LONG TERM VARIABLE PROPERTIES OF RUNOFF PROCESS IN A MOUNTAINOUS FORESTED CATCHMENT

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This paper investigates the changes of fundamental hydrological properties with paying attention to climate change and forest growth change after thinning by using long term (24 years) data records at Futatsumori research area in Nakatsugawa City, Japan. The discharge ratio estimated as the ratio between streamflow and rainfall volume over a certain area and time, as a function of the catchment state conditions. Some seasonal cyclic variations or long term trends are derived from the hydrological data. The long term discharge ratio in all analysis cases exhibits a decreasing trend and it is assumed to be caused from increases of temperature, evapotranspiration and rainfall interception with growth of forest. Comparison of discharge ratio between the period of 1984 to 1989 and 2002 to 2007 have resulted for 100 and 200 mm rainfall event are 11% and 14%, respectively. The highest difference of discharge ratio was observed in summer season (Jun-Aug) pointing at 15% and 19%, respectively. Therefore the results of decreasing recent discharge ratio imply that the dealing with discharge ratio coefficient as constant value is not appropriate. In other word the result of response against both growth of forest and temperature rising also show water resource may decrease in future, if rainfall situation was same.

Key Words: *Long Term Hydrological Monitoring, Climate Change, Growth of Forest, Mountainous Forest Catchment, Thinning Effect*

1. Introduction

Forests are the most plentiful source of the cleanest water are often located in the mountains and thus provide the first opportunity to store, filter, release water for downstream uses; provide the earliest opportunity to measure precipitation and streamflow; and its change frequency in seasonal, flood peak, and others[1)], thereby allowing water managers to forecast supplies and adjust downstream water storage systems. Recently, the hydrological impacts of climate change and other forms of forest management and vegetation growth are recognized globally. The Forest Division of Gifu Prefecture is implementing catchment and forest management projects by estab-

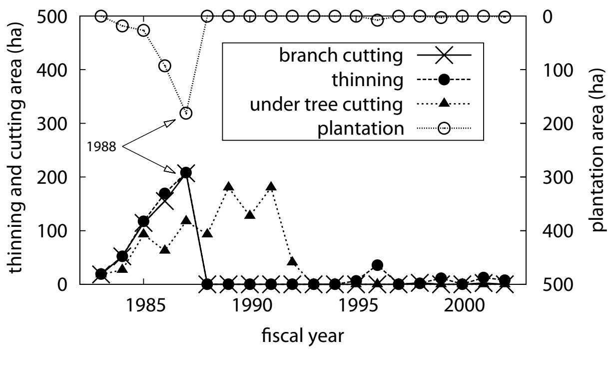


Fig-1 Distribution time of thinning, cutting and planting area at Futatsumori experimental forest lishing experimental forest[2] at Futatsumori research area in Nakatsugawa City, Japan. It were continually thinning, branch cutting and removal of the smaller trees, grasses (under tree cutting) in cover area around 208.5 ha for the period of 1983 to 1988 and small thinning area in 1995 and 1998. Forest is recovering with young trees gradually at same area around 298.5 ha (**Fig-1**). Responses in streamflow to forest recovery may be almost immediate or considerably delayed, depending on climate, topography, soils and other factor[3]. Several studies have documented the reduction of water yield in region undergoing expansion of growing forest plantation[4]. Hibbert[5] reported increases in streamflow proportional to the amount of cover removed. Thinning, logging and planting operation can alter the conditions and processes involved in the generation of streamflow[6]. Therefore the objective of this paper is to quantify the change in streamflow ratio (discharge ratio) as a function of the catchment state condition. To provide this objective we analyzed long term of precipitation and streamflow data, furthermore to investigates the potential influencing factor of the fundamental hydrological properties changes.

