STREAMFLOW REGIONALIZATION IN WESTERN MONTANA

By

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INTRODUCTION

The snow and rain on snow dominated hydrology of western Montana's mountainous terrain is very complex. Nevertheless, we are faced with growing needs for accurate estimates of water yield and timing from ungaged mountain watersheds. While nationwide there have been numerous methodologies developed for estimation of flood frequencies and average annual water yield (ARS 1977), we know we can't expect to apply these models directly to western Montana situations.

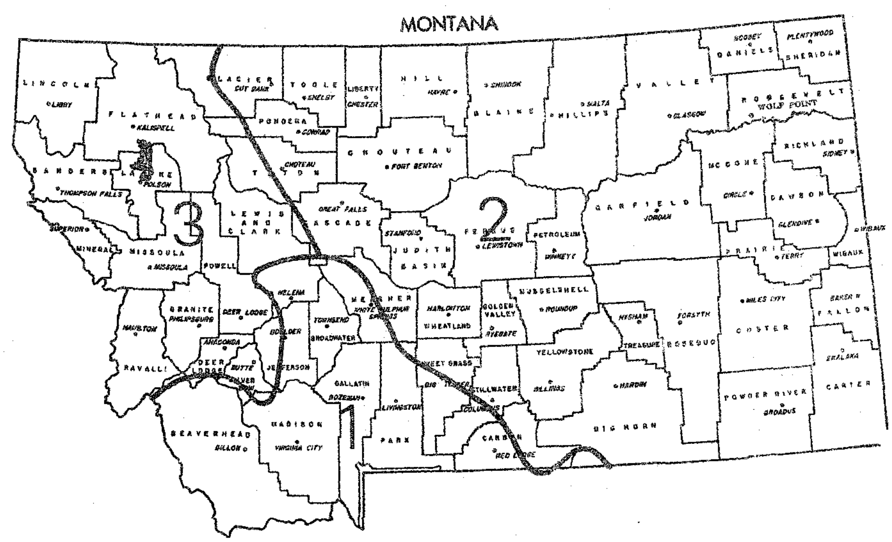
The models which have been developed for use in Montana have all been based on input-output characteristics. The accuracy of each new modeling methodology has improved because of the improvements achieved in the estimation of mountain precipitation.

PREVIOUS WORK

It is generally recognized that every watershed is unique in its combination of climatic, physiographic, vegetational, geologic and edaphic factors. It might be expected that the hydrologic character of every watershed would be unique. But if regions of relative homogeneity of the watershed factors, or their combined effect on hydrologic character, can be defined, then we may build models for estimation of flows which produce little prediction error (Sopper and Lull 1970).

Boner and Buswell (1970) divided the state into three hydrologic regions (Figure 1). Regression models to predict flood flows and average annual yield were developed for each region. Ten basin and climatic independent variables were used in the equations. Standard errors of estimate varied with dependent variables and ranged from 26 to 180%. The authors concluded that this performance was unacceptable and that the principal reason for inadequacy was that basin characteristics, particularly geology and basin precipitation (valley observations, ESSA Weather Bureau 1969), could not be accurately described from available information.

BONER & BUSWELL REGIONS 1970 figure 1



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Farnes (1971, revised 1978; 1976) developed regionalization procedures for estimating peak flows and average annual water yield. The former method relied on the definition of three general climatic areas which influence peak flows in Montana and the subsequent identification of 6 regions for peak flows estimating equations (Figure 2). The latter method identified 4 precipitation zones and developed models for runoff prediction based on average annual basin precipitation. Variation about the regressions is classified "alpine-rocky" or "deep soil-heavily timbered". Estimation accuracy is claimed within 15% for most streams (Figure 3).

