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STREAMFLOW REGIONALIZATION IN WESTERN MONTANA[1]

by

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The rain-on-snow-dominated hydrology of western Montana's mountainous terrain is very complex. This complexity makes it difficult to estimate water yield and timing from ungauged mountain watersheds. Nevertheless, such estimates are needed.

Numerous methodologies have been developed nationwide to estimate flood frequencies and average annual water yield (U.S. Agricultural Research Service 1977), yet hydrologists caution that these models should not be expected to provide predictions applicable to western Montana.

Models developed for use in Montana have been based on input-output characteristics. In general, precipitation data have been used as inputs, and data from measured stream flow have been used as outputs. More accurate estimation of mountain precipitation has improved each generation of models.

This paper reviews previous attempts to regionalize stream flow estimation in western Montana and presents two methods currently being used.

Previous Regionalization Attempts

Previous attempts to regionalize streamflow estimations were based on basic hydrologic principles. For example, the combination of climatic, physiographic, vegetational, geologic and edaphic factors is unique in every watershed. So, if regions with relatively homogeneous watershed factors could be defined, it should be possible to build flow-estimation models that produce little prediction error.

Boner and Buswell (1970) divided Montana into three hydrologic regions (Figure 1). They developed regression models to predict flood flows and average annual water yield in each region. Ten basin and climatic variables were used in linear regression equations. Standard errors of estimate varied according to which dependent variable was used in each equation; the range was from 26 to 180 percent. The authors decided that these equations were not acceptable. They concluded that available information did not adequately describe basin characteristics, particularly geological characteristics and basin precipitation (valley observations, U.S. Weather Bureau 1969).

Farnes (1971; revised 1976, 1978) developed regionalization procedures to estimate peak flows and average annual water yield. When estimating peak flows, Farnes relied on the definition of three general climatic areas that influence peak flows in Montana and the subsequent identification of six regions for peak-flow estimation (Figure 2). In estimating average annual water yield, Farnes identified four precipitation zones and developed models for runoff prediction based on

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[1] *Presented at the Western Snow Conference, April 20-23, 1982, Reno, NV.*

average annual basin precipitation. Errors in predictions were attributed to "alpine-rocky" or "deep-soil, heavily timbered" conditions. Farnes claimed that runoff estimation accuracy was 15 percent for most streams (Figure 3).

Farnes' improvement on the Boner and Buswell attempt can be attributed almost entirely to the development of U.S. Soil Conservation Service (SCS) mountain precipitation maps for Montana (1971; revised 1978). Data for these maps were derived from snow-survey information. Development and expansion of the snow-survey and Sno-tel systems in Montana have allowed more accurate determination of mean annual mountain precipitation.

Johnson and Omang (1976) divided Montana into seven geographic areas and developed regression equations to estimate the magnitude and frequency of floods in those regions (Figure 4). The models used drainage area, main-channel slope, mean annual precipitation and an areal-weighting factor to reduce unexplained variance.

Regions were delineated by uniformity of skew coefficients.[2] Precipitation data were obtained from the SCS maps. Nevertheless, the average standard estimate error for floods of selected return periods was more than 60 percent in all regions.

New Regionalization Models

Two prediction methods were recently adapted for use in western Montana. The first uses procedures developed by Orsborn (1975, 1976, 1978) to delineate hydrologic regions. The second uses channel geometry to estimate average annual discharge and mean annual flood (Wahl 1977, Williams 1978, Harenberg 1980).

If a watershed is considered the integrator of all climatic, physiographic and land-use factors, a basic input-output model may be formed:

$$Q_{AA} = C(P \times A)$$

where Q_{AA} = discharge (average annual) in cfs.
P = mean basin precipitation (inches)
A = watershed drainage area (mi^2)
C = coefficient that varies as a function of climatic, physiographic and land-use factors.

The coefficient, C, was used to define six hydrologically homogeneous regions in Montana (Figure 5). The boundaries of these regions were placed arbitrarily to coincide with major topographic features. Region O (eastern Montana) was not included in the model, and no attempt was made to delineate it from adjacent region 1 (central Montana). The data base included 140 streams with adequate discharge records. The coefficient, C, was determined for each stream, and a hydrologic region was arbitrarily defined by a range of coefficients. The widths of the coefficient ranges were chosen to insure adequate sample sizes for the regression model in each region. Logarithm transformations were used to achieve variance homogeneity. The regional models are "best-fit" equations for the data in each region. Watershed areas and mean basin precipitation were obtained from Johnson and Omang (1976) (Figure 6).

