THE INFLUENCE OF SNOWMELT IN EVALUATING SMALL HYDROPOWER GENERATION POTENTIAL

by
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Introduction

Recent changes in Federal Energy Regulatory Commission rules and the high cost of thermal power generation have prompted a surge of interest in small hydropower (less than 25 MW) development in the Western U.S. In the Pacific Northwest, where 80 percent of energy generation is hydroelectric, wholesale power rates have risen to six times the 1975 cost per kilowatt hour (kwh). In Washington State, for instance, over 500 small scale hydro sites are currently under consideration for development. By various estimates, the economically feasible hydro development potential (primarily small) is as high as 5000 MW in Washington, and as high as 50,000 MW in the 11 western states (not including Alaska, where the potential is estimated to range from 20,000 to 50,000 MW, some of which is associated with large sites).

Although a surplus of energy production capacity in the Northwest is forecast for the next decade, the relatively low installation and operating costs of small hydro facilities makes long-term investment in this resource attractive. For instance, the Pacific Northwest Power Planning Council (1983), in its draft planning document, recommends additional (primarily small) hydro development as the next supply increment after all economically feasible conservation savings have been realized.

Hydrologic Site Feasibility Assessment

One of the most important considerations in evaluating the economic feasibility of a potential hydroelectric facility is the hydrology of the stream which will generate the power. Both total water yield (mean annual runoff) and its distribution throughout the year must be known to calculate the potential generation for a proposed plant. The seasonal distribution of runoff is an important concern, since the demand for power is not constant through the year. Generally, in the Pacific Northwest, power generated during the high heating demand winter months is more valuable than power generated in the spring or summer, although transmission interties to the Southwest allow marketing of power in the Southwest's higher demand summer months, albeit at a lower price than could be derived from power sales in the Northwest.

In addition to estimation of the mean water yield and its seasonal distribution, the accuracy of such estimates is of critical concern, especially since many sites have marginal economic feasibility. Accurate estimation is difficult because of the paucity of data available for the often-remote sites. Nevertheless, errors in hydrologic estimation can, for some sites, be large enough to make the difference between economic viability and infeasibility of a potential hydroelectric development.

Another major consideration in assessing sites is the effect of orography on the mean runoff. The mean annual runoff of a catchment (neglecting interbasin groundwater movement and long term storage changes) is equal to the mean basin precipitation less evapotranspiration. In mountainous areas, precipitation usually increases with altitude due to the lifting and resultant cooling of moisture-laden air masses. Evapotranspiration usually decreases with altitude, and the combined effect is a pronounced increase in runoff with elevation. In the North Cascade Mountains of Washington, runoff varies from about 50 - 60 inches at the lower elevations to 150 - 200 inches at higher elevations (Tangborn and Rasmussen, 1976). Unfortunately, these orographic variations are extremely complex, and are affected by catchment orientation, "shadowing" effects of other ranges or

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large mountains, and distance from the Cascade Crest. Further, precipitation data are scarce at high elevations, and the data that are available are invariably of questionable quality due to measurement difficulties. For these reasons, the use of isohytel maps for estimation of runoff is not a practical alternative.

For hydroelectric feasibility analysis, estimation of runoff on a daily time scale is necessary. Although more accurate estimation is possible for longer averaging periods, the daily interval is necessary to account for the maximum generating capacity of a proposed plant. The probability distribution of daily runoff (often referred to as the flow duration relationship) is a function of snowpack accumulation and melt, the areal and temporal distribution of precipitation, vegetation cover, groundwater storage and release, and soil moisture accumulation and release. In addition, both the area-altitude distribution of a catchment, and its surface orientation strongly influence the accumulation and ablation of snow. Therefore, the snow accumulation and ablation process controls streamflow throughout part of the year, and for the economic reasons noted above, runoff during the snow accumulation period can be extremely important in determining the economic viability of a hydroelectric development.

