JOURNAL OF THE KOREAN SOCIETY OF AGRICULTURAL ENGINEERS, MAY. 2005, pp. 77-86

한국농공학회지
제47권 제3호

Pollutant Load Characteristics of a Rural Watershed of Juam Lake

주암호 농촌 소유역 오염부하특성

Han Kuk-Heon* · Yoon Kwang- Sik · Jung Jae-Woon****
Yoon Suk-Gun · Kim Young-Joo*****
한 국 헌 · 윤 광 식 · 정 재 운 · 윤 석 군 · 김 영 주

Abstract

A monitoring study has been conducted to identify hydrologic conditions, water quality and nutrient loading characteristics of small watershed in Juam Lake. Climate data of the watershed were collected; flow rate was measured and water quality sampling was conducted at the watershed outlet for this study. Water quality data revealed that T-P concentrations meet I grade of lake water quality standard during non-storm period, but degraded up to II~III grade of lake water quality standard during storm period. The observed T-N concentrations always exceeded lake water quality standard. Therefore, T-P was identified as limiting chemical constituent for eutrophication of Juam Lake. T-P concentration of non-storm period also revealed that point source pollution is not serious in the watershed. Three year monitoring results showed that the observed T-N losses were 10.85~18.88 kg/ha and T-P losses were 0.028~0.323 kg/ha during six month (Mar. - Oct.), respectively. Major portion of runoff amount discharged by a few storm events a year and nutrient load showed apparent seasonal variation. Huge runoff amounts were generated by intense storms, which make application of water treatment or detention facilities ineffective. Monitoring results confirmed that water quality improvement by abating nonpoint source pollution in rural watershed of monsoon climate should be focused on source control. T-P losses from paddy field seemed to consist of significant amount of total load from study watershed. Therefore, management of drainage from paddy field is considered to be important for preventing algal blooming problem in Juam Lake.

Keywords : water quality, rural watershed, monitoring, pollutant load

* Div. of Environment & Ecology, NIAST, RDA, Suwon
** Department of Biosystems & Agricultural Engineering (Institute of Agricultural Science & Technology), Chonnam National University
*** Institute of Agricultural Science & Technology, Chonnam National University
** Corresponding author. Tel.: +86-62-530-2158
Fax: +82-62-530-2159
E-mail address: ksyoon@chonnan.ac.kr

I. Introduction

Lake water quality is largely determined by ambient nutrient inputs from the watershed. Nutrients lost in surface runoff can cause eutrophication and excessive algal growth in receiving water bodies. Of particular concern are Nitrogen (N) and phosphorus (P), because these essential plant nutrients limit algal growth in fresh waters. Most lakes have much larger ambient nutrient loads than background because of human activities in the watershed such as agriculture and urbanization. Therfore, many lakes across the country have reduced value as drinking water supplies because of algal blooms caused by excessive nutrient inputs. Both nitrogen and phosphorus loadings are important in stimulating lake fertility, but in most cases the phosphorus limits plant production in lakes. Juam Lake is an example of a lake resource that does not meet the optimal quality for a water supply because of excessive algal bloom.

It was realized recently that water quality improvement is hardly achievable without the proper control of nonpoint source pollution, which, in turn, is closely related to land use and rainfall event. The land use in Korea includes about 65% forest and 20% farmland, where runoff from forest is thought to be natural, but drainage water from farmland is suspected as a key pollution source. The rainfall of the Asian monsoon region, including Korea, is concentrated and intensive during the growing season of rice and many other crops, when fertilizer runoff into rivers and lakes may be quite high (Yoon et al., 2003). The extent of non-point source pollutants related to erratic climatic events and landuse methods may differ greatly from place to place and year to year. Therefore, quantitative evaluation on nutrients losses from agricultural and rural watersheds under various climatic and management conditions are important for nutrient management and environmental control.

In rural watersheds, nonpoint sources are considered as one of the major sources of stream pollution. In spite of the evident presence of non-point pollution sources in Juam Lake watershed, there were neither sufficient data nor adequate information about the extent and role in the deterioration of the quality of the lake water resources. Water quality improvement measures for Juam Lake have been established, but most of them focused on in-lake measures and overlooked importance of watershed management. The main reason why watershed management is not considered first hand is that spatial and temporal variations and magnitude of pollutant load from watershed have not been identified. The main objectives of this study were to figure out whether the stream water quality meets lake water quality standard and seasonal variation of nutrient loading characteristics to identify water quality management measures.

