Membrane and Water Treatment, *Vol. 10, No. 1 (2019) 083-089*
DOI: https://doi.org/10.12989/mwt.2019.10.1.083

Effect of interflow and baseflow on nutrient runoff characteristics in agricultural area

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(Received May 16, 2018, Revised August 16, 2018, Accepted August 30, 2018)

Abstract. The most common way of reducing non-point source pollutants from agricultural areas is the installation of reservoirs. However, this method is only effective for surface runoff of settleable pollutants. This study was conducted to estimate the effect of interflow, baseflow, and surface runoff on pollutant runoff in a small agricultural catchment. Runoff of organic matters, SS, and T-P were directly proportional to the rainfall variation, while ammonia and nitrate were inversely proportional to the amount of rainfall. The interflow and baseflow was only 46% of the total stream flow, but the nitrate load reached 78%. The interflow as a nutrient transport pathway should be considered for managing a stream water quality. It requires careful attention and appropriate control methodology such as vegetation to consider the influence by interflow. The reservoir as a dry extended detention pond (DEDP) has function of nutrient captor.

Keywords: baseflow; surface runoff; interflow; livestock manure; non-point source

1. Introduction

Agricultural activities such as cultivation, fertilizer and pesticide application, confining livestock facilities, and grazing, cause nonpoint source (NPS) pollution and are the USA's major NPS contributor (USEPA, 1997a, b). In case of South Korea, over 85% of livestock manure is being applied to agricultural land as a form of liquid fertilizer or compost. The excessive application of livestock manure fertilizers causes eutrophication of soil and groundwater, as the nutrients are accumulated in the agricultural land. Increased nitrogen and phosphorus concentration in the soil and groundwater significantly leads to outbreak of algal blooms in closed-watersheds.

Currently, countermeasures to control algal blooms have been focusing on point sources such as wastewater treatment plants (WWTP) and non-point sources such as surface runoff during rainfall. However, investigations on the outbreak of algal blooms and the establishment of countermeasures have been limited. Therefore, it is necessary to consider other pathways such as interflow and baseflow aside from surface runoff for NPS management. Both interflow discharged on a relatively short term and baseflow discharged over a long term as nutrient transport pathways are significant in regulating stream water quality (Kim and Lee 2009). Interflow is a lateral movement of water in the unsaturated zone, or vadose zone, that first returns to the surface or enters a stream prior to becoming groundwater (Ward and Trimble 2004). Interflow is sometimes interchangeable with through-flow; however, through-flow is specifically a subcomponent of interflow that returns to the surface, as overland flow, prior to entering a stream or becoming groundwater (Fetter 2001). Interflow is especially known as a major pathway for a soil with low hydraulic conductivity (Stevens *et al.* 1999), so nutrient transfer through the interflow is an indispensable factor for watershed mass balance.

Inflow of pollutants by baseflow continuously affects the water quality of a watershed by inflowing throughout the year along a large area (Choi *et al*. 2014, Jang *et al.* 2011). Baseflow is influenced by various topographic and geological factors such as land slope and subsurface storage structure, climatological characteristics, and land cover (Rumsey *et al.* 2015). Baseflow is also influenced by soil characteristics related to infiltration rate, hydraulic conductivity, and groundwater recharge (Pirastru and Niedda 2013). Consequently, baseflow is greater under conditions with high rates of penetration, groundwater storage, and recharge.

According to Choi *et al*. (2014), the range of baseflow contribution rate in the four major rivers in South Korea was 49~57% by rainfall and basin characteristics and averaged at 54%. USGS (2002) reported that the nitrate-nitrogen loading rate by baseflow was over 50% in 40% of 148 regions in the U.S. Schilling and Wolter (2001) reported that quantifying the baseflow contribution of pollutants to stream loads is an important consideration in assessing the impact of agricultural fertilizers on stream water quality.

This study was conducted to estimate the effect of interflow, baseflow, and surface runoff on pollutants runoff in a small agricultural catchment.