Simulation of Discharge in Ungaged Catchments

We have developed an approach for estimating streamflow for ungaged catchments that is based on explanation of the discharge of similar gaged catchments in terms of the basin topography (surface area and orientiation as a function of elevation). The method is exploits a functional relationship between runoff and topography, developed for a set of gaged catchments, which is then applied to the ungaged catchment for which the required topographic parameters have been calculated. Through this process, the observed long-term streamflow of the gaged catchments is explained by each catchment's unique area-altitude and surface orientation characteristics. Assuming that these gaged catchments have been selected to have a common runoff-altitude function with that of the ungaged catchment, the application of these relationships should explain the observed flow at each gaging station by:

$$R_{g_k} = \sum_{i=1}^{n} r_i A_{g_{ik}}, \quad k = 1, \ldots m$$

where

R_{g_k} = observed runoff at gaging station for basin k

r_i = average runoff per unit area for area within altitude increment i, i = 1, 2, ... n

$A_{g_{ik}}$ = fraction of gaged drainage basin's total area within altitude increment i for basin k, i = 1, 2, ... n

If the number of basins m available equals or exceeds the number of altitude increments, n values for r_i, i = 1, ... n can be obtained using least-squares techniques. An accuracy evaluation can be performed by applying the process to several gaged catchments, not used to estimate the parameters, r_i, and treating them as ungaged. A comparison is then made of the predicted versus observed daily discharge. On this basis, an estimate of the variance of the prediction error for the ungaged basin(s) can be determined.

Application of Equation (1) is made by computing, for an ungaged catchment, the area-altitude distribution, A_u then applying the equation directly, substituting A_u for A_g. The equation can be applied to annual, seasonal, or daily runoff, via one of two methods. Annual runoff can be estimated for the ungaged station, then disaggregated to daily flow using the same ratios of daily to annual flow as are observed at an index basin, which has a similar surface area and orientation distribution with altitude. This index basin can be a composite made up of nearby, gaged basins that, when combined will closely resemble the topography of the ungaged catchment. This method has the advantage that short term variations are smoothed, but it can ignore important variations in the seasonal distribution of runoff if the area-altitude distributions of the ungaged and key station are too dissimilar. Alternately, the runoff fractions r_1, r_2, etc. can be estimated on a daily basis, thus preserving the seasonal variations, but introducing short-term variability into the coefficients that is most likely an artifact of the estimation procedure. A third procedure is to compute the coefficients on a daily basis, then to perform a moving average to reduce the variability.

The installation of a streamflow gaging station at the diversion site is another means of reconstructing historical discharge. The accuracy of streamflows reproduced by this method is highly dependent on the length of record obtained, and on the availability of long-term records from nearby streamflow stations. Generally, project planning requirements are such that lengthy gage records cannot be obtained, however, it is possible to improve the accuracy of estimated flows by combining estimates made using gage information and those made using the area-altitude method.

Regardless of which approach is followed, estimates can be made of the annual, monthly, and daily runoff. These estimates are progressively less accurate because of the reduced averaging effect, and because the short-term estimates reflect (unknown) differences in snowpack accumulation and ablation timing. In addition, the daily distribution of runoff is strongly a function of slope orientation during the snowmelt period (typically March - June in much of the western U.S.)

Plant Sizing Considerations

Sizing of a proposed hydroelectric facility is dependent on environmental, hydrologic, and geologic factors in addition to financial and political feasibility. Although only hydrologic factors are considered in this study, there is often an important interdependence of the various criteria. A notable example is low flow requirements for fisheries protection (Boese and Keely, 1981).

Plant construction costs can be separated into those associated with the intake structure, penstocks, generating station, and transmission lines. Generally, all increase with increased plant size in a manner that is site-dependent. An approximate mean cost per KW of installed generating capacity is $1000 - 1500, depending on the site. A critical decision that must be made is the design flow, or maximum generating capacity of the station. The inherent uncertainty in the hydrologic estimation suggests that staged construction may be appropriate, but there has generally been a reluctance among small hydro developers to recognize the uncertainty explicitly.

