Water Science & Technology **Vol 53 No 2 pp 79–91** © IWA Publishing 2006

Evaluation of nutrient loads from a mountain forest including storm runoff loads

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Abstract Water quality and flow rates at a weir installed on the end of Aburahi-S Experimental Watershed (3.34 ha) were measured once a week from 2001 to 2003 and in appropriate intervals from 30 min to 6 h during five storm runoff events caused by each rainfall from 8 mm to 417 mm. The average annual loads of total nitrogen (TN) and total phosphorus (TP) were calculated to be 19.0 and 0.339 kg ha^{-1} y^{-1} from the periodical data by using the integration interval-loads method (ILM), which did not properly account for storm runoff loads. Three types of $L(Q)$ equations ($L = aQ^b$) were derived from correlations between loading rates L and flow rates Q obtained from the periodic observation and from storm runoff observation. $L(Q)$ equation method (LQM), which was derived from the storm runoff observation and allowed for the hysteresis of discharge of materials, gave 9.68 and 0.159 kg ha^{-1} y^{-1}, respectively, by substitution of the sequential hourly data of flow rates. $L(R)$ equation ($L = c(R - r)^d$) was derived from the correlations between the loads and the effective rainfall depth ($R - r$) measured during the storm runoff events, and $L(R)$ equation method (LRM) calculated 9.83 ± 1.68 and 0.175 ± 0.0761 kg ha^{-1} y^{-1}, respectively, by using the rainfall data for the past 16 years. The atmospheric input-fluxes of TN and TP were 16.5 and 0.791 kg ha^{-1} y^{-1}.

Keywords Atmospheric deposition; forest; nitrogen; nutrient loads; phosphorus; storm runoff

Introduction

Natural forests as well as planted forests have been believed to reduce pollutant loads deposited from the atmosphere, and to discharge a clean and steady stream water percolated through the biogeochemical filter of the forest ecosystem. This is true during dry days when the discharge mainly consists of groundwater. When intensive rainfalls cause storm runoffs, however, the streams discharge a large volume of muddy water accompanying large amounts of nutrients. A lot of studies of the nutrient loads from mountain forests have been reported in North America and Europe as well as in Japan (Martin *et al.*, 2000; Kunimatsu *et al.*, 2001). The small watershed method has been used in the objection, and flow rates were continuously recorded at the weir on the end of the watershed, where the concentrations of nutrient were measured periodically, for example weekly or once a month. These previous studies, however, have some substantial defects; first, they measured only inorganic nitrogen and phosphorus with few exceptions (Kunimatsu *et al.*, 2001), secondly, storm runoff loads were not properly accounted for (Smith and Stewart, 1977), thirdly, they did not involve any information on the fluctuations of the annual loads caused by the changes of hydrological conditions in every year, and fourthly, any reasonable methods for calculating the material loads fluctuating from day to day as well as from year to year have not been confirmed. It is necessary to evaluate the

doi: 10.2166/wst.2006.041

comprehensive amounts of the total loads of nitrogen and phosphorus accounting for the storm runoff loads in order to assess the state of the eutrophication of a certain lake or inland sea lying in a mountainous and rainy region such as the Asian monsoon area.

The integration interval-loads method has been widely, in other words unconsciously, used for evaluating the material loads of a river. However, the method does not contain procedures for evaluating storm runoff loads. That is the fatal defect of the method in the rainy area. The $L(Q)$ equation method had proposed for more than a quarter-century the evaluation of loading rates (Johnson, 1979; Yamaguchi *et al.*, 1980). However, it has been scarcely used for the purpose, and besides could not calculate the loads for a period when flow rates were not measured. In order to simulate the water quality of a large lake with some kind of mathematical model, it is necessary to evaluate the changes of loading rates for long periods before and after the eutrophication of the lake had began. We had proposed the $L(R)$ equation method, which makes that possible by using the past rainfall data, which are readily supplied from some suitable public or private establishments who measure precipitation in the region.

At the Aburahi-S experimental watershed, we obtained the weekly concentrations and flow-rate data, the data of five storm runoffs and the sequential flow rate data of every 10 minutes in three years after 2001, and the rainfall data for 16 years since 1988. In this study, these data were used to assess that the $L(R)$ equation method is most appropriate for the evaluation of the comprehensive annual loads of the nutrients.

Methods

Experimental conditions

The experimental forest observed in this study is Aburahi-S, which lies in the basin of Lake Biwa located around the central part of the main island of Japan, as shown in Figure 1. Aburahi-S (N 34°51′41″ and E 136°16′08″) is the small watershed of 3.34 ha on the granite bedrock and at an altitude from 312 m to 479 m. Japanese cypress (*Chamaecyparis obtusa* Sieb. et Zucc) were planted on 58% of the watershed in 1965, and in September 1999 the second thinning was carried out. Deciduous broadleaf trees including Japanese red pines (*Pinus desiflor* Sieb. et Zucc) grew on the remaining upper part of the watershed. A small number of the pines were also left in the stand of the planted Japanese cypress.