FARNES' PEAK FLOW REGIONS 1972 figure 2

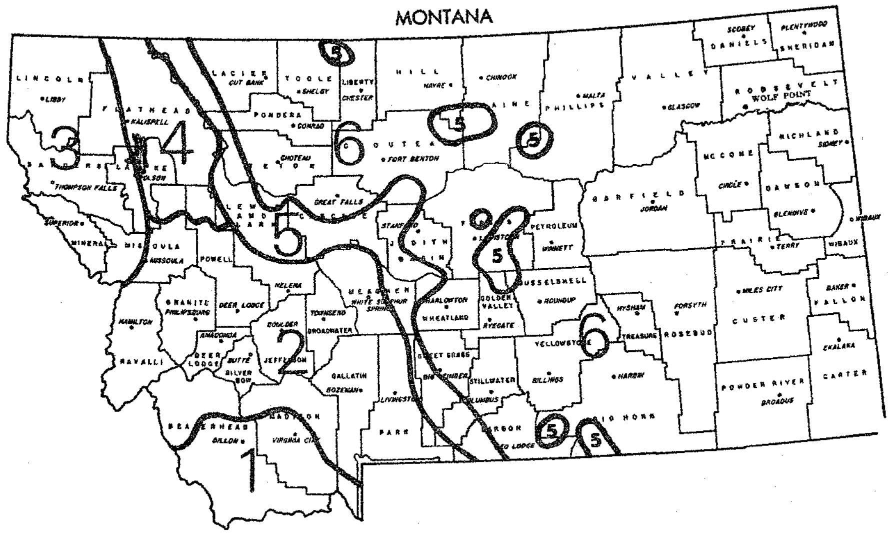
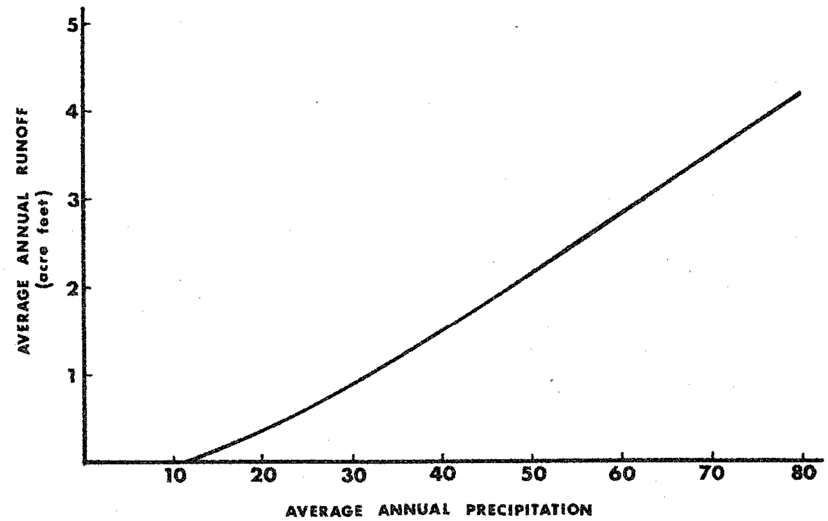