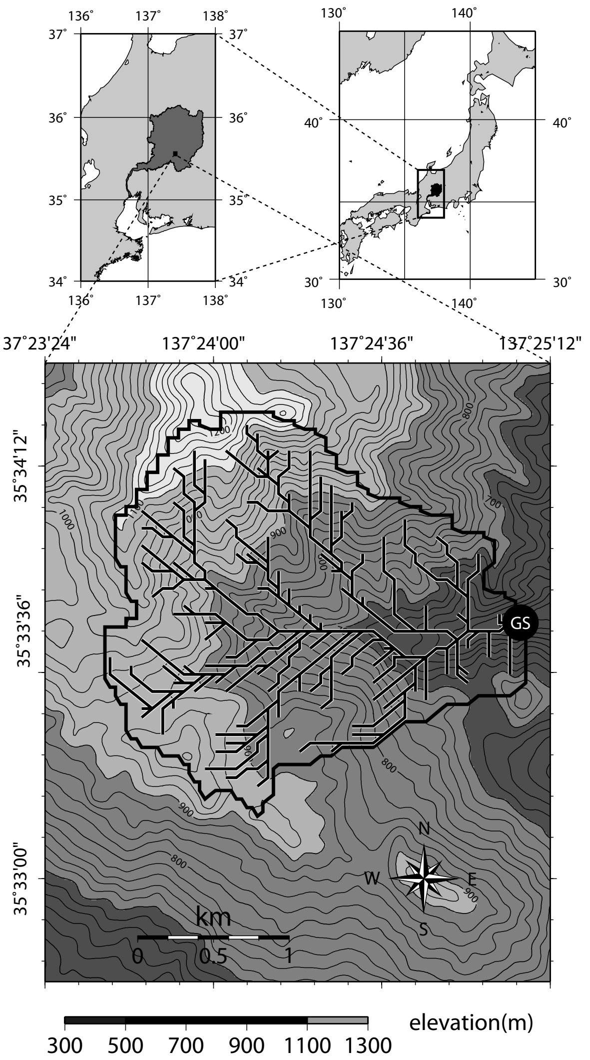


Fig-2 Study area in Futatsumori, Nakatsugawa City of Gifu Prefecture which is part of the Kiso River system, Japan

2. Case Study

(1) Study Area

Fig-2 shows the topographical, geographical and contours of study area in Futatsumori, Nakatsugawa City of Gifu Prefecture, Japan. It is one of part of the Kiso River system. The study area was established in mountainous forested catchment of Futatsumori with longitude arorund 137°24′E, latitude 35°33′N and elevation was 500 m to 1300 m. The average annual precipitation was 2284.7 mm. GS (the Gaman Stream lower catchment, 300 ha) was observed to analyze the effect of forest growth on discharge ratio, hydrological cycle and water yield where dominant forest types are Japanese cedar and cypress. The long-term hydrological data for the period of 1984 to 2007 were measured by the Forest Division of Gifu Prefecture.

(2) Climate Trend

In particular, temperature has proved useful in investigations of streamflow generation[7, 8, 9]. We measured the monthly temperature data from three nearby site because of no long term temperature data in Futatsumori site. The sites were Higashimori site (one of sub-catchment area in Futatsumori area) with longitude around 137°24′E, latitude 35°34′N and elevation was 1019 m, Kurokawa site and Nakatsugawa site. Kurokawa and Nakatsugawa data were collected during 24 years data from AMeDAS (Automated Meteorological Data Acquisition System) of Japan Meteorological Agency. **Fig-3** presents comparison mean and quartiles monthly temperature data during 24 years. Nakatsugawa city temperature is higher than Kurokawa and Higashimori temperature. It shows the urban area was around 2 °C higher than the rural land and mountain area. In order to determine the temperature as climate trend surrounding catchment area, Kurokawa long term temperature

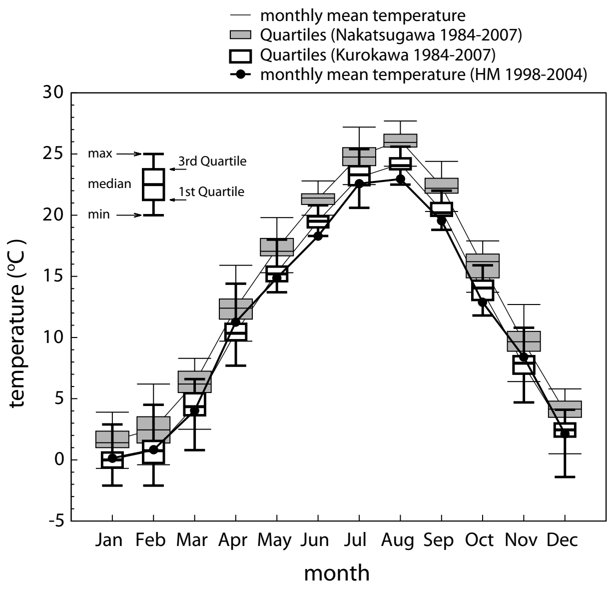


Fig-3 Monthly mean temperature at three nearby sites, Kurokawa, Nakatsugawa and HM (Higashimori)

