ESTIMATING MONTHLY DISTRIBUTION OF AVERAGE ANNUAL PRECIPITATION IN MOUNTAINOUS AREAS OF MONTANA

by
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ABSTRACT

Many computerized models and Geographic Information Systems (GIS) are being used to estimate average annual precipitation in mountains of the Western United States. In most areas, there is a good correlation between average annual precipitation and elevation and most models use elevation to distribute annual precipitation to unmeasured areas. There is an increasing need to distribute these annual values to monthly averages. Some models use elevation to distribute monthly precipitation. Some models use the monthly distribution for long-term valley stations to distribute annual precipitation in higher elevations. Studies in Montana show there is a significantly different distribution of monthly precipitation between valley and the mountain areas, particularly in the winter and spring months. Comparisons for some watersheds in Montana are shown and proposed procedure for distributing annual precipitation into realistic monthly increments is presented.

INTRODUCTION

In recent years, there has been a proliferation of computerized models and Geographic Information Systems (GIS) used to depict average annual precipitation in equation or map form (Custer, et al, 1994; Daly, et al, 1994; Hungerford, et al, 1989; Molnau and Newton, 1994).

Since there is a good correlation between average annual precipitation and elevation in mountainous areas, most models utilize elevation as one of the main variables to distribute precipitation between locations where precipitation has been measured.

Hydrologic modelers and precipitation data users now desire monthly or even daily estimates of precipitation at unmeasured locations in addition to annual precipitation. Analysis of precipitation station data in Montana shows that average monthly precipitation correlates with elevation but the slope of the distribution varies by months. Typically, higher elevations receive a greater proportion of their annual precipitation during the winter months (October - March) while lower elevations receive a greater portion of their annual precipitation in the spring (April - June). The percentage of annual precipitation that falls in the summer-fall (July - September) is generally small in high elevations and larger in lower elevations. At some lower elevation stations, the 3-month summer-fall component is greater than the 6-month winter accumulation. It is imperative that these relationships be understood in order to accurately estimate the precipitation occurring at unmeasured locations.

STUDY AREA

The 1961-90 average precipitation patterns for most mountainous areas in Montana were analyzed. There were some similarities in regionalized areas. Examples of seven different patterns from different regions across the state are presented. The generalized locations of the seven areas are shown in figure 1.

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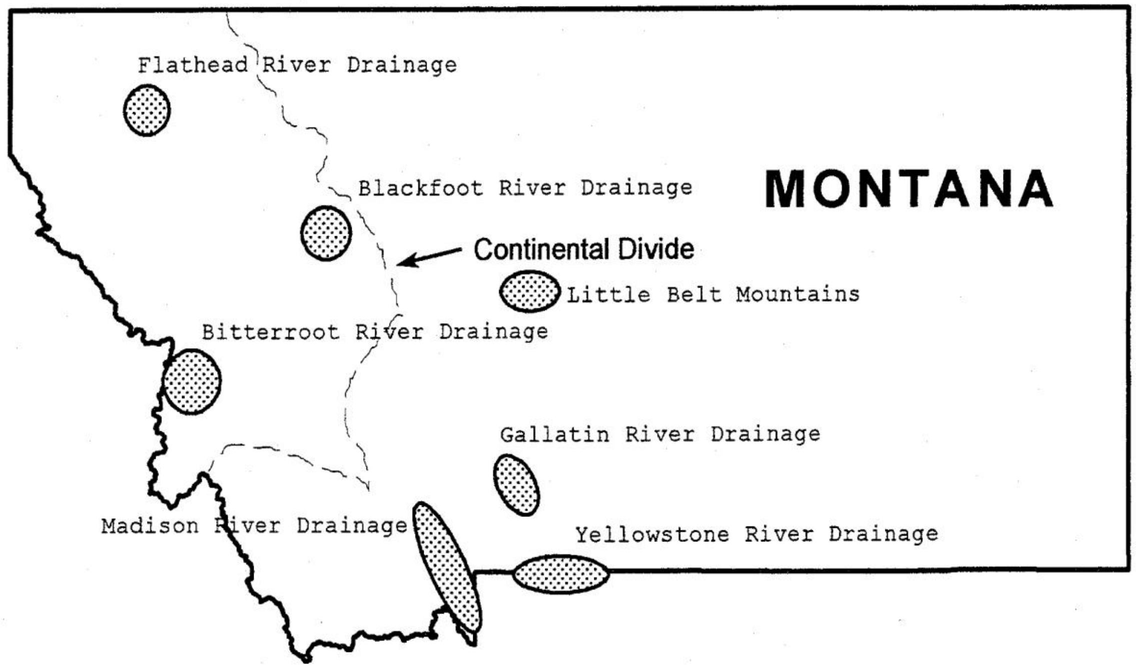

Figure 1. Locations in Montana where precipitation patterns are presented.

METHODS

The earliest average annual precipitation maps were produced by the National Weather Service (NWS) and were based on data obtained at climatological stations. Statewide maps were quite general and since there were few stations in the mountainous areas, the average annual precipitation was underestimated for most mountainous areas. Incorporating snow survey measurements (Farnes, 1971) helped correct the average annual precipitation in mountains areas. Implementation of the SNOTEL (Snow Survey Telemetry) System by Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service, has provided snow, temperature and precipitation measurements at approximately 74 mountain locations in Montana and over 550 locations in the western United States. SNOTEL data, storage precipitation gage data obtained by NRCS and others, and NWS climatological data has been analyzed to determine the relationship between elevation and annual, seasonal and monthly precipitation. Annual and monthly 1961-90 precipitation averages for NRCS and NWS stations were obtained from the NRCS Centralized Database System (CDBS) residing in Portland, Oregon.