Sixteen randomly chosen streams were removed from the data base before regression analysis. These watersheds were categorized according to their location on Figure 5 and the

Table 1

Test Streams (not in regressions).

Map Ident.	USGS GAG Number	Name	Hyd. Region	Yrs. of Record	Area	PPT	QAA Meas.	Regional-ization Pred.	SCS Pred.	Channel Geometry Prediction
A	6-160	Horse Prairie Ck.	2	7	325	18	109cfs	113	77.9	
B	6,260	Birch Ck.	2	27	36	36	29.3	24.8	37.7	
C	6-355	Norwegian Ck.	2	9	78	25	48.5	37.4	35.6	
D	6-845	S.F. Sun River	3	20	157	21	94.4	98.3	56.6	
E	6-760	Newland Ck.	2	8	6.7	18	2.9	2.3	1.6	
F	6-885	Muddy Ck.	2	34	314	12	122	73	0	
G	6-920	Two Medicine Riv.	4	36	317	36	381	449	332	
H	6-950	Birch Ck.	4	30	105	35	159	145	104	
I	6-1970	Big Timber Ck.	4	12	74.6	25	76.9	74	39	
J	6-2105	W.F. Rock Ck.	3	10	66.9	38	66.5	75.8	77.2	
K	12-3265	Trout Ck.	3	6	34.8	36	36.6	37.3	36.4	
L	12-3295	Flint Ck.	2	29	208	31	99	124	161.9	
M	12-3700	Swan River	3	48	671	52	1148	1046	1319	1234
N	12-3780	Mission Ck.	2	9	74.8	48	71.7	69.1	129.4	
O	12-3550	Flathead Riv.	4	19	450	55	971	971	963	920
P	12-3425	W.F. Bitterroot	3	29	317	32	286	303	264	236

AVERAGE REGIONALIZATION PREDICTION ERROR — 12.5%
AVERAGE SCS PREDICTION ERROR — 35%
AVERAGE CHANNEL GEOMETRY PREDICTION ERROR — 10%

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[2] *Skew is a measure of the asymmetry of the flood frequency distribution. Kottegoda (1980) discusses the unreliability of regional skewness in the definition of hydrologically homogeneous areas (see references).*

Figure 1
Boner and Buswell Regions, 1970

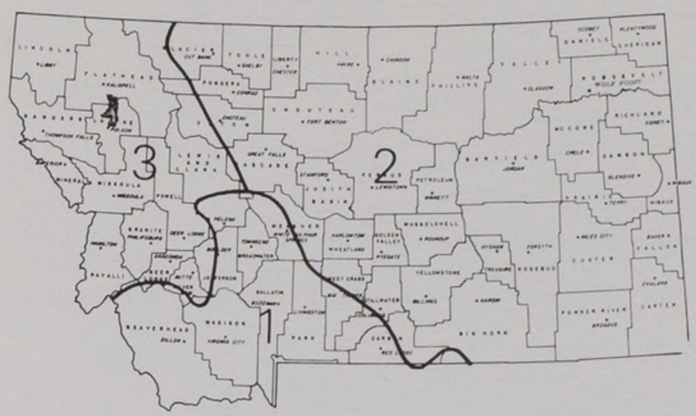
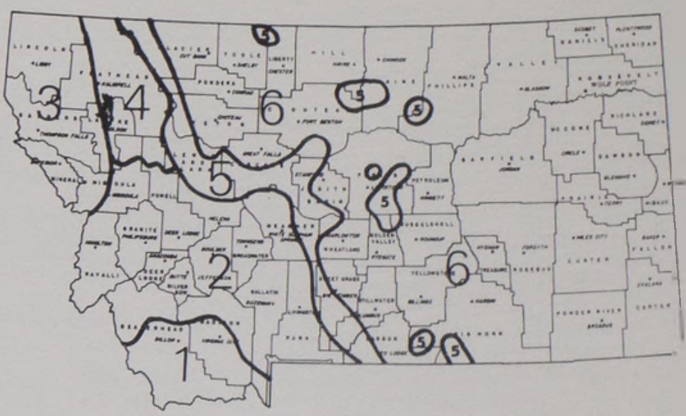


Figure 2
Farnes' Peak Flow Regions, 1972



appropriate regional regression equations were then applied. Analysis of the test streams produced an average absolute prediction error of 12.5 percent. This compares to an average SCS prediction error of 35 percent on the same test streams (Farnes 1978) (Table 1).