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ISSN: 2005-8624 (Print), 2092-7037 (Online)

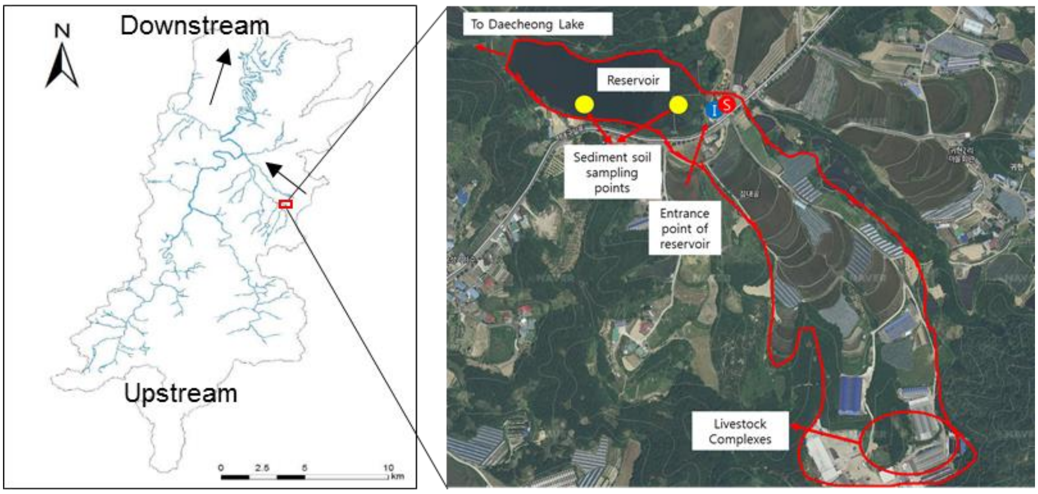

Fig. 1 Monitoring catchment with sampling point

Table 1 Characteristics of monitored rainfall event

Event No.	Date	ADD* (day)	Total rainfall (mm)	Rainfall duration (hr)	Ave. rainfall intensity (mm/hr)	Runoff duration (hr)
Event 1	2018-04-04	12	53.0	62.0	0.85	120.0
Event 2	2018-04-14	2	24.5	10.2	2.41	48.0
Event 3	2018-04-22	7	38.5	44.2	0.87	206.0
Event 4	2018-05-01	6	47.0	24.2	1.94	51.2
Event 5	2018-05-13	4	14.5	20.0	0.73	33.2
Event 6	2018-05-23	3	26.5	11.3	2.30	31.0

*ADD: Antecedent dry days

2. Material and methods

2.1 Experimental site description

A small reservoir that was investigated in the study is connected to a tributary of the Kum River located in the upper region of Daecheong Lake, a major drinking water resource of the surrounding region. The effective catchment area flowing to the reservoir was 15.80 ha, and the land utilization ratio was 15.0% of upland field (2.37 ha), 19.3% of livestock complexes (3.05 ha), and 28.0% of paddy field (4.42 ha), 8.9% of forest (1.40 ha), 28.9% of miscellaneous land (4.56 ha). The livestock complexes are rearing about 400 cattles to date.

2.2 Sampling

Sampling points of surface runoff and interflow were selected at the end of the catchment basin before entering the reservoir. Fig. 1 shows the sampling points and the catchment area. Point S is located below a small ditch where water merges in the catchment area and flows into the reservoir. This point is where surface runoff samples were collected during a rainfall event. Point I indicates interflow sampling point and the samples were collected from underground well.

The surface runoff samples were collected by SIGMA 9000 (auto sampler). To observe the initial runoff characteristics in terms of the amount of pollutants that were washed down from the livestock complexes and agricultural land during a rainfall event, samples were collected every 1 hr interval from right after the rainfall until the water level returned to normal. Sediment soil was collected at two different site; the outer side and the entrance point of the reservoir.

The monitoring was carried out for about 2 months; and there were 6 effective rainfall events that satisfied the standard of over 5 mm of total precipitation based on 5-minute precipitation data of Korea Meteorological Administration (KMA). The range of antecedent dry days (ADD) were 2 to 12 days, and the rainfall duration and runoff duration ranged from 10.2 to 62.0 hr and 31.0 to 206.0 hrs, respectively. Thus, the average rainfall intensity was 0.73 to 2.41 mm/hr (Table 1).