The stream draining the Aburahi-S Experimental Watershed is perennial and not polluted by any anthropogenic sources except for forest working. A ferroconcrete waterway (width 1.5 m, length 6 m, height 0.9 m) was installed on the stream at the end of the watershed, and fitted up with a stainless steel plate for a full-width weir on the out-flow side of the waterway. The stream water was collected once a week (as a rule, at around 15.00 every Thursday) from May 1995 to December 2003. Storm-runoff observations were carried out during the five events caused by rainfalls from 8 mm–417 mm in depth,

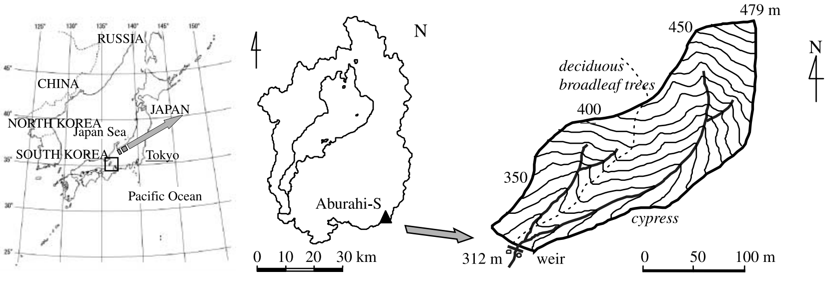

Figure 1 Aburahi-S Experimental Watershed

and water samples were taken up at appropriate intervals (0.5–6 hours) before it began to rain until the water level of the stream returned after it stopped raining. The methods of measuring atmospheric deposition and precipitation, the evaluation of flow rates, and the methods of chemical analysis were the same as those written in the previous paper (Kunimatsu *et al.*, 2001).

Methods of evaluating the material loads

The loads L_i, namely the amount of materials flowing out downstream through a fixed site of a river, are calculated from the data of concentration C_i and flow rate Q_i measured at time t_i.

$$L_i = C_i Q_i \tag{1}$$

There are some methods of evaluating the loads during a certain interval; however, we could not find any definite methods or a way of measuring, which appreciate duly the loads caused by storm runoffs. We had proposed the $L(R)$ equation method (Kunimatsu and Sudo, 1997), which makes it possible by using base-flow data, storm runoff data and daily precipitation data.

Integration interval-loads method (ILM). The method has been used widely in the studies on nutrient balance and dynamics in the forest ecosystem. The loading amounts of materials are calculated by integrating continuously each interval-load, which is obtained from the moment loading rate L_i and the interval for one half of the period from the previous measurement t_{i-1} to the next measurement t_{i+1}.

$$L = \Sigma L_i (t_{i+1} - t_{i-1})/2 \tag{2}$$

The data of C_i and Q_i are usually obtained by periodic observations.

L(Q) equation method (LQM). It is well known that L_i are related with Q_i by the following equation.

$$L_i = a Q_i^b \tag{3}$$

where a and b are coefficients obtained from the logarithmic linear regression of the relationship between L_i and Q_i by the least-squares method. Q_i are calculated from the water-levels, which are read out at an appropriate interval t from the continuous recording media obtained at a weir. Then, L is calculated with ILM.

$$L = \Sigma a Q_i^b t \tag{4}$$

There are some ways of obtaining the data of C_i and Q_i for the leading $L(Q)$ equation. In this study, we used three kinds of data set as follows:

LQM_1: based on $L_1(Q)$ equation regressed on the data obtained by periodic observation.

LQM_2: based on $L_2(Q)$ equation regressed on the data measured during storm runoffs.

LQM_3: it is well known that the relationship between flow rates and loading rates during storm runoff shows a hysteresis characteristic of the material. So, the storm–runoff data were divided into two sets of the data, namely the data obtained during the increasing period of flow rate and those during the decreasing period. Then, a set of two $L_3(Q)$

equations were obtained with regression of the two data sets.

$$L_{3\mathrm{I}}(Q) = \Sigma a_I Q_{\mathrm{i}}^{b\mathrm{I}} t \quad (Q_{\mathrm{i}} - Q_{\mathrm{i}-1} > 0) \tag{5}$$

$$L_{3\mathrm{D}}(Q) = \Sigma a_{\mathrm{D}} Q_i^{b\mathrm{D}} t \quad (Q_{\mathrm{i}} - Q_{\mathrm{i}-1} < 0) \tag{6}$$

where subscripts of I and D represent the increasing period and the decreasing period, respectively.