Table 1 shows the seasonal components of average annual precipitation for selected stations in seven areas in Montana. These areas are the Flathead, Blackfoot, and Bitterroot River drainages west of the continental divide and the Madison, Gallatin, and Yellowstone River drainages and Little Belt Mountains east of the divide. Monthly precipitation distribution for these seven areas is shown in figures 2 through 8.

Table 1. Seasonal Distribution of 1961-90 Average Annual Precipitation for Seven Areas in Montana.

Drainage Station	Elevation m	Oct-Mar % Annual	Apr-June % Annual	July-Sept % Annual	Average Annual Precipitation mm
Flathead River					
Noisy Basin	1841	58.7	24.1	17.2	1930
Emery Creek	1326	56.0	27.9	16.1	1011
Hungry Horse Dam	963	54.9	25.0	20.1	870
West Glacier	961	54.4	25.8	19.8	739
Kalispell, WSO	904	45.3	31.6	23.1	416
Blackfoot River					
Copper Camp	2118	69.6	19.2	11.2	1341
Copper Bottom	1585	60.0	26.4	13.6	686
Lincoln RS	1394	48.4	30.8	20.8	475
Ovando 9SSE	1297	45.6	30.7	23.7	381
Bitterroot River					
Twin Lakes	1984	68.9	19.9	11.2	1684
Twelvemile Creek	1707	65.5	21.6	12.9	1156
Darby	1183	47.1	31.5	21.4	403
Hamilton	1076	43.3	32.1	24.6	338
Madison River					
Black Bear	2423	67.0	21.2	11.8	1567
Madison Plateau	2179	62.4	22.5	15.1	1085
Whiskey Creek	2073	60.6	23.0	16.4	930
West Yellowstone	2030	50.5	26.8	22.7	563
Hebgen Dam	1978	53.8	25.8	20.4	765
Ennis	1510	26.2	43.0	30.8	335
Gallatin River					
Shower Falls	2469	49.4	33.3	17.3	1318
Lick Cr.	2091	46.3	35.6	18.1	884
Bozeman MSU	1480	44.1	41.6	25.3	483
Belgrade Airport	1357	31.8	41.8	26.4	369
Yellowstone River					
Fisher Creek	2774	62.9	23.4	13.7	1499
White Mill	2652	61.1	23.6	15.3	1194
NE Entrance	2240	47.2	28.2	24.6	640
Tower	1911	40.6	30.3	29.1	432
YNP (Mammoth)	1890	39.4	31.6	29.0	390
Gardiner	1608	31.5	35.8	32.7	255
Little Belt Mountains					
Spur Park	2469	55.7	27.7	16.6	1054
Deadman Creek	1966	49.3	30.4	20.3	701
WS Springs 10N	1659	31.6	37.4	31.0	398
WS Springs	1585	29.8	38.9	31.3	341
Ft. Logan 3ESE	1434	22.0	42.6	35.4	277

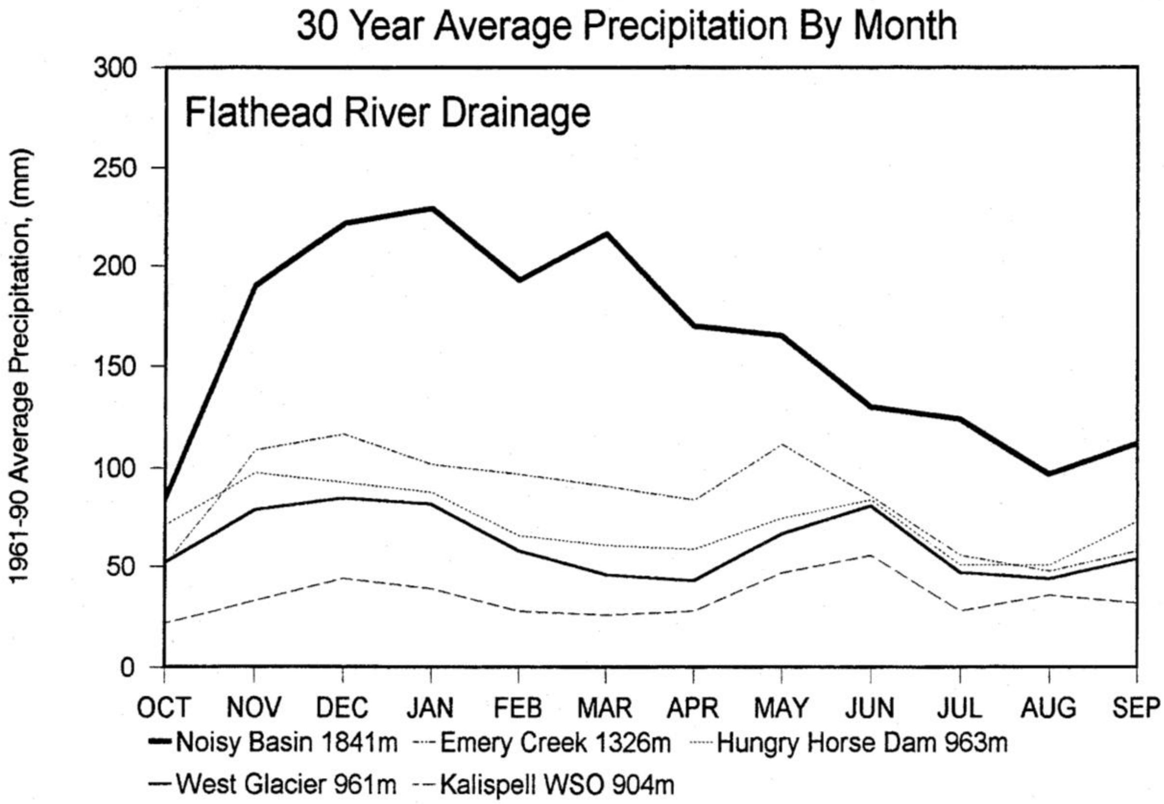

Figure 2. 30-Year Average Annual Precipitation by months for Flathead River Drainage.