2.3 Analysis

For organic compounds, TOC (total organic carbon-high temperature combustion oxidation method, ES04311.1c), BOD (biochemical oxygen demand, ES04305.1b), and SS (suspended solid, ES04303.1b) were analyzed by Korea standard methods (2017). For nitrogen analysis, T-N by ultraviolet/visible spectrophotometry-oxidation method (ES 04363.1b, Korea standard methods), NO_3-N by ion chromatography (ES 043613.1a and ES 043613.2a, Korea standard methods), and NH_3-N by Hack nitrogen, ammonia Nessler method (8038) were measured. T-P and PO_4-P by ultraviolet/visible spectrophotometry method (ES 04362.1c and ES 04360.2c) were also analyzed by Korea standard methods (2017). The nitrogen (ES04862) and phosphorus (ES04863.1) in sediment soil were analyzed by Korea standard methods (2017). In addition, the fraction of soil phosphorus was analyzed using the procedure by Chang & Jackson (1957).

2.4 Runoff contribution ratios

The event mean concentrations (EMCs) were calculated using each runoff rate and the concentration of pollutants. The EMC is calculated by the discharged mass during an event divided by discharged volume (Wu *et al.* 1998).

$$EMC(mg/L) = \frac{\sum_{t=0}^{t=T} C(t) \cdot q_{run}(t)}{\sum_{t=0}^{t=T} q_{run}(t)} \qquad (1)$$

where, t is rainfall duration; $C(t)$ is pollutant concentration at time t; $q_{run}(t)$ is runoff rate.

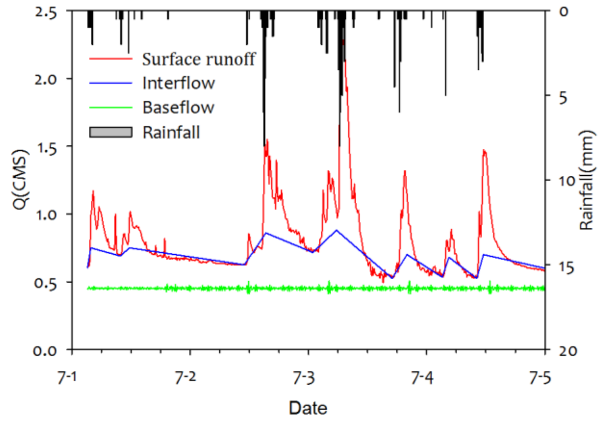

Fig. 2 Hydrograph of surface runoff, interflow and baseflow

Hydrographs were derived and divided among the surface runoff, interflow, and baseflow. The flow rate of surface runoff was measured by a water flowmeter unit during rainfall, and the interflow was measured through water level readings at the monitoring well. The baseflow was measured at the monitoring well during dry weather.

Throughout the previous study for about 6 months on the same site, the flowrates of interflow and baseflow were determined to be around 78 % (interflow 48% and baseflow 30%) of the total flow. The results are shown in Fig. 2. The same flowrate ratio of baseflow was applied for this study. The pollutant loads of surface runoff, interflow and baseflow were determined by each flow rate and EMCs, thereafter the runoff contribution ratios were derived by the loading ratios.

3. Results and discussion

3.1 Hydrographs and polluto-graphs of surface runoff

The surface runoff and interflow showed similar trend of variation according to the rainfall. Both surface runoff and interflow immediately reacted according to the rainfall; especially the surface runoff reacted more immediately since it was highly influenced by rainfall intensity than interflow. The concentration variations of BOD, COD_{Mn}, TOC, SS, T-N, and T-P ranged at 2.7~14.9 mg/L, 5.3~18.7 mg/L, 4.5~16.7 mg/L, 8.8~470.4 mg/L, 2.7~9.2 mg/L, and 0.1~6.5 mg/L, respectively. The differences between maximum and minimum concentrations were significant in SS (53-fold) and T-P (65-fold). The maximum concentration of pollutants increased as rainfall increased (Event 1 and 4).

