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Flood Event Loadings of Nitrogen and Phosphorus from the Yahagi River to Chita Bay, Japan

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Abstract

A 4-year data set of continuous monitoring of suspended matter and nutrients concentration has been analyzed to evaluate the inter-annual variability and the effects of flood events on the sediment transport and nitrogen, phosphorus loadings from the Yahagi River to Chita Bay, Japan. Nitrogen was mainly loaded in dissolved form, which accounted for 59% to 88% of the annual loads, while phosphorus was mainly loaded in particulate form (45% to 78%). Loads of suspended matter and total phosphorus (T-P) by the historical flood event of the Tokai Heavy Rainfall accounted for 83% and 65% of the annual loads, respectively. Particulate phosphorus (PP) load by the Tokai Heavy Rainfall accounted for up to 1.1 to 3.2 times of the annual T-P load of the other years. Molar ratio of dissolved total nitrogen (DTN) load to dissolved total phosphorus (DTP) load during the observation period varied from 29.5 to 41.1, while the ratio of total nitrogen (T-N) load to T-P load was relatively lower (10.9 to 23.8). The concentrated load of suspended matter which occurs during flood events is found to have a great impact on the nutrients runoff to the coastal sea both in quality and quantity.

Discipline: Watershed and regional resources management /Fisheries
Additional key words: long-term monitoring, nutrients, suspended matter, Tokai Heavy Rainfall

Introduction

At flooding time, rivers discharge large amounts of terrestrial soil substances which originate from the erosion of forests and farmlands. In Japan, rivers show high variability of discharge because they are short, steep and exhibit very flashy flow regimes compared to most continental rivers[19]. Therefore, it is very difficult to evaluate the importance of suspended matter load on nutrient runoff by the strong seasonal and episodic variability of freshwater and suspended matter load.

In major rivers in Japan, it is generally recognized that most of the phosphorus runs off in the form of particulate rather than dissolved form during the high flow stages[2,12], and most of the total annual load of the suspended matter occurs during the several days of flood-events in a year[14,16]. Consequently, continuous monitoring is essential to evaluate the importance of suspended matter load on nutrient runoff[4].

However, detailed studies on continuous monitoring of nutrient runoff in Japan are based on the data of around one or two years and few studies were made on the year to year variability. In order to evaluate such variability of the suspended matter load and its contribution on the nutrient runoff to coastal marine environments, continuous monitoring of suspended matter and nutrient concentration was conducted for 4 years in the Yahagi River including the record high discharge event of the Tokai Heavy Rainfall[11] during the observation period.

The Yahagi River located in a central district of Honshu Island is the main river that flows into Chita Bay (Fig.

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1). The drainage basin covers 1,830 km^2 which comprise 96% of the total drainage area of the Chita Bay (1,911 km^2), includes the urban areas of Toyota and Okazaki, agricultural fields, and mountain area. The population in the watershed was about 700,000 in 1995. There are many dams for agricultural and industrial use as in the cases of many rivers in Japan (Fig. 1) and domestic waste water through sewage disposal plants and drainage from the fields flow into the Yahagi River.

Materials and methods

Turbidity was monitored continuously for 4 years at Yonezu discharge monitoring site (Stn. Y) located around 10 km from the river mouth (Fig. 1) from 7 June 2000 to 9 June 2004 with light scattering type turbidity sensors (Alec Electronic Co., ATU40-8M or COMPACT-CLW). The turbidity time series data were collected at 1 m above the bottom with 10 min intervals. Instruments were maintained once or twice a month to clean off attached organisms, together with water sampling for chemical analysis. Water samples were filtered with Whatman GF/F filters for chemical analysis of suspended matter and determination of concentration of suspended matter (SS). Turbidity (NTU) was converted to SS using the calibration data for each sensor.

Water samples for dissolved nutrients analysis were immediately filtered through 0.45 μm Millipore Millex-HV filters into acid washed polypropylene tubes and were frozen at –20ºC until laboratory analysis. Dissolved inorganic nutrients (nitrate, nitrite, ammonium, phosphate, and silicate) concentrations were determined according to the standard method using TRAACS 800 (Buran Lubbe Co.). Dissolved total phosphorus (DTP) and dissolved total nitrogen (DTN) were determined following the methods of Menzel & Corwin[6] and Solórzano & Sharp[10], respectively.