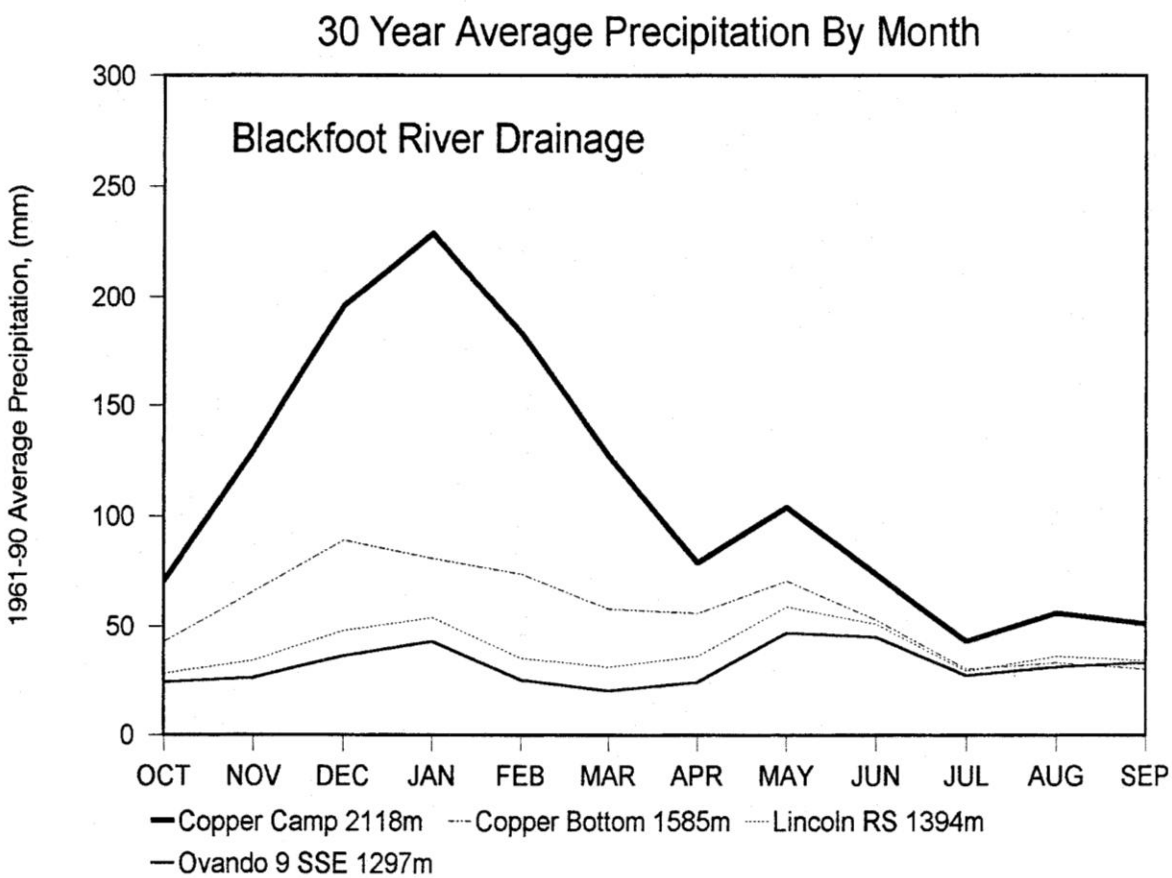

Figure 3. 30-Year Average Annual Precipitation by months for Blackfoot River Drainage.