FIGURE 3. FARNES' MOUNTAIN HYDROLOGY, 1978

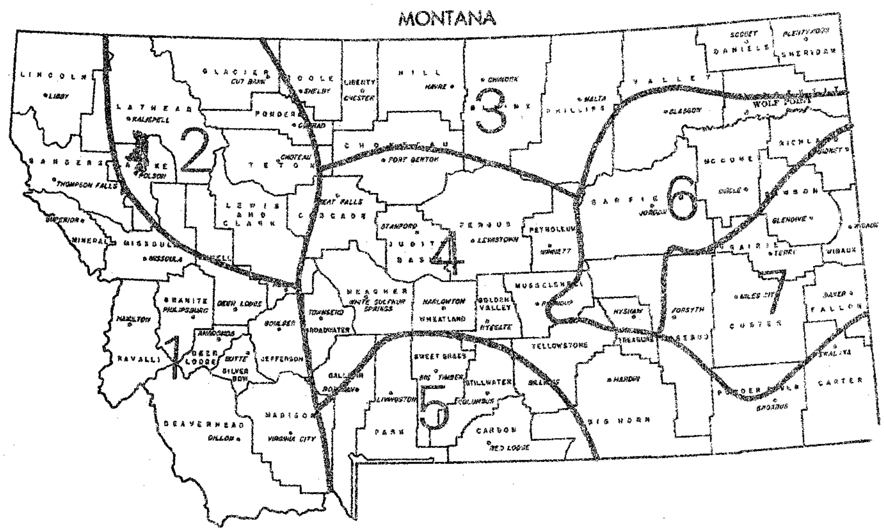


The tremendous improvement over the Boner and Buswell (1970) attempt is attributable almost entirely to the development of the S.C.S. mountain precipitation maps for Montana (SCS 1971, revised 1978). The data base for these maps were the snow survey information. Development and expansion of the snow survey and Sno-Tel systems in Montana have allowed the more accurate determination of mean annual precipitation model inputs.

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 homogeneity of skew coefficients. Precipitation data were obtained from the S.C.S. maps. Nevertheless, the average standard error of estimate for floods of selected return periods was greater than 60% in all geographic regions.

JOHNSON & OMANG REGIONS 1976 figure 4

MONTANA



NEW REGIONALIZATION MODELS

Two methodologies have been adapted for use in western Montana. The first employs procedures developed by Orsborn (1975, 1976, 1978) for the delineation of homogeneous hydrologic regions. The second employs channel geometry to estimate average annual discharge and mean annual flood (Wahl 1977, Williams 1978, Harenberg 1980).

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

$$Q_{AA} = C(PxA)$$

where Q_{AA} = discharge (average annual) in cfs.

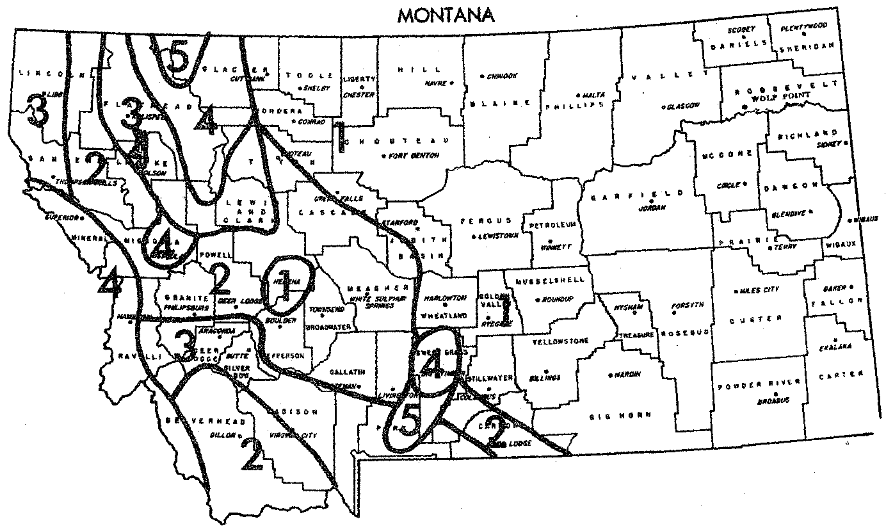
P = mean basin precipitation (inches)

A = watershed drainage area (mi^2)

C = coefficient which varies as a function of climatic, physiographic and land use factors.