Suspended matter samples for particulate nitrogen (PN) were analyzed with an elemental analyzer (FISONS EA1108). Particulate phosphorus (PP) concentrations were determined by an ignition method of Andersen[1]. For inorganic phosphorus fractionation of particulate phosphorus, the procedures of Williams et al.[17] were adopted for serial extraction of the inorganic phosphorus for separation into the following three fractions. Details of the procedures are described in the report of Tanaka[12,13].

1) Phosphorus extracted by the citrate - dithionite - bicarbonate procedure (CDB-P): most of the iron phosphate minerals and adsorbed phosphate.
2) Phosphorus extracted by 1 N-sodium hydroxide solution (NaOH-P): aluminium phosphorus and any iron-bound phosphorus forms not extracted in the CDB treatment.
3) Phosphorus extracted by 1 N-hydrogen chloride solution (HCl-P): varieties of apatite (calcium phosphate).

Organic phosphorus (Org-P) concentration was calculated from the difference between PP and the sum of the three inorganic phosphorus forms: Org-P = PP – (CDB-P + NaOH-P + HCl-P).

River discharge data were provided by Toyohashi Office of Rivers (Chubu Regional Bureau, Ministry of Land, Infrastructure, Transport and Tourism).

Results

1. Runoff processes of suspended matter and N, P

Figure 2 shows the time series records of the daily averaged discharge at Stn. Y in the Yahagi River from 8 June 2000 to 7 June 2004. The average discharge was 42.3 m^3/s during the observation period. After three months from the start of the observation, the largest recorded flood

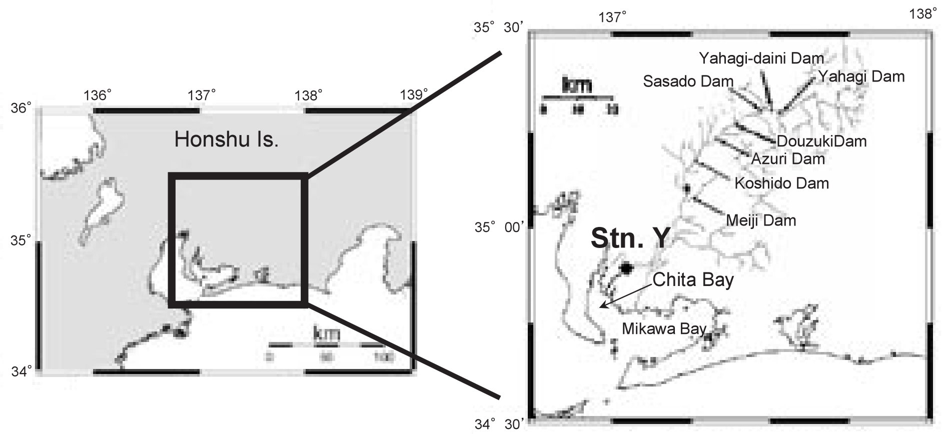

Fig. 1. Map of the monitoring locations in the Yahagi River and its drainage area