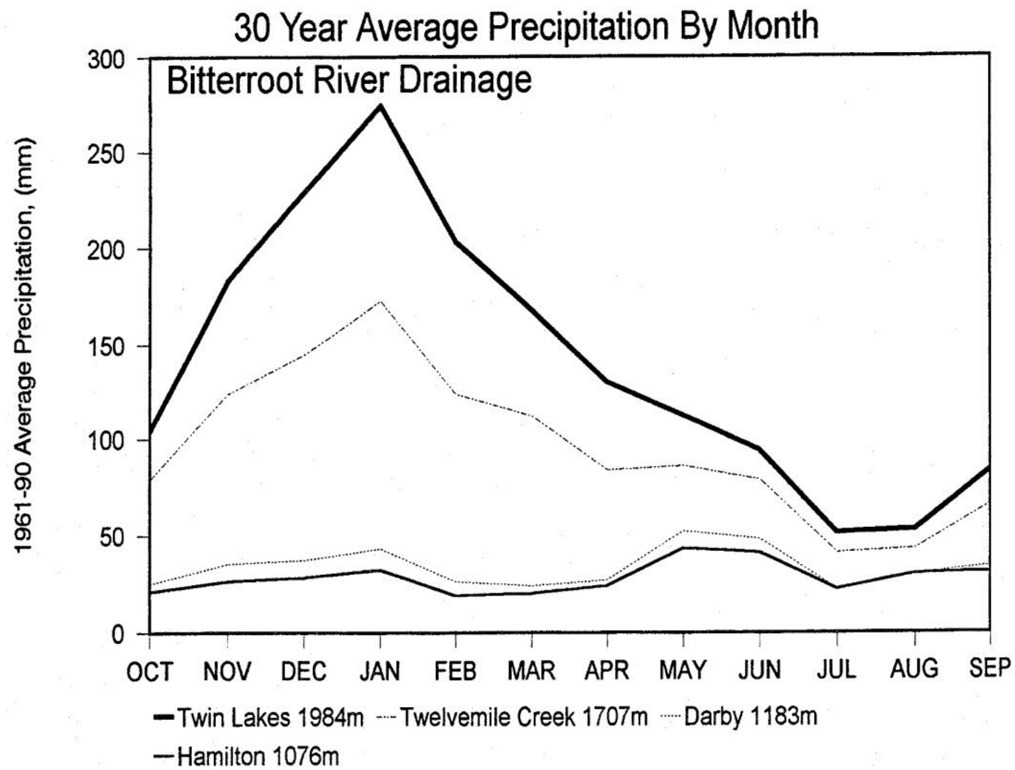

Figure 4. 30-Year Average Annual Precipitation by months for Bitterroot River Drainage.

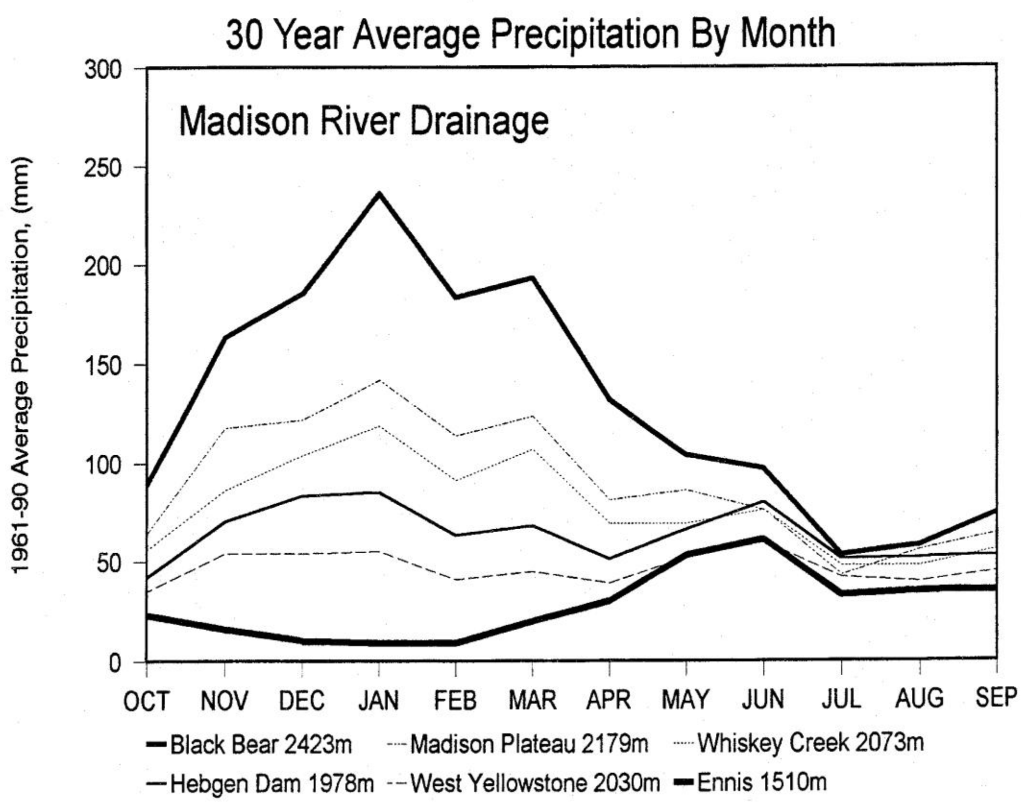

Figure 5. 30-Year Average Annual Precipitation by months for Madison River Drainage.

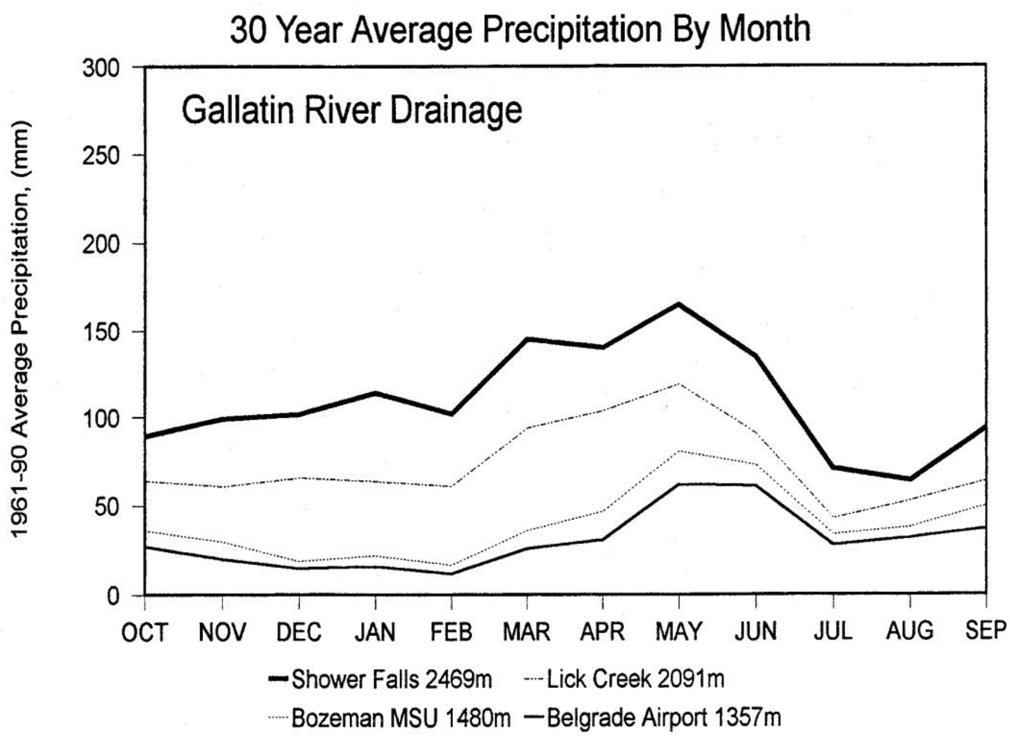

Figure 6. 30-Year Average Annual Precipitation by months for Gallatin River Drainage.