L(R) equation method (LRM). The method was developed in order to evaluate the annual load including every storm runoff load for a year, and to calculate the loads of past years from the past rainfall data (Kunimatsu and Sudo, 1997). It is based on an assumption that it consists of the annual base-flow load L_{B} and the annual net storm-runoff load L_{S}. "Net" does not include base-flow load.

$$L = L_{\mathrm{B}} + L_{\mathrm{S}} \tag{7}$$

Observations are carried out on a day not affected by rains. In other case, the data not affected by rains are selected from the data obtained by periodic observations. After dividing a year into the dry season and the rainy season, L_{B} is given by the summation of the base-flow loads for the dry season L_{Bd} and the rainy season L_{Bw}, which are calculated from the lengths of each season and the average values of the concentration and the flow rate.

$$L_{\mathrm{B}} = L_{\mathrm{Bd}} + L_{\mathrm{Bw}} \tag{8}$$

Detailed observations during storm runoffs are carried out for more than four rainfall events. Net storm runoff load L_{Si} by the event i is calculated by subtracting the base flow load from the total runoff load which is calculated by using ILM. It was shown that the net storm runoff loads are related with the depths of the rainfalls R_{i} by the following equation.

$$L_{\mathrm{Si}} = c(R_{\mathrm{i}} - r)^d \tag{9}$$

This equation is called the $L(R)$ equation, where c and d are the coefficients obtained from the logarithmic linear regression by the least-squared method, and r is the non-effective rainfall, which is estimated from R-intercept of the equation obtained by linear regression of the relationship between R_{i} and net discharges Q_{Si}.

$$Q_{\mathrm{Si}} = pR_{\mathrm{i}} + r \tag{10}$$

where p and r are the coefficients obtained from the regression. The annual net storm runoff load is calculated by the summation of each storm runoff load obtained by using the $L(R)$ equation and R_{i} larger than r for a year.

$$L_{\mathrm{S}} = \Sigma c(R_{\mathrm{i}} - r)^d \tag{11}$$

Results and discussion

Long-term fluctuations of loading rates

The loading rates of nutrients, which were the momentary amounts at each sampling time, were calculated from the weekly data obtained at the Aburahi-S experimental watershed, and plotted in Figure 2. The loading rates during the summer season were generally larger than those during the other seasons. This is because it is rainy in the summer in the area. Some needle-like peaks were occasionally found from early summer to autumn, when heavy rains were caused by passage of a rain front at the end of the rainy season and of

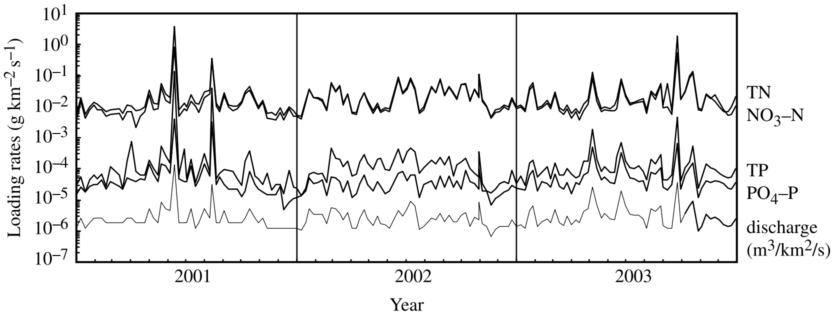

Figure 2 Fluctuations of loading rates of nutrients and discharge observed at Aburahi-S experimental watershed. The data were obtained from the weekly observations

typhoons. Namely, the loads of total nitrogen (TN) and phosphorus (TP), which include particulate constituents, increased from hundreds to a thousand times those before the heavy rain. This was because the concentration of TN changed several times and that of TP more than ten times, in addition the flow rate increasing momentarily more than a hundred times. The changing of dissolved materials appears to be within almost the same range as that of the flow rate, because the concentration of these materials was not affected so largely by the flow rate. These results show that in order to obtain an accurate estimate of annual loads, it is inevitable to evaluate the runoff loads, particularly those caused by intensive rainfalls over about hundred mm in depth, as accurately as possible.

Inaccuracy of loading rates evaluated by ILM

In order to evaluate the total load for a year by ILM, periodic observations in frequency from once a week to once a month have been conducted in many studies. However, the loading rate of a river usually changes daily, hourly or even momentarily in the rainy areas, mainly because of unpredictable rainfalls, as mentioned above. It seems to be clear from Figure 2 that the ILM, in this case based on the weekly data, could not exclude the uncertainty of underestimation or overestimation resulting from a momentary condition from which the sample was taken up only once a week. The average annual-loads calculated in three years' weekly data are shown in Table 1. The annual loads of TN and TP, and the discharge ratio were 19.0 and 0.339 kg ha^{-1} y^{-1}, and 0.75 respectively, which averaged the values of 29.3, 7.14 and 20.6 kg-N ha^{-1} y^{-1}, and 0.900, 0.039 and 0.077 kg-P ha^{-1} y^{-1}, and 1.01, 0.53 and 0.69 obtained is 2001, 2002 and 2003, respectively. The loads of TN and TP were much larger than those evaluated using another method mentioned below, especially that of TN was larger than the atmospheric deposition. When the data obtained on 14 June 2001 and 25 September 2003 were taken off as abnormal or extreme values with ignoring the inverse cases, it is a familiar scenario, with 6.25 and 7.31 kg-N ha^{-1} y^{-1}, 0.057 and 0.045 kg-P ha^{-1} y^{-1}, and 0.56 and 0.57 for discharge ratio were obtained.