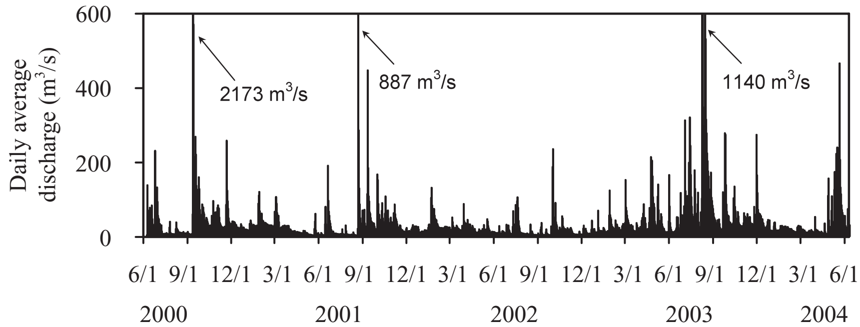

Fig. 2. Time series records of daily averaged discharge at Stn. Y

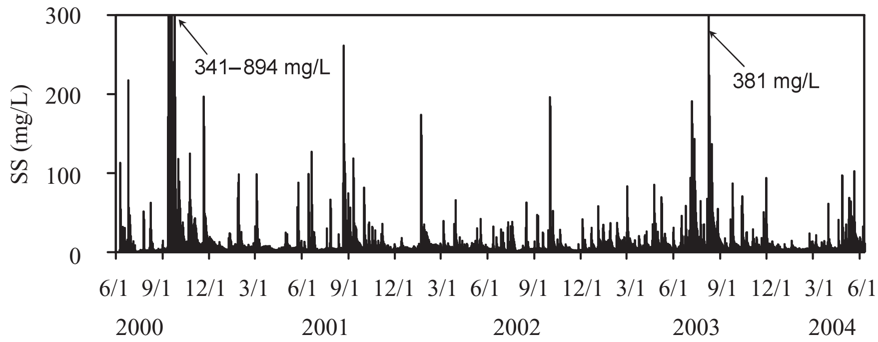

Fig. 3. Time series records of daily averaged SS at Stn. Y

(Tokai Heavy Rainfall) occurred from midnight of 11 to 12 Sept. 2000 with peak discharge and daily average discharge of 4,300 m^3/s and over 2,000 m^3/s, respectively. The high flow (over 200 m^3/s) continued over one week. The cumulative weekly discharge from 12 to 18 Sept. 2000 reached up to 3.3×10^8 m^3, which corresponds to 1/4 of the total discharge in 2000. Several other large floods also occurred mainly by typhoons and/or in the autumn rain season, such as on 22 Aug. 2001 during Typhoon Pabuk (over 800 m^3/s) and on 9 Aug. 2003 during Typhoon Etau (over 1,000 m^3/s).

Figure 3 shows the time series records of daily averaged SS concentration. Because of the instrument troubles, the SS data on 10 Sept. – 27 Oct. 2000 and 9 March – 6 April 2001 were estimated from the relationship of SS and discharge[14]. SS concentration was generally below several mg/L during normal flow. However, marked increases of SS concentration were observed corresponding to the high flow stages (Fig. 2). The SS concentrations measured by water sampling after the Tokai Heavy Rainfall on 13 and 14 Sept. 2000 were 894 mg/L and 571 mg/L, respectively, and maintained the high level even after one week (180 mg/L on 20 Sept.). Such high SS concentrations were also observed on 22 Aug. 2001 during Typhoon Pabuk (261 mg/L) and on 9 Aug. 2003 during Typhoon Etau (381 mg/L), continuing the high level (over 100 mg/L) after 4 days.

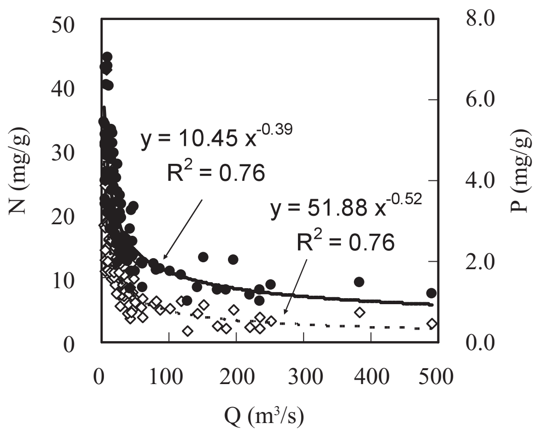

Fig. 4. Relation of hourly averaged discharge (Q) and nitrogen (◇) and phosphorus (●) concentration in the suspended matter at Stn. Y

Both nitrogen and phosphorus concentrations in the suspended matter at Stn. Y showed statistical relationships for the discharge dependence and exponentially decreased with increasing discharge (Q) to constant values over Q = 200 m^3/s (Fig. 4). Figure 5 shows the variation of phosphorus fractions in the suspended matter during the observation period and Fig. 6 shows the comparison of phosphorus fractions in the suspended matter and their