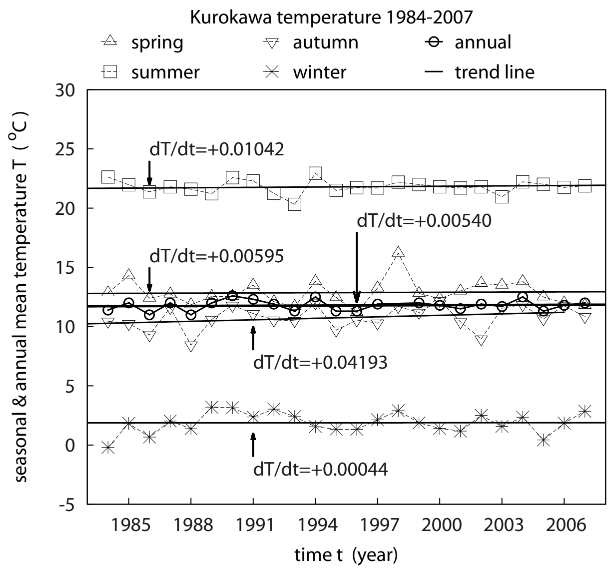


Fig-4 Seasonal Variation of Kurokawa temperature

data is appropriate. According to **Fig-3**, the season defined as follows; Dec, Jan, Feb are winter with the lowest average temperature; Mar, Apr and May are spring with snow begins to melt, stream well with runoff and temperature increases more rapidly; Jun, Jul, Aug are summer with the highest temperature; Sep, Oct and Nov are autumn with decrease temperature more rapidly. Mountainous forest systems are particularly sensitive to changes in climate, with small changes having the potential to produce significant effects. Higher temperatures and changing rates of temperature may cause changes to

Table-1 Summary statistics and linear regression of variation Kurokawa temperature

Summary statistics		Linear regression	
mean	11.8 °C	slope	0.00540
standard deviation	0.5 °C	intercept	0.00427
minimum	11.0 °C	determination R^2	0.00410
1st quartile	11.4 °C		
median	11.9 °C		
3rd quartile	12.0 °C		
maximum	12.6 °C		

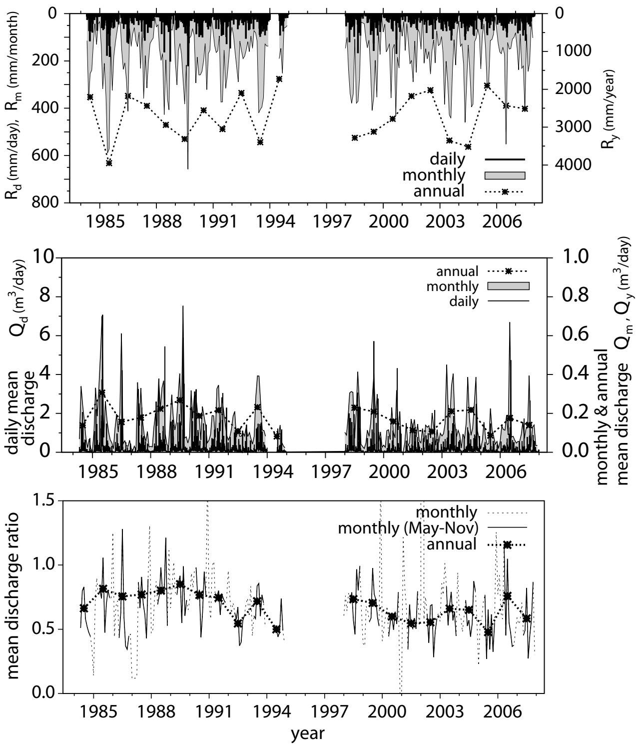


Fig-5 Long time variation of daily, monthly and annual rainfall (a), discharge (b) and discharge ratio (c) during 24 years

growth trees[10]. **Fig-4** shows seasonal and annual mean temperature at Kurokawa as assume as catchment temperature. Annual mean temperature trend is +0.0054 °C over the last 24 years. Winter, spring, summer and autumn temperature have increased by 0.00044 °C, 0.00595 °C, 0.01042 °C and 0.04193 °C, respectively. The summary statistics (**Table-1**) shows the coefficient correlation is small and have weak trend.