The inevitable arbitrariness of ILM was shown by using the everyday data which we had measured everyday around 10:00 am for a year at Ieta Bridge crossing over Mano River (watershed area of 16.4 km^2) in Lake Biwa basin in the following. It was assumed that an observation in frequency of once per n days was carried out for a year. A virtual data set obtained by the observation could be picked up sequentially from the everyday data. The procedure was repeated n times, moving it for each one day. Then, n annual loads L_{ni} were calculated with ILM from the n data sets. In order to investigate the variation of the annual loads, the coefficients of variation cv were calculated, and plotted against the frequencies of the virtual periodical observations in Figure 3. The cv values calculated from the data of 7-days interval observations L_{7i}, for instance, were 0.54 for

Table 1 Annual average loads of Aburahi-S Experimental Watershed calculated with the methods of ILM, LQM and LRM, and of the atmospheric deposition.

Items	Discharge from Abrahi-S experimental watershed									Atmospheric deposition 3 years (kg ha^{-1} y^{-1})
	Concentration[2] 3 years (mg l^{-1})	Average annual loads[1] (kg ha^{-1} y^{-1})								
		ILM	LQM$_1$	LQM$_2$	LQM$_3$	LRM				
		3 years	3 years	3 years	3 years	3 years (%)[3]		16 years (cv %)		
TN	0.772	19.0	7.25	9.45	9.68	9.95	(72)	9.82	(17)	15.3
DN	0.719	13.3	7.05	8.67	8.81	8.89	(71)	8.75	(15)	13.3
NH_4^+-N	0.013	0.208	0.116	0.078	0.073	0.182	(39)	0.181	(9.4)	6.02
NO_2-N	0.003	0.027	0.014	0.020	0.017	0.018	(57)	0.017	(11)	0.009
NO_3-N	0.597	8.47	5.27	7.24	7.42	7.24	(73)	7.12	(16)	5.24
TP	0.0057	0.339	0.0560	0.107	0.159	0.168	(82)	0.160	(39)	0.824
DP	0.0032	0.0440	0.0310	0.0300	0.0294	0.0380	(63)	0.0373	(14)	0.633
PO_4-P	0.0016	0.0245	0.0153	0.0155	0.0153	0.0204	(51)	0.0201	(10)	0.521
Discharge ratio[4]	–	0.75	0.57	0.57	0.57	0.48	(75)	0.50	(16)	1,702 mm y^{-1}

[1] Average values for 3 years were calculated by using the data obtained from 2001 to 2003, and those for 16 years from 1988 to 2003.

[2] Concentrations were arithmetic means of the weekly data for the 3 years.

[3] Percentage of storm runoff loads and discharge to each total values. The original data of the total discharge and the storm runoff were 852 and 647 in mm y^{-1}, respectively.

[4] Discharge ratio was discharge/precipitation, and the average precipitation for 16 years and cv were 1667 and 17%.

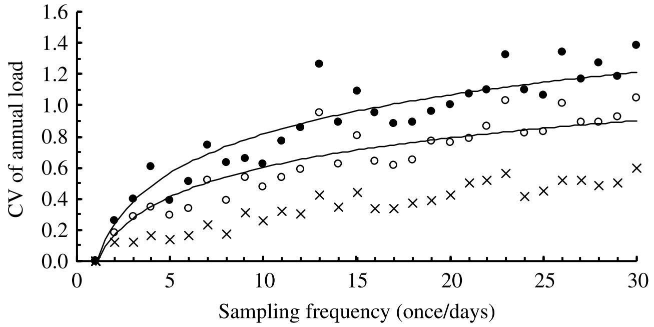

Figure 3 Relationship between sampling frequency and coefficient of variation of the annual loads calculated with ILM and data measured once a day at Ieta Bridge of Mano River for a year. ○; TN, ●; TP, × ; discharge

TN and 0.74 for TP, and that of discharge was 0.23. It appeared that the annual loads calculated with ILM vary widely depending on only the sampling frequency. Consequently in order to obtain accurate data with ILM, samples must be taken up at a higher frequency, perhaps once a day or an hour. However, it is usually impossible to collect and to analyze water samples in such high frequency for a long time. Therefore it is necessary to develop another method for making it possible to evaluate more reliably total load based on the more realistic observation.