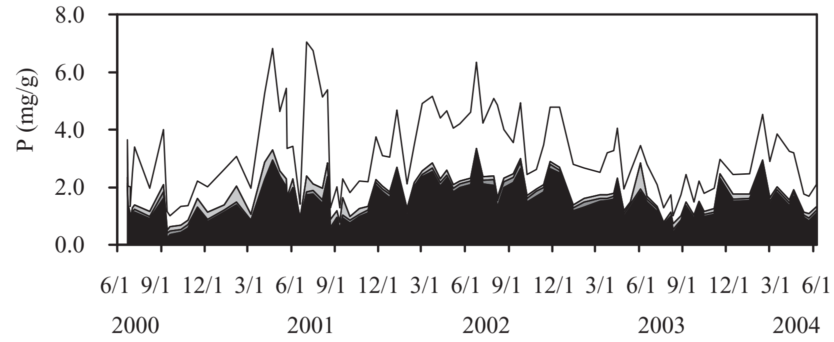

Fig. 5. Time series records of phosphorus fractions in the suspended matter at Stn. Y

■: CDB-P, ■: NaOH-P, ■: HCl-P, □: Org-P.

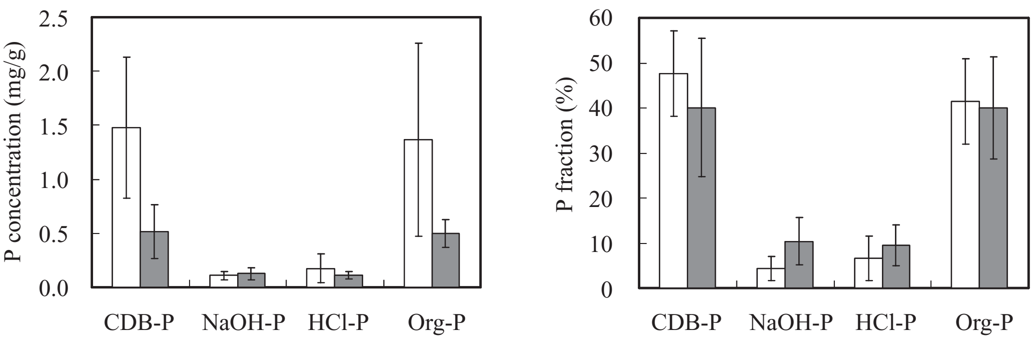

Fig. 6. Phosphorus fractions in the suspended matter and their percentages in the total observations (□) and during the flood events (■) at Stn. Y

Error bars are standard deviation (n = 92: total observation, n = 6: flood events).

percentages between the total observations and during flood events (over 200 m^3/s). CDB-P and Org-P were the dominant fractions of phosphorus in the suspended matter, accounting for up to 48% and 41% of PP in total observations, respectively, while it was only around 10% or less for the NaOH-P and HCl-P. Inorganic phosphorus (CDB-P + NaOH-P + HCl-P) comprised over 50% of the PP. The CDB-P and Org-P concentrations in the suspended matter (average; CDB-P: 1.47 mg/g, Org-P: 1.37 mg/g) decreased considerably during high flow stages over 200 m^3/s (average; CDB-P: 0.52 mg/g, Org-P: 0.50 mg/g), while the percentage of NaOH-P and HCl-P increased slightly.

Time series records of DTN, DTP concentrations and DTN:DTP molar ratios at Stn. Y are shown in Fig. 7. The DTN and DTP at Stn. Y ranged 43–147 μM (average: 81 μM) and 0.61–6.5 μM (average: 2.4 μM), respectively. Enhanced DTP concentration was observed from winter 2000 to summer 2001 after the Tokai Heavy Rainfall, suggesting the effects of increasing colloidal-P concentration by the accompanied events such as landslides, restoration works and soil erosion[3]. Molar ratio of DTN:DTP at Stn. Y was 40 on average which was much higher than the Redfield ratio (N:P = 16) [8].

2. Year to year variation of N, P load

Table 1 shows the annual river flow (m^3) and SS, N, P load (tons) from the Yahagi River, together with the flood event loadings in one week after the Tokai Heavy Rainfall (12–18 Sept. 2000) and Typhoon Etau (9–15 Aug. 2003). Annual load of each N and P fraction was estimated for the period of 8 June 2000 – 7 June 2004 (4 years: each year starting 8 June and ending on 7 June of the next year). The SS runoff was calculated by multiplying hourly averaged discharge (Q) and SS concentration estimated from turbidity. Particulate nitrogen (PN) and particulate phosphorus (PP) loads were calculated from the estimated PN and PP concentrations based on the relationship between the discharge and N, P concentrations in the suspended matter (Fig. 4). The DTN and DTP loads were estimated using the observed daily average discharge and linearly interpolated daily DTN and DTP concentrations from the biweekly or monthly observed data.

