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A study on water quality change by land use change using HSPF

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ABSTRACT

Non-point source pollutant load reductions were calculated using the Hydrologic Simulation Program-Fortran (HSPF) model under the assumption that landuse pattern was changed according to land purchases. Upon the simulation of non-point pollutant and areas with high land purchase ratios to select a buffer zone, the Namgang dam Reach 11, Imha dam Reach 10, and the Reach 136 watershed of the main river were found to rank high for the construction of buffer zones. Assuming that the forms of the purchased lands were changed to wetlands, biological oxygen demand (BOD) loads were changed through the HSPF model. No changes of BOD were present in the Namgang dam and the Imha dam watersheds. BOD loads in Reach 136 according to landuse change were analyzed through a flow duration analysis based on the total maximum daily loads of the United States. The flow duration analyses undertaken to examine changes in BOD of main river Reach 136 watershed indicated a shift of 0.64 kg/d from 3.16 to 2.52 during high flow. The change of BOD under the conditions of moist, mid-range and dry were 11.9%, 9% and 4.5%. At the low flow condition, the variation range in the BOD load was from 0.58 kg/d to 0.41 kg/d.

Keywords: BOD, Buffer-strip, Flow duration, HSPF, Land purchasing

1. Introduction

Due to the fast pace at which industrialization and population growth rates have developed and progressed, polluting substances have been discharged into the rivers of South Korea at a rate that exceeds the natural self-purification capacities of the waters, resulting in alarmingly high levels of pollution. Pollution in watersheds can be classified into point source pollutants and non-point source pollutants [1]. In the case of South Korea, further studies on non-point source pollutants are needed for the total pollutant load management undertaken as part of the efforts to manage water quality levels [2]. After the 1980s, the treatment rates for point pollution sources such as industrial and municipal wastewater were improved. However, for non-point source pollutants that occur in rural farmlands and roads, the water quality improvement has not been encouraging [3, 4]. In South Korea, its river environment management policies were undertaken mostly with a focus on performing physical and chemical content measurements and evaluations that were not accompanied by adequate efforts to protect river ecosystems. In the case of advanced countries, artificial and uniform river management practices have resulted in several problems, and a number of social and technological solutions to restore rivers that were once artificially modified to their original states are being explored in various aspects [5]. In some advanced countries, river ecosystem restoration movements and practices have been implemented throughout the country [6]. South Korea must also introduce policies for riverine areas to minimize the inflow of non-point pollutants into the water systems of the Four Major Rivers to improve water quality levels [7].

The riverine areas serve as important buffer zones that vertically and horizontally connect water ecosystems and wildlife ecosystems and are considered especially important in terms of the management of river ecological environments [8, 9]. Riverine areas also play a significant role in maintaining the overall sizes of rivers and the adaptability of rivers to environmental changes, and have been reported as being important elements with respect to the hydrological river management practices associated with flood and drought control [10]. Buffer strips that have high bio-diversity, species concentrations, and high biological productivity exist within riverine areas, and because of this, riverine areas especially require further ecological management [11, 12]. In light of this, some countries have put significant efforts to manage riverine areas upon developing an understanding of their importance [13].

South Korea established a legal basis to create and manage river-

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ine areas upon enacting laws in 1999 to manage and support the water systems of the four major rivers [14]. The development of riverine areas results in the removal of riverine vegetation, which lowers natural self-purification capacities and causes a rise in the concentration of pollutants in riverine areas that typically have high delivery ratios. This leads to the inflow of pollutants to rivers in greater amounts than other regions. In light of this, in order to improve water quality and maintain adequate water volumes, it is especially important to manage water resources using natural methods such as the planting of trees along riverine areas [15]. Lands that especially play an important role in mediating the effects of pollutants on sources of water supply must be purchased to strictly manage as buffer zones applied with strict environmentally friendly land use regulations. To this end, it would be practical to designate lands that are within a certain distance from riverine areas as absolute conservation zones and further set these areas as buffer zones in which the installation of artificial facilities is prohibited. It is necessary to prevent the formation of areas subject to the inflow of pollutants in areas adjacent to riverine areas. Buffer zones established along rivers play an important role in maintaining river ecosystems and the inhibition of pollutant inflows [16]. Of the current land purchases along the Nakdong river basin, the area of lands purchased in the administrative zones of Andong city, Cheongsong-gun, Cheongdo-gun, Sancheong-gun, and Jinju city amounts to an area of 12,464,000 m^2 or 89.1% of total land purchases. The purchased lands were used to form buffer zones (3,599,000 m^2, 33% completion by the end of 2012) in which trees, shrubs, and herbaceous plants were planted, wetlands were formed, and common reeds and giant miscanthus were planted to purify polluting substances.