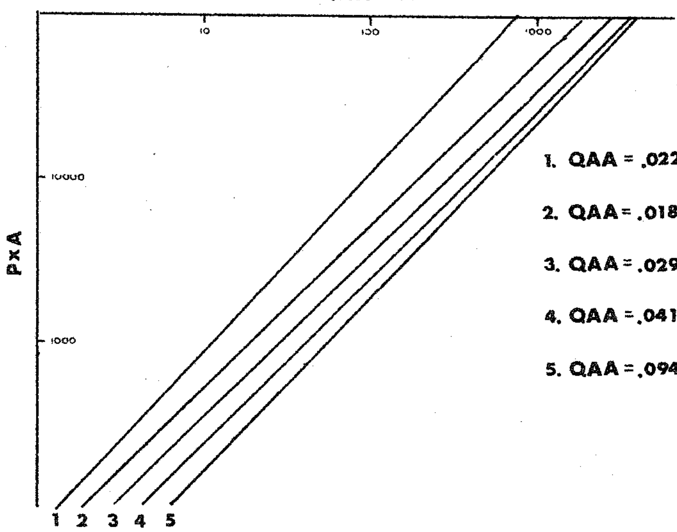
The coefficient, C, was used to define six homogeneous regions of hydrologic character in the state (Figure 5). The model for Region 0 (eastern Montana) was not developed and no attempt was made to delineate it from adjacent Region 1. The data base included 140 streams with adequate discharge records. Coefficient, C, was determined for each stream. A hydrologic region was arbitrarily defined by a range of coefficients. The widths of the coefficient ranges were chosen to produce adequate sample sizes for the regression model in each region. Log transformations were used to achieve homogeneity of variance. 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).

STREAMFLOW REGIONS figure 5



Regional Regression Equations figure 6

QAA cfs



1. $QAA = .0222\,(P \times A)^{.9042}$
2. $QAA = .0186\,(P \times A)^{1.0042}$
3. $QAA = .0292\,(P \times A)^{1.0026}$
4. $QAA = .0411\,(P \times A)^{.9954}$
5. $QAA = .0949\,(P \times A)^{.9244}$

Sixteen randomly chosen streams were removed from the data base before the regression analyses. These watersheds were then located on Figure 6 and the appropriate regional regression equations were applied. The test streams produced an average absolute prediction error of 12.5%. This compares to an average S.C.S. (Farnes 1978) prediction error of 35% on the same test streams (Table 1).

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

TABLE 1

TEST STREAMS (Not in regressions)

MAP IDENT.	USGS GAGE NUMBER	NAME	HYD. Region	Yrs. of Record	AREA	PPT	QAA MEAS.	QAA PRED.	SCS PRED.
A	6-150	Horse Prairie Ck.	2	7	325	18	109cfs	113	78
B	6-260	Birch Ck.	2	27	36	36	29	25	38
C	6-355	Norwegian Ck.	2	9	78	25	49	37	36
D	6-845	S.F. Sun River	3	20	157	21	94	98	57
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	77	74	39
J	6-2105	W.F. Rock Ck.	3	10	66.9	38	67	76	77
K	12-3265	Trout Ck.	3	6	34.8	36	37	37	36
L	12-3295	Flint Ck.	2	29	208	31	99	124	162
M	12-3700	Swan River	3	48	671	52	1148	1046	1319
N	12-3780	Mission Ck.	2	9	74.8	48	72	69	130
O	12-3550	Flathead Riv.	4	19	450	55	971	971	963
P	12-3425	W.F. Bitterroot	3	29	317	32	286	303	264

AVERAGE REGIONALIZATION PREDICTION ERROR - 12.5%

AVERAGE S.C.S. PREDICTION ERROR - 35%

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

$$Q_{AA} = \frac{.0336\ (\text{Bankfull channel width})^{.76}(\text{Area})^{.49}(\text{Ppt.})^{1.04}}{(\text{stream gradient})^{.21}} \qquad R^2 = .98$$