In addition to the problem of estimating mean flows and related values, such as the p percent exceedance flow, which is usually used to size the plant (traditionally, $20 < P < 30$ has been used), there is the problem of the timing and variability of future flows. Even if the mean is estimated correctly, there is always a chance that extremely low runoff may occur during the early years of project operation, when the venture will usually be most susceptible to economic failure. In general, future runoff is unpredictable for lead times longer than several months, however, it should be possible to estimate the risk of the types of extreme low runoff that could lead to project failure, and to incorporate the analysis of such risks into the planning process. To our knowledge, such an analysis has not previously been attempted for small hydro feasibility analysis.

Low Altitude Versus High Altitude Sites

Some insight into the effect of snowmelt on the feasibility of small hydro development can be gained by comparison of a low altitude and high altitude catchment. Two such catchments, are considered here. The first, Woods Creek, is currently in operation. The second, Troublesome Creek, is being assessed for possible installation of a small hydro plant. Both catchments are located in the Skykomish River Basin of Western Washington (Figure 1). Table 1 gives some pertinent statistics for both sites, and a summary of advantages and disadvantages of low and high altitude catchments that are typical for the Cascade Mountains. Area-altitude histogroms for both sites are given in Figure 2.

An analysis was made to determine the comparative value of each catchment for hydroelectric development. Woods Creek has little or no snow accumulation in most years,