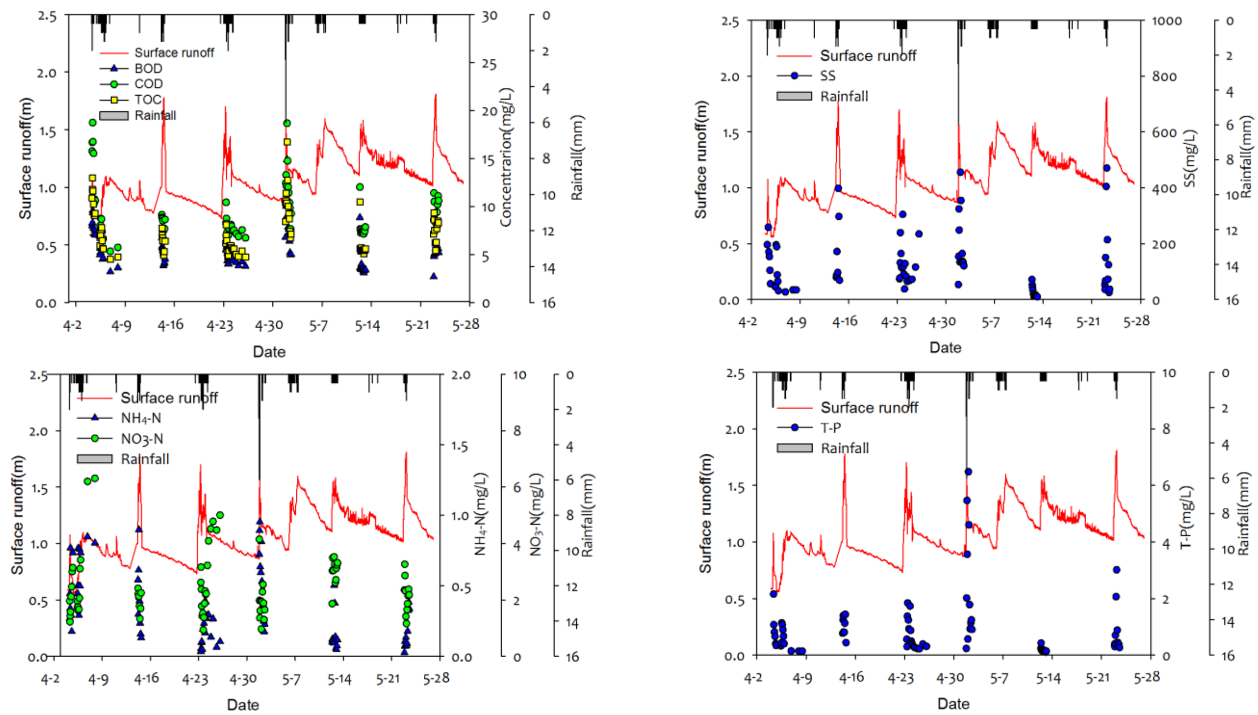

Fig. 3 Hydrograps and polluto-graphs of surface runoff

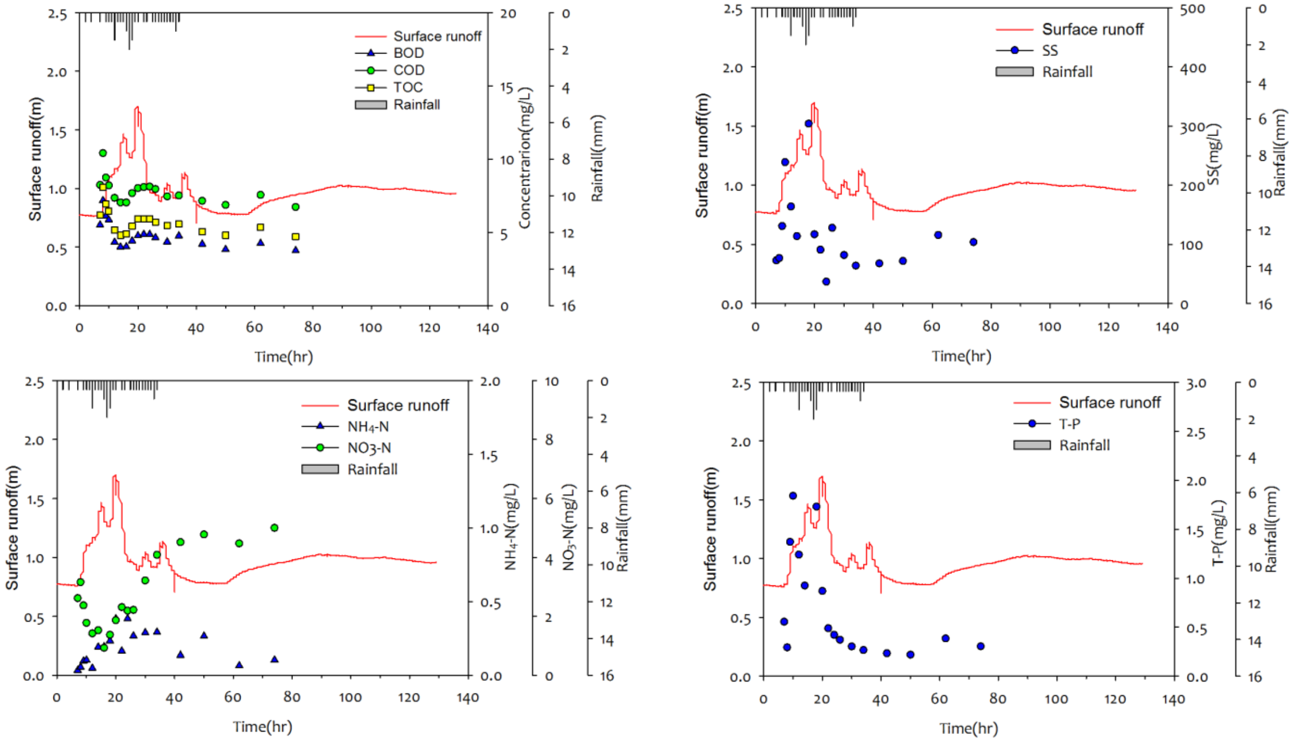

Fig. 4 Polluto-graphs during Event 3

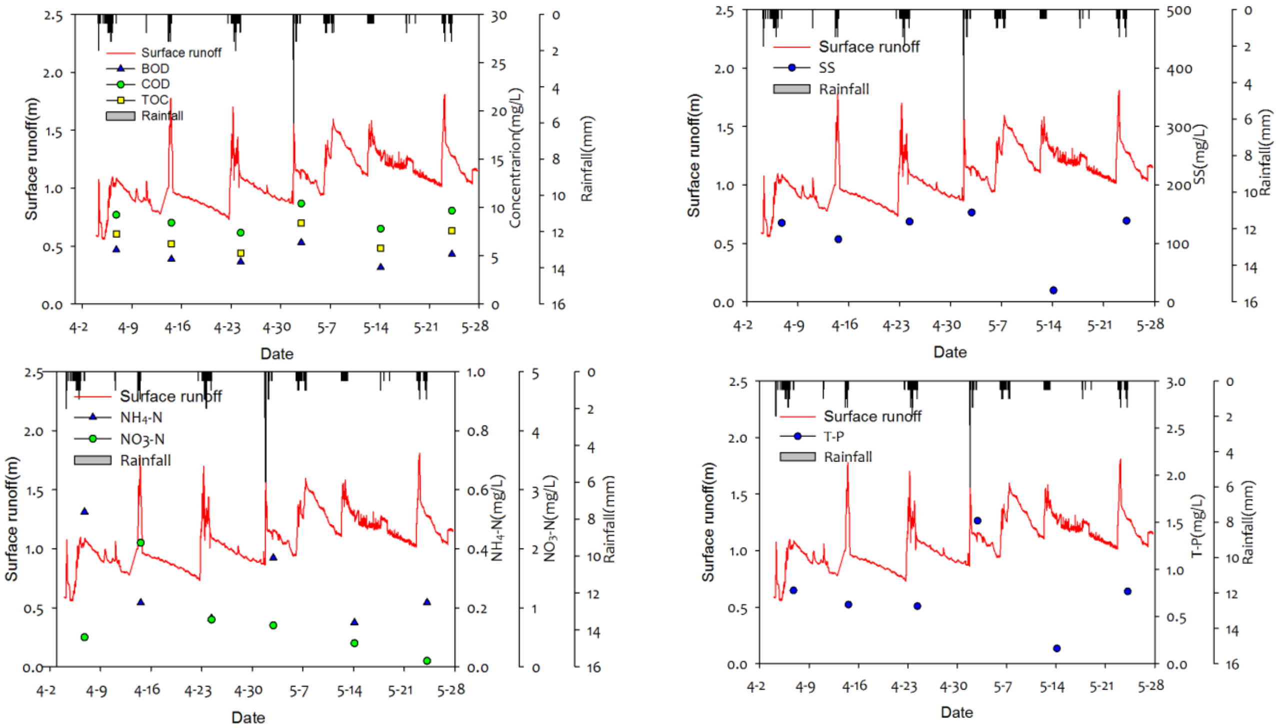

Fig. 5 Hydrograph of surface flow and EMCs

Fig. 3 shows the hydrograph and each pollutant concentration by surface runoff from the catchment area. In case of organic matters (BOD, COD_{Mn} and TOC), SS, and T-P, the runoff concentration also increased with the runoff flow rate by washout effect. Meanwhile, NO_3^--N showed an opposite trend by dilution effect.

Detailed variation of pollutant concentration during Event 3 is presented in Fig.4. The peak flow occurred at 12 hrs after the rainfall and the concentration rapidly decreased after the peak flow. The pollutant (BOD, COD_{Mn}, TOC, SS and T-P) concentration increased at the beginning of rainfall and gradually decreased. Runoff of organic matters, SS, and T-P were directly proportional to the amount of rainfall,

