WATERSHED PHOSPHORUS TOTAL MAXIMUM DAILY LOAD MANAGEMENT

Paris Honglay Chen[1], David Da-Wei Tsai[2*]

ABSTRACT

This research was to investigate and initiate the land-use strategies management of phosphorus total maximum daily load (TMDL) in Taiwan. The processes in this study were divided in two parts. The first part was to simulate the phosphorus TMDL model with subroutines of GIS, hydraulic, sediment, BOD, and nitrogen modules in the watershed. We focused on adsorption/desorption, wash-off and scour effect as the major parameters. The results exhibited that the goodness of fit was acceptable and the wash-off effect was the key parameter in this study area. We also found out there is highly correlated between phosphorus concentration and sediment in the study site. The second part of this study was to demonstrate the method of management planning in land-use. According to the evaluation results, we got the best reduction rate and peak reduction rate after reducing the slope-land agriculture activities. The best reduction rate and peak reduction rate were significant, 9.43% and 2.61% respectively, being equivalent to 3.4 tons pure phosphorus about 71.4 tons fertilizer (台肥寶效 1 號有機質複合肥料, #1 Special Organic Compound Fertilizer) per year in such small watershed. Although the management method is excellent and useful, the phosphorus concentration still didn’t reach the national standard yet. It might be caused by the residence effects and it need to do the further reduction plan on it. We hope this strategic procession can help government to establish watershed management policy in Taiwan.

Key Words: Phosphorus Management, TMDL Management, Land-use management, Shuili-stream watershed

INTRODUCTION

Nutrient management including of carbon, nitrogen and phosphorus is one of the most important missions in watershed management. Phosphorus loading has great impact on ecological environment, especially for eutrophication. Total maximum daily load (TMDL) has been proved as one of the most efficient way to manage watershed. This study tried to adapt this concept to simulate the total phosphorous load and efficiency of different land-use strategies.

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METHODS

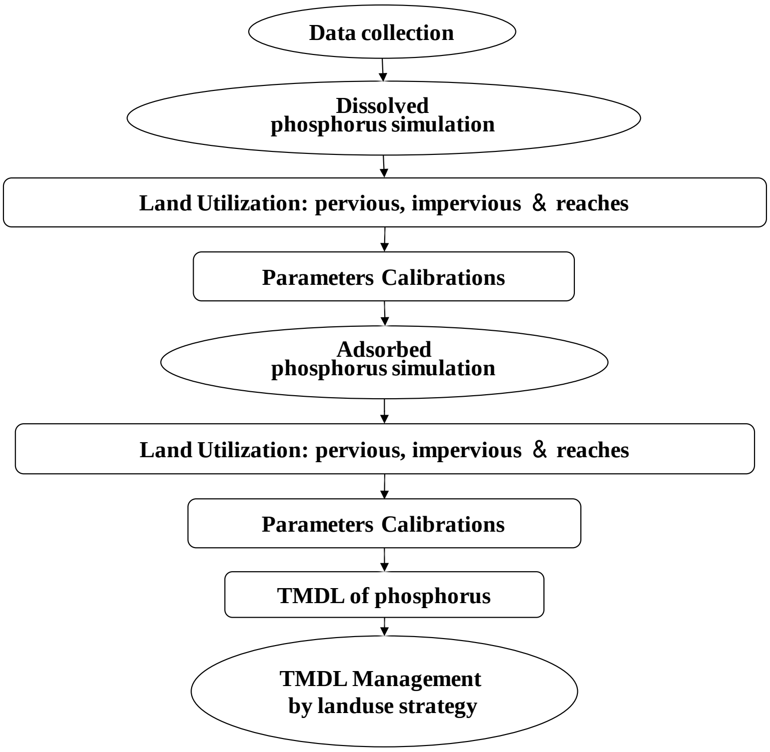


Fig. 1 The flow chart of methodology

The methodology was illustrated in figure 1. We applied the official model of TMDL management developed from USEPA to simulate the TMDL strategies for total phosphorous management in watershed (USEPA, 2004a). According to the model processes, water temperature, dissolved oxygen, BOD, total nitrogen and total phosphorus were simulated and calibrated in sequent. We took the Shuili-stream watershed as our study site and the required data were collected including of meteorological (The Central Weather Bureau, 2009a; 2009b), geographic (Chan and Tsai, 2008a), hydrological (Chan and Tsai, 2008c) and water quality data (Taiwan Power Co., 1998~2003; Chan and Tsai, 2008b; 2008d). In each simulation step, we divided the watershed to pervious land, impervious land and reaches to simplify the complicated nature system. We took the difference between observations and simulations divided by observations as the "improved rate" to estimate the importance of each parameter.

RESULTS AND DISCUSSION

Total load simulation

1.1 Water body

In this study, the adsorption/desorption of phosphate to inorganic sediment of the adsorbed phosphate simulation was focused. The exchange of nutrient between the dissolved state and adsorption on suspended sediment was calculated through using a linear isotherm approach. The formula was presented as Eq. (1) (USEPA, 2004b):

$$SNUT(J) = DNUT \times ADPM(J) \qquad (1)$$

where:

SNUT (J) = equilibrium concentration of adsorbed PO4 on sediment fraction J

(mg/kg)

DNUT = the equilibrium concentration of dissolved PO4 (mg/l)

ADPM (J) = adsorption parameter (or K_d) for sediment fraction J (l/kg)

J= types of sediment (J=1, for sand; J=2, for silt; J=3, for clay)

From the equation, the adsorption coefficient (K_d) was obviously the key parameter to determine the concentration of adsorbed phosphate. Since lacking of related study on K_d, the default value in the model ($K_d=10^{-10}$ ml/g) was adapted and the simulation results were shown in table 1. The sum of square error (SSE) was applied to present the model performance and SSE = 0.013 showed the acceptable results were calculated. The whole calculation results could be exhibited in figure 2, most data fitted well with the observations except the June one.

Table 1 The results of initial simulation for total phosphorus load

Date	Observations (mg/L)	Result (mg/L)
02.26	0.009	0.016
04.17	0.010	0.003
06.11	0.145	0.051
08.13	0.017	0.004
10.27	0.061	0.005
12.10	0.008	0.031
SSE		0.013

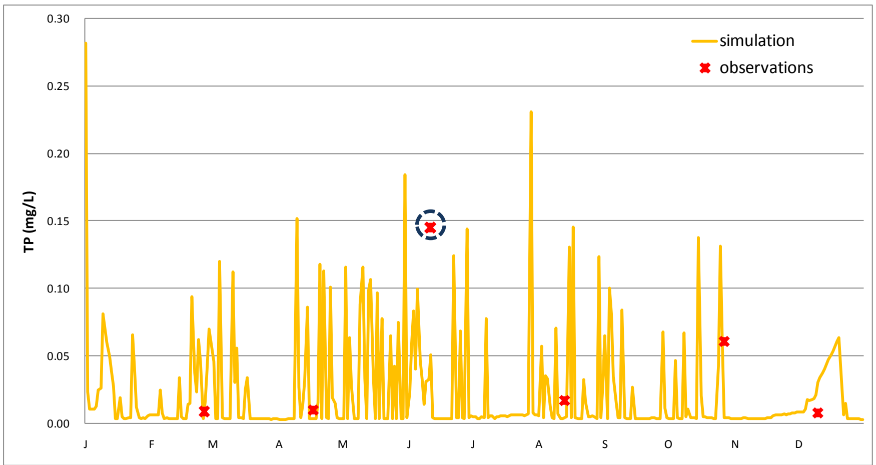


Fig. 2 The variation of the results in the initial simulation

Land

Since the adsorbed phosphate was the key issue here, the erosion factor was essential to discuss on the land portion. In this model, two behaviors related to erosion, wash-off and scour were simulated. The wash-off effect was estimated by the equation as Eq. (2) (USEPA, 2004b):

Table 2 The results of total phosphorus load after calibrating the washoff effect (1)

Date	Observation-s (mg/L)	Initial simul-ation (mg/L)	Result (mg/L)								
			POTFW =1	POTFW =2	POTFW =3	POTFW =4	POTFW =5	POTFW =6	POTFW =7	**POTFW =8**	POTFW =9
02.26	0.009	0.016	0.017	0.017	0.017	0.017	0.017	0.017	0.017	**0.017**	0.017
04.17	0.010	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	**0.003**	0.003
06.11	0.145	0.051	0.063	0.074	0.086	0.097	0.109	0.120	0.132	**0.143**	0.155
08.13	0.017	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	**0.004**	0.004
10.27	0.061	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	**0.005**	0.005
12.10	0.008	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	**0.031**	0.031
SSE	-	0.013	0.011	0.009	0.008	0.006	0.005	0.005	0.004	**0.004**	0.004
Improved Rate (%)	-	-	15.83	29.60	41.31	51.03	58.65	64.12	67.55	**68.87**	68.11

Table 3 The results of total phosphorus load after calibrating the washoff effect (2)

Date	Observatio-ns (mg/L)	Results (mg/L)					
		POTFW=7.8	POTFW=7.9	**POTFW=8.1**	POTFW=8.2	POTFW=8.3	POTFW=8.5
02.26	0.009	0.0170	0.017	**0.017**	0.017	0.017	0.017
04.17	0.010	0.0034	0.0034	**0.003**	0.003	0.003	0.003
06.11	0.145	0.1411	0.1422	**0.145**	0.146	0.147	0.149
08.13	0.017	0.0042	0.0042	**0.004**	0.004	0.004	0.004
10.27	0.061	0.0045	0.0045	**0.005**	0.005	0.005	0.005
12.10	0.008	0.0307	0.0307	**0.031**	0.031	0.031	0.031
SSE	-	0.003998	0.003991	**0.003984**	0.003985	0.003988	0.004002
Improved Rate(%)	-	68.788	68.845	**68.893**	68.890	68.866	68.756

$$WASHQS = WSSD \times POTFW \tag{2}$$

where:

WASHQS = flux of phosphate associated with detached sediment washoff (quantity/ac per interval)
WSSD = washoff of detached sediment (tons/ac per interval)
POTFW = washoff potency factor (quantity/ton)

That equation was controlled by the wash-off potency factor (POTFW) and the fitting process was performed in the table 2. The best improved rate compared to the initial simulation was concluded as POTFW = 8. For searching the more accurate parameter value, the calibration was calculated again and the results showed in table 3. The model accuracy was further improved when POTFW = 8.1 shown as table 3 and finally the best improved rate of 68.89% and SSE of 0.004 were carried out. Comparing to other related researches in Taiwan which claimed POTFW was ranged as 0.001-2.6 (Chang, 2004; Huang, 2004), this paper selected high value for this parameter.

On the other hand, the scour effect was evaluated in the model by the Eq. (3) (USEPA, 2004b):

Table 4 The results of total phosphorus load after calibrating the scour effect

Date	Observations (mg/L)	Results (mg/L)		
		POTFS=1	POTFS=1	POTFS=8
02.26	0.0090	0.017	0.017	0.017
04.17	0.0095	0.003	0.003	0.003
06.11	0.1450	0.145	0.145	0.145
08.13	0.0165	0.004	0.004	0.004
10.27	0.0610	0.005	0.005	0.005
12.10	0.0075	0.031	0.031	0.031
SSE	-	0.003984	0.003984	0.003984

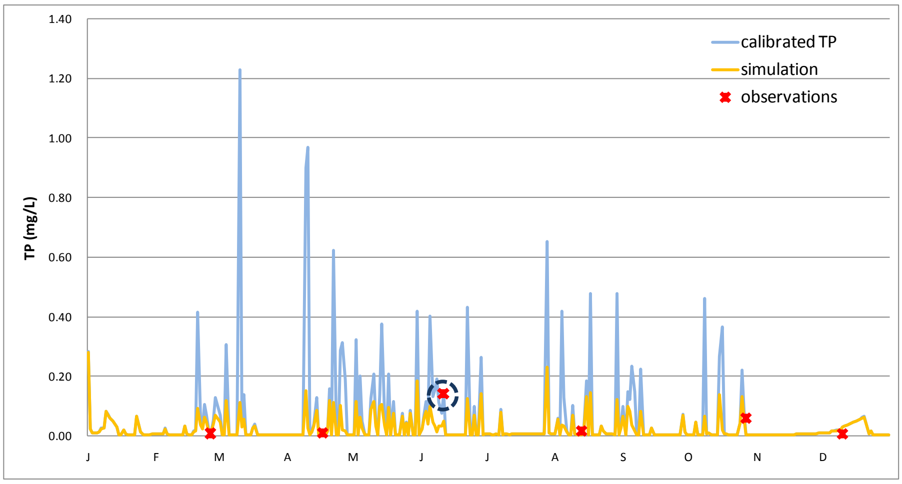


Fig. 3 The comparison of initial simulation and calibrated results

$$SCRQS = SCRSD \times POTFS \quad (3)$$

where:

SCRQS = flux of phosphate associated with scouring of the matrix soil (quantity/ac per interval)

SCRSD = scour of matrix soil (tons/ac per interval)

POTFS = scour potency factor (quantity/ton)

This study tried to calibrate the key factor, scour potency factor (POTFS) to find out the effect of scour. The result could be shown as table 4 and no effect from scour behavior was concluded. In this section the wash-off effect which was more important than the scour in erosion for phosphate simulation was demonstrated. The improvement from erosion calibration could be illustrated on figure 3. After the modification process, the loading of phosphate was obviously increased and the fitness on June data was improved clearly.

In order to prove the key factor in total load simulation of phosphate, the relationship between phosphate and flow/sediment was further discussed. Because phosphate was partial dissolved in water, the flow quantity might have great effect on the simulation. The comparison of flow and phosphate variation was shown in figure 4. That figure provided the information that there was certain degree of relationship in between but not apparent. The regression analysis was presented in figure 5 and proved that phosphate was not highly related with flow quantity since R^2 = 0.3738.

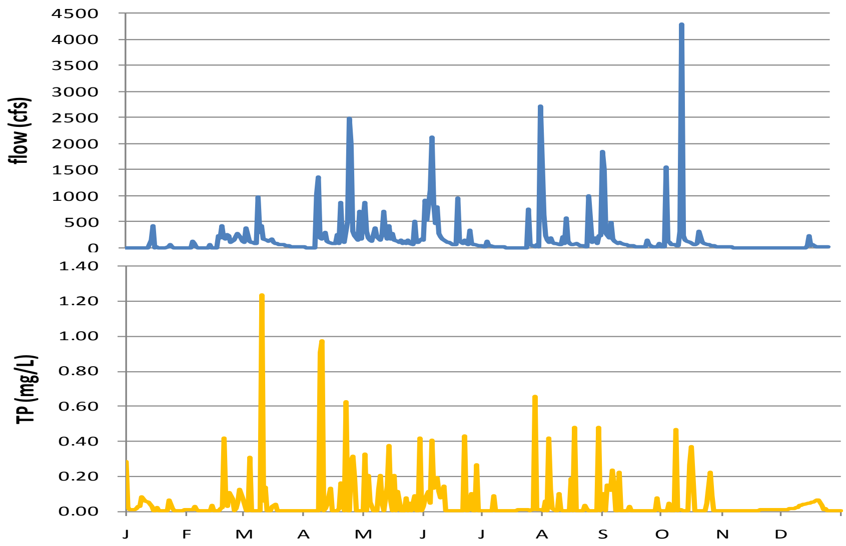


Fig. 4 The comparison of phosphate and flow quantity

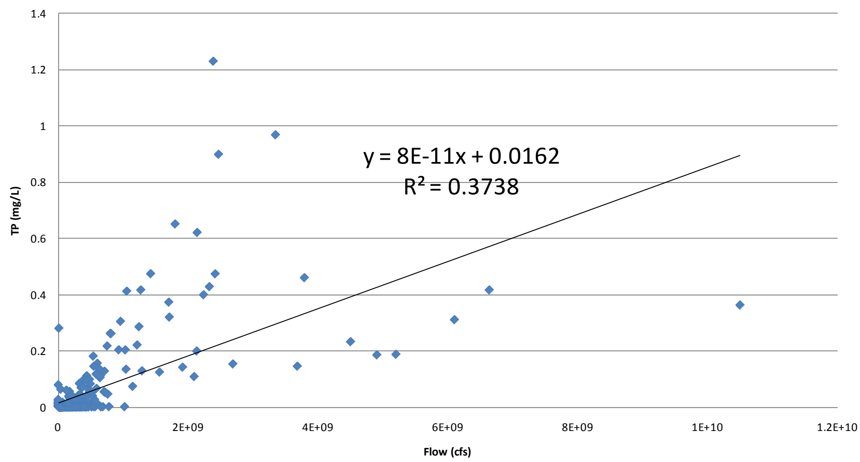


Fig. 5 The regression analysis between phosphate and flow quantity

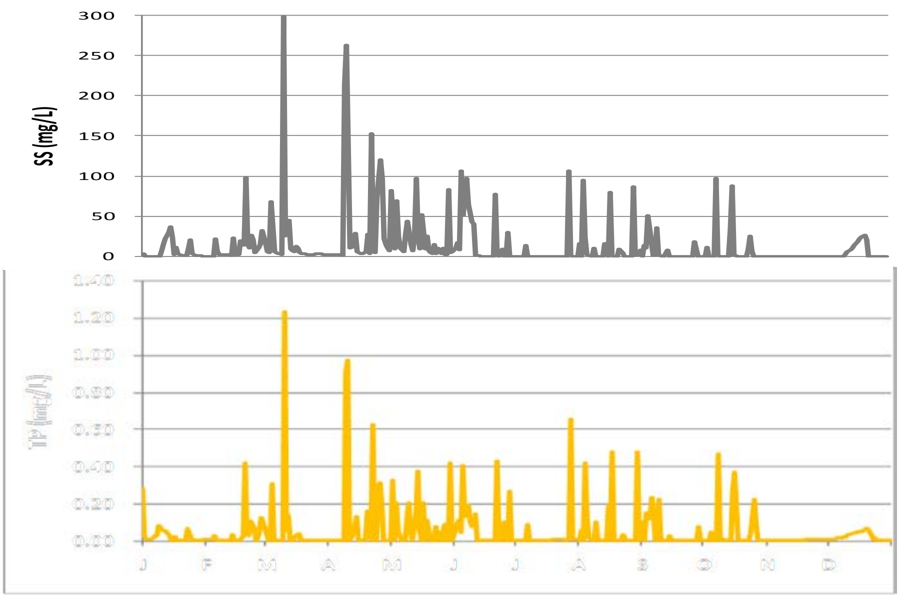


Fig. 6 The comparison of phosphate and suspended solid