The Hydrologic Simulation Program-Fortran (HSPF) model developed by the U.S. Environment Protection Agency has operated in conjunction with BASINS (Better Assessment Science Integrating Point and Non-Point Source) for efficient land management. The HSPF model has widely used for water quality managements in watersheds [17, 18]. Additionally, the prediction of water quality change by landuse change is possible for this model. The HSPF provides water quality outputs as the annual average value and daily outputs for seasonal pattern.

In the previous study [19], the verifications of the model were performed with the parameters such as flow rate, biological oxygen demand (BOD), total nitrogen (TN) and total phosphorus (TP). The flow data from 15 stations were used for the verification of flow and the water quality data of 26 sites within Nakdong river basin were verified in the model. The coefficients of determination, R^2 of flow rate were satisfied with the parameters including the seasonal patterns. The range of R^2 value of the flow rate is 0.71-0.93. The BOD difference range between the measured value and the simulated value was 0.5-20%. In case of TN, 1.9-28.6% difference was observed except two sites. There were large differences in two sites due to low flow measurement. TP is much larger than other parameters by 0.8-55.3% difference. Since TP concentrations from the measurements and the results of the model were very small values, it was very difficult to verify TP with the model.

The total maximum daily loads (TMDL) in the Ministry of Environment of South Korea regulates the BOD and TP criteria. The construction of buffer strips was closely related the TMDL. However, TP concentration was very low in this area and the change of TP with the model would not be expected to occur on the presence or absence of buffer zoned. For these reasons, it was decided to study only BOD among the water quality parameters in this study.

This study used non-point source pollution loads of each watershed units of the Nakdong river basin determined in previous research [20] and the data of land purchases along the study area from 2006 to 2015 to designate buffer zones. The purpose of this study is to simulate the BOD reduction according to the buffer zone setting using the HSPF model.

2. Selection of Study Sites and Research Methods

The Nakdong river basin is located 127°29′-129°18′ East and 35°03′ -37°13′ North in the Southeast region of the Korean peninsula and the basin accounts for an area of 23,702 km^2, which is approximately 1/4 of the total area of South Korea. The basin is partially included in the administrative zones of 3 metropolitan cities and 5 provinces: Busan Metropolitan City, Daegu Metropolitan City, Ulsan Metropolitan City, and Gyeongsangnam-do, Gyeongsangbuk-do, Jeollanam-do, Jeollabuk-do, and Gangwon-do. Gyeongsangbuk-do is the administrative zone that accounts for the largest portion of the basin at approximately 60%. Gyeongsangnam-do accounts for 34.1% of the basin, Daegu Metropolitan City 3.9%, Jeollabuk-do 1.1%, and Gangwon-do 0.9%.

The Nakdong river basin was divided into six dams upstream areas and the main stream area for the model simulation. Each sub-watershed in 6 dams upstream areas was named by the name of the dam area and the number of reach. In the case of mainstream, the watersheds were named as the reach number. HSPF model was operated with 209 small sub-watersheds within 6 watersheds including mainstream area. The status of purchased land within Nakdong river basin was shown in Fig. 1. The end of each watershed was identified as the location of dam in Fig. 1.

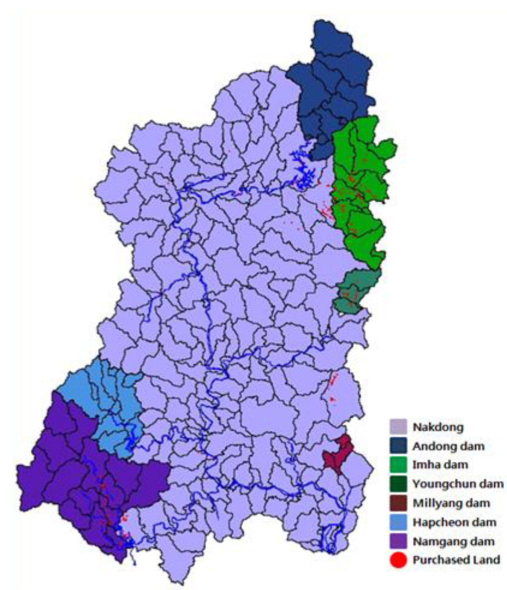

Fig. 1. The status of purchased land and 7 watersheds in Nakdong river basin.