Derivation of *L*(*Q*) and *L*(*R*)

L(*Q*) *equations*. The relationship between the loading rates and the flow rates measured with the periodic observation at Aburahi-S for the three years were plotted in Figure 4. $L_1(Q)$ equations logarithmically regressed with the least squared method were written in the figure. The data obtained from the storm run-off observations of the five rainfalls from 8 mm to 417 mm in depth were plotted in the same way on the same figure, in which the equations of $L_2(Q)$, $L_{3I}(Q)$ and $L_{3D}(Q)$ were derived in the above procedures. About 95% of the flow rate data obtained by the periodic observation distributed in the narrower range from 0.01 to $1\,m^3\,km^{-2}\,s^{-1}$, on the other hand those obtained from the storm runoff events distributed in the wider range from 0.01 to $7\,m^3\,km^{-2}\,s^{-1}$. The coefficients of determination for $L_1(Q)$, $L_2(Q)$, $L_{3I}(Q)$ and $L_{3D}(Q)$ for TN were 0.78, 0.96, 0.98 and 0.98, respectively, and those for TP were 0.77, 0.86, 0.92 and 0.93. The coefficients for the dissolved components were larger than those for TP.

L(*R*) *equation*. The net storm runoff loads calculated from the five rainfall events were plotted against the depths of the corresponding rainfalls in Figure 5. Nitrogen as well as phosphorus showed good linearity, but the five events were not sufficient in number of samples to derive statistically reliable *L*(*R*) equations. However, the observations of storm runoff events are not so easy that it is difficult to repeat so many times. Then, the data were supplemented with values calculated with LQM_3 using hourly flow-rates of the selected storm runoff events from the data recording water level at the weir. It was shown that there were not significant differences between the five observed data and the 17 calculated data plotted by black and white circles, respectively, in the figure. Then, *L*(*R*) equations regressed from all the data were written on the figure. The coefficients of determination of nitrogen and phosphorus exceeded 0.9, and these correlations were significant at 0.1% level.

Reliability of LQM and LRM

At the Aburahi-S Experimental watershed, we could use the weekly periodical data and the sequential flow rate data of every 10 minutes obtained for three years after

2001, the storm runoff data of the five rainfall events, and the rainfall data from 1988 to 2003. In order to assess the reliability of LQMs and LRM, the net storm runoff loads calculated with L(Q) and L(R) were compared with the observed values of the five rainfall events, as shown in Figure 6. LQM_1 and LQM_2 calculated smaller values than LQM_3, especially for TP. The reasons were thought from Figure 4 to be: $L_1(Q)$ were derived from the data involving few data around the high flow rate, the number of the data during decreasing period tended to be larger than that during increasing period, which affected the slope of $L_2(Q)$. The values calculated with LQM_3 were well coincident with the observed values, except TN of an unusually intensive rainfall such as 417 mm. Consequently LQM_3 takes account of the effects of the hysteresis in its procedure and $L_3(Q)$ has the high determination coefficients, so it is considered that LQM_3 is the most reliable method in LQMs. The values calculated with LRM were well coincident with the observed values, though slight deviations from the 1:1 line were found in the data of 151 mm as shown in Figure 6.

Comparison of the annual loads calculated with ILM, LQM and LRM

The annual loads calculated with ILM, LQMs and LRM by using the data of three years were compared in Table 1. As mentioned above, ILM using the discontinuous data usually includes the inevitable and unscientific arbitrariness; therefore we don't argue details here any more. Both LQM_1 and LQM_2 became clear to have the tendency of underestimating the storm-runoff loads in Figure 6, and calculated lower values than LQM_3. The effect of hysteresis on TP was larger than that on TN as shown in Figure 4,