II. Monitoring Methods

1. Site Description

In 2001, a stream water quality monitoring program, as a part of a research regarding water quality and watershed management, had been initiated for a rural watershed (Oenamcheon watershed) of Juam Lake located in Jeonnam Province for three years (Fig. 1). The drainage

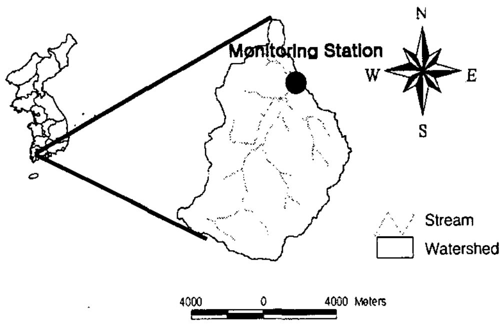

Fig. 1 Location map of study watershed.

area of the watershed is 58.41 ㎢ and its outlet is located at the Sapyeong bridge, located in Hwasun-gun. The main tributary is 15.65 ㎞ long. Most of paddy fields are located near the tributaries and livestock farms are scattered in the watershed area. Land use of the watershed was 4,826 ha forest (82.6%); 575 ha paddy fields (9.8%); 212 ha upland (3.6%); and 228 ha residential and other uses. Total population was 2,092. And 567 heads of cattle, 349 herds of swine and 5,515 herds of poultry were raised in the watershed.

2. Rainfall and Stream Flow Measurements

A set of water level gauge with logger (Orphimedes, Germany) and a gauging staff were installed at the watershed outlet (Fig. 1). Rainfall data were collected from the nearest weather station in Nam-myeon, Hwasun-gun. The water level gauge was used to measure the stream level every twenty-minute automatically during the study period and checked with the measured water level by the gauging staff reading. Flow measurement was conducted by a wading method during non-storm period using current meter. Current meter or float was used for measuring discharge during storm period. All measurements were carried out from May 1, 2001 to October 30, 2003. But, monitoring during winter and early spring seasons was not conducted.

3. Samplings and Sample Analyses

Water samples were collected biweekly during non-storm period. Additional samples were collected during the storm events. Three to seven samples were manually collected for each storm event depending on storm size. Water samples were placed in insulated and ice filled chests and brought to the lab. All samples taken for chemical analyses were refrigerated at 0 to 4 ℃ soon after collection until analyses. Water samples were shaken to obtain homogeneous aliquots for total-N (T-N) and total-P (T-P) analysis. Ammonia-N, nitrate-N, and PO_4-P were determined in aliquots which were centrifuged and filtered through 0.45 ㎛ Millipore filters. Chemical analysis for total-N, nitrate-N, and ammonia-N were conducted using standard methods as described in the FWPCA manual (USDI, 1971). All P determinations were made using the iso-butanol extraction method described by Golterman and Clymo (1969).

Ⅲ. Monitoring Results and Discussion

1. Rainfall and Stream Flow

Fig. 2 shows observed monthly rainfall and those of 30 year average. Average annual rainfall of the study watershed is 1,368 mm. Long-term record revealed that rainfall of summer (June to September) consists 65% of annual rainfall.

Therefore, intensive nonpoint source pollution of the specific period is inevitable in monsoon climate region such as Korea. Drought occurred in spring season of the year 2001 and summer rainfall was much less than the average except June when the rainfall amount was 354 mm, which was one and a half times higher than that of normal year. Rainfall amount of August in 2002 was remarkably high, 768 mm, which was about three times of long-term average monthly rainfall. Rainfall condition of the year 2003 was similar to normal years. Rainfall conditions in 2001 and 2002 were quite different from normal years, stream flow conditions and pollutant load characteristics might be different from those of normal years.

Fig. 3 represents the derived stream stage-discharge relationship at the watershed outlet. Stream flow rate was determined by converting observed stream stage using stage-discharge relationship. Fig. 4 shows observed daily rainfall and stream discharge. Only a few high rainfalls generated significant runoff. Base flow was about 0.05 m^3/s before the storms of June 24 in 2001, daily mean discharge increased up to 56.17 m^3/s by the storm, which resulted 9 million m^3 of runoff into Juam Lake within two days. In 2002, 322 mm storm occurred during August 6~9 generated 139.7 m^3/s of daily discharge on August 7 and 35.6 m^3/s on the next day, which made 18million m^3 inflow to the lake within three days. Storm water detention facilities which handle initial flush are often recommended for urban nonpoint source pollution control. But, the effect of initial flush in rural watershed is not distinct and runoff variation is so severe, detention facilities and treatment facilities can't be effectively adopted in these conditions.