Table 1. Purchase Land Ratio Status

Watershed	Location (Reach number)	Ratio (%)	Rank
Namgang dam	Gyeongsangnam-do Jinju city (Namgang dam Reach 16)	0.022	1
Imha dam	Gyeongsangbuk-do Cheongsong gun(Imha dam Reach 10)	0.014	2
Imha dam	Gyeongsangbuk-do Cheongsong gun (Imha dam Reach 9)	0.014	3
Youngcheon dam	Gyeongsangbuk-do Yeongcheon city (Youngcheon dam Reach 1)	0.013	4
Namgang dam	Gyeongsangnam-do Sancheong gun, Jinju city (Namgang dam Reach 11)	0.010	5
Imha dam	Gyeongsangbuk-do Andong city(Imha dam Reach 1)	0.009	6
Imha dam	Gyeongsangbuk-do Yepngyang gun (Imha dam Reach 6)	0.009	7
Youngcheon dam	Gyeongsangbuk-do Yeongcheon city, North of Pohang city (Youngcheon dam Reach 3)	0.009	8
Imha dam	Gyeongsangbuk-do Cheongsong gun (Imha dam Reach 14)	0.008	9
Namgang dam	Gyeongsangnam-do Jinju city, Sacheon city (Namgang dam Reach 5)	0.006	10

Table 2. Index of Study Area Selection within Nakdong River Basin

Score according to land purchase ratio ranking		Score according to Non-point source pollutants loading ranking	
1-5 ranking	10 point	1-30 ranking	10 point
6-10 ranking	8 point	31-60 ranking	8 point
11-15 ranking	6 point	61-100 ranking	6 point
16-20 ranking	4 point	101-150 ranking	4 point
21-29 ranking	2 point	151-200 ranking	2 point

In order to calculate non-point source pollutant load reductions brought on by the creation of buffer zones, i.e., the alteration of landuse pattern, which is the purpose of the study, areas in which large purchases of land are possible and watersheds that are subject to large loads of non-point pollutants must be identified and applied to the HSPF model. The geoprocessing expansion function of Arc-view was used to overlap a map outlining land purchases along the Nakdong river basin to calculate the area of land purchases within the basin. Land purchases were found to be undertaken in the order of urban outskirts, mountain areas, and rural farmlands. Table 1 shows the land purchase ratios of the Nakdong river basin, in which land purchases were undertaken most actively in Jinju city (Namgang Reach 16, Reach 11), Cheongsong-gun (Imha dam Reach 10, Reach 9), and Yeongcheon city (Youngcheon dam Reach 1).

Study sites were selected by establishing a comprehensive priority that considers land purchase ratios and non-point source pollutant loads. In order to identify the areas with high nonpoint pollution loads and high land purchase ratio, the scoreboard was made by Table 2. For example, from the 1st to the 5th watersheds in the land purchase ratio within Nakdong river basin are 10 points. The simulation results of non-point source pollutant loads of each watersheds presented in previous studies [11] and the rankings of land purchase ratios were applied with point scoring standards as shown in Table 2, in order to establish the rankings regarding the priority of areas to be designated as buffer zones. The land purchase ratio was calculated by the ratio of purchasing land area to watershed area through Arc-View Geological Information system.

The results of applying the scoring standards, as shown in Table 3, indicated that the Namgang dam watershed No. Reach 11 had the highest scores, followed by the Imha dam Reach 10 watershed. Three areas were tied as having the third highest scores, 4 areas were tied as having the 6th highest scores, and 6 areas were tied as having the 10th highest scores. Namgang dam Reach 11 and Imha dam Reach 10 watersheds, which had the highest ranks, were selected to be designated as buffer zones. Considering that the third ranking areas were mostly mountain areas that were difficult to assess changes in water quality, Reach 136, an area in the main river, was additionally selected rather than an area that was upstream from the dam. The 3 selected watersheds including Reach 11 of the Namgang dam watershed, Reach 10 of the Imha dam watershed, and Reach 136 of the main river were applied to the HSPF model to simulate the water quality according to the creation of buffer zones. Before land use conversion, annual averages of BOD values of Namgang dam Reach 11, Imha dam Reach 10 and Reach 136 were 0.859 mg/L, 1.383 mg/L and 0.358 mg/L based on the results of previous research [12].

