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Peak Stream Discharge During Thirty Years of Sustained Yield Timber Management in Two Fifth Order Watersheds in Washington State

Abstract

Analysis of rainfall and peak flow from 1951 to 1980 by means of regression models was performed on two watersheds in southwestern Washington to examine the effects of timber harvesting on peak flow magnitude. One watershed contained timber between 45 and 60 years of age and had experienced no logging during the study period. The other watershed was being actively harvested and roaded at a rate of approximately 344 Ha/yr. From examination of regression models, no change in peak flow magnitude could be detected in either watershed for the 1951 to 1980 period.

Introduction

The results of watershed studies indicate that peak flows in rain-dominated systems of the Pacific Northwest have been shown to increase, decrease or remain unchanged after logging and road construction. Harr (1979) states that whether or not a change occurs depends on what part of the hydrologic system is altered and how permanent the alteration is. Clearcut timber harvest was implicated by Anderson and Hobba (1959) as increasing annual flood peaks through reduction in evapotranspiration and alteration in snow accumulation and melt rates. In initial hydrologic measurements in logged watersheds at the H. J. Andrews experimental forest (HJA), Rothacher (1970) found peak flows to have increased by some 200 percent due to increases in soil moisture after logging, allowing more water to be seen as runoff. In the Alsea Basin study, Harris (1977) reported a 20 percent increase in peak flow on Needle Branch Creek and a 2 percent increase on Deer Creek as compared to Flynn Creek, the control watershed, but considered such increases to be statistically insignificant since the mean of the peaks fell within the prediction limits. Hornbeck (1973), Har *et al.* (1975), and Ziemer (1981) also reported increases after logging due to differences in soil moisture. In further examination of HJA data, Harr (1979) reports that the normally large winter peak flow events, occurring after sufficient rainfall had occurred to restore soil moisture deficits, were similar between logged and unlogged areas. Peak flow increases were found to occur in fall and early winter storm events prior to soil saturation. Examining the effect of other forest practices, Harr *et al.* (1975) found increases in peak flow to be proportional to the percent of the watershed occupied by compacted soil areas (roads, landing, and skid trails) where increases were observed when compacted surfaces exceeded 12 percent of watershed area. Other observers have reported peak flows to be reduced by logging. Cheng *et al.* (1975) attributed peak flow reduction to be due to decreased soil pore space, thus forcing water through slower routes. Harr and McCorison (1979) demonstrated reduced peak flow in clearcut areas in western Oregon and attributed the reduction to be the result of decreased snow accumulation and increased melt rates. Christner and Harr (1982) examined long-term precipitation records for western Oregon and concluded that no significant climatic change had occurred over the last 35 years that could affect peak stream flow.

Such mixed results indicate that the particular hydrologic system in question must be well defined prior to interpretation of peak flow relationships. The majority of the peak flow research in the Northwest has been accomplished on watersheds ranging from 13 to 21 Ha in size. Because of the difficulty in quantification of hydrologic variables, peak flow relationships on larger streams have not been examined in as much detail as small watersheds. Lyons and Beschta (1983) detected an apparent trend toward peak flow increase in the Middle Fork Willamette river, a 665 km^2 watershed in Oregon, in association with a particularly heavy increase in logging activity. Increasing trends such as this are important in examining downstream response to logging activities, particularly in relation to erosion of stream bed and banks, fish habitat, and flooding. This case study was undertaken in an attempt to evaluate whether the trends observed by Lyons and Beschta occurred elsewhere.

The objective of this study was to examine peak discharge in relation to timber harvest through use of historical stream flow records on two watersheds: one in a state of forest regrowth and the other having experienced a relatively rapid rate of harvest during the last ten years.

Watershed Characteristics

The Deschutes watershed is located in the foothills of the Cascade Mountains in southwestern Washington state. The Deschutes River flows in a northwesterly direction to Budd Inlet at the southernmost end of Puget Sound. Total watershed area encompasses some 429 km^2 of which 232 km^2 occur in the headwater area examined in this study. The principal salmonid species utilizing the river are Coho salmon (*Oncorhynchus kisutch*), Steelhead (*Salmo gairdneri*), and Cutthroat trout (*S. clarki*).