Nitrogen was mainly loaded in the dissolved form, which accounted for 59% to 88% of the annual loads, while phosphorus was mainly loaded in the particulate form (from 45% to 78%). The highest yearly T-N, T-P flux was observed during the year of the Tokai Heavy Rainfall (2000-2001). During the flood event of the Tokai Heavy Rainfall, the SS flux in a week reached 25.5 × 10^4 tons, which corresponds to over 4 times of annual SS flux in the next year (2001–2002) and 10 times of the annual SS flux in 2002–2003. By this high SS flux, PN and PP flux during the flood event of the Tokai Heavy Rainfall also reached up to 1.6–6.2 times (PN) and 1.7–7.2 times (PP) of the annual flux of the other years. Consequently, the contribution of flood events was very high in the annual flux of the year of flood events. River water discharge during the flood event of the Tokai Heavy Rainfall comprised 24% of the annual discharge (2000–2001), while SS, T-N and T-P comprised 83%, 45% and 65%, respectively. Such high contribution of flood events was also observed during the flood event of Typhoon Etau (9–15 Aug. 2003).

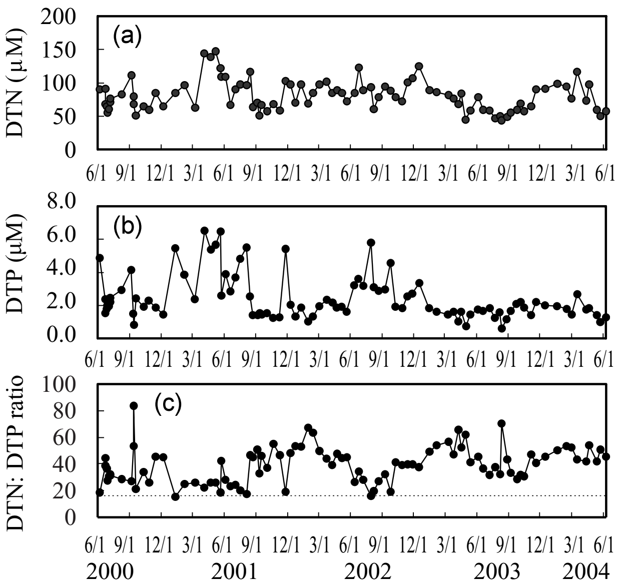

Fig. 7. Time series records of DTN(a), DTP(b) and DTN: DTP molar ratio (c) at Stn. Y
The dotted line in (c) denotes the Redfield ratio (= 16).

With respect to year to year variation, water discharge varied from the minimum of 8.6 × 10^8 m^3 (2002–2003) to the maximum of 20.5 × 10^8 m^3 (2003–2004), ranging 2.4 times during 4 years of observation. On the other hand, SS load varied much more than that of the discharge, ranging up to 12 times from 2.5 × 10^4 tons (2002–2003) to 30.7 × 10^4 tons (2000–2001). T-N ranged from 10.9 × 10^2 to 25.7 ×10^2 tons N (2.3 times which is near to the range of the water discharge), while T-P had a range of 1.0 × 10^2-5.2 × 10^2 tons P (over 5 times).

Table 2 shows the N:P molar ratios of annual loads. PN: PP ratios were very low and almost constant (5.7–6.5) compared to the DTN:DTP ratios (29.5–41.1). T-N:T-P ratios ranged widely (10.9–23.8) and showed the highest values in 2002-2003, decreasing with the increasing SS load. T-N:T-P ratios during the flood events of Tokai Heavy Rainfall and Typhoon Etau were very low (<10) by the high SS load.

Discussion

Particulate phosphorus (PP) load during the historic flood event of the Tokai Heavy Rainfall accounted for up to 1.1 to 3.2 times of the annual T-P load of the other years (Table 1). Moreover, even in the years of relatively low discharge (2001–2002 and 2002–2003), almost a half of P load was in PP. These observations suggest that the P load from land is mainly a function of erosion during the flood events as already reported in the Ohta River and several major rivers in Japan[12].