An area of 1.25 km^2 of the main river Reach 136 was purchased of a total area of 299.65 km^2; an area of 0.75 km^2 was purchased of a total 71.72 km^2 area of the Namgang dam Reach 10; and a 1.09 km^2 area was purchased of the total 77.79 km^2 area of the Imha dam Reach 10. However, in terms of the ratio of the watershed area to the designated buffer strips, the Imha dam Reach 10 watershed was found to have the highest ratio of 1.4%, as Reach 136 of the main river and the Namgang dam Reach 11 had a ratio of 0.42% and a ratio of 1.05%, respectively.

The landuse status of the three selected areas, of the Namgang dam Reach 11, the Imha dam Reach 10, and Reach 136 of the main river watershed, was shown in Table 4. Most of the watershed areas were mountains and rural farmland areas.

Table 3. Ranks of Study Areas for the Modeling

Watershed & Reach No.	Location	Rank
Namgang dam Reach 11	Gyeongsangnam-do Sancheong gun, Jinju city	1
Imha dam Reach 10	Gyeongsangbuk-do Cheongson gun	2
Imha dam Reach 14	Gyeongsangbuk-do Cheongsong gun	3
Main Stream Reach 136	Gyeongsangbuk-do Gyeongju city, Cheongsong gun	3
Namgang dam Reach 7	Gyeongsangnam-do Sancheong gun	3
Namgang dam Reach 16	Gyeongsangnam-do Jinju city	6
Imha dam Reach 9	Gyeongsangbuk-do Cheongsong gun	6
Youngcheon dam Reach 1	Gyeongsangbuk-do Yeongcheon city	6
Namgang dam Reach 15	Gyeongsangnam-do Jinju city, Sacheon city	6
Imha dam Reach 1	Gyeongsangbuk-do Andong city	10
Imha dam Reach 6	Gyeongsangbuk-do Yeongyang-gun	10
Youngcheon dam Reach 3	Gyeongsangbuk-do Yeongcheon city, North of Pohang city	10
Namgang dam Reach 10	Gyeongsangnam-do Sancheong gun	10
Namgang dam Reach 14	Gyeongsangnam-do Sancheong gun, Hadong-gun	10
Main Stream Reach 114	Gyeongsangbuk-do Andong city, Uiseong-gun	10

Table 4. Landuse Pattern of Each Watersheds

	Namgang dam Reach 11	Imha dam Reach 10	Main Stream Reach 136
Total area	71.72 km^2	77.79 km^2	299.65 km^2
Buffer strip area	0.75 km^2	1.09 km^2	1.25 km^2
Agriculture	10.9%	23.3%	6.5%
Forest	64.4%	62.1%	85.5%
Urban	3.3%	2.2%	1.4%
Wetland	2%	8.3%	4.9%
Etc.	19.4%	4.1%	1.7%

The existing purchased lands were assumed to have been formed as wetlands and forest lands among the five different land cover codes (Urban or Built-up land, Agricultural land, Forest land, Wetland, Water) of the HSPF model and each of the three areas was applied to the HSPF model.

3. Results and Discussion

3.1. Estimation of BOD Change According to the Buffer Strips Construction

Upon running the HSPF model by applying the two codes (wetland, forest land) among the five land cover codes of the HSPF model, the average annual BOD loads for both codes were found to be the same (Table 5). When buffer zones were designated as wetlands or forest lands, both cases were found to have the same average annual BOD loads that were generated from non-point source pollutants. These results indicated it would be possible to assume that non-point source pollutant sources in wetlands or forest lands have the same effect on water quality. In other words, the capacity to reduce non-point source pollutant loads can be regarded as being the same in both wetlands and forest lands.

Considering that changing buffer zones into either wetlands or forest lands does not yield any changes in overall BOD loads, the HSPF model was operated with the buffer zones set as wetlands [12].

According to the results of Table 5, the buffer zones creations of the three watersheds, the Namgang dam Reach 11, the Imha dam Reach 10, and Reach 136 of the main river, were converted to wetlands for the simulation. A comparison of the changes in annual average BOD loads, as presented in Table 6, indicated an average reduction of pollutant loads by 0.17 kg/d in the case of the main river Reach 136 and no differences in the cases of the Namgang dam Reach 11 and the Imha dam Reach 10. In light of the fact that the model presents results in the form of annual averages, changes in the values during the summer season, a period in which non-point source pollutant loads are greatest and the effects of rainfall are the highest, were determined through flow duration analyses.