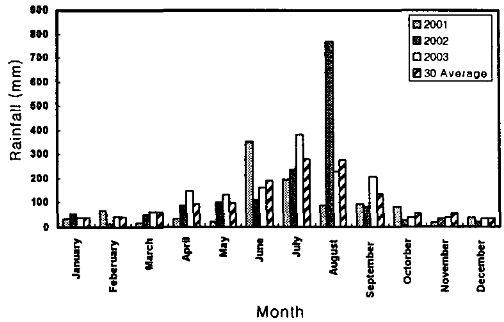

Fig. 2 Observed monthly rainfall and 30 year average monthly rainfall.

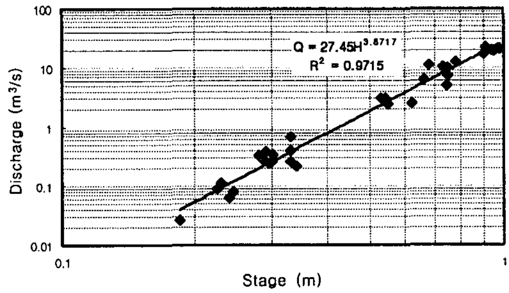

Fig. 3 Stage-discharge relationship at the watershed outlet.

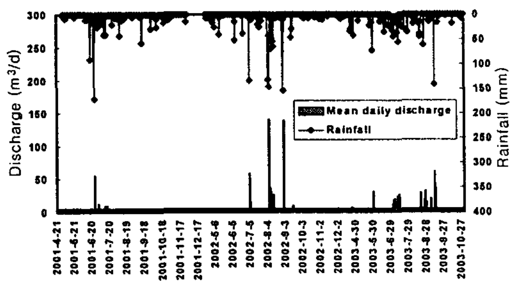

Fig. 4 Observed daily rainfall and stream discharge.

2. Water Quality of Stream

Figures 5 and 6 show observed concentrations of T-N and T-P of stream during study period. Winter and early spring data were not included as mentioned before. During non−storm period, concentrations of T−N showed 1.45~3.98, 1.14~4.79, and 1.43~2.83 ㎎/L for the 2001, 2002, and 2003, respectively, whereas they were 1.57~3.97 ㎎/L, 0.87~4.93 ㎎/L, 1.59~2.47 ㎎/L for storm flow. The average concentrations of T−N were 2.81, 2.41, and 2.07 ㎎/L for non−storm period of 2001, 2002, and 2003, respectively. Those of storm flow were 2.86, 2.84, and 1.89 ㎎/L, respectively

T−P concentrations of non−storm period showed 0~0.0172, 0.0004~0.0256, and 0.0006~0.044 ㎎/L for the 2001, 2002, and 2003, respectively, whereas they were 0.0027~0.0273, 0.0004~0.0564, and 0.0148~0.2276 ㎎/L, respectively for storm flow. The average

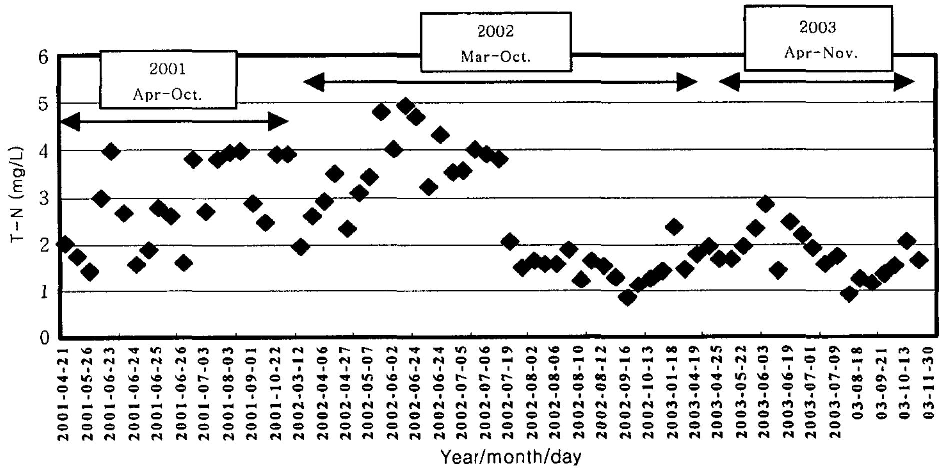

Fig. 5 The observed concentrations of T-N in stream during study period.