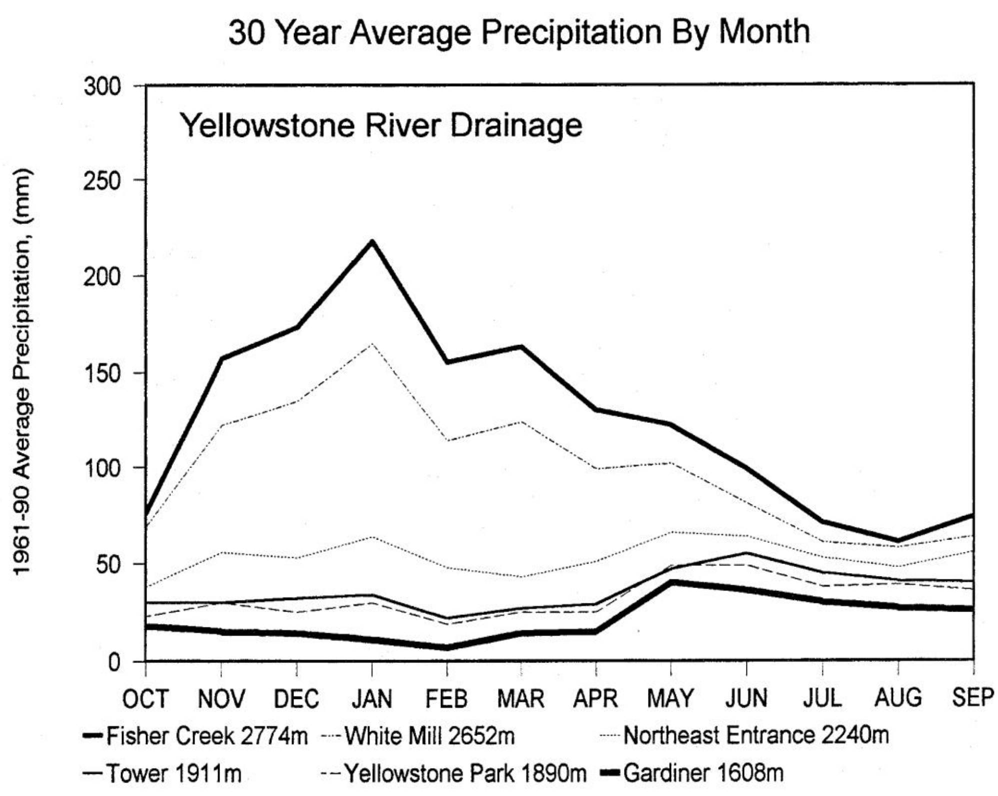

Figure 7. 30-Year Average Annual Precipitation by months for Yellowstone River Drainage.