Table 2 Distribution of pollutant EMCs in each rainfall event

Runoff	Items	EMC (mg/L)					
		Event 1	Event 2	Event 3	Event 4	Event 5	Event 6
Surface runoff	BOD	5.6	4.6	4.4	6.4	3.8	5.2
	COD_{Mn}	9.2	8.4	7.4	10.4	7.8	9.7
	TOC	7.3	6.3	5.3	8.4	5.8	7.6
	SS	134.8	106.9	137.1	152.6	19.5	138.6
	T-N	4.8	3.3	5.4	4.8	4.4	3.9
	T-P	0.8	0.6	0.6	1.5	0.2	0.8
Interflow	BOD	10.5	17.4	12.5	11.5	11.8	10.9
	COD_{Mn}	11.3	18.2	15.3	8.3	10.0	16.6
	TOC	6.7	11.7	8.9	8.9	8.7	9.2
	SS	2.5	2.3	2.4	2.5	3.2	3.5
	T-N	15.3	15.7	13.5	14.8	17.9	12.0
	T-P	0.3	0.8	0.6	0.2	0.2	0.2

Table 3 Nitrate runoff by interflow, baseflow, and surface runoff

Event	Rainfall (mm)	Surface runoff			Interflow & Baseflow		
		Flow (m^3)	NO_3-N (mg/L)	Load (kg)	Flow (m^3)	NO_3-N (mg/L)	Load (kg)
Event 1	53.0	89,760	0.5	44.9	74,800	3.1	231.9
Event 2	24.5	56,112	2.1	117.8	35,719	6.0	214.2
Event 3	38.5	189,597	0.8	151.7	147,875	3.7	547.2
Event 4	53.0	36,723	0.7	25.7	44,148	1.8	79.4
Event 5	14.5	40,747	0.4	16.3	44,229	3.1	137.0
Event 6	26.5	31,711	0.1	3.2	35,754	2.0	71.4
Total	210.0	444,650	-	359.6	382,525	-	1,281.1

while nitrate was inversely proportional to the amount of rainfall.

3.2 EMCs of Pollutants

EMCs were estimated using the monitoring results of 6-rainfall event and the results are shown in Fig. 5~6 and Table 2. In surface runoff, the BOD, COD_{Mn} and TOC EMCs range were 3.8~5.2 mg/L, 7.4~10.4 mg/L, and 5.3~8.4 mg/L, respectively. SS and T-P EMCs ranged at 19.5~152.6 mg/L and 0.2~1.5 mg/L. Generally, SS showed high EMCs by inflow of particulates, and it was especially prominent in Event 4 when precipitation was high. In the case of T-P, the runoff occurs in a state adsorbed on the soil or particulate matter rather than a dissolved substance.

Event 5 which relatively has a small amount of precipitation and weak rainfall intensity showed lower pollutants EMCs than other events. Therefore, the SS and T-P EMCs presented similar variation according to the rainfall. T-N EMCs ranged at 3.3~5.4 mg/L, and T-N was uninfluenced by the amount of rainfall unlike other pollutants.