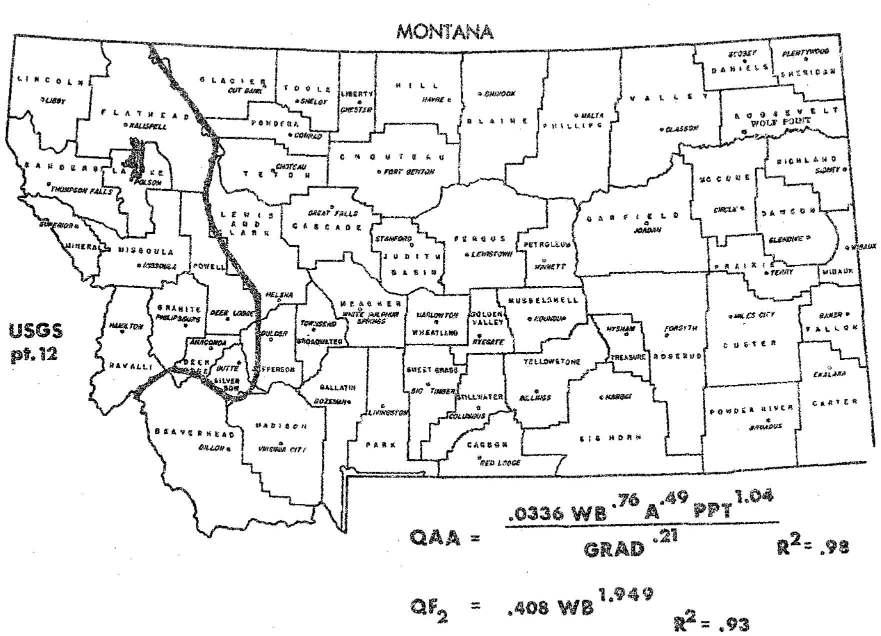
Further, mean annual flood:

$$QF_2 = .408\ WB^{1.949}$$

$$R^2 = .93 \qquad \text{(Figure 7)}$$

Three streams withheld from the data base to test the models had an average prediction error for both Q_{AA} and QF_2 of 10%.

figure 7



MODEL SENSITIVITY

The greatest source of prediction error in regionalization is, of course, a mis-delineation of region boundaries. In the first method, particularly where non-consecutive regions adjoin, huge errors of estimation are possible. First-hand knowledge of a stream's general behavior in relation to other streams in the region is necessary before application of the models.

The second method was developed only for streams draining into the Upper Columbia River Basin. These regional boundaries are well defined and the models should not be used outside them.

Errors in measurement of input variables and parameters are also possible. A complete model sensitivity analysis would involve solution of partial differential equations, but acceptance of a few assumptions allow a more simple numerical solution.

It is reasonable to assume that the geomorphic characteristics required as input for the models may be accurately measured. Watershed area (A) and channel gradient (GRAD) can be quite accurately determined from U.S.G.S. or Forest Service topographic maps. Similarly, bankfull channel width (WB) may be measured accurately in the field.

Estimation of mean basin precipitation (P) is not so easily accomplished. The largest scale routinely available for the mountain precipitation maps is 1:250,000. The U.S.G.S. maps are typically 1:25,000. Some land management agency maps may be larger scale. Isohyetes must be transferred to the larger scales then the aerially weighted mean basin precipitation must be determined.

If we assume that a 10% error in precipitation estimation is possible, then we may estimate the associated discharge prediction error. In the general regionalization models:

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

and

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

if fixed values for inputs are used,

WB = 1, A = 1, Grad = 1,

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

since $(1)^b = 1$, then

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

The coefficient, d, in all models is nearly 1.0. Thus an error of 10% in precipitation estimate will produce an error of about 10% in prediction of Q_{AA}.

SUMMARY

Regional models have been developed for prediction of average annual discharge and mean annual flood for ungaged streams in western Montana. These models utilize precipitation estimates derived from snow survey information. Their performance is superior to previous modeling efforts which is attributable largely to improvements in our characterization of mountain precipitation.

Region placement errors are the major source of prediction error. However, even with our good information on mountain precipitation, estimates of mean basin precipitation are possible. A model sensitivity analysis finds that a 10% error in precipitation estimate will produce about a 10% error in prediction of Q_{AA}. A prediction error of less than 20% is inherent in the procedures. The combined possible error of 30% is still superior to previous methodologies developed for western Montana.

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