Assuming that stream channels are formed by predominant flows and that average annual discharge is strongly correlated with mean annual flood in a homogeneous region (Orsborn 1976, Dunne and Leopold 1978), channel dimensions should also provide a means of estimating flows.

Channel characteristics of 40 streams (Pt. 12; Upper Columbia River Basin) in western Montana were obtained from the U.S. Geological Survey files. Basin characteristics were taken from Johnson and Omang (1976) and Boner and Buswell (1970). A stepwise regression, using logarithm transformations for homogeneity of variance, resulted in:

$$Q_{AA} = \frac{.0336\ (\text{Bank-full channel width})^{.76}(\text{Area})^{149}(\text{Ppt.})^{1.04}}{(\text{stream gradient})^{.21}}$$

$R^2 = .98$

Further, mean annual flood (QF_2):

$$QF_2 = .408\ (\text{Bank-full channel width})^{1.949}$$

$R^2 = .93$ (Figure 7)

Three streams withheld from the data base to test the models had an average prediction error of 10 percent for both QAA and QF_2.

Prediction Error and Model Sensitivity

There are two basic types of errors associated with regionalization techniques. The first involves misdelineation of region boundaries and the second involves model sensitivity. The first method, based on Orsborn's input/output ratios, can be unreliable, particularly when used to evaluate areas where non-consecutive regions adjoin. For example, if a Region 1 stream was classified in Region 3, huge estimation errors would result. Thus, general knowledge of a stream's hydrologic behavior in relation to other streams in the region is necessary before the models can be applied.

The second method, based on channel geometry, was developed for streams draining into the Upper Columbia River Basin. This boundary is well-defined, and the models should be used only in the region.

Sensitivity analysis allows the assessment of relative change in model output caused by a change in inputs. With simple models, derivatives of output with respect to input may be taken, and the

Figure 3
Farnes' Mountain Hydrology, 1978

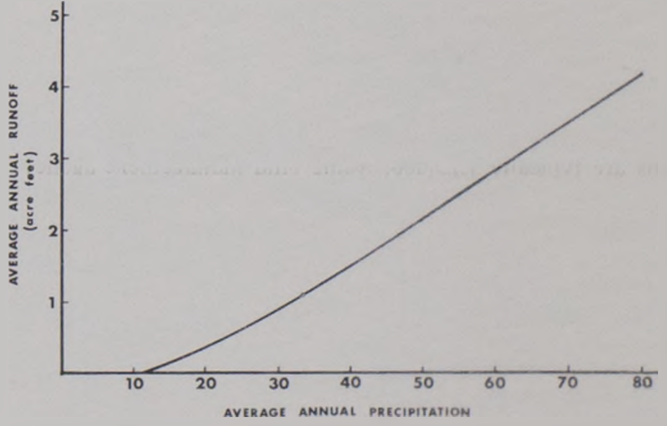


Figure 4
Johnson and Omang Regions, 1976

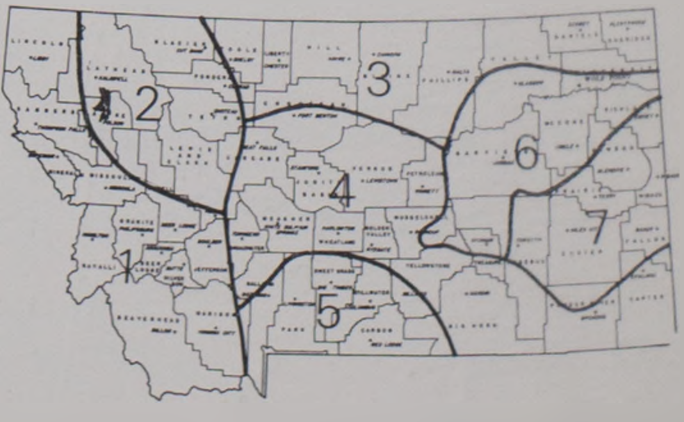
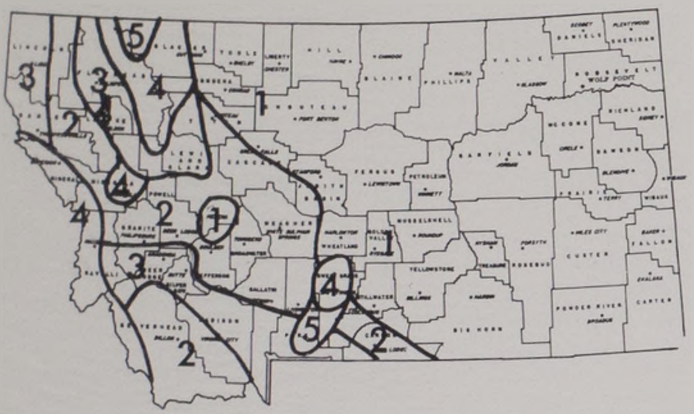


Figure 5
Streamflow Regions



sensitivity expressed as explicit functions.