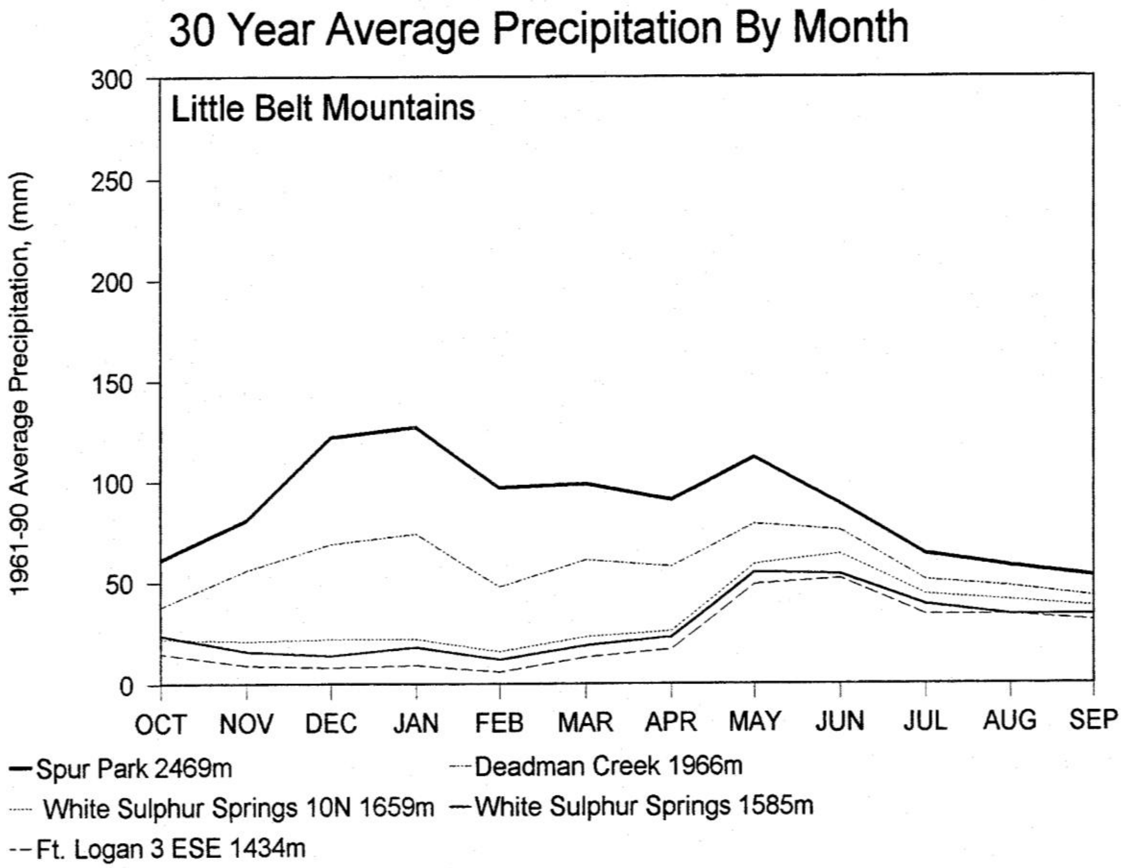

Figure 8. 30-Year Average Annual Precipitation by months for Little Belt Mountains.

RESULTS AND DISCUSSION

The higher elevations always receive a higher percentage of their annual precipitation during winter months (October-March) than do the lower elevations (table 1). In higher elevations, the spring (April-June) component is a much smaller percent of the annual precipitation than the winter, and the summer-fall (July - September) component is only about 10 to 20 percent of the annual precipitation. In lower elevations, usually occupied valley areas, the percentage of annual precipitation that occurs in the spring period is the largest of the seasonal precipitation components for drainages east of the Continental Divide. The summer-fall component for lower elevations east of the divide approaches or exceeds the winter component. West of the divide, the percentage of the annual precipitation that occurs during the winter period at lower elevations is still the largest seasonal component followed by the spring period with the summer-fall period showing the least amount. However, in the lower elevations, the winter period is not as large a component as it is in higher elevations.

For modelers or others not aware of this distribution, serious error can be produced in monthly or shorter period precipitation estimates if the distribution of precipitation at the valley stations is transferred to higher elevation areas.

It appears the most accurate average annual precipitation maps would be generated by determining the average annual precipitation first. In addition to SNOTEL and NWS data sites, data from snow courses could be incorporated using localized algorithms between snow water equivalent (SWE) and annual precipitation at SNOTEL sites (figure 9). It is necessary to multiply snow course SWE by .91 for standard federal cutter or .94 for sharpened cutter to correct for overmeasurement with snow tubes (Farnes, et al, 1983) and to adjust for canopy cover (Farnes, 1971; McCaughey, et al, 1995) if any, at snow courses. This additional data from snow course sites can double or triple the data base for mountain areas in most western states.

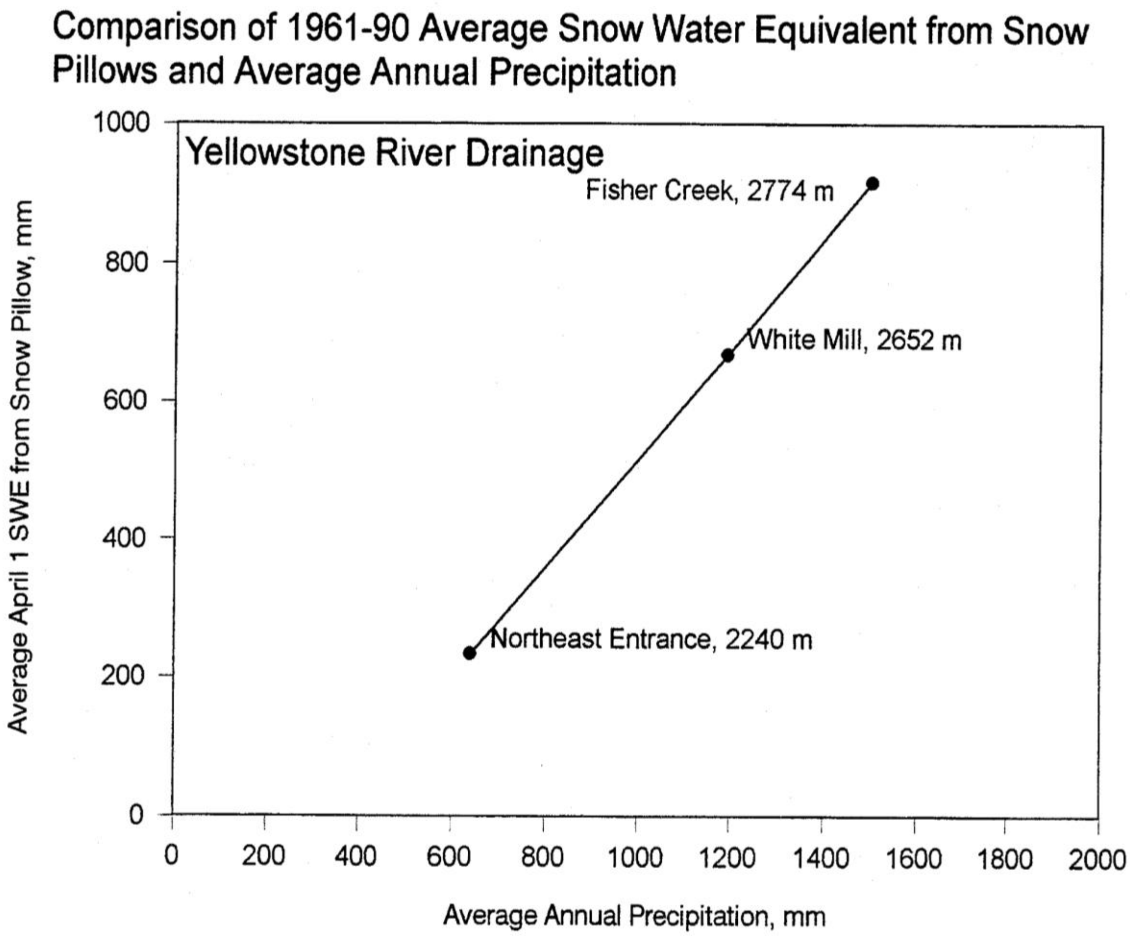

Figure 9. Comparison of 1961-90 Average Snow Water Equivalent from Snow Pillows and Average Annual Precipitation for Yellowstone River Drainage.