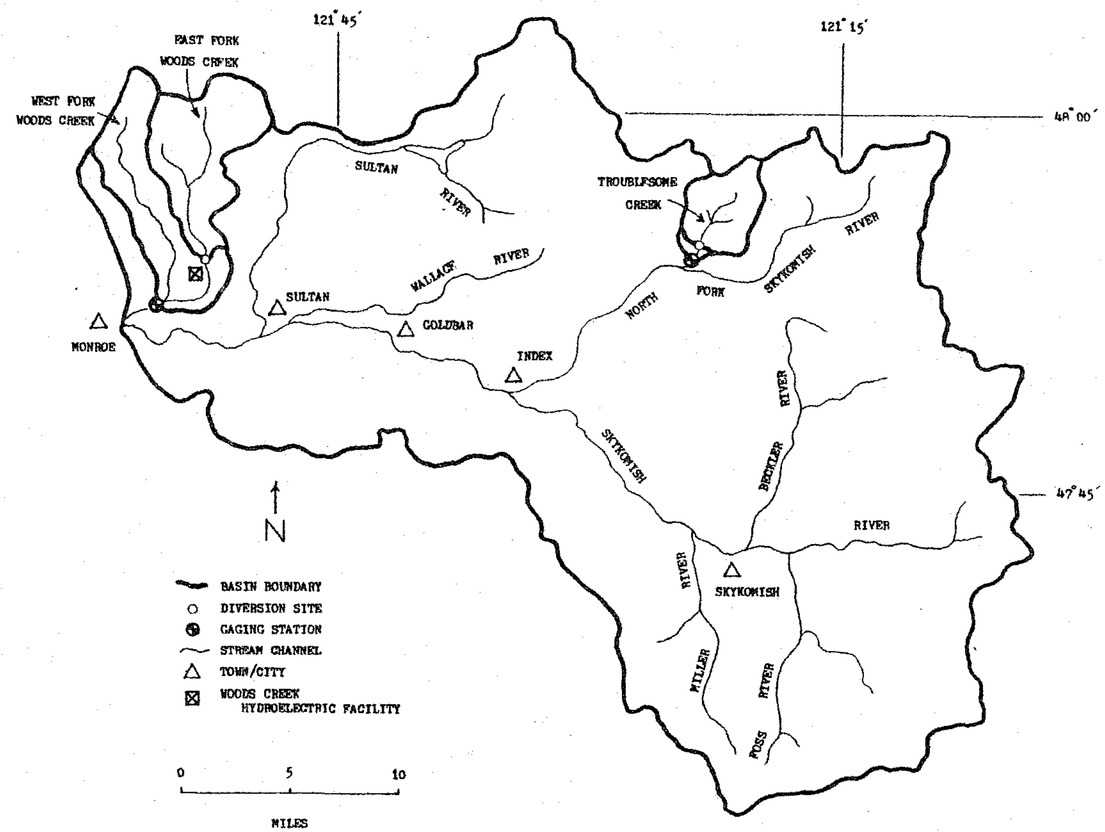

Figure 1. Skykomish River watershed, North Cascades, Washington

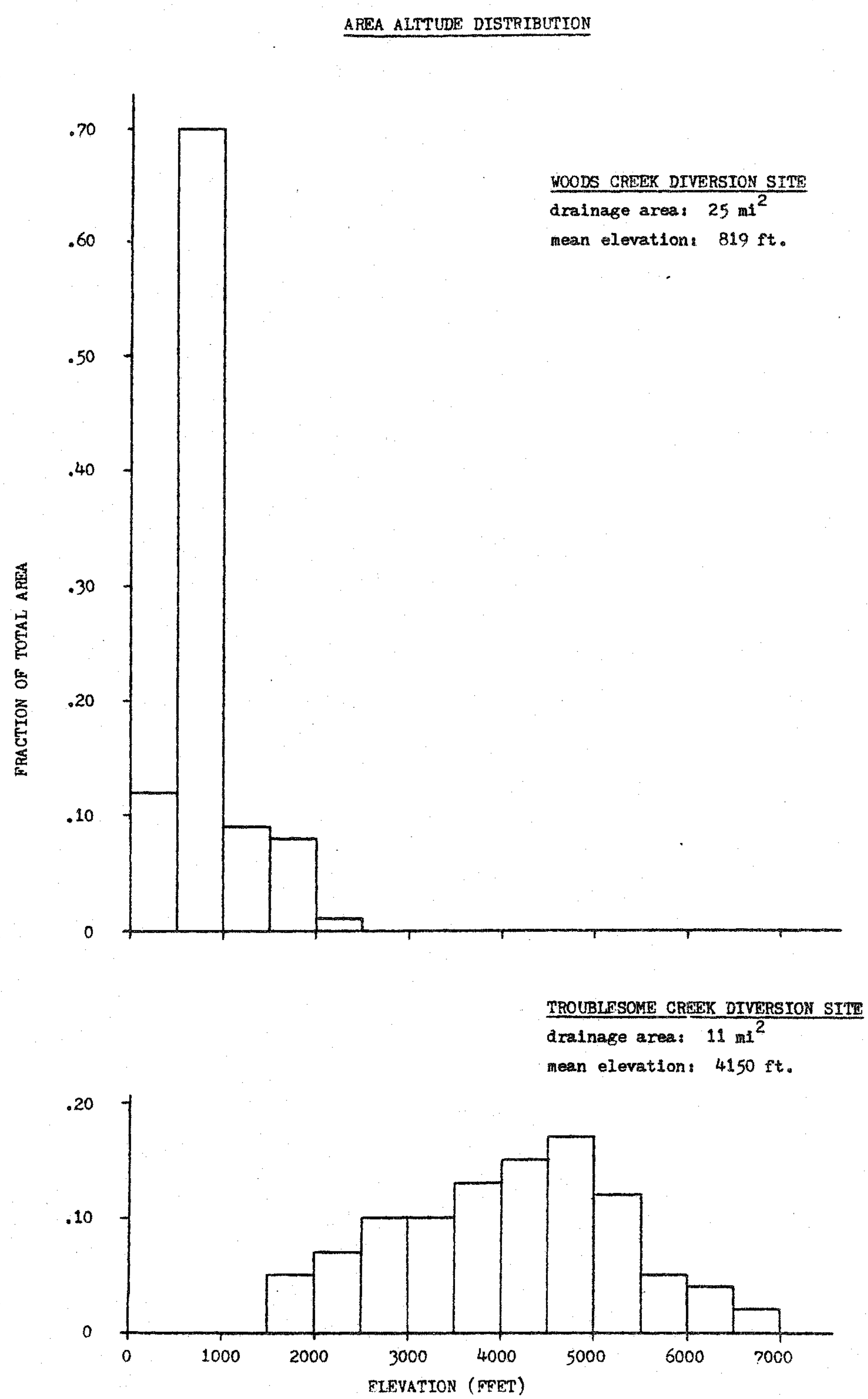

Figure 2. Area-altitude distributions of Woods and Troublesome Creeks.

while most of the annual precipitation in the Troublesome Creek catchment occurs as snow. Also, since Woods Creek is a low elevation catchment, its mean annual runoff is substantially less than that of Troublesome Creek. Although the stream gage records for these two catchments do not coincide, an adjustment was made to the Troublesome Creek record so

Table 1. Characteristics of two diverse watersheds considered for small hydro development.

	Woods Creek			Troublesome Creek		
Drainage area above diversion (mi^2)	25.0			10.6		
Mean annual runoff, 1947-71						
(in)	41.3			168.0		
(cfs/mi^2)	3.0			12.4		
(cfs)	76			132		
Basin mean altitude (ft)	800			4000		
Time of Sustained Peak Discharge	December - January			June		
Design parameters						
Hydrostatic head (ft)	72			340		
Penstock length (ft)	230			6000		
Pipe diameter (in)	48			54		
Rated discharge (cfs)	144			300		
Instream flow required (cfs)	7			14		
Mean Generation[1]	Winter	Summer	Annual	Winter	Summer	Annual
Millions of Kwh	1.5	0.8	2.3	8.7	10.7	18.8
Rated size (mw)			.65			7.6

[1] winter = November-April, summer = May-October

that it corresponds to the 1947 - 71 period of record for Woods Creek. Hydrographs of the daily mean and maximum and minimum discharges are given in Figure 3. The potential generation at each site (Figure 4) is based on approximate design parameters (Table 1).

The high snowmelt runoff during the April - June period for Troublesome Creek is disadvantageous for two reasons. First, the maximum discharge occurs at a time of year when wholesale power rates are low due to a surplus of hydropower. Second, much of the extreme discharge occurs over a relatively short period of time and cannot be utilized economically. The advantage of this site, like most high elevation sites, is that a high hydrostatic head is available for a comparatively short penstock length.

This brief comparison illustrates the relative advantages of high and low elevation sites. The advantages of low elevation sites are that a relatively higher fraction of the runoff occurs during the winter months when power demand (rates) are highest. The period of high flow lasts longer, and construction costs are generally lower due to improved access and less rugged topography. The primary advantages of high elevation sites are high heads, high specific runoff, and in some cases reduced instream flow requirements.