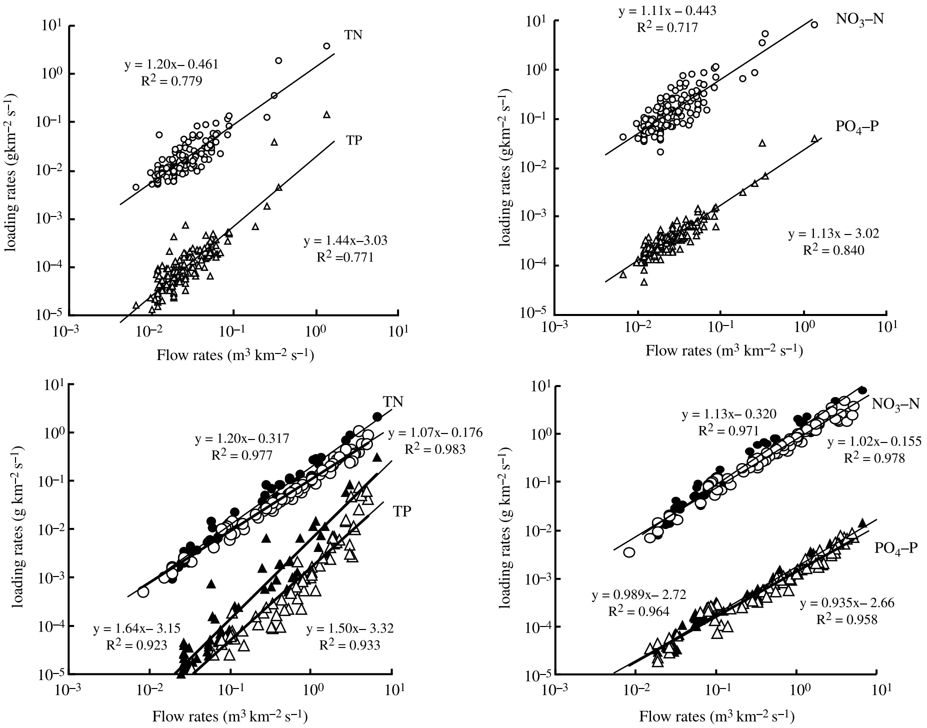

Figure 4 Relationship between the loading rates and the flow rates obtained at Aburahi-S Experimental Watershed (2001–2003). The upper two figures show the data obtained with the weekly periodical observations. The lower two ones were drawn with the data obtained from the storm-runoff observations. ●, ▲; increasing period of flow rates, ○, △; decreasing period of flow rates

so it was thought that LQM_3 calculates more reasonable loads than LQM_2. LRM gave slightly larger values than LQM_3, except for NO_3-N.

Material balance evaluated with LRM

It was shown in Table 1 that there was a distinct difference in the content of particulate form between nitrogen and phosphorus. Namely, 89% of the nitrogen flux of 9.95 kg ha^{-1} y^{-1} was discharged in the dissolved forms from the data of LRM, and 80% of the phosphorus flux of 0.187 kg ha^{-1} y^{-1} was in the particulate form. The input fluxes of nitrogen into the forest measured with the bulk deposition method for the three years was 16.5 kg ha^{-1} y^{-1} on average, so that 40% of nitrogen remained in the forest, in other words purified by the forest. The input of phosphorus was 0.791 kg ha^{-1} y^{-1}, 76% of which was eliminated through the forest ecosystem. The average precipitation was 1,702 mm y^{-1} calculated from 1770 mm y^{-1} in 2001, 1393 mm y^{-1} in 2002 and 1944 mm y^{-1} in 2003. There was rather a large difference between the discharging ratio

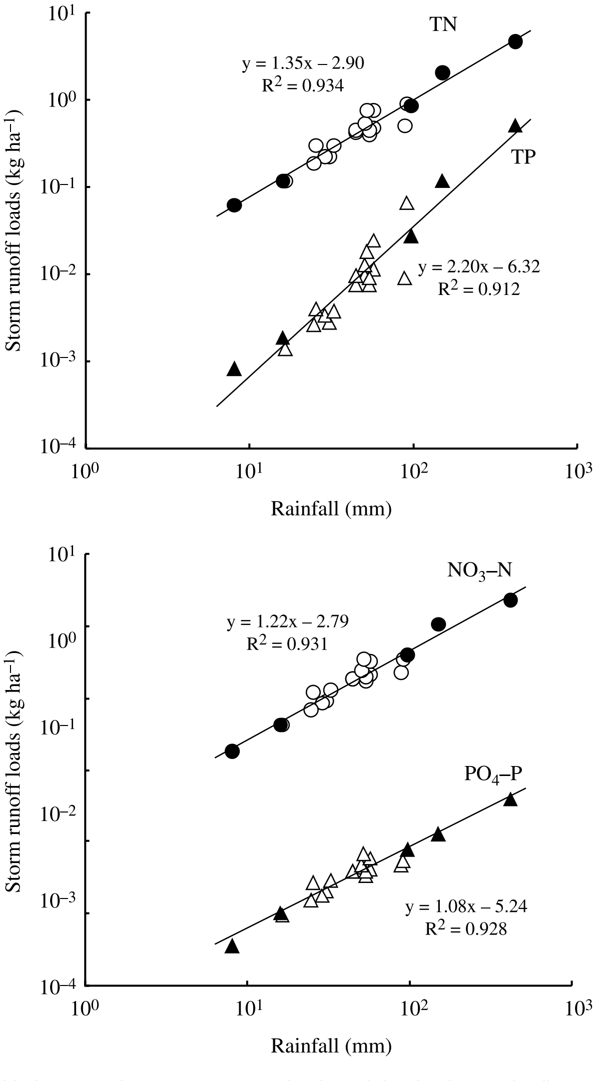

Figure 5 Relationship between the net storm runoff loads and the depths of rainfalls. ●, ▲; observed data from the five storm runoff events, ○, △; data calculated with $L_3(Q)$ equations and each set of hourly flow rate data during selected 17 storm runoffs

calculated with LRM (0.48) and those with LQMs (0.57). Judging from the annual precipitation and the evapotranspiration of the forest in these regions of 880–840 mm y^{-1} (Suzuki and Fukushima, 1985), it was thought that the ratios obtained with LQM and LRM were reasonable values and that the ratio of 0.75 with ILM was too large.

