEL ERRORS OF JANUARY – JULY RUNOFF (KSFD)

water year	actual runoff	simulated runoff	error	% error/actual
1965	1444	1600	+156	+10.8
1970	1143	1224	+81	+7.1
1971	1559	1537	–22	–1.4
1972	1510	1574	+64	+4.2
1973	771	699	–72	–9.3
MEAN	1285	1327	41	+2.3
σ	330	382	90	

FIGURE 4

HYDROGRAPH OF SPRING RUNOFF, 1972



HYDROGRAPH OF SPRING RUNOFF, 1973

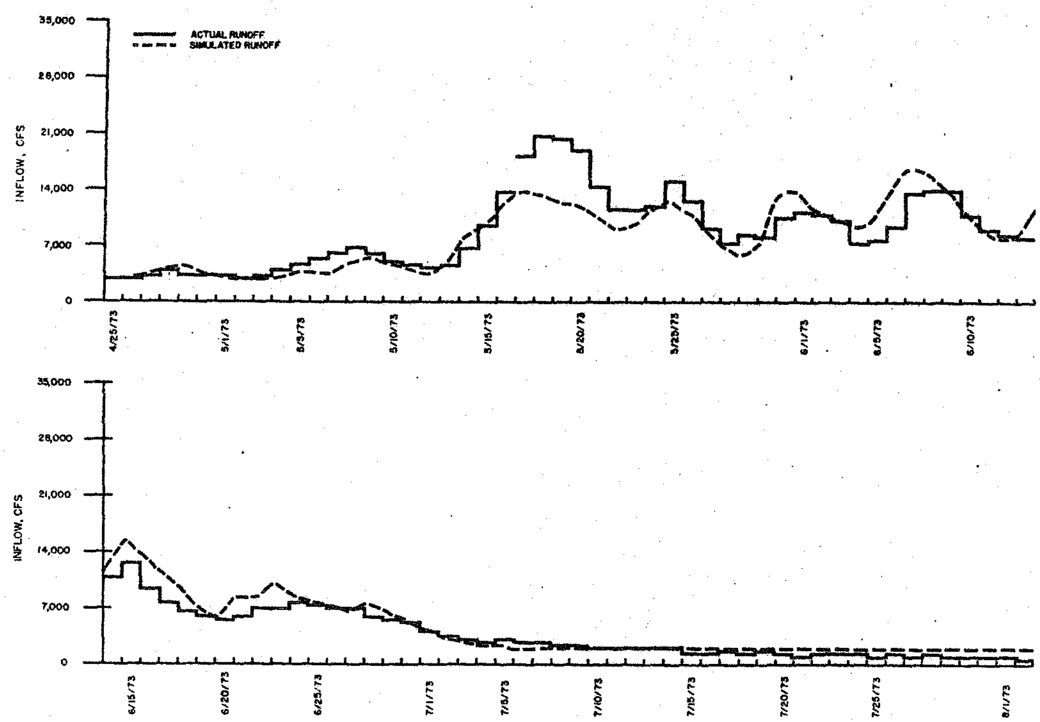


FIGURE 6

result was an increase of 7 to 9 percent, depending on weather sequences, in the January through July runoff in the 5-year sample. This suggests that runoff would be increased by 7 to 9 percent if the snow pack is increased by 10 percent. Other studies have shown an increase in runoff greater than 10 percent could be expected so our low results surprised us.

Use in Flood Control

The model has also been used to estimate when the spring flood threat at Columbia Falls, Montana, is essentially over. At this time the Hungry Horse discharge can be reduced to minimum permitting a more rapid refill. To do this, the model is run daily with the subsequent days of the 1916 extreme weather sequence, which produced a large flood, as the forecasted weather input. When the simulated peak flow at Columbia Falls, as forced by the 1916 weather, drops below 50,000 cfs, the flood threat is assumed over for the season indicating the prudence of a minimum outflow operation.

Use in Volume Forecasting

We plan to test the model's ability to generate updated estimates of the distribution of seasonal runoff into the Hungry Horse reservoir. On any date, the forecasted weather input would consist of a historical set of seasonal temperature and precipitation which would operate on the snow pack generated in the model by actual weather to date. The result would be a distribution of seasonal runoffs. We only have 13 years of weather data to use as the historical set. We are considering expanding this set to 100 years or more by developing a regression model based on auto-correlations and cross-correlations of temperatures and precipitation, in a manner similar to that reported in reference 5. From this procedure, 100 or more different volume forecasts can be produced from which a mean and standard deviation can be calculated allowing for probability statements about the expected seasonal runoff which can be updated on a daily basis.

Comparing the statistical volume forecasting model for Hungry Horse used currently by the CRFS, described in reference 4 (Figure 4), with the total simulated January-July runoff of the Basin Model (Figure 3) shows that for the five years tested, the Basin Model produced a smaller mean error and standard deviation than the statistical model with a full season of actual weather as input. The statistics are not strictly comparable to base any firm conclusions on since the five years for the CRFS model are all independent years and three years of the other model are dependent years with only two years independent.

Conclusions

This basin model is experimental but does show that a major basin with a large snow melt component can be reconstituted on an annual basis with good results. Some adjustments are still needed to the coefficients and perhaps some additional precipitation stations are needed to better simulate the broad range of runoff, An addition of a three-dimensional soil moisture index table has the potential to also improve the model's skill. The model's most important aspect is its ability to build up and melt the basin snow pack with only temperature and precipitation inputs. The uses of a Basin Model are as varied as the many facets of hydrology. It can be for planning flood control operations, streamflow forecasting, and for studies assessing cloud seeding benefits. Additional research could also demonstrate that the use of the Basin Model approach will provide an improved method of forecasting the volume of seasonal runoff.

ACKNOWLEDGEMENTS

I wish to thank Don Kuehl of the National Weather Service for his counseling in the techniques of streamflow reconstitution and Robert Griffin, Bonneville Power Administration, for his initial design and programming of the Basin Model used in this study.

REFERENCES

1. Rockwood, D. M., "Streamflow Synthesis and Reservoir Regulation", U. S. Army, Division North Pacific, Portland, Oregon. Technical Bulletin No. 22, January 1967.

2. U. S. Army, Division North Pacific, "Program Description and User Manual for SSARR Model", Portland, Oregon. September 1972.

3. Columbia Basin Interagency Committee, "Derivation of Procedure for Forecasting Inflow to Hungry Horse Reservoir, Montana". November 1964.

4. Feyerherm, A. M. and Bark, L. Dean, "Probability Model for Simulating Temperature and Precipitation, Third Conference on Probability and Statistics in Atmospheric Science". June 1973.