With complex models such as these, solution of the partial differential equations is difficult; however, use of a few assumptions allows a simpler analysis. For example, watershed area (A) and channel gradient (GRAD) can be accurately determined from topographic maps. Similarly, bank-full channel width (WB) can be measured accurately in the field. While measurement errors of these parameters are possible, they will be relatively small. To simplify further the sensitivity analysis, we may assign a fixed value (measured without error) of 1 to all three parameters.

Accurate mean basin precipitation (P) estimates are not so easily accomplished. The largest scale routinely available for mountain precipitation maps is 1:250,000; Geological Survey maps are typically 1:25,000. Some land management agency maps may be larger scale. However, in most cases, isohyetes must be transferred to larger scales, and the aerially weighted mean basin precipitation then determined. If a 10 percent error in precipitation estimate is assumed, the associated discharge prediction error can be estimated.

In the regional models:

$$Q_{AA} = a(P\ A)^d$$

and

$$Q_{AA} = \frac{a(WB)^b\,(A)^c\,(P)^d}{(GRAD)^e}$$

if the fixed values for inputs are used,

$WB = 1,\ A = 1,\ GRAD = 1,$

and

$P = 1 \pm 10\%$ measurement error $= 1.1$ or $.9$

then, since (1) to any power = 1, in both regional models

$$Q_{AA} + \Delta Q_{AA} = a\,(P)^d$$

where ΔQ_{AA} = the relative change in Q_{AA} caused by measurement error in P

The coefficient, a, is a constant and will not alter the relative change in Q_{AA}. The coefficient, d, is nearly 1.0 in all models (Figures 6 and 7). Thus, a 10 percent error in precipitation estimate will produce an error of about 10 percent in Q_{AA} prediction.

Summary

This paper describes new regional models developed to predict average annual discharge and mean annual flood for ungauged streams in western Montana. These models use precipitation estimates derived from snow-survey information. Their performance is superior to previous modeling efforts, largely because of improvements in the quantification of mountain precipitation.

Region delineation errors are the major cause of prediction error. However, accurate estimates of mean basin precipitation are difficult, despite good information on mountain precipitation. A model sensitivity analysis found that a 10 percent error in precipitation estimate will produce about a 10 percent error in Q_{AA} prediction. Test streams indicate the new models have an average prediction error of less than 20 percent. Thus, a combined possible error of 30 percent is still superior to the possible errors generated by previous methodologies developed for western Montana.

Figure 6
Regional Regression Equations

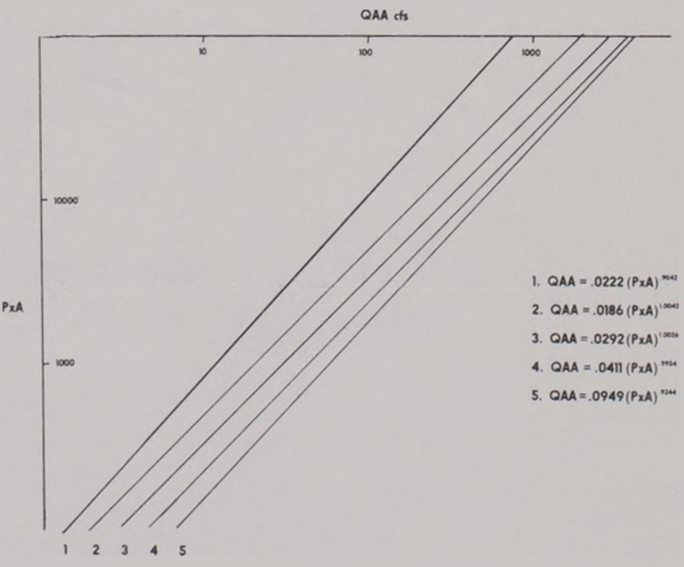


Figure 7

$$QAA = \frac{.0336\ WB^{.76}\ A^{.49}\ PPT^{1.04}}{GRAD^{.21}} \qquad R^2 = .98$$

$$QF_2 = .408\ WB^{1.949} \qquad R^2 = .93$$

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