Elevations range from 100 m at the stream gauge to approximately 1120 m, of which 10 percent lies above 850 m. The winters are generally mild with the major precipitation occurring as rain from Pacific Ocean frontal systems. Snow accumulations of 25 to 40 cm occur for short periods above 850 m in elevation. Annual average precipitation ranges from approximately 130 cm in the lower basin near the stream gauge to 210 cm in the headwaters area.

The headwater portion of the Deschutes watershed consists of long straight "v"-shaped valleys and smooth steep slopes, commonly 70 percent (35°) and steeper. Soils are moderately deep (50 to 100 cm) to shallow (less than 40 cm) loams and clay loams developing from volcanic ash mixed with basalt, andesite, basaltic breccia, and welded tuff residuum with local inclusions of sedimentary rock. The lower watershed was partially influenced by continental glaciation during the last glacial period. Slopes are 30 percent (17°) or less and ridges are broad and smooth. Soils developed on the glacial silts, clays, and sand and gravel deposits are highly variable, ranging from clay with low permeability to highly permeable soils developing on glacial outwash. Soil stability is generally good, with one isolated area of earth-flow slump terrain associated with deeply weathered tuff and breccia rocks.

Douglas-fir (*Pseudotsuga menziesii*) is the principal timber species in the basin with western hemlock (*Tsuga heterophylla*) and Pacific silver fir (*Abies amabalis*) at the upper elevations. The area has been continuously harvested over the past 30 years (Figure 1) when some 11,344 Ha or 49 percent of the project area was harvested. Currently, stand age on 44 percent of the area is less than 15 years. Road construction has been continuous during the same period, resulting in a road density of 3.08 km/km^2. The major form of timber harvest has been clear cutting using high lead cable systems. During early stages of basin development, tractor skidding methods were employed on some of the more gentle terrain in the lower basin. Minimal site preparation activities have been required, with broadcast burning accomplished in areas of particularly heavy slash concentrations. All clearcut units have been regenerated with Douglas-fir.

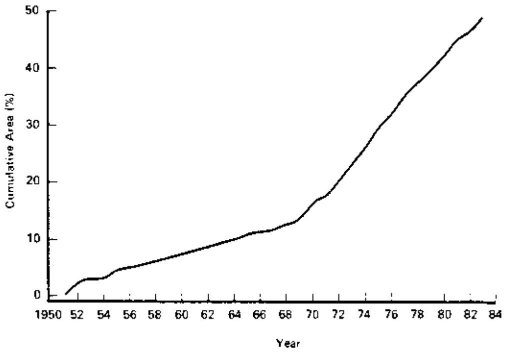

Figure 1. Cumulative area harvested in the Deschutes basin between 1951 and 1983.

The Naselle watershed occupies 141.9 km^2 on the southwest Washington coast in the southern portion of the Willapa Hills. The Naselle River flows in a southwesterly direction emptying into Willapa Harbor. Elevations range from sea level to approximately 760 m. Periods of snow are rare with the dominant precipitation occurring as long duration moderate intensity rain from north Pacific Ocean storm systems. A strong orographic enhancement is present with annual average precipitation ranging from 255 cm near the river mouth to 305 cm at the upper elevations.

The soils in the Naselle basin are deep and fine textured developing from weathered basalt, fine-grained siltstone and graywacky sandstone rocks on steep slopes exhibiting a dendritic drainage pattern.

The principal timber species is western hemlock with some Douglas-fir and sitka spruce (*Picea sitchensis*). There was no timber harvest during the 30-year time period examined for this study. The stand age ranges from 45 to 60 years. Road density is 1.41 km/km^2 and no new road construction has taken place during the period over which stream flow data was examined for this project.

Methods

Peak flow data from the U.S. Geological Survey (USGS) gage near Rainier Washington was used for the Deschutes River. Continuous data was recorded at this site between 1949 and 1975 and a crest gage has been maintained since 1975. The Naselle River gage has been operative since 1929.

Peak flow was defined as the maximum instantaneous discharge above the established base flow for each stream. The base discharge levels selected by the USGS were 112 m^3/s for the Naselle and 56 m^3/s for the Deschutes. For this study, 67 peak flow events were identified on the Deschutes and 43 on the Naselle.

Storm rainfall corresponding to each peak flow event was obtained from representative National Oceanic and Atmospheric Administration (NOAA) weather stations. Storm rainfall was defined as the amount of rainfall on the day the peak flow occurred and the previous three days. Although there is no record of snow accumulation amounts, field observations since 1975 have shown that the larger stream flow events resulted from rain on snow.