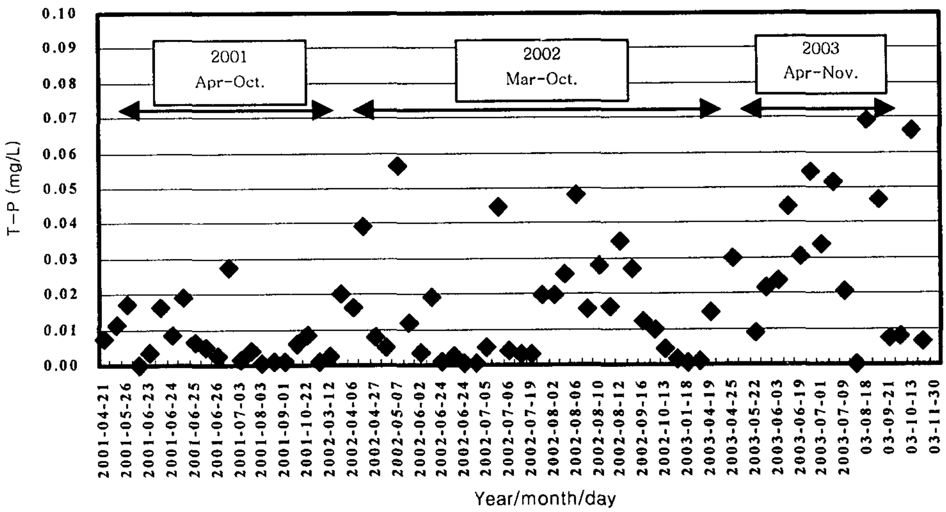

Fig. 6 The observed concentrations of T-P in stream during study period.

Table 1 The mean concentrations of T-N and T-P during study period.

	Non-storm flow	Storm flow
T-N (mg/L)	2.11	2.15
T-P (mg/L)	0.010	0.022

Table 2 Nutrient load (May-Oct.) from the watershed during study period.

	Non-storm flow	Storm flow
T-N (kg/ha)	6.33	34.24
T-P (kg/ha)	0.09	0.48

concentrations of T−P during non−storm period were 0.0046, 0.01, 0.02 mg/L in 2001, 2002, and 2003, respectively. Those of storm flow were 0.01 mg/L, 0.02 mg/L, and 0.06 mg/L, respectively.

The overall mean concentrations of T−N were 2.11 mg/L for non−storm period and 2.15 mg/L for storm flow during study period. The mean concentrations of T−P were 0.01 mg/L for non−storm flow and 0.022 mg/L for storm flow during study period. T−N concentrations did not show a large difference between non−storm period and storm flow. But T−P concentrations have increased a lot during storm period. Water quality data revealed that T−P concentrations meet the I grade of lake water quality standard during non−storm period, but degraded to II~III grade of lake water quality standard during storm period. The observed T−N concentrations always exceeded lake water quality standard for. Water quality indicated that nonpoint source pollution could be major problem in Juam watershed in terms of T−P which is limiting factor of algal blooming of the lake.

3. Nutrient load from the watershed.

Nutrient load from the watershed was estimated using observed discharge and water quality data. The observed nutrients load from May to October is presented in this paper since all three years have the data for that period. Table 2 shows observed nutrient load by non−storm flow and storm flow. Daily nutrient load followed pattern of stream flow and governed by only a few storms. Nutrient load in rural watershed depends upon rainfall and subsequent runoff amount from the watershed. T−N load by storm flow was more than five times of non−storm flow load. T−P load by storm flow was five times higher than that of non−storm flow (Table 2). Overwhelming load and concentrations exceeding lake water quality standard, nonpoint source pollution should be a major concern for the abatement of T−P load and eutrophication of the lake. Water quality and nutrient load data confirmed that nonpoint source pollution was major problem in rural area such as the Juam watershed rather than point source pollution.