Importance of storm-runoff loads

LRM is an indirect method. However, it offers two important advantages. First LRM makes it possible to isolate storm-runoff load from the total annual load. The percentages of the storm-runoff load to the total load were calculated from the data of the observed three years and shown in Table 1. The ratio of TP (82%) was much larger than that of DP (63%) and distinctly larger than that of TN (72%). DN showed similar values to TN. Storm runoff occupied 75% of the total discharge.

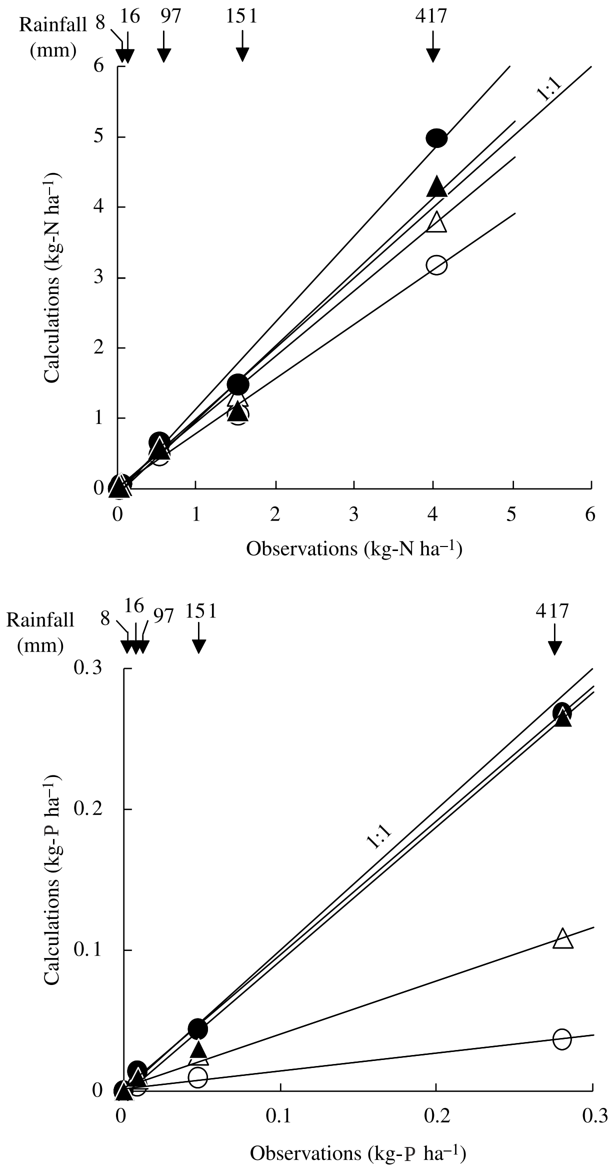

Figure 6 Identification of the storm runoff loads calculated with LQMs and LRM by the observed values. ○; LQ1, Δ; LQ2, ●; LQ3, ▲; LRM

Long-term fluctuation of the loading rates evaluated with LRM

Secondly LRM has a distinguished function to evaluate past annual loads from daily rainfall data measured in the past with another aim or those obtained by nearby offices such as a dam control office, a school, a firehouse and so on, if the forest has not been disturbed so intensively as to change the material flux. While LQMs do not calculate any values without the data of sequential flow rate recorded at a weir. The daily rainfalls have been measured at the Aburahi-S Experimental Watershed since 1996 and at the Aburahi-N Experimental Watershed at northwestern 2.5 km since 1988. The results calculated from these data of the past 16 years, which were not revised, are shown in Table 1 and Figure 7. The average value and *CV* of the precipitations were 1667 mm and 17.1%, respectively. The load of TN was 9.83 kg ha^{-1} y^{-1} and agreed well with the value calculated from the data for the three years. TP was calculated as a slightly smaller value, which seemed to be affected with the smaller value of precipitation. It seemed to result from the difference in the precipitation, which affected TP more strongly than TN. The yearly variations were not so large and on almost the same levels as that of the precipitation, except for TP. Judging from the large *CV* value and the violent fluctuation of TP in Figure 7, it was suggested that it might not give any reasonable results to assess the eutrophication of a water body by using the loading rate measured from one to a few years.