3. Methodologies

(1) Rainfall, Discharge and Discharge Ratio

Bosch and Hewlett[3] suggest that streamflow response also depends on the mean annual precipitation of the area. The daily data from 1984 to

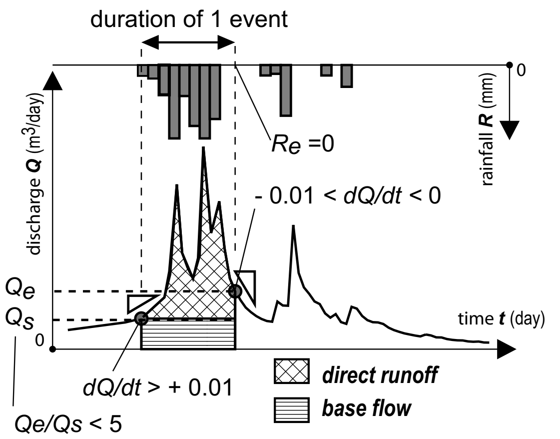


Fig-6 Conceptual representation of extracting unit hydrograph

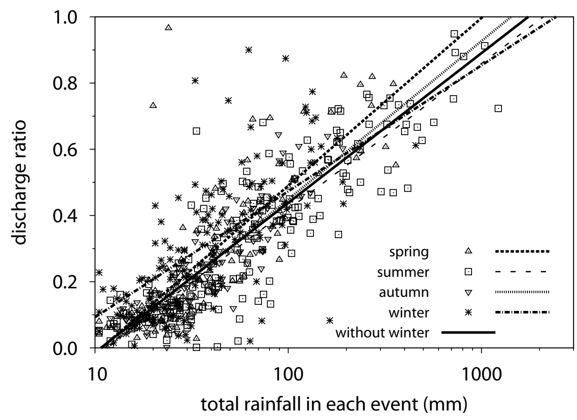


Fig-7 Seasonal trend between total rainfall in each event (mm) and discharge ratio

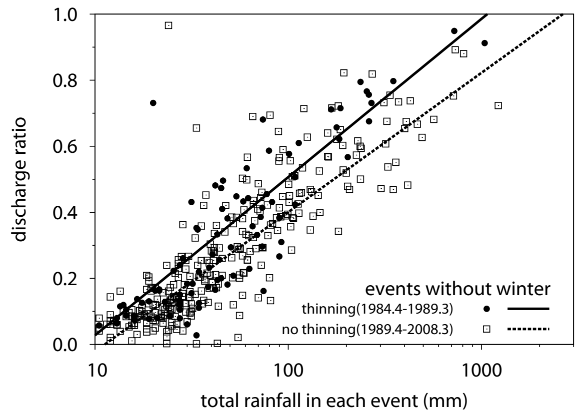


Fig-8 Differences of discharge ratio f in period of thinning and no thinning without winter events data

1993 and ten minute data from 1994 to 2007 have been recorded by the Forest Division of Gifu Prefecture. The ten minute data were amended to daily data in order to produce similar responses. **Fig-5 (a), (b), (c)** show daily, monthly and annually data for rainfall, discharge and discharge ratio f during period. f in **Fig-5(c)** is taken as combination of the proportion of rain that becomes streamflow (discharge), discharge event period, and daily extract event flow. f estimated as the ratio between streamflow Q (m^3/day) and rainfall R (mm) over a certain area A (m^2) and time t (day), as a function of the catchments state conditions.

$$f = \frac{\int Qdt}{10^{-3}RA} \tag{1}$$

The results in **Fig-5 (a), (b), (c)** shows two contrasting in peak flow before and after 1994. In these case, an aliasing hydrograph after 1994 at lower rates. It may an effect of ten minute data that has many sinusoidal amended to daily data that may plotted at low sinusoidal. **Fig-5(c)** also shows monthly discharge ratio with a higher variability of the error measures in snow dominated term as a dashed line compared to rainfall dominated term as a solid line. Thus we must pay attention to discuss about winter precipitation and discharge ratio later. Periods of rainfall and discharge data available for analysis have been taken from 1984 to 2007, but fewer data have not been recorded on 1995, 1996 and 1997 caused by instrument trouble.

(2) Unit Hydrograph

Under the natural conditions, the assumptions of the unit hydrograph cannot be satisfied perfectly. The unit hydrograph at the catchment outlet is then estimated the value of unit discharge with time. Suitable duration of unit hydrograph of each event was one day. These were drawn in **Fig-6**, event of the parameters is $-0.01 < dQ/dt < 0$. The relative value of terminal discharge of ending against starting $Q_e/Q_s < 5$. This conception is mainly based on slope that observed during the discharge increases as the stage rises and conversely the discharge decreases as the stage falls.