Table 3 summarizes observed monthly nutrient load. Nutrient losses of June to July in 2001 were 9.25 kg/ha and 0.025 kg/ha for T−N and T−P, respectively, which constitute 82 and 91% of losses during the six month of May to October. The single storm occurred June 24 generated T−N 4.24 kg/ha, T−P 0.015 kg/ha, which was equivalent to 85% of T−N and 84% of T−P load of the June and constitute 38% of T−N, 53% of T−P load of observed six month

T−N and T−P loads were 17.57 kg/ha, 0.297 kg/ha, respectively during July and August in 2002, which were 93% of T−N and 91% of T−P load of the six month. High rainfall in August

Table 3 Monthly nutrient load from the watershed.
Unit: kg/ha/month

Year/Month	Rainfall (mm)	T-N	T-P
2001/05	21	0.05(0.5%)	0.0003(1.1%)
2001/06	354	5.17(47.6%)	0.0174(63.0%)
2001/07	197	4.08(37.6%)	0.0078(28.4%)
2001/08	91	0.60(5.5%)	0.0001(0.5%)
2001/09	92	0.33(3.0%)	0.0007(2.6%)
2001/10	86	0.62(5.8%)	0.0012(4.4%)
Total	841	10.85(100%)	0.0276(100%)
2002/05	103	0.40(2.1%)	0.0036(1.1%)
2002/06	111	0.11(0.6%)	0.0002(0.1%)
2002/07	238	4.59(24.3%)	0.0212(6.6%)
2002/08	768	13.00(68.9%)	0.276(85.3%)
2002/09	86	0.76(4.0%)	0.0114(3.5%)
2002/10	25	0.02(0.1%)	0.0109(3.4%)
Total	1331	18.88(100%)	0.3234(100%)
2003/05	131	1.33(12.3%)	0.013(6.4%)
2003/06	160	0.22(2.0%)	0.0038(1.9%)
2003/07	384	4.00(36.9%)	0.0568(27.8%)
2003/08	231	2.25(20.7%)	0.1004(49.2%)
2003/09	205	3.00(27.7%)	0.0295(14.4%)
2003/10	30.8	0.04(0.4%)	0.0007(0.3%)
Total	1111	10.84(100%)	0.2042(100%)

alone, which was 57% of rainfall of the six month, generated 68% of T−N, 85% of T−P loads of the six month. T−N load increased 165% and T−P increased 566% in 2002 compared to those observed in 2001. This showed that T−P losses were influenced more than that of T−N by rainfall conditions.

4. Observed Load vs. Estimated by Unit Load Method

The unit load by the Korean Ministry of Environment has been often applied to assess pollutant load from ungauged watershed such as Juam Lake watershed even though it was not designed for that purpose. Table 4 shows comparison between observed load from the study watershed by monitoring data and the unit load. Observed load were 40.57 kg/ha and 0.56 kg/ha for T−N and T−P, respectively. On the contrary, estimated loads by the unit load were 26.25 kg/ha and 3.69 kg/ha for T−N and T−P, respectively. There was a big difference of load estimation for T−P in particular.

Table 4 Comparison between observed and estimated nutrient load.

	Observed load	Estimated by Unit Load Method
T-N (kg/ha)	40.57	26.25
T-P (kg/ha)	0.56	3.69

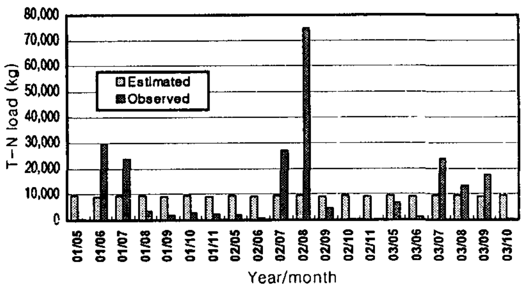

Fig. 7 Comparison between monthly observed and estimated T-N load by unit load method.

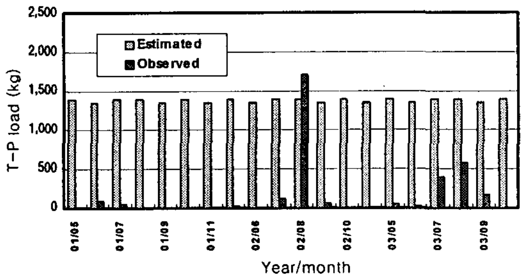

Fig. 8 Comparison between monthly observed and estimated T-P load by unit load method.