Weyerhaeuser Company has been monitoring rainfall in the upper Deschutes watershed since 1975 with continuous recording instruments in conjunction with a streamflow monitoring network. To provide rainfall data for the years previous to 1975, correlations using monthly rainfall between nearby NOAA stations at Cougar, LaGrand and Olympia were made. The best relationship was obtained between the Weyerhaeuser gage and the NOAA station at Cougar 6E ($r^2 = 0.94$) 40 km south of the Deschutes basin (Figure 2). The relationship between individual storm events at Cougar and the Deschutes during the 1976 to 1980 period, when both stations were operative, produced an $r^2 = 0.86$ $p \leq 0.01$ (Figure 3). The largest precipitation event at both stations resulted from rain on snow.

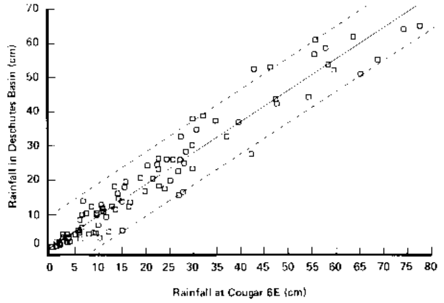

Figure 2. Relationship between total monthly rainfall in the upper Deschutes watershed and the NOAA station at Cougar 6E.
Rainfall Deschutes = 0.2685 + 0.9098 x rainfall at Cougar 6E $r^2 = 0.94$ ($p \leq 0.01$)

Rainfall recorded at the NOAA station located at the town of Naselle near the river mouth was used to characterize precipitation events for the Naselle watershed. No direct measurement of precipitation was available for the headwaters of the Naselle basin. Examination of an isohyetal map prepared from rainfall data from 1930 to 1957 by the NOAA river forecast center in Portland, Oregon showed the headwaters area to receive some 17 percent more average annual precipitation than at the river mouth (Anonymous, 1964). Since no other rainfall data were available, the rainfall recorded at the official Naselle station was used.

To examine temporal changes in peak flow magnitude in relation to land management, a regression method described by Lyons and Beschta (1983) which relates total storm rainfall to peak discharge was used to remove as much of the variation in discharge as possible attributable to rainfall, thus allowing temporal examination of the normalized data. Although there may be some shortcomings in this storm-rainfall-flow analyses since snow melt contribution could not be determined, unusually large precipitation or rain on snow events can be accounted for. A plot of the flow residuals against time was then used to examine the relationship between increasing clear-cut area and peak flow magnitude. Increasing values of the flow residuals in time would indicate increasing peak flows.