The second step would be to distribute annual precipitation to monthly increments using procedures similar to that shown in figure 10. It is necessary to check the sum of monthly increments and/or adjust curves so the total of all months equals 100 percent of the annual. Another possible procedure is similar only the accumulated precipitation is plotted and then curves developed for each month (figure 11). For this method, it is necessary to subtract the accumulated values to determine individual monthly precipitation but the total of all months will always equal 100 percent of the annual. The data suggests the relationship for accumulated precipitation through some of the months are curvilinear. If there is any significant part of the watershed, at either higher or lower elevations that those used in the relationship, significant errors could be generated in elevations above or below those used to develop the curvilinear relationship.

For models using monthly precipitation to develop precipitation maps, it is suggested that accumulated monthly values be checked against annual values obtained independently with elevation (figure 12). Using only monthly values does limit the available data base since monthly values for snow course data is not readily available. However, monthly data for snow course sites could be developed as discussed above to expand the data base for mountainous areas.

CONCLUSION

Developing accurate and realistic average annual and average monthly precipitation maps or relationships requires an intimate knowledge of precipitation patterns and distribution. These patterns change from one area to another and are related to prevailing storm directions, shape and orientation of mountain ranges, upwind mountain barriers and distance from moisture source. Accurate precipitation maps using GIS techniques or accurate precipitation-elevation relationships can be developed but only when all of the variability affecting precipitation is considered.

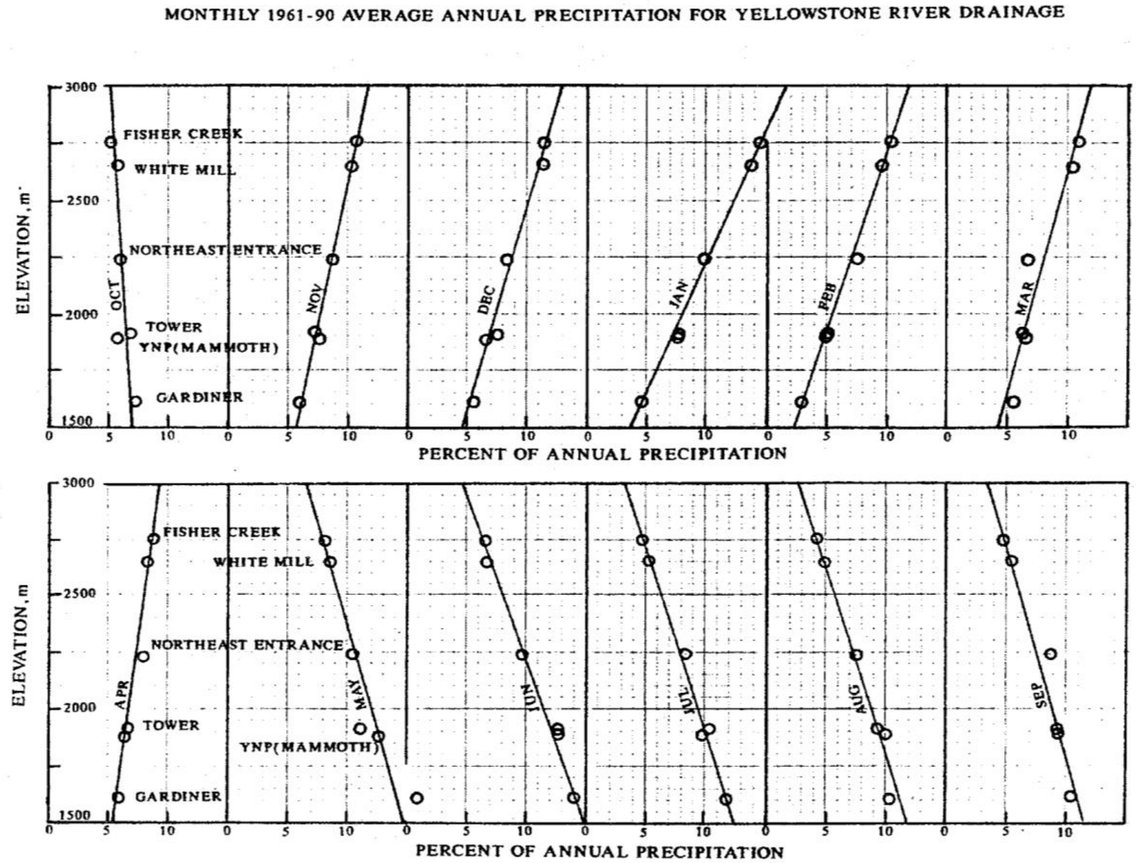

Figure 10 Percent of 1961-90 Average Annual Precipitation by Months for Stations in Yellowstone River Drainage