Identifying delivery ratio is recommended to overcome shortcoming of the unit load method and give seasonal variation of load. Figures 7 and 8 show the monthly observed load and the estimated monthly nutrient load by unit load method. Those Figures reveal that it is hard to find general trend of delivery ratio for three years due to erratic climate conditions. For example delivery ratios of T−P for August were 0.04, 122, and 28.9% in 2001, 2002, and 2003, respectively. Long−term data may figure out a certain trend of delivery ratio for drought, normal, and flooding years but problem is the lack of long−term monitoring data up to now. Unit load method should be avoided to assess pollutant load from ungauged watershed and watershed management planning.

5. Rainfall-Load Relationships

Water quality and stream flow data are required to determine pollutant load. Flow rate can be determined by measuring continuous stream stage with automatic water level gauge if stage−discharge relationship is set up. But water quality sampling and analysis need labor and cost. Rainfall and load relationship was checked to figure out possibility of load estimation solely using rainfall information. Figures 9 and 10 represent rainfall and nutrient load relationship of the study watershed. As expected the results showed poor relationship both of T−N and T−P.

Runoff is vehicle of chemical transport, but, runoff amount is not proportional to rainfall amount even under the same amount of rainfall depending on the antecedent moisture conditions of a watershed. Chemical characteristics such as solubility, adsorption, and degradation are influential in determining the magnitude and processes by which a given chemical is transported. Nitrate could be transported toward surface bodies of water in soluble form in either surface flow or subsurface runoff. However, because of its low adsorption characteristics, nitrate easily leaches out of the surface soil mixing zone with infiltrating water (Baker and Laflen, 1982). Thus, it is more likely to move to surface water through subsurface flow than through surface runoff. Nitrogen concentration of stream is much affected by NO_3−N, which would appear into stream after infiltration, but part of phosphorous, which is adsorbed to soil, is not transported until runoff generation and subsequent sediment transport. This different transport mechanism might be the reason why rainfall−load relationship of T−P is poorer than that of T−N.

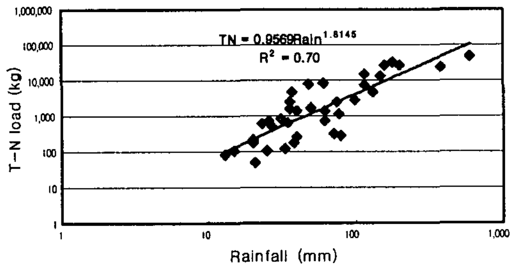

Fig. 9 Rainfall- T-N load relationship (May-Oct.)

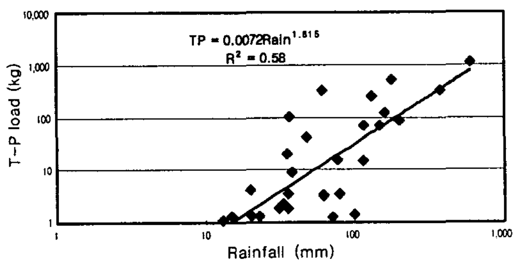

Fig. 10 Rainfall- T-P load relationship (May-Oct.)

6. Watershed Management and Load from Paddy Field

Recently, some studies have conducted on nutrient losses by surface drainage from paddy field in Korea and reported that improper management of drainage could impair ambient water environment (Hong and Kwun, 1989; Shin and Kwun, 1990; Kim and Cho, 1995; Oh et al., 2000; Cho et al.,2002; Yoon et al., 2003). By estimating point source and non-point source pollutant loads into Lake Biwa (Kawara et al., 1996) showed that rice paddy fields contributed the largest amount of contaminant load to the lake in Japan.

Table 5 shows comparison of nutrient load from the watershed and estimated load from paddy field in the watershed. Water quality of drainage from a paddy plot near the outlet of the watershed was simultaneously monitored. Observed average concentrations of drainage water from the paddy field were 3.30 mg/L and 0.07 mg/L for T-N and T-P, respectively. Nutrient load was determined by observed water quality data and estimated water budget considering inspected water management practice of paddy field (assumption of 60 mm retention before drainage) since measurement of continuous flow rate of drainage have not been conducted.

The study showed that about half of T-P load to stream was contributed by paddy fields (575 ha) while T-N load from paddy fields was estimated as 15% of T-N load of watershed during rice cultivation period. Since T-P losses from paddy field consist of significant amount of total losses from study watershed, management of drainage from paddy field is considered to be important for preventing from algal blooming problem of receiving water body.