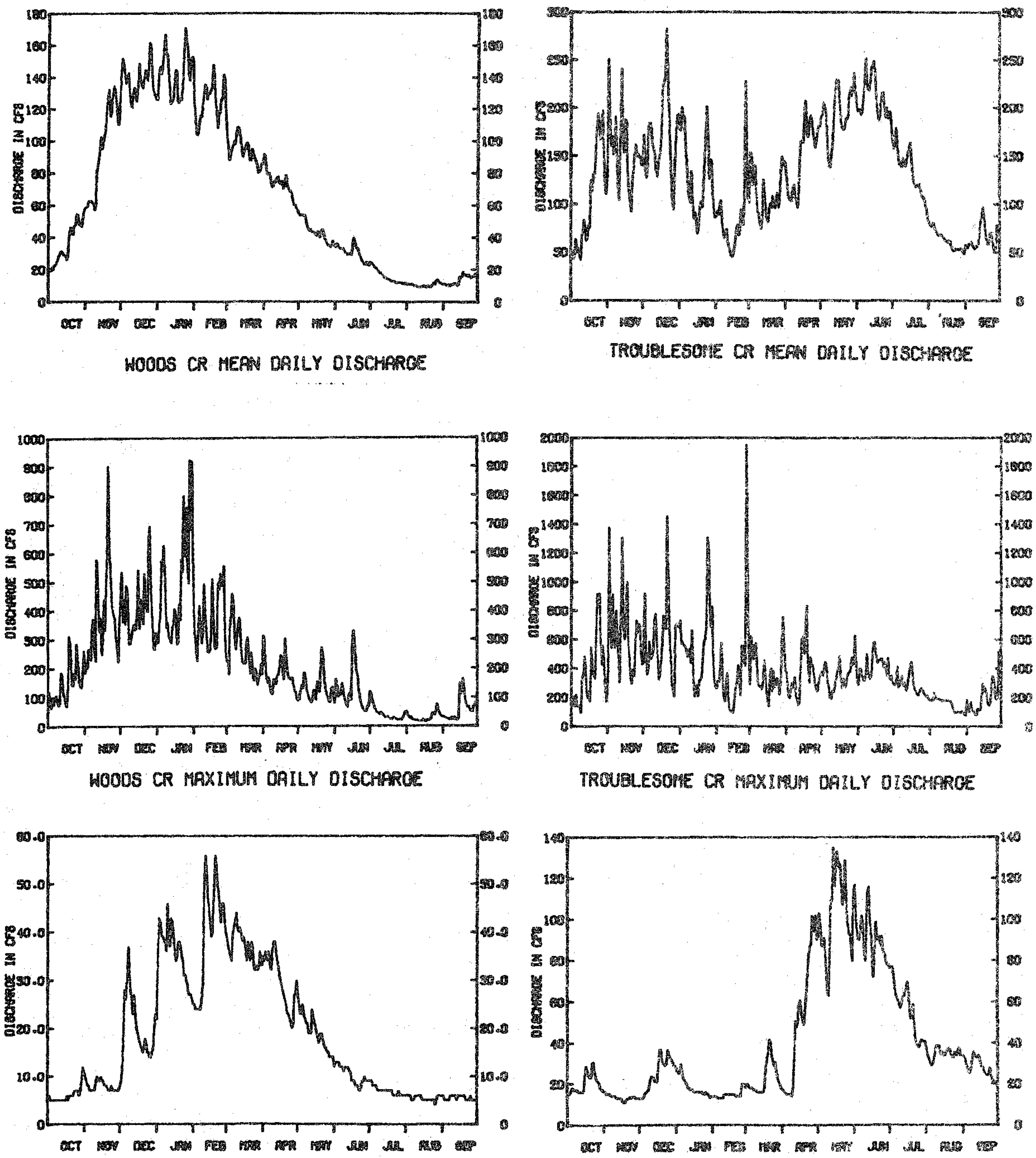

Figure 3. Daily mean, maximum, and minimum streamflows for Woods and Troublesome Creeks in cfs.