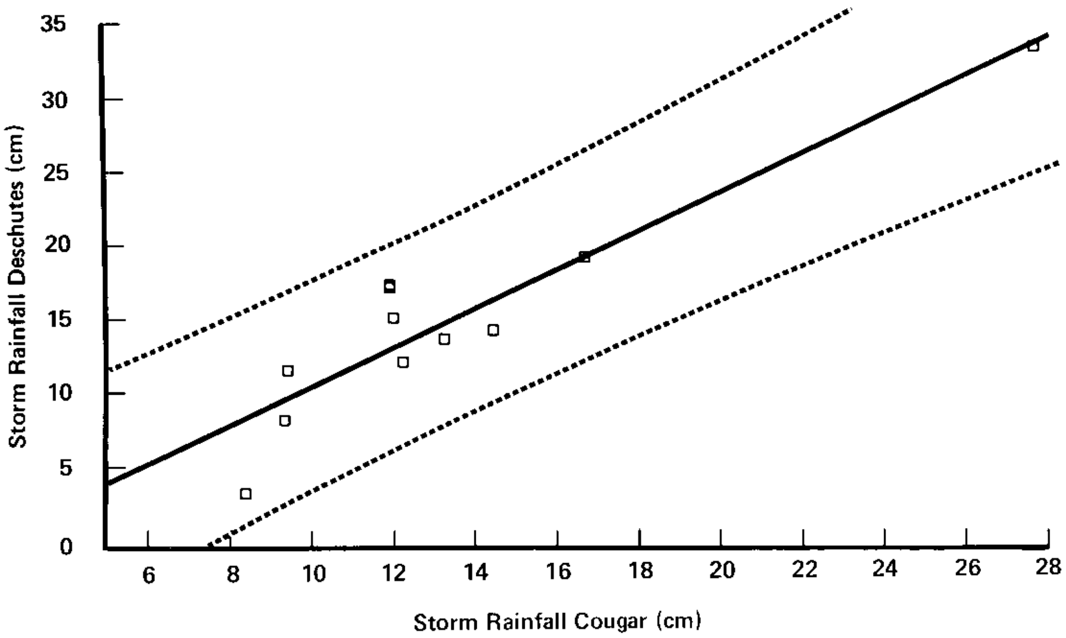

Figure 3. Relationship between storm rainfall at the Weyerhaeuser weather station in the Deschutes basin and the NOAA weather station at Cougar 6E. $r^2 = 0.86$ $p \leq 0.01$, 95 percent confidence limits indicated.

Results and Discussion

Regression of peak flow and storm rainfall events using a model of the form: $q = ax^b$ was performed for the Deschutes and Naselle river basins. While this model represented the data reasonably well, the r^2 was improved slightly by a linear relationship (Figures 4 and 5). This analysis showed that, although significant, less than half of the variation in peak flow magnitude could be accounted for by storm rainfall ($r^2 = 0.45$ $p \leq 0.01$ for the Deschutes and $r^2 = 0.34$ $p \leq 0.01$ for the Naselle) (Figure 4).

The large variance could be caused by inability to accurately account for the amount of storm precipitation contributing to the hydrograph peak and other factors, such as antecedent soil moisture, snow melt, and precipitation form and intensity. These parameters must be more rigorously quantified before developing general predictive capabilities. Lyons and Beschta (1983) reported a similar relationship ($r^2 = 0.38$), and found that the addition of a time variable into the equation was significant, suggesting a possible increase in peak discharge as timber harvesting progressed.

A plot of the flow residuals for both the Deschutes and Naselle watersheds showed no time trends in peak flow magnitude (Figures 6 and 7). From this analysis, differences in peak flow between an actively harvested watershed and one at or approaching hydrologic maturity could not be demonstrated.

This case analysis indicates that care must be exercised not to assume that changes in stream discharge necessarily correspond to a particular level of timber harvest. A wide range of hydrologic factors and the level and duration of their alteration must be considered. Secondly, watershed size must be considered in interpreting research results. It has been demonstrated in small watershed studies that peak flow has been affected by timber harvesting and the road network. Similar evidence does not exist for northwest river systems the size of the Deschutes and Naselle. Because of the normal progression in timber harvesting, only a small percentage of a large watershed is harvested at one time. Even with the increased rate of harvest in the Deschutes after 1970, it was distributed throughout the basin and unlike the harvesting effects demonstrated in small watershed studies, no effect in peak flow magnitude could be detected. Care must be exercised in the use of models based on data from small watershed studies for the purpose of predicting conditions in large watershed systems since the results can be misleading.