4. Result

Season is important variable that affect the streamflow response to logging[6]. We analyzed the trend in different seasons with rainfall as the predictor variable. Seasonal analyses in **Fig-7** indicate that trends exist in spring, autumn and summer allow us to infer if forest cover change were affecting rainfall-discharge ratio relationship and the winter trend had some variability

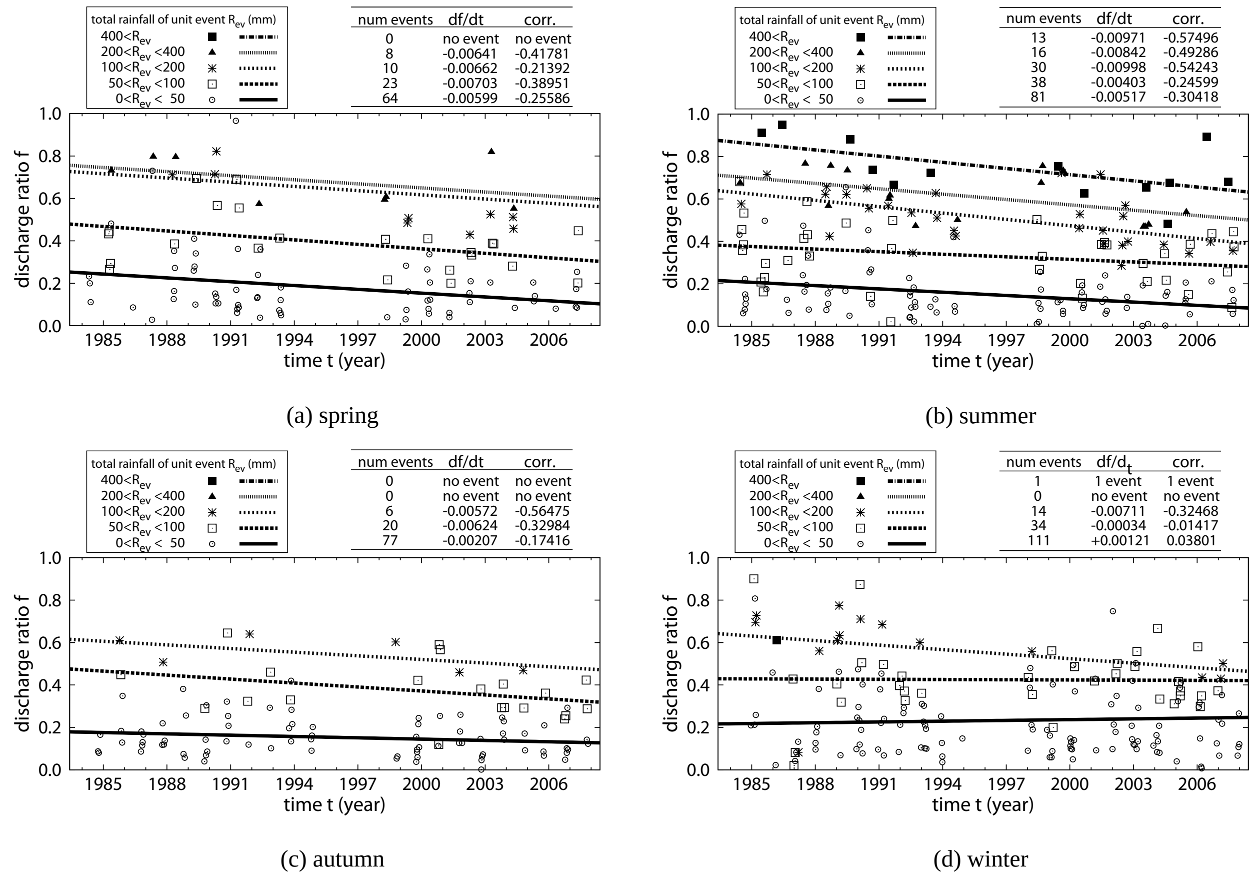
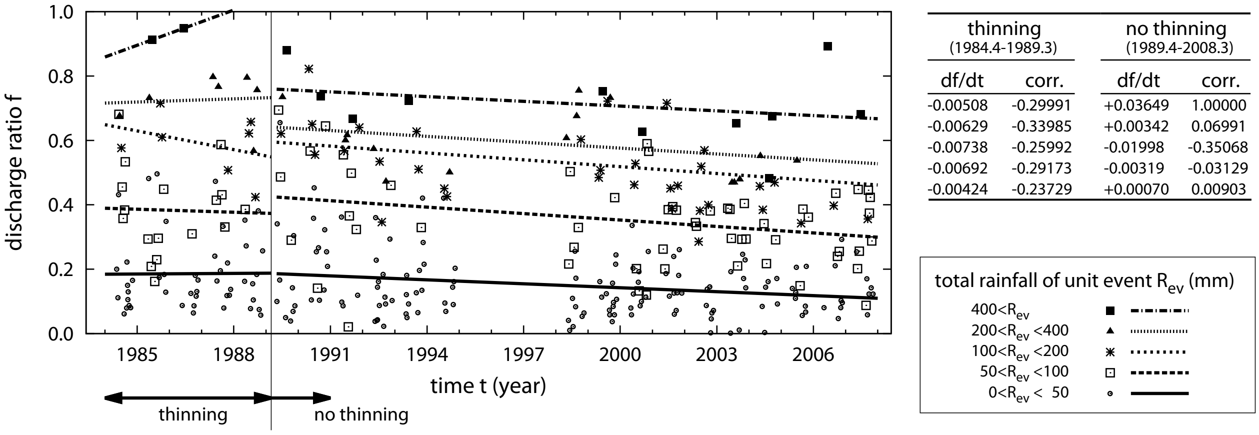


Fig-9 Relationship between partition of total rainfall event and discharge ratio during period

of errors and interpreted as an evidence of **Fig-5(c)**. **Fig-8** shows comparison of discharge ratio trend between the period of thinning and no thinning were analyzed without winter data. We estimated an average reduced of discharge ratio about 11% and 14% for 100 mm and 200 mm of rainfall, respectively. Therefore the results imply that the dealing with discharge ratio as constant value is not appropriate. It can be attributed to growth of forest effect when forest cover change after 14 years after planting. Land use change can direct the runoff response of a catchment, depending on the rainfall partitioning[11]. The total rainfall of unit event has a large variation through the catchment area. The shorts rain occur mainly bigger than 400 mm and the long rain occur smaller than 50 mm. The relationship rainfall variability with discharge ratio in season can be described by **Fig-9, -10**. **Fig-9(a), (b), (c)** related to **Fig-7** which decreasing of discharge ratio in each event rainfall during the growing season. This is likely due to relatively a new vegetation slightly growth at the early stage and become more mature, their take up more water through transpiration. In addition, more mature forest typically have greater leave area index and consequently higher canopy interception, leading to more water loss[12]. In winter(**Fig-9(d)**), the trend of discharge ratio is increasing in total rainfall per event smaller than 50 mm with 111 events. It may some error data have been recorded and may snow dominated at area as same as seasonal analysis in **Fig-5(c), -7**.**Fig-9(b)** showed that response of discharge ratio were very rapid and significant with proportionately larger rainfall in summer. The analysis of **Fig-10** during periods showed that a break in the trend or change point that indicates the effect of thinning and no thinning activity. Discharge ratio increases shown in proportion of high rainfall due to thinning, but they are short-lived due to rapid growth of vegetation. During period without thinning showed reduction of discharge ratio where plantation took place cumulatively. In other word it can reduce high flow by storing them in the soil, which means less chance for floods and enhance low flow which means less chance for droughts. Factors such as the total forested area, forest age and tree density can interactively affect duration of these responses[12].



thinning (1984.4-1989.3)		no thinning (1989.4-2008.3)	
df/dt	corr.	df/dt	corr.
-0.00508	-0.29991	+0.03649	1.00000
-0.00629	-0.33985	+0.00342	0.06991
-0.00738	-0.25992	-0.01998	-0.35068
-0.00692	-0.29173	-0.00319	-0.03129
-0.00424	-0.23729	+0.00070	0.00903

Fig-10 Discharge ratio change in period thinning and no thinning without winter events data

5. Conclusion

Consider long-term annual changes, adjustment time scales, the seasonal pattern of flows, and changes in both annual and seasonal figure was indicating that removal of trees was designed to improve the growth potential of the younger tree. This research also focusing on the understanding the changes in the hydrological regime is important because it will affect downstream water availability, vegetation cover stage influence at this partitioning point compare the forested catchment including the old situation and the new situation. A good understanding of the hydrological processes is important for the assessment of the water resources, their management and conservation on global and regional scales[13]. Factors such as forest age and thinning should be incorporated to more accurately predict the hydrological effects of forest growth in the future.

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