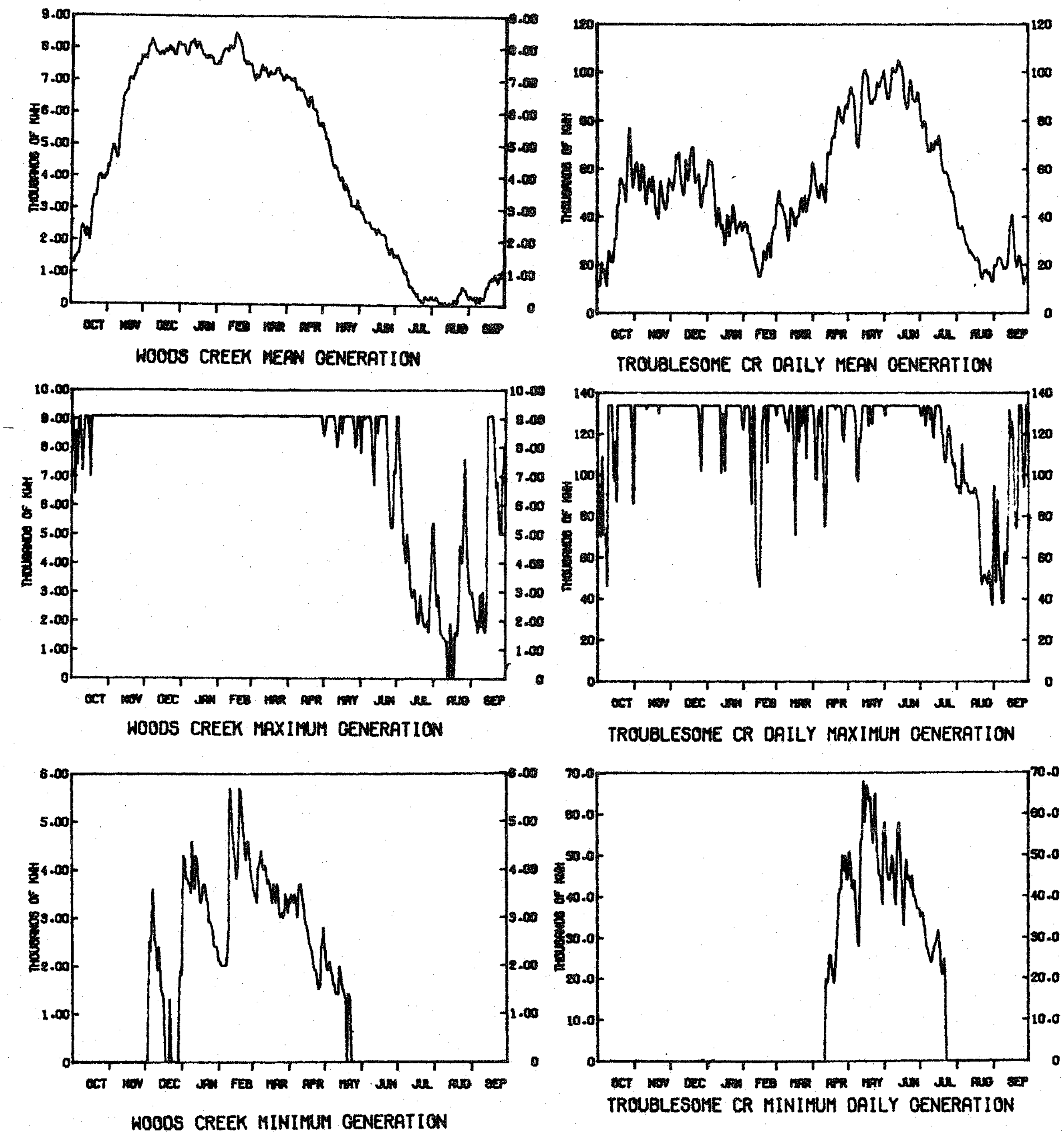

Figure 4. Daily mean, maximum, and minimum potential generation of Woods and Troublesome Creeks in thousands of kwh.

Conclusions

Small scale hydro as an energy source is highly dependent on the hydrologic characteristics of each potential site. Generally, it appears that those basins located in the more remote, higher altitude watersheds are more economically viable because of greater precipitation rates and higher hydrostatic heads. Snowmelt plays a significant role in energy production, however, the rapid melting of snow in the spring months is a distinct disadvantage from the standpoint of energy generation in climates where the greatest energy demand is for winter heating.

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