Figure 7 appears to show that the annual loads might have a certain relationship with the annual precipitation. Then the scatter diagrams of the annual precipitations vs. the annual loads are shown in Figure 8. We found two important facts from the Figure: first the loads of the dissolved substances such as NO_3-N, sodium ion and so on apparently increased proportionally to the depth of the annual precipitations. TN, which included 89% DN, showed also nearly the proportional relationship. However, such a relationship was not found on TP, which contained 79% PP. Secondly intensive rainfall such as

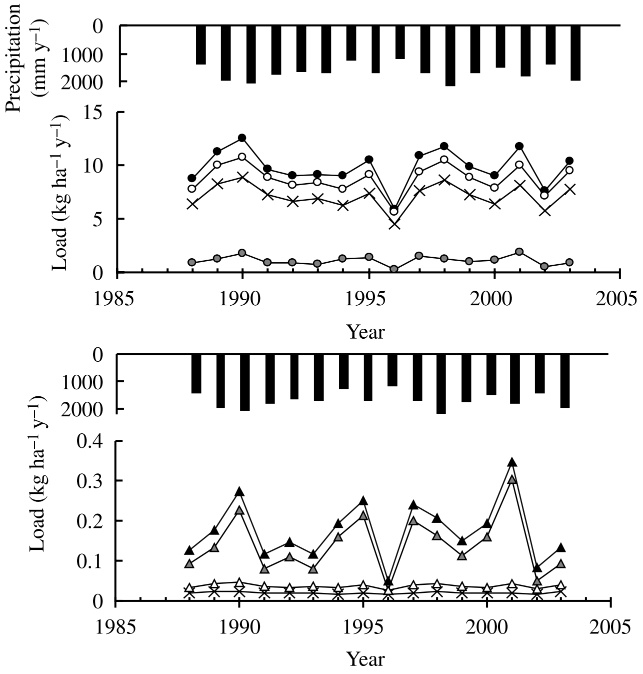

Figure 7 Long-term fluctuations of the annual loads evaluated with LRM from the daily rainfall data in the past (Aburahi-S Experimental Watershed). ●; TN, ○; DT, ●; PN, ×; NO_3-N, and ▲; TP, △; DP, ▲; PP, ×; PO_4-P

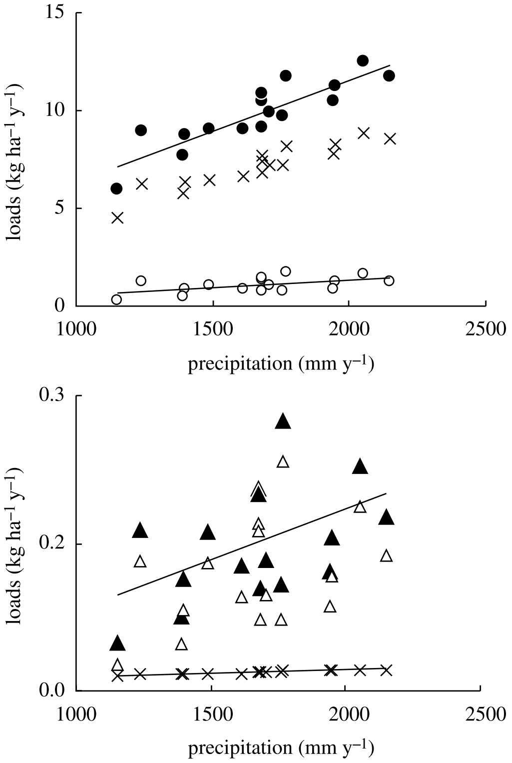

Figure 8 Relationship between the annual precipitations and the loading rates calculated with LRM and rainfall data. ●; TN, ○; PN, ×; NO_3-N, ▲; TP, Δ; PP, and ×; PO_4-P

exceeding 100-200 mm increased the annual loads of TP and TN much more strongly than the total amounts of the annual precipitations. Those substances contain particulate components. These important characteristics have been elucidated for the first time by developing LRM.

Conclusion

ILM has been widely used for evaluating the material loads from the forests. However, it has no scientific rationality because the flow rate always changes in a stream owing to unpredictable rainfalls. The loading rates of TN and TP of Aburahi-S Experimental Watershed calculated with LRM using the data measured for three years were 9.83, 0.175 $kg\,ha^{-1}\,y^{-1}$, respectively, which did not show any increasing or decreasing tendencies during 16 years since 1987. The load of TN changed every year in rather narrow range around the average value (cv ± 17%), increased in proportion to the annual precipitations, and was discharged 72% of the total during storm runoffs. That of TP did not show such a tendency, changed in wider range (cv ± 43%), and was discharged 82% of the total during storm runoffs. The eliminating rates of the atmospheric input-fluxes of TN of 16.5 $kg\,ha^{-1}\,y^{-1}$ and TP of 0.791 $kg\,ha^{-1}\,y^{-1}$ were estimated as 40% and 76%, respectively. Consequently, LRM, which makes it possible to calculate the annual loads and the storm-runoff loads by using the past precipitation data, was shown to be the effective method for the environmental as well as the biogeochemical studies of the forests.

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