In the case of interflow, BOD, COD_{Mn} and TOC EMCs ranged at 10.5~17.4 mg/L, 8.3~18.2 mg/L, and 6.7~11.7 mg/L, respectively. SS and T-P EMCs ranged at 2.3~3.5 mg/L and 0.2~0.8 mg/L. All the EMCs variations were uninfluenced by rainfall unlike the surface runoff.

3.3 Nitrate runoff ratios

The nitrate runoff ratios were derived according to the surface runoff, interflow, and baseflow loading rate. The loads were calculated using each flow rate and EMCs. The total flow during the monitoring period was 444,650 m^3 by surface runoff and 382,525 m^3 by interflow and baseflow. In addition, the total nitrate loads were 359.6 kg by runoff and 1,281.1 kg by interflow and baseflow, respectively.

Therefore, interflow and baseflow were only 46% of the total stream flow, but the nitrate load reached 78%. The results of runoff ratio in this study are very similar to that of the studies using Web-based Hydrograph Analysis Tool System (Shin *et al.* 2006 and Lim *et al.* 2005). So far, most of the nitrogen by livestock manure fertilizer spraying are known to be removed by plants (Lim *et al.* 2009), since only surface runoff ratio as the drain ditch was considered. As a result, the amount of flow rate of the interflow is also significant as well as the surface runoff.

The case of soluble pollutant such as nitrate is more influential in terms of pollutant runoff. Therefore appropriate control methodology such as vegetation to consider the influence by interflow is required.

3.4 Reservoir's function

The nutrient concentration in sediment soil of the reservoir were investigated and the results are presented in