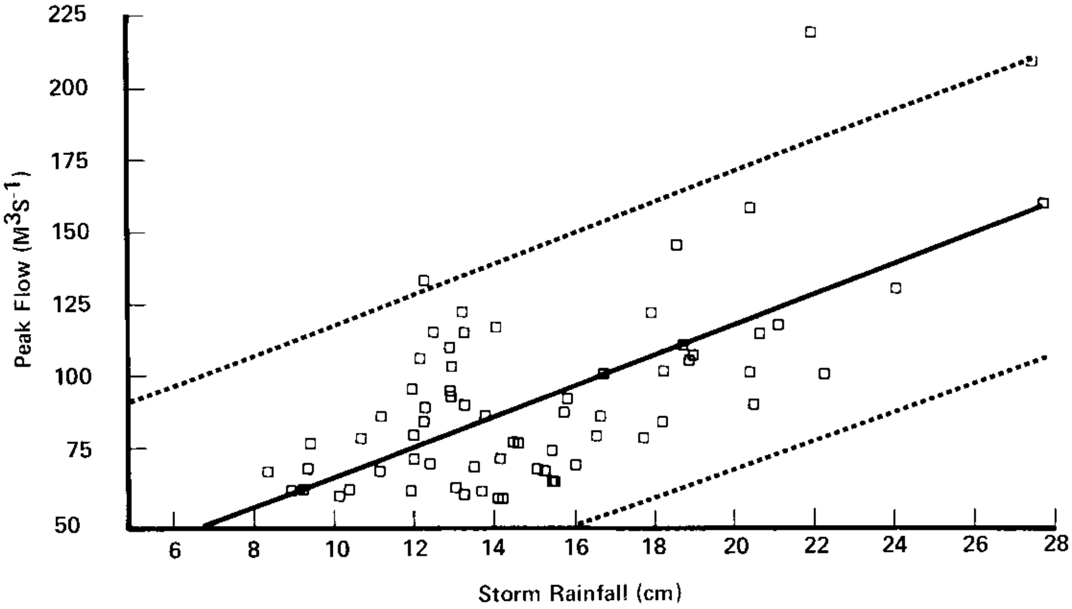

Figure 4. Relationship between peak flow and storm rainfall for the Deschutes watershed. $r^2 = 0.45$ $p \leq 0.01$, 85 percent confidence limits indicated.

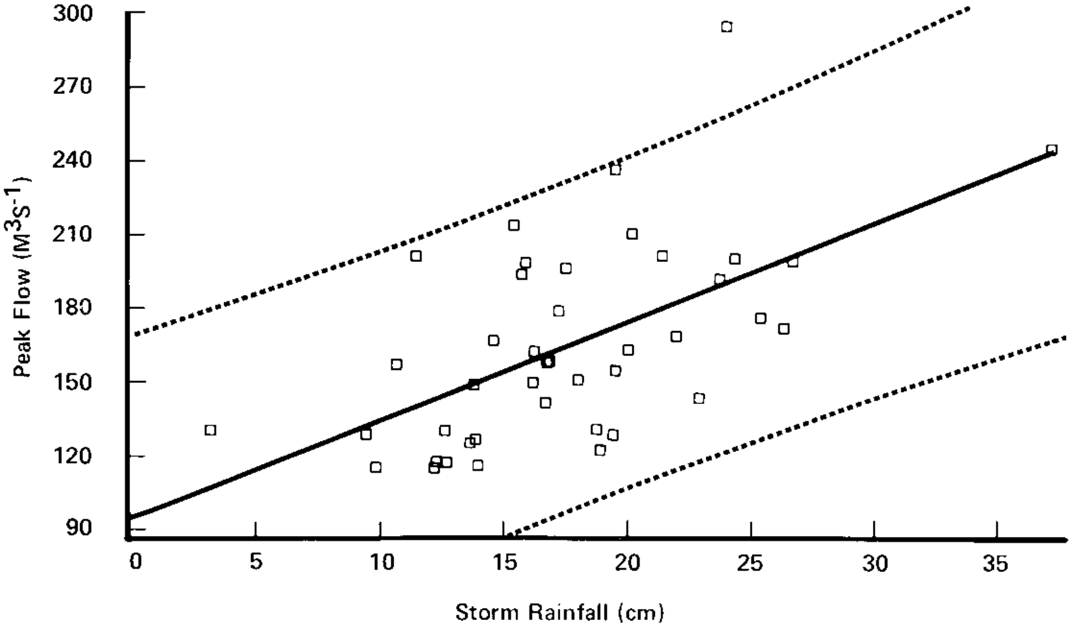

Figure 5. Relationship between peak flow and storm rainfall for the Naselle watershed. $r^2 = 0.34$ $p \leq 0.01$, 95 percent confidence limits indicated.