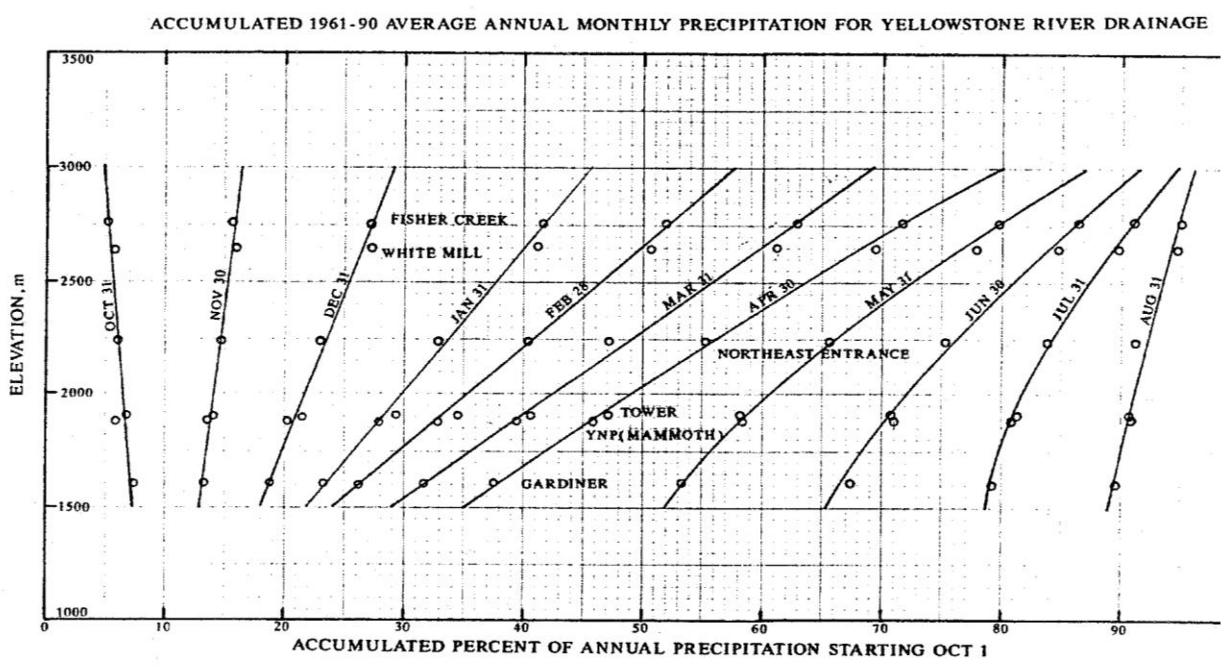

Figure 11 Percent of 1961-90 Average Annual Precipitation Accumulated by Months Starting October 1 for Yellowstone Riv Drainage.

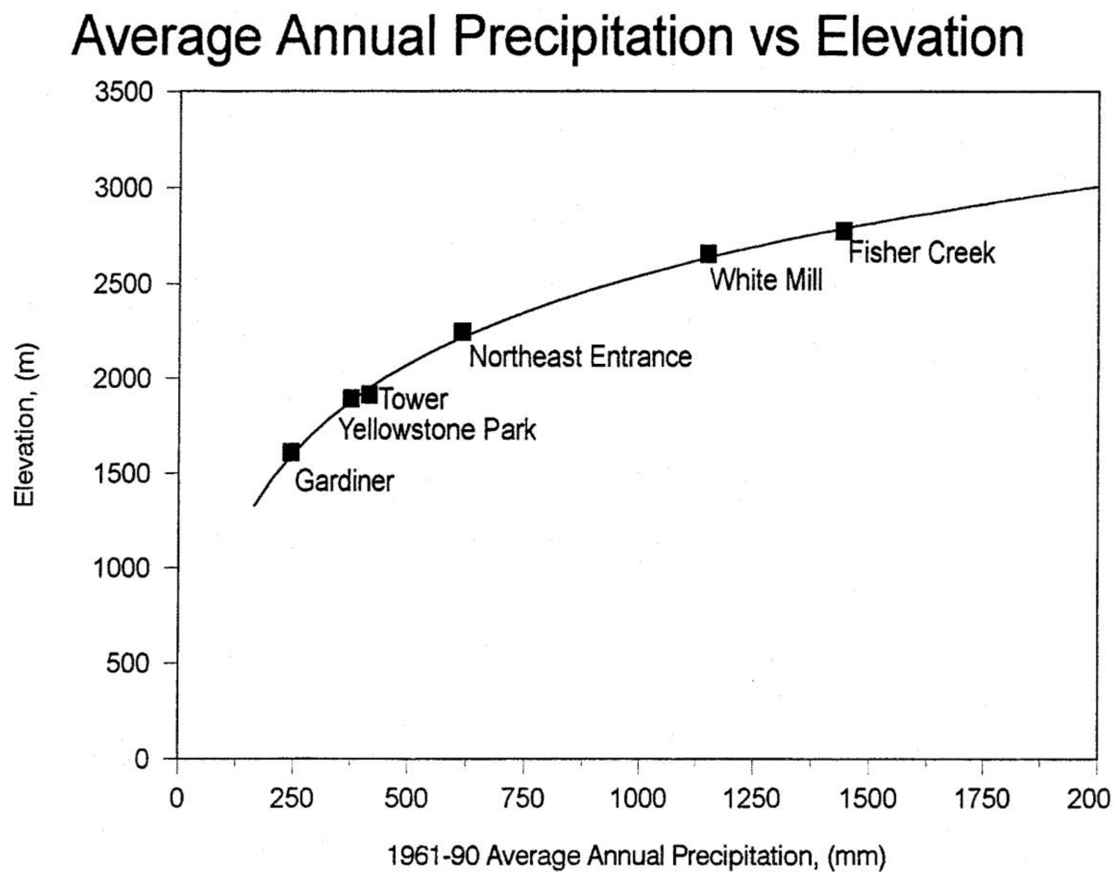

Figure 12. 1961-90 Average Annual Precipitation Compared to Elevation for Yellowstone River Drainage.

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