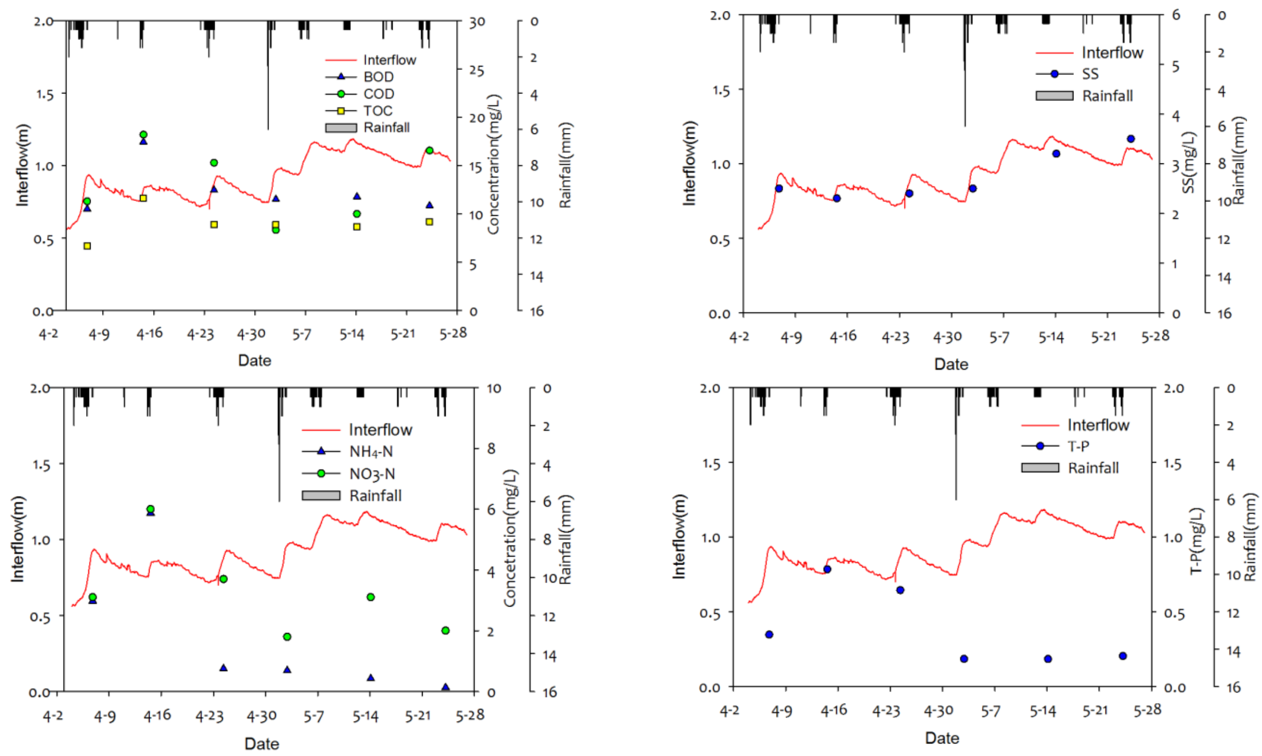

Fig. 6 Hydrograph of interflow and EMCs

Table 4 Nutrient concentrations in sediment soil of the reservoir

Site*	Depth (cm)	T-P (mg/kg)	T-N (mg/kg)	Extracted phosphate concentration (mg/L)				
				Pi-water	Pi-Aluminum	Pi-Iron	Pi-Calcium	Pi-Occluded
1	Topsoil	1,022	4,353	0.026	0.000	6.527	0.012	0.000
	0~30	2,602	3,642	0.023	0.000	8.017	0.000	0.000
	30~80	1,082	4,754	0.015	0.000	4.829	0.000	0.000
	80~130	714	3,482	0.122	0.000	4.716	0.002	0.000
2	Topsoil	922	2,911	0.017	0.000	9.827	0.000	0.000
	0~50	2,635	5,566	0.005	0.000	3.515	0.000	0.000
	50~100	953	4,152	0.062	0.000	12.310	0.005	0.000
3	0~20	1,050	4,135	0.014	0.000	8.546	0.000	0.000
	20~40	1,025	3,512	0.012	0.000	7.456	0.000	0.000
	40~60	1,302	3,524	0.005	0.000	6.206	0.000	0.000
	60~80	1,207	6,632	0.004	0.000	4.572	0.000	0.000

*Site 1 and 2 are boundary area of the reservoir and site 3 is near the entrance of the reservoir.

Table 4. The sediment soil samples were collected at two different sites in the reservoir according to depth. Sample 1 and 2 were collected from the boundary area of the reservoir while sample 3 was collected from near the entrance point of the reservoir (Fig. 1). In the boundary area of the reservoir, the concentrations of T-P and T-N ranged in 714~2,635 mg/kg and 2,911~5,566 mg/kg. T-P highly existed at 0~30 cm of depth, and T-N presented highly at 50 cm of depth. With near the entrance point, the concentrations of T-P and T-N ranged in 1,025~1,400 mg/kg and 3,512~6,632 mg/kg according to the soil depth. T-P and T-N highly existed near 50 cm of depth. Although the depth at which the sample was taken is different, the similar concentration distribution was shown. The concentration of TN and TP in the sediment soil higher near the entrance of the reservoir higher than the boundary area. This is because the pollutants are firstly accumulated at entrance part.

The nitrogen and phosphorus concentration were relatively high compared to general soil, and it seems that the T-P and T-N were considerably accumulated within the sediment of the reservoir due to influence of non-point pollutant. For reference, the phosphorus and nitrogen concentrations in compost that discharged from the livestock complexes were 6,050 mg-P/kg and 32,094 mg-N/kg, respectively.

The results of sequential extraction of phosphorus species is shown in Table 4. The Pi-Iron refers to phosphate that is bound to iron and the compound has strong binding; however, it is possibly re-extractable in anaerobic or acidic condition (Amaizah *et al.* 2012). Livestock manure has high iron component, thereby the large Fe-bound fraction seems to be due to livestock manure. Abdala *et al*. (2015) reported consecutive application of manure to soil effects to increase of Fe and Al amounts in soils. As a result, the reservoir was feasible to carry out supplement function such as a dry extended detention pond (DEDP) to trap nutrients.

4. Conclusions

The effect of surface runoff and interflow on pollutants runoff in agricultural area has been investigated in this study.

- The runoff of organic matters, SS, and T-P were directly proportional to the amount of rainfall, while nitrate was inversely proportional to the amount of rainfall by dilution effect.
- Interflow and baseflow was only 46% of the total stream flow, but the nitrate load reached 78%.
- The interflow as a nutrient transport pathway should be considered for managing stream water quality.
- It requires careful attention and appropriate control methodology such as vegetation to consider the influence by interflow.
- The reservoir as a dry extended detention pond (DEDP) has a function of nutrient captor.

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