CDB-P was one of the dominant fractions of PP (Fig. 5) which is originating from the phosphorus rich soil substance in farmlands[12]. In contrast to the dissolved phosphorus which is immediately utilized by the phytoplankton in the sea, CDB-P loaded from the rivers is trapped in the surface sediments and acts as a dissolved phosphate buffer through adsorption and desorption of phosphate, releasing phosphate gradually[5,13]. Therefore, CDB-P is pooled as

Table 1. River flow and SS, N, P load (tons) from the Yahagi River during the period of June 2000 to June 2004

Periods	Discharge ×10^8 (m^3)	SS ×10^4 (ton)	DTN ×10^2 (ton)	PN ×10^2 (ton)	T-N ×10^2 (ton)	DTP ×10^2 (ton)	PP ×10^2 (ton)	T-P ×10^2 (ton)	PN/T-N (%)	PP/T-P (%)
8 June 2000 – 7 June 2001	13.8	30.7	15.0	10.6	25.7	1.13	4.10	5.2	41	78
8 June 2001 – 7 June 2002	10.8	5.7	11.2	2.4	13.6	0.61	0.86	1.5	17	59
8 June 2002 – 7 June 2003	8.6	2.5	9.6	1.3	10.9	0.56	0.45	1.0	12	45
8 June 2003 – 7 June 2004	20.5	13.7	17.5	5.0	22.5	0.94	1.89	2.8	22	67
12–18 Sep. 2000 (after Tokai Heavy Rainfall)	3.3	25.5	3.5	8.1	11.6	0.17	3.22	3.4	70	95
9–15 Aug. 2003 (after Typhoon Etau)	3.4	7.5	2.1	2.4	4.5	0.10	0.95	1.1	53	90

Table 2. DTN:DTP, PN:PP and T-N:T-P molar ratios of annual load from the Yahagi River during the period of June 2000 to June 2004

Periods	DTN:DTP	PN:PP	T-N:T-P
8 June 2000 – 7 June 2001	29.5	5.7	10.9
8 June 2001 – 7 June 2002	41.0	6.1	20.5
8 June 2002 – 7 June 2003	37.9	6.5	23.8
8 June 2003 – 7 June 2004	41.1	5.8	17.5
12–18 Sep. 2000 (after Tokai Heavy Rainfall)	46.1	5.6	7.6
9–15 Aug. 2003 (after Typhoon Etau)	46.3	5.6	9.5
4 year mean	37.4	6.0	18.2

the potentially bio-available inorganic phosphorus in the coastal marine sediments[15].

The T-N load also increased during the flood events however the increase was not so drastic like T-P. Most of T-N consists of dissolved component (DTN), and DTN concentrations did not show any relationship with the discharge.

It is known that nutrient ratio (N:P ratio) would change the phytoplankton species composition in the environment[9,18]. The 4 year mean molar ratio of TN:TP in runoff from the Yahagi River to Chita Bay was 18.2 (Table 2) and was near to the Redfield ratio[8] of 16, which is the average N:P molar composition ratio in phytoplankton cells. On the other hand, average ratios of DTN:DTP and PN:PP load were 37.4 and 6.0, respectively, suggesting the considerable decrease in N:P molar ratios with increasing SS runoff in the bay. These observations indicate the large effects of the concentrated suspended matter load during flood events to N:P molar ratios in the environment.

Thus, the concentrated load of suspended matter which occurs during flood events is found to have a great impact on the nutrients runoff to the coastal sea both in quality and quantity. P load from point sources have been reduced by sewage disposal plants and impoundment of rivers by dams which trap nutrients as particulate forms on the bottom of the reservoir as a result of sedimentation of microalgal blooms[18], indicating the increasing proportion of non-point source of P load. In agricultural land in Japan, P fertilizers are often used in excess amounts and are accumulating in the soil mainly as inorganic phosphorus such as CDB-P and NaOH-P[7]. The PP load during flood events including agricultural phosphorus loss from soil erosion is becoming more important for the eutrophication of the coastal sea because of the reduced point-source inputs of phosphorus.

Acknowledgments

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