Table 5. Results of BOD with the Landuse Change (unit: kg/d)

Main river Reach 136		Namgang dam Reach 11		Imha dam Reach 10	
Wetland	Forest land	Wetland	Forest land	Wetland	Forest land
1.18	1.18	0.16	0.16	1.08	1.08

Table 6. BOD Results with the Landuse Change by HSPF

Location	Annual average of BOD (kg/d)	
	No alteration of landuse	After creating wetland
Main river Reach 136	1.35	1.18
Namgang dam Reach 11	0.16	0.16
Imha dam Reach 10	1.08	1.08

3.2. Flow Duration Analysis

BOD reductions were analyzed with the flow duration. The flow duration analyses were performed using the TMDLs method of the United States to estimate the BOD. The flow duration analysis was conducted upon applying the five flow duration categories typically: high flows (0-10%), moist conditions (10-40%), mid-range conditions (40-60%), dry conditions (60-90%) and low flows (90-100%) as order of flow. Since the model results were provided as daily flow and BOD data, the BOD data were resorted according to flow order. The results of the BOD load reductions were as shown in Table 7. The main river Reach 136 presented reductions of 0.64 kg/d during high flows, 0.17 kg/d during moist conditions, 0.1 kg/d during mid-range conditions, 0.05 kg/d during dry conditions and 0.17 kg/d during low flows. Annual average of BOD was also found to be reduced as 0.17 kg/d from 1.35 kg/d to 1.18 kg/d. In the case of the Namgang dam Reach 11 and the Imha dam Reach 10, there were no notable changes in annual average BOD loads upon the buffer zones creation of wetland. On the other hand, the flow duration analysis results indicated that BOD loads increased by 0.02-0.03 kg/d during high flows for both areas. There were, however, no further identified changes in BOD loads in other categories of flow rates other than the high flow condition.

Fig. 2. BOD curve with flow duration analysis in main river Reach 136.

The BOD changes of the main river Reach 136 according to the flow duration analysis were presented in Fig. 2. The concentrations were reduced by 20% during high flows, by 11.9% during moist conditions, by 9% during mid-range conditions, by 4.6% during dry conditions, and by 29.3% during low flows. The reduction rates indicated that the highest levels of reduction occurred during low flows and this was considered to be the case due to the relatively low BOD loads of the period. On the other hand, the non-point pollutant load reduction during high flows was found to be the highest at approximately 0.64 kg/d.

4. Conclusions

Since the water quality varies with the amount of rainfall, the flow duration analysis has been done with the land use change assumption. The conversion of purchased lands to buffer zones was expected to largely reduce non-point source pollutants, as passing through a buffer zone. However, the results showed reductions along the main river Reach 136 and no reductions in upstream watersheds where dams were located in. The Reach 136 of the main river watershed having the largest creations of buffer zones, i.e., the area having the largest area of purchased lands, presented the highest reductions of BOD loads. When considering the ratio of the watershed area to the buffer zones, a larger buffer zones was concluded to not only improve the water quality; Reach 10 of the Imha dam had the highest buffer zone ratio of 1.4%, and Reach 136 of the main river and Namgang dam Reach 11 had a ratio of 0.42% and a ratio of 1.05%, respectively. As shown in Table 5, main river Reach 136 watershed having large amounts of forest lands presented larger measurements of non-point source pollutant loads, and this indicated that non-point source pollutant loads were not directly linked to the status of land use. Although the areas of purchased lands contributed to the reduction of non-point source pollutant loads, the results of this study indicated that a simple increase in the ratio of buffer zones did not necessarily result in the improvements to water quality. Based on these results, the locations and the distances of buffer zones to a river may also be considered as important factors. With respect to the methods of reducing non-point source pollutants by designating buffer zones, the results of this study indicated that the length of a buffer zone to a river must be considered to yield an effective buffer effect of a riverine area within a watershed. In consideration of the difficulties associated with ascertaining the appropriate conditions used to designate buffer zones, the establishment of buffer zones in their optimal locations is expected not to be an easy project.

Table 7. BOD of the Flow Duration Analysis (unit: kg/d)

	Main Stream (Reach 136)		Namgang dam (Reach 11)		Imha dam (Reach 10)	
	Before	After	Before	After	Before	After
High flows	3.16	2.52	2.42	2.45	1.00	1.02
Moist conditions	1.43	1.26	1.14	1.14	0.08	0.08
Mid-Range conditions	1.10	1.00	0.96	0.96	0.06	0.06
Dry conditions	1.10	1.05	0.78	0.78	0.05	0.05
Low flows	0.58	0.41	0.71	0.71	0.05	0.05

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