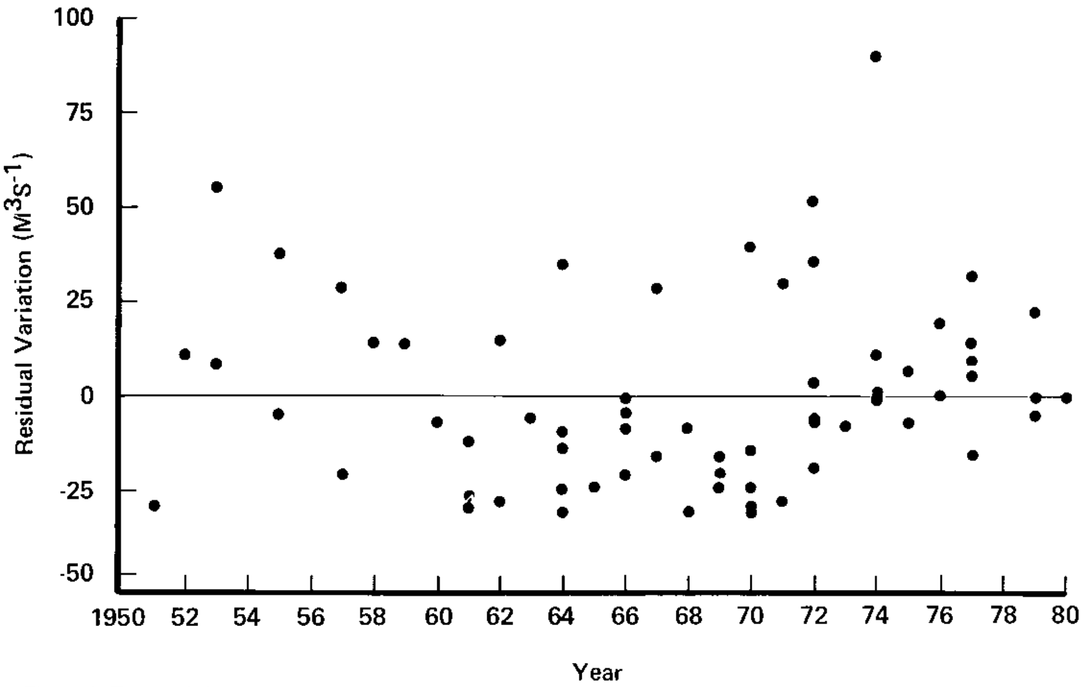

Figure 6. Temporal distribution of the flow residuals from the regression of 67 peak flow events in m³/s and corresponding storm rainfall in centimeters for the Deschutes River basin.

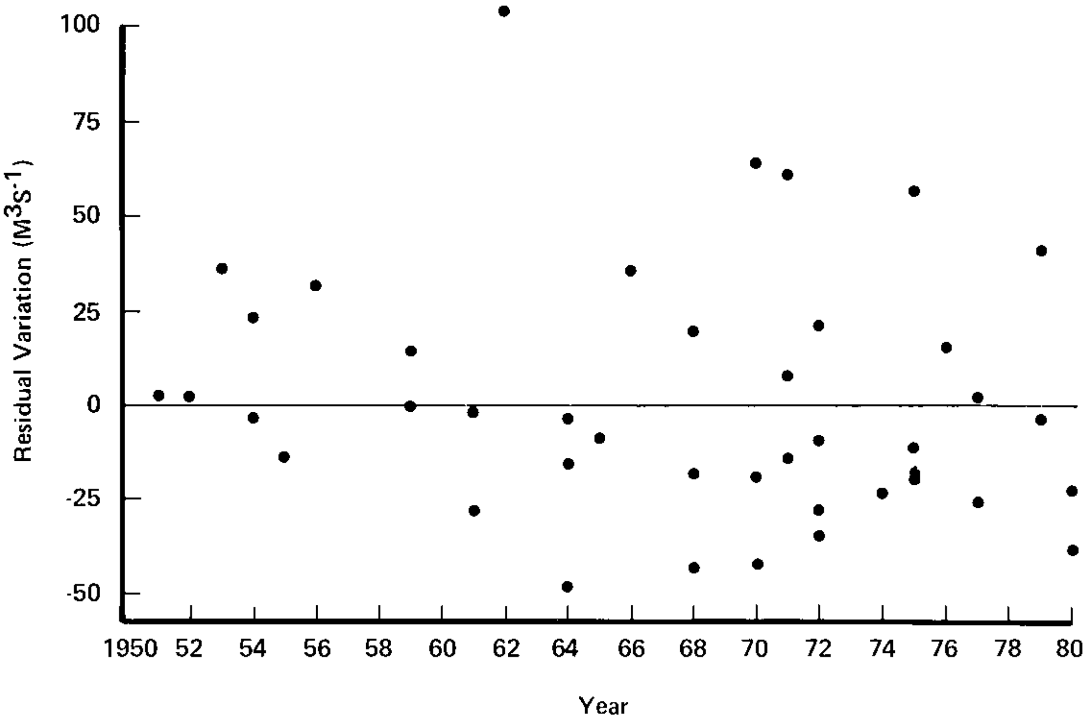

Figure 7. Temporal distribution of the flow residuals from the regression of 43 peak flow events in m³/s and corresponding storm rainfall in centimeters for the Naselle River basin.

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