Table 5 Comparison between the nutrient load from watershed and load from paddy fields.

	Load from Watershed (May-Oct.)	Load from paddy field (May-Oct.)
T-N (kg)	236,983.1	35,220.9
T-P (kg)	3,337.3	1,507.9

Ⅳ. Summary and Conclusions

A monitoring study has been conducted form April to October, 2001-2003, to identify hydrologic conditions, water quality and nutrient loading characteristics of small watershed in Juam Lake. The overall mean concentrations of T-N were 2.11 mg/L for non-storm period and 2.15 mg/L for storm period. The mean concentrations of T-P were 0.01 mg/L for non-storm period and 0.022 mg/L for storm period. Water quality data of this study revealed that T-N concentrations were not much varied between storm and non-storm period while T-P concentrations were increased much during storm period compared to non-storm period. Water quality data revealed that T-P concentrations meet the I grade of lake water quality standard during non-storm period, but degraded to the II~III grade of lake water quality standard during storm period. The observed T-N concentrations always exceeded lake water quality standard. T-P was identified as limiting factor for algal blooming of Juam Lake. T-P concentration of non-storm period also revealed that point source pollution is not serious in the watershed.

Three year monitoring results showed that the observed T-N losses were 10.85~18.88 kg/ha and T-P losses were 0.028~0.323 kg/ha during six month (May.-Oct.), respectively. Nutrient load from the watershed was governed by a few intensive rainfall events and flow volume was found to be a key factor to estimate the load reasonably for rural area where nonpoint source pollution is dominating.

Stream water quality improvement couldn't be effectively achieved by treatment facilities due to low concentration and huge volume of runoff related to the rainfall characteristics of monsoon climate. Therefore, water quality improvement by abating nonpoint source pollution in rural watershed of monsoon climate should be focused on source control.

T-P losses from paddy field was found to contribute a significant amount of load from the study watershed and management of drainage from paddy field was considered to be important for preventing from algal blooming problem of the Juam Lake. Water management practices including effective use of rainfall and diminishing drainage from paddy field is desirable for water environment conservation in rural watershed such as the Juam Lake.

References

1. Baker, J. L. and J. M. Laflen. 1982. Effects of corn residue and fertilizer management on soluble nutrient losses. Transactions of the ASAE 25(2): 344-348.
2. Cho Jae-Young, Han Kang-Wan, Choi Jin-Kyu, Kim Young-Joo, and Yoon Kwang-Sik. 2002. N And P Losses from Paddy Field Plot in Central Korea. Soil Sci. Plant Nutr., 48(3): 301-306.
3. Golterman, H.L., Clymo, R.S., 1969. Methods for Chemical Analysis of Fresh Waters. Blackwell Sci. Publ., Oxford.
4. Hong, S. K., S. K. Kwun, 1989. Characteristics of Pollutant Loading into Streams from Flooded Paddies-On the Special Reference to Total Kjeldahl Nitrogen and Total Phosphorous. Journal of the Korean Society of Agricultural Engineers. 31(3): 92-102. (In Korean)
5. Kawara O, Hirayama K, and Kunimatsu T., 1996. A Study on Contaminanat Loads from the Forest and Rice Paddy Fields. Water Sci. Technolo., 33: 159-168.
6. Kim, B.Y., Cho, J.K., 1995. Nutrient Effluence by the Outflowing Water from the Paddy Field during Rice Growing Season. Korean Comm. Irrig. And Drain. 2, 150-156. (In Korean)
7. Oh, S. Y., J. S. Kim, K. S. Kim. 2000. Mass Balance of Pollutants at a Paddy Field Area during Irrigation Period. Proceedings of the 2000 Annual Conference. The Korean Society of Agricultural Engineers. Ansung. Korea. pp.617-622. (In Korean)
8. Shin, D.S., S.K. Kwun. 1990. The Concentration and Input/Output of Nitrogen and Phosphorus in Paddy Fields. Korea Journal of Environmental Agriculture 9(2): 133-141. (In Korean)
9. U. S. Department Of Interior. 1971. FWPCA Methods for Chemical Analysis of Water Wastes, Natl. Environ. Res. Center, Ohio.
10. Yoon, Chun G., J.H. Ham, J.H. Jeon. 2003. Mass Balance Analysis in Korean Paddy Rice Culture. Paddy and Water Environment 1(2): 99-106.