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### Quantification of the effect of forest harvesting versus climate on streamflow cycles and trends in an evergreen broadleaf catchment

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## **Quantification of the effect of forest harvesting versus climate on streamflow cycles and trends in an evergreen broadleaf catchment**

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**Abstract** A new method known as Unobserved Component – Dynamic Harmonic Regression (UC-DHR) was applied to a 39-year record of rainfall and streamflow for three sub-catchments of the Sarukawa Experimental Watershed in southwestern Japan. Some 25% of the timber was harvested from one of the sub-catchments in May-July 1982 and the objective was to quantify the magnitude of this effect relative to the effects of climate cycles (e.g. Southern Oscillation Index). The observed effects of inter-annual climate cycles (i.e., 0.89-1.36 mm/d) were seen to be comparable (i.e., 0.70-1.17 mm/d) to the effects of harvesting 25% of the standing timber. This result underlines the importance of always quantifying the effect of climate on streamflow response when harvesting impacts are studied. [117 words]

**Keywords** evergreen broadleaf forest; growing stock; harvesting impact; humid temperate; Southern Oscillation Index; Unobserved Components – Dynamic Harmonic Regression

## 1 Introduction

### **Forests and water resources during climate changes**

Forests and water are both important natural resources. Many research studies related to land-use change (e.g., deforestation or afforestation, vegetation change, urbanization and others) have effectively described relationships between forests and water resources. The rainfall-streamflow process is complex, because of the various pathways of water flow within a catchment. In addition, long-term rainfall and streamflow records may be affected by trends of climate change. Thus, to understand forest and water relationships, one must quantitatively evaluate the effects of both forest management and climate on the modification of water resources.

### **Previous harvest experiments for broadleaf tree species**

The world's forest growing stock is composed of two-thirds broadleaf trees and one-third coniferous trees (FAO 2010). Coniferous species clearly dominate the growing stock in Europe, North and Central America. Broadleaf species comprise more than 98% of the total growing stock in Africa, Oceania and South America. Even in Asia, broadleaf species make up about 60% of the total growing stock (FAO 2010).

We list here the effect of partial harvesting and clear cutting on streamflow generation in temperate broadleaf old-growth forests in Japan and worldwide, ignoring studies of new plantations of deciduous trees (Table 1a and b). Broadleaf forests were further divided into deciduous and evergreen forests. Broadleaf forest catchments are all in deciduous broadleaf forests in North America (Lynch and Corbett 1990, Hornbeck et al. 1993). Evergreen broadleaf results are represented by a few studies from Taiwan (Hsia and Koh 1983) and New Zealand (Pearce et al. 1980). In Japan, several reports analysed paired-catchment experiments within deciduous forests. These studies were in the snow-affected region of East Japan, such as Gumma, Yamagata and Hokkaido, and analysed various deciduous broadleaf species (Nakano 1971, Shimizu et al. 1994). Most evergreen broadleaf forests are in warm and humid regions of West Japan, and data are lacking that can be used to compare harvesting impacts on hydrology in such forests.

The results of previous harvesting experiments using broadleaf tree species are shown in Table 1a and b and Figure 1a and b. Figure 1a shows the relationship

between annual rainfall at a site and streamflow change after tree removal in the first year after the treatment. Previous experiments for evergreen broadleaf tree species were mainly in regions with more than 2,000 mm/year of rainfall (Pearce et al. 1980, Hsia and Koh 1983), and those for deciduous broadleaf tree species were in regions with less than 1,100 mm/year (Lynch and Corbett 1990, Hornbeck et al. 1993). Experiments in areas with moderate rainfall represent mixed species forests with broadleaf and coniferous trees. In this range, the relationship between pre-harvest rainfall and rainfall increase after harvesting varied greatly. Figure 1b shows the relationship between percentage of area harvested and the streamflow change after tree removal in the first year after the treatment. The tendency of streamflow to increase after harvest is related to the extent of harvesting. The streamflow increase after harvest was  $\leq 100$  mm/year when 20% of the trees were removed.

Table 1a & b

Figure 1a & b

### **Traditional method of identifying forestry-related hydrological change**

Many paired catchment experiments have been reported. During our review, paired, nested or grouped catchment studies were considered strong evidence, and studies based on after-the-fact analyses of existing data or less rigorous experiments on large catchments were considered circumstantial evidence (Hibbert 1971). Increased water yield after harvesting trees was partly controlled by rainfall amount and percentage of area harvested (Bruijnzeel 2004, Brown et al. 2005).

Andréssian (2004) indicated that the traditional method using paired catchments shows a linear relationship between annual rainfall and streamflow amounts. Thus, the problem with this method is that it uses annual data and assumes a linear relationship between rainfall ( $P$ ) and streamflow ( $Q$ ), so a long calibration period is needed. When using annual data, most observers agree that  $P$  and  $Q$  should have a linear relationship. However, this relationship should naturally be nonlinear in more detailed time-series. Furthermore, rainfall amount frequently changes interannually, especially in the humid study region. It is difficult to calculate the range of this amount if the calibration period is only 5 to 9 years in such a region. Suppiah (2004) reported long-term rainfall trends associated with recent climate change or Southern Oscillation Index (SOI).

### **New method of identifying forestry-related hydrological change**

Some studies have investigated the effect of land-use change on streamflow in a catchment over a shorter period than a year. Zégre et al. (2010) detected the influence of land-use change on streamflow amount using daily time series data and a hydrologic model. Ssegane et al. (2013) expressed the daily relationship between groundwater level and streamflow amount as a regression equation, and compared a treated catchment with a control catchment. Tamai (2010) examined the effect of vegetation change history on flow duration curves in paired catchments.

Previously, inference drawn from time-trend studies was weaker than that from paired catchment studies, simply because there was no climatic control to separate vegetation cover and climatic effects (Whitehead and Robinson, 1993). Recently, Chappell and Tych (2012) developed a new method for time-series analyses of hydrologic data. Their work was the first application the Unobserved Components – Dynamic Harmonic Regression (UC-DHR) model for catchment hydrologic data. Their technique uses a single time series (monthly, fortnightly, or daily), evaluating model estimation associated with uncertainty information and a non-linear analysis. Their method can be used for quantitatively evaluating and comparing the effect of forest management versus climate on modifying water resources, and can also be used for non-paired catchments. These characteristics are suitable for regions lacking extensive datasets, such as the humid tropics of many developing countries.

### Study aim

The aim of this study is to quantitatively evaluate the effect of forest management versus climate on altering water resources in a catchment. A new method for quantifying the relative impacts on streamflow and evapotranspiration resulting from climate change and changes in agroforestry and forestry systems has been developed by Chappell and Tych (2012).

The present study focuses on the effects of a 1982 partial harvest on streamflow recorded in an evergreen broadleaf sub-catchment of the Sarukawa Experimental Watershed. This experimental watershed is one of five long-term forest experimental watersheds observed and managed by the Forestry and Forest Products Research Institute of Japan. The Sarukawa Experimental Watershed has three sub-catchments, where high quality hydrologic observations have been made over more than 39 years and where the history of the growing stocks is well known (Shimizu et al. 2008, Asano et al. 2011). The watershed is suitable for validation of UC-DHC because it has: (1) evergreen broadleaf trees in a humid region with high annual mean rainfall, streamflow and evapotranspiration ( $P = 3,000$  mm/year,  $Q = 1,800$  mm/year,  $P-Q =$  about 1,200 mm/year); (2) partial harvesting (i.e., harvesting 43% of the drainage area and 25% of the growing stock); (3) 39 years of high-quality daily rainfall and streamflow data.

The study has two objectives.

*1 Quantify effects of climate cycles and trend on hydrologic records:* UC-DHR was used to extract seasonal amplitude from rainfall and streamflow records and to compare with the Southern Oscillation Index (SOI). The SOI has been shown to regulate climate in the Asia-Oceania region, e.g., Thailand, India, Australia and Japan (Lie et al. 1998, Shrestha and Kostaschuk 2005, Jin et al. 2005, Chandimala and Zubair 2007, Fu et al. 2013, Räsänen and Kummu 2013, Sun et al. 2014).

*2 Quantify effects of harvesting impacts on hydrologic records:* The harvesting impact on hydrologic records was quantified using the UC-DHR approach. The objective was to determine if forestry-related change in streamflow was larger than the dynamics associated with the climate.

## 2 Study site and method

### Study site

The Sarukawa Experimental Watershed was established for forest hydrological studies in a warm temperate rain forest of Miyazaki Prefecture, Japan. This catchment is in the upstream portion of the Oyodo River, where it flows through the city of Miyazaki. Hydrologic observations began in 1959. The results of observations from this experimental watershed were gradually released in the years following 1967, when standard observation methods were established. Thus, observational data for the 39 years of 1967–2005 were summarized and published every 10 or 20 years during this period (Forest Influences Unit, Kyushu Branch Station 1976, Takeshita et al. 1996, Shimizu et al. 2008, Asano et al. 2011). These reports include summarized daily rainfall and daily streamflow and an outline of site conditions, geology, and other information on the watersheds. The watershed includes three small sub-catchments (Figure 2), i.e., Sarukawa No. 1 (Srkl), Sarukawa No. 2 (Sr2), and Sarukawa No. 3 (Sr3). Srkl and Sr2 adjoin each other and Sr3 is about 1 km east-northeast of Sr2 (Asano et al. 2011; Table 2 summarizes basic information).

This climate classification of the study site is “the Pacific Ocean side area in southern Kyushu” (Uchijima et al. 2003). In this area, there is a heavy rain period called a “Tsu-yu”, caused by an atmospheric pressure pattern from May through July. Rainfall during this period constitutes about 30% of annual precipitation. Moreover, because there may be typhoons with heavy rain in June–November, the climate of this area has strong interannual variation (Uchijima et al. 2003).

Figure 2

Table 2

### Forest history and harvesting

Shimizu et al. (2008) estimated the history of change in the growing stock of the Sarukawa Experimental Watershed using a double sampling method based on a combination of aerial photographs and plot-survey data (Figure 3). Srkl and Sr2 have natural evergreen broadleaf trees and Sr3 is covered by mixed forests with natural evergreen broadleaf and coniferous trees, planted in 1957 when observations commenced in the watershed (Shirai et al. 1962). Two paired harvesting experiments have been conducted in the watershed. First, clear cutting was done in 1965–1966, with Srkl and Sr3 as treated catchments and Sr2 as the control. Later, there was a partial harvest in 1987, using Sr2 as the treated catchment and Srkl and Sr3 as the controls.

Figure 3 indicates that the growing stock of Srkl and Sr3 declined to  $50 \text{ m}^3 \text{ ha}^{-1}$  in 1966 after the first harvesting experiment. The 1982 experimental harvest also reduced the growing stock of Sr2. Even though Sr2 was only partially harvested in 1982, its growing stock has always been greater than those of Srkl or Sr3. Sr2 was partially harvested from May through July 1982. Thus, we selected July 1982 as the starting point of this study, i.e., when the forest cover changed in the UC-DHR

analysis. This partial timber harvest covered 43% of the drainage area and constituted  $705.1 \text{ m}^3 \text{ ha}^{-1}$  (Takeshita et al. 1986). This timber extraction volume is equivalent to 25% of the growing stock, as surveyed in 1974. Harvesting was undertaken in streamside areas with larger trees near the hilltops left un-harvested. Vegetation in Srk2 was allowed to recover naturally without planting.

For the first paired harvest experiment, observational data collected during the first stage (1959–1966) were considered inaccurate and lacked sufficient calibration data, and so have never been published. Komatsu et al. (2007) used initial hydrologic data from 1959 to 1965 as equivalent to other observation data. However, these data do not contain observed values and were extrapolated using the empirical formula of Shirai et al. (1962) to roughly approximate and address the amount of annual evapotranspiration observed in the region. Thus, in our study, UC-DHR was adapted for the Srk2 partial harvest experiment in 1982, using only reliable and higher quality daily rainfall and streamflow data collected between 1967 and 2005.

### Figure 3

#### Dataset for analysis

For adaptation restrictions of UC-DHR, a sufficiently long hydrologic record is needed to meet the analysis objective. Chappell and Tych (2012) used a 7-year dataset (2.5 years before harvest and 4.5 years afterward) for their UC-DHR analyses. Thus, it is probable that a dataset covering 2–3 years before and after harvest is adequate to investigate harvesting impacts on a streamflow record. Nevertheless, 20–30 years of data would likely be required to investigate relationships for long-term trends and cycles as extracted from hydrologic records and climate indices such as SOI. As there may be considerable variation in seasonal rainfall from year to year, flow records over 20–30 years are required to address flow regimes (Shaw et al. 2010). Thus, the 39-year data of the present study are sufficient to describe streamflow patterns at the study site. The results will be useful in evaluating the effects of land-cover change on streamflow in both humid temperate regions and the humid tropics, where the extent of forested areas are being reduced by various pressures such as socioeconomic factors.

#### UC-DHR analysis

Chappell and Tych (2012) first described the UC-DHR model as an application for measuring hydrologic change. We explain the analysis procedure briefly as follows.

UC-DHR is a type of univariate UC model, a group of models that includes basic structural and dynamic linear models (Harvey 1984, West et al., 1985). UC-DHR characterizes trend ( $T_t$ : interannual), short-term periodic ( $C_t$ : cyclical annual and sub-annual and zero-mean observation error ( $e_t$ , with variance,  $\sigma_e^2$ ) components. The simulated time series of rainfall, and, streamflow ( $y_t$ ) were calculated using

$$y_t = T_t + C_t + e_t. \quad (1)$$

The most important component characterized in the present study is  $C_t$ , which is calculated via

$$C_t = \sum_{i=1}^{S_s} (a_{i,t} \cos(t\omega_i) + b_{i,t} \sin(t\omega_i)), \quad (2)$$

where  $a_{i,t}$  and  $b_{i,t}$  are stochastic Time Variable Parameters (TVPs) that define the amplitude of the harmonic sine and cosine components, and  $\omega_i$ ,  $i = 1, 2 \dots, S_s$  are fundamental and harmonic frequencies associated with periodicity in the series. In this study, trends of rainfall, and, streamflow are modelled using an integrated random walk process, and all TVPs in the periodic component are modelled using scalar random walk processes.

For rainfall and streamflow in the three watersheds (Sr1, Sr2, and Sr3), daily means were calculated for each month from a daily dataset. Each individual record was analysed by UC-DHR which is an algorithm within the CAPTAIN Toolbox (<http://captaintoolbox.co.uk>).

July 1982, the date of the Sr2 partial harvest, was set as the point of water balance change (the 'intervention point'). The harvest effect is such that the data (e.g., strength of a trend) were estimated separately in the periods before and after the selected time. Both mean and slope of the trend and amplitudes of harmonic components can be estimated in this way. The Noise Variance Ratio (NVR) is the volatility of the estimated states and TVPs of the UC-DHR model. This was set to  $NVR = 16$  by trial and error of S-fitting of the data. If the step change in the trend at the intervention point is larger than the standard deviation, then a step change is said to be observable in the time series (Chappell and Tych, 2012). The Sarukawa Experimental Watershed has about 15.5-year hydrological data before harvest on May to July 1982. Thus, we calculated the step increase of peak value from the first month after harvest to that of the long-term average before harvest.

Seasonal amplitudes of rainfall and streamflow were compared with trends in the SOI. The SOI is defined as the normalized pressure difference between the island of Tahiti and Darwin, Australia. There are several slight variations of SOI values calculated at various centres. Here, we calculated the SOI based on the method of Ropelewski and Jones (1987). This uses a second normalization step and was the standard method of the Climate Analysis Centre of the University of East Anglia in 1987. Allan et al. (1991) described the processing of these data. Also see Können et al. (1998) for details of the early pressure sources and methods used to compile the series from 1866 onwards. SOI trend was shown by scaled and smoothed values using the Integrated Random Walk Model in the CAPTAIN Toolbox.

### 3 RESULTS

#### Results of UC-DHR applied to rainfall and streamflow records

The UC-DHR model was applied to each individual rainfall and streamflow record from Sr1, Sr2 and Sr3 during the 39-year study period. Twenty-five percent of the growing stock of Sr2 was harvested during May–July 1982. For the streamflow record, results are provided for both the treated catchment of Sr2 and control catchments of Sr1 and Sr3.

Both the seasonal (annual and sub-annual cycles) and trend (inter-annual

cycles and drift) components were identified within each time series. For example, Figure 4 shows UC-DHR results of all components of the rainfall time series (without harvest), together with observed data and model uncertainty. The power spectrum of the rainfall record showed strong harmonic periodicity (peaks at 12.1, 5.9, 4, 3, 2.4, and 2 months). Thus, these automatically calculated values were used for the UC-DHR analysis of rainfall. For all streamflow records, power spectra of the observed values did not have peaks as well defined as the harmonics. Thus, an alternative method of manually establishing the harmonics for UC-DHR analysis was conducted, using peaks of 12, 6, 3, and 2.4 months. Regarding rainfall trend, there was less rain between 1967–1971 and 1995–1997 (Figure 4).

Figure 4

### Seasonal amplitudes in the hydrological record and SOI data

Figure 5 shows that the seasonal amplitudes of rainfall were largely synchronized with the SOI trend (Figure 5). However, there was a portion of this period in which this relationship was reversed. Although SOI was relatively low, seasonal amplitude in rainfall had a high value in June 1993, and the heaviest rain occurred in this month (48.5 mm/d for the monthly average). Further, seasonal rainfall amplitude was relatively low but the SOI relatively high from May to June 1974. The temporal variations of seasonal amplitudes in streamflow were similar to those in rainfall (Figure 5). That rainfall amplitude generally exceeded that of streamflow (Figure 5).

Figure 5

### Streamflow trend with uncertainty

Figure 6 shows streamflow trends and seasonally adjusted data for Srk1, Srk2 and Srk3 for the entire study period (Figure 6abc) and a zoomed-in depiction of data for 1978 to 1987 (Figure 6def). The harvested Srk2 basin does show a step increase in streamflow at the end of the harvesting period, however, this change was not sustained for more than 2 years (Figure 6d). While step increase in streamflow was much smaller for control basin Srk1 (Figure 6e), the apparent change in control basin Srk3 was comparable to that in the harvesting basin (Figure 6f). This suggests that the step increase in streamflow between the 1981-82 period and 1982-83 period relates mostly to the step increase in rainfall (and hence streamflow) between the two periods, rather than a harvesting affect.

## 4 DISCUSSION

### SOI impacts on basin rainfall and streamflow

The SOI index represents the strength of the trade winds. When the index is positive, trade winds are strong and when negative, those winds are weak. Therefore, a low or high SOI is representative of an El Niño or La Niña event, respectively. In a La Niña event, sea surface temperature in the West Pacific Ocean tropical zone rises and cumulonimbus cloud activity increases there. For this reason, in summer it becomes easy to forecast that Pacific high pressure systems will periodically form off the northern coasts of Japan. These systems are readily affected by warm, moist air arriving on southerly winds from southwestern Japan, including Okinawa and Amami. For this reason, during summer on the Pacific Ocean side of northwestern Japan, temperatures tend to remain high during the long daylight hours and the chance of rain increases.

During a La Niña event, there is a tendency for rainy season precipitation to increase on the Pacific Ocean side in south Kyushu, where the study site is located. Therefore, when the SOI becomes high, a La Niña event develops and rainfall increase is expected. Positive correlation was found via the seasonal amplitudes of a hydrological record and a SOI trend (Figure 5). For these periods, it is believed that local climate was generally modulated by the global climate.

Seasonal amplitude of the relationship between rainfall and SOI reversed in some periods, such as 1967, 1973, 1978, 1981, and 1993. Consequently, local climate conditions in the city of Miyazaki (25 km from Sarukawa Experimental Watershed) over the past 119 years (1886–2005) were investigated, using a historical meteorological database of the Japan Meteorological Agency (2014). According to this database, 1993 had the maximum annual precipitation at Miyazaki. The precipitation, which exceeded 1,000 mm in southern Kyushu from a seasonal rain front and typhoon No. 4 (Nathan) over 13 May to 25 July of that year, caused a serious landslide disaster and flood damage in this area. In contrast, 1967, 1973, 1978 and 1981 were years with little rain, assigning them to 10th, 7th, 9th and 6th places for annual precipitation at Miyazaki. These years had little rainfall during the “Tsu-yu” rainy season, about 30–60% of the average for a typical year (Uchijima et al. 2003). Rainfall during the rainy season was 500 mm in southern Kyushu, about 30% of the annual amount (Uchijima et al. 2003). Thus, the years in which the seasonal amplitude of the hydrologic record did not synchronize with the SOI had the maximum or local minimum in the historical meteorological record. The local rather than regional climate represented by the SOI is believed to have strongly affected the hydrologic record in these years.

### Quantification of harvesting effects on the streamflow record

Harvesting within 43% of the drainage area (but only 25% of the entire tree volume) did give an increase in streamflow in Srk2 that was larger than the standard deviation on the trend (Figure 6). Streamflow typically increases after harvesting, because evapotranspiration in the harvested area is expected to decrease (Brown et al 2005) Stednick’s (1995) found that some studies needed harvesting over 50% of the basin for water balance changes to be observed, but in other studies harvesting of only 15% of the basin could result in observable hydrological change. The step increase in

streamflow for the three basins was: a) 2.06 mm/d for Srk2 (treated catchment); b) 0.89 mm/d for Srk1 (control catchment); c) 1.36 mm/d for Srk3 (control catchment). If the step increases in Srk1 and Srk3 relate to climate cycles and trend, then the effect of harvesting against the controls Srk1 and Srk3 is therefore:

1/ 1.17 mm/d (Srk2-Srk1 step increase) giving the equivalent of  $1.17 \times 365 = 427$  mm/year, and

2/ 0.70 mm/d (Srk2-Srk3 step increase) giving the equivalent of  $0.70 \times 365 = 256$  mm/year, respectively.

Table 1 shows the effect of timber harvesting on change in streamflow (mm/year) from 16 studies conducted in broadleaf old-growth forests. As different proportions of the timber volume were harvested, the table also shows values (mm/year) if 25% of the timber had been harvested. These recalculated values are considerably smaller than the 427 mm/year equivalent or 256 mm/year equivalent. The Sarukawa basins did however receive considerably more rainfall, namely 3,046 mm/year (averaged over 1967 to 2005), giving, streamflow of 1,755 mm/year (averaged over 1967 to 2005), and so 1,291 mm/year evapotranspiration. This increase of water yield of 256 or 427 mm/year was, therefore, 20% or 33% of mm/year evapotranspiration. These values bracket the actual percentage of the harvested growing stock.

The lack of a persistent impact on water yield over several years may be related to rapid regeneration in the Srk2 catchment. A secondary forest of *Quercus serrata* and *Mallotus japonicus* is visible in the harvested areas of Srk2. *M. japonicus* has the capacity to actively regenerate (Yamagawa et al. 2006, Yamagawa and Ito 2008).

**Figure 6**

## 5 CONCLUSION

The UC-DHR algorithm was applied to a 39-year record of rainfall and streamflow for three sub-catchments of the Sarukawa Experimental Watershed in southwestern Japan. Some 25% of the timber was harvested from one of the sub-catchments (Srk2) in May-July 1982. The observed effects of inter-annual climate cycles in the control basins Srk1 and Srk3 produced a streamflow increase at the same time as the harvesting that covered the range 0.89-1.36 mm/d. Similarly, the increase in streamflow resulting from harvesting 25% of the standing timber in Srk2 (once the climate effects had been removed) produced an increased in streamflow of 0.70-1.17 mm/d. This result underlines the importance of always quantifying the effect of climate on streamflow response when harvesting impacts are studied.

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Figure 2. Contour map of study areas within Sarukawa Experimental Watershed; NO1 (Srk1), NO2 (Srk2), and NO3 (Srk3). Shaded area represents 25% harvest cutting area of Srk2 in 1982.

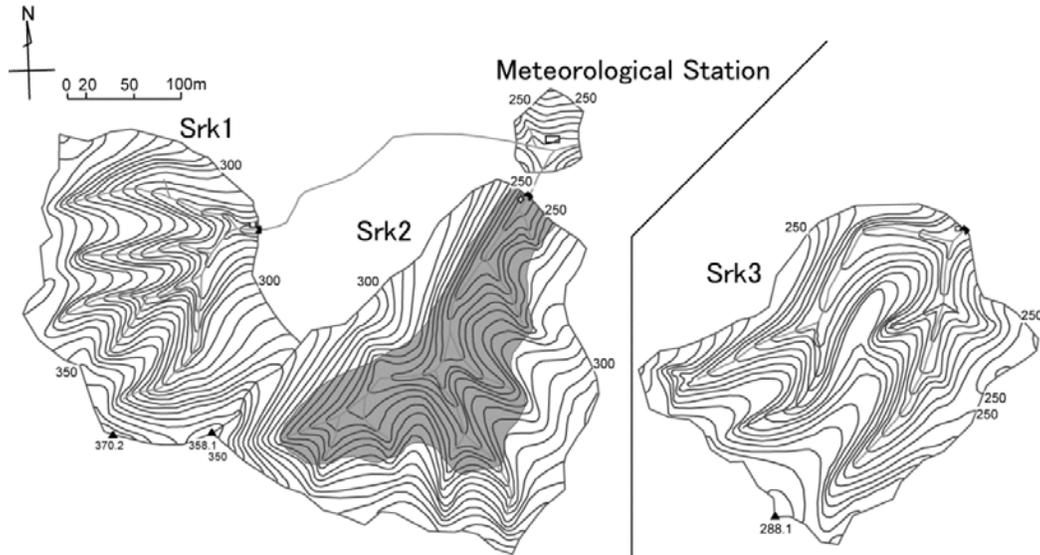


Figure 3. Growing stock variation history in Sarukawa Experimental Watershed. Data estimated by Shimizu et al. (2008).

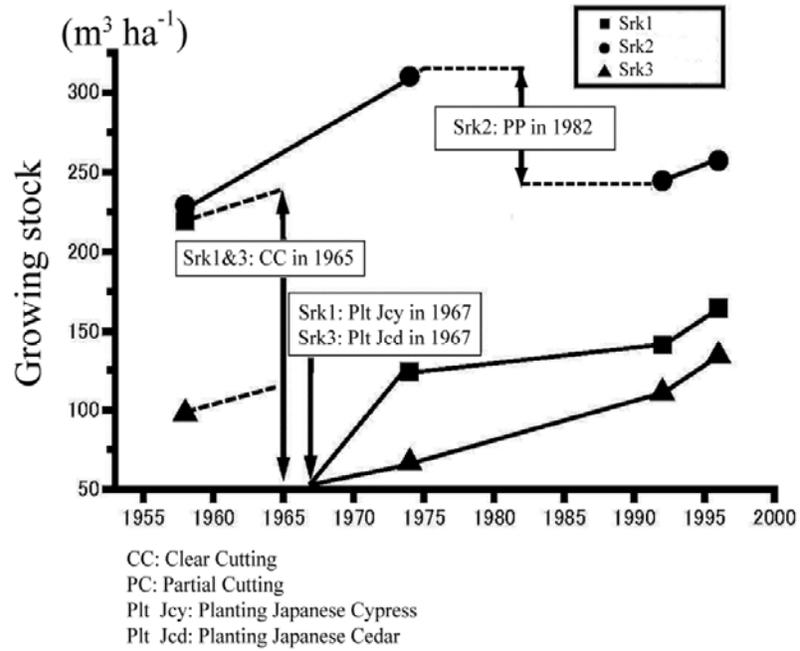


Figure 4. Observed and modelled rainfall for Saruakwa Experimental Watershed. Upper panel: observed (solid line) and modelled (dashed line) power spectra; lower panel: observed rainfall time-series and UC-DHR modelled rainfall time-series together with uncertainty band ( $\pm$ standard deviation in grey shading). Observed data are shown as seasonally adjusted. Trend comprising interannual cycles and drift is also shown. x-axis is the year and y-axis is monthly streamflow (mm/d).

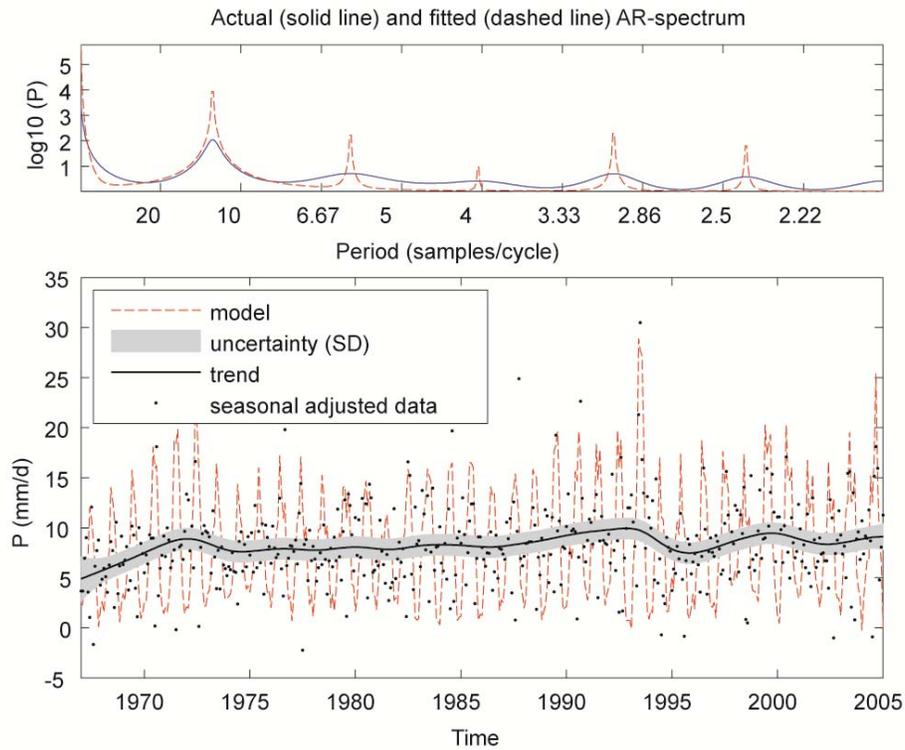


Figure 5. Seasonal amplitudes of rainfall and streamflow in Srk1, Srk2 and Srk3, and SOI trends. Seasonal amplitudes are shown as log values. SOI trend is shown in scaled and smoothed values, using Integrated Random Walk Model.

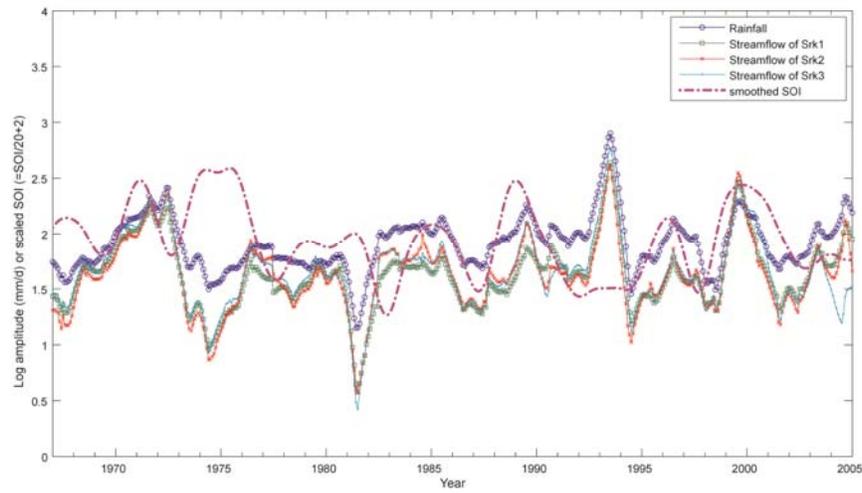


Figure 6. Streamflow trends and seasonally adjusted data for Srk1, Srk2 and Srk3. Left panels depict entire period and right panels zoom in on harvest period of July 1982. Blue line shows seasonally adjusted data and black line is trend with uncertainty band ( $\pm$ standard deviation in grey shading). Green horizontal lines are mean values before and after harvest.

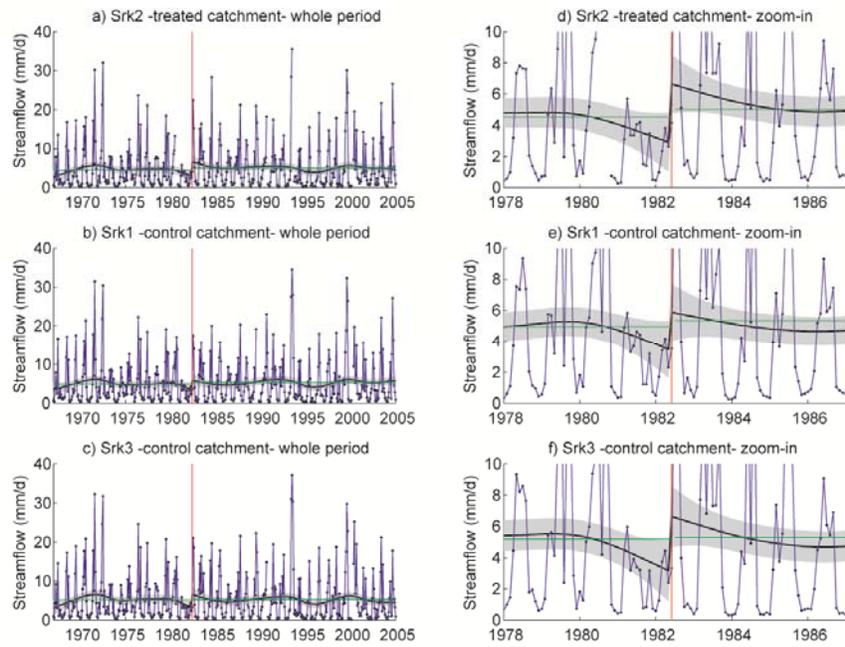


Table 1a. Review of the effects of partial harvest or clear cutting on runoff generation of broadleaf old-growth forests in temperate regions worldwide (ignoring new plantations of deciduous trees).

Reference	Country Catchment name	Forest type	Annual rainfall of site (approx. mm/year)	Percent -age of the area harvested (1-100%)	Change in runoff after tree removal (+/- mm/year) in first year after the treatment	Change in runoff of after tree removal (+/- % change)	Period over which the post-cutting runoff values averaged (years)	Expected runoff change after 25% tree removal (mm/year)
Pearce et al. 1980	Maimai, New Zealand M7	Evergreen broadleaf	2600	100	650	42	0 <sup>1)</sup>	163
Pearce et al. 1980	Maimai, New Zealand M9	Evergreen broadleaf	2600	75	540	35	0 <sup>1)</sup>	180
Hsia and Koh 1983	Lien-Hua-Chi, Taiwan, LHC-4	Evergreen broadleaf	2100	100	448	58	7	112
Swift and Swank 1981; Swank and Helvey 1970	North Carolina USA; Coweeta WS13	Mixed deciduous broadleaf and conifer	1900	100	380	43	3	95
Swift and Swank 1981; Swank and Helvey 1970	North Carolina USA; Coweeta WS13	Mixed deciduous broadleaf and conifer	1900	100	360	40	3	90
Hornbeck et al. 1970 Hornbeck et al. 1993	New Hampshire USA; Hubbard Brook WS2	Mixed deciduous broadleaf and conifer	1340	100	347	40	8	87
Fahey and Jackson 1997	New Zealand; Big bush DC 4	Mixed evergreen broadleaf	1530	94	344	68	3	91
Fahey and Jackson 1997	New Zealand; Big bush DC 1	Mixed evergreen broadleaf	1530	83	312	61	3	94
Swank et al. 2001	North Carolina USA; Coweeta WS7	Mixed deciduous broadleaf and conifer	1890	100	265	28	11	66
Swift and Swank 1981; Swank and Helvey 1970	North Carolina USA; Coweeta WS28	Mixed deciduous broadleaf and conifer	2320	65 <sup>2)</sup>	220	15	12	85

Hornbeck et al. 1993	New Hampshire USA; Hubbard Brook WS5	Mixed deciduous broadleaf and conifer	1340	95	152	18	8	40
(continue of Table 1a)								

(A continuation of Table 1a)

Reference	Country Catchment name	Forest type	Annual rainfall of site (approx. mm/year)	Percent-age of the area harvested (1-100%)	Change in runoff after tree removal (+/- mm/year) in first year after the treatment	Change in runoff of after tree removal (+/- % change)	Period over which the post-cutting runoff values averaged (years)	Expected runoff change after 25% tree removal (mm/year)
Swank and Miner 1968	North Carolina USA; Coweeta WS 1	Mixed deciduous broadleaf and conifer	1725	100	150	20	10	38
Lynch and Corbett 1990; Hornbeck et al. 1993	Pennsylvania USA; Leading Ridge WS3	Deciduous broadleaf	1060	43 <sup>2)</sup>	137	31	NA <sup>3)</sup>	80
Jonson and Kovener 1956	North Carolina USA; Coweeta WS19	Mixed deciduous broadleaf and conifer	2032	22 <sup>2)</sup>	71	4	7	81
Lynch et al. 1980; Hornbeck et al. 1993	Pennsylvania USA; Leading Ridge WS2	Deciduous broadleaf	1060	24 <sup>2)</sup>	51	12	NA <sup>3)</sup>	53
Hornbeck et al. 1987; Hornbeck et al. 1993	New Hampshire USA; Hubbard Brook WS4	Mixed deciduous broadleaf and conifer	1340	33 <sup>2)</sup>	20	41	8	15
Notes: 1) No pre-treatment data for logged basins were available. Thus, the effect of forest removal on water yield was assessed by comparing water yield of two logged basins and one un-logged basin (M8) with that of a control basin (M6); 2) basal area; 3) unavailable data.								

Table 1b. Review of the effects of partial harvest or clear cutting on runoff generation of broadleaf old-growth forests in temperate regions in Japan (ignoring new plantations of deciduous trees).

Reference	Prefecture; Catchment name	Forest type	Annual rainfall of site (approx. mm/year)	Percent -age of harvesting are (1-100%)	Change in runoff after tree removal (+/- mm/year) in first year after the treatment	Change in runoff after tree removal (+/- % change)	Period over which the post- cutting runoff values averaged (years)	Expected runoff change after 25% tree removal (mm/year)
Nakano 1971	Hokkaido; Kamikawa-Kitatani	Mix deciduous broad- leave and conifer	1440	85	268 <sup>1)</sup>	33	11	79
Nakano 1971	Gunma; Takaragawa- Shozawa	Mix deciduous broad- leave and conifer	1780	100	276 <sup>1)</sup>	19	11	69
Nakano 1971	Yamagata; Kamabuchi No.2	Mix deciduous broad- leave and conifer	2080	100	212 <sup>2)</sup>	10	8	53
Shimizu et al. 1994	Gunma;Takaragawa- Ichigosawa	Mix deciduous broad- leave and conifer	840 (warm season Jun to Oct)	53	33 <sup>3)</sup>	14 <sup>4)</sup>	5	16

Notes: 1) Second year after tree removal; 2) Fifth year after tree removal; 3) 5-year average after cutting; 4) values calculated from comparison with runoff ratios before and after treatment.

Table 2 Basic information on Sarukawa Experimental Watershed.

Name	Sarukawa Experimental Watershed		
Sub-catchment	NO1 (Srk1)	NO2 (Srk2)	NO3 (Srk3)
Observation period	1959- (but published on 1967-2005)		
Location	N31°51', E131°13'		
Drainage area (ha)	6.6	9.2	8.2
Mean slope of catchment	34.4	32.3	32.3
Mean direction	N54E	N10E	N26E
Mean elevation (a.s.l.)	262.9-370.2m	232.3-358.1m	202.4-288.1m
Geology	Mainly shale (and sandstone, limestone, conglomerate are seen )		
Soil type	Brown forest soil (B <sub>a</sub> , B <sub>c</sub> , B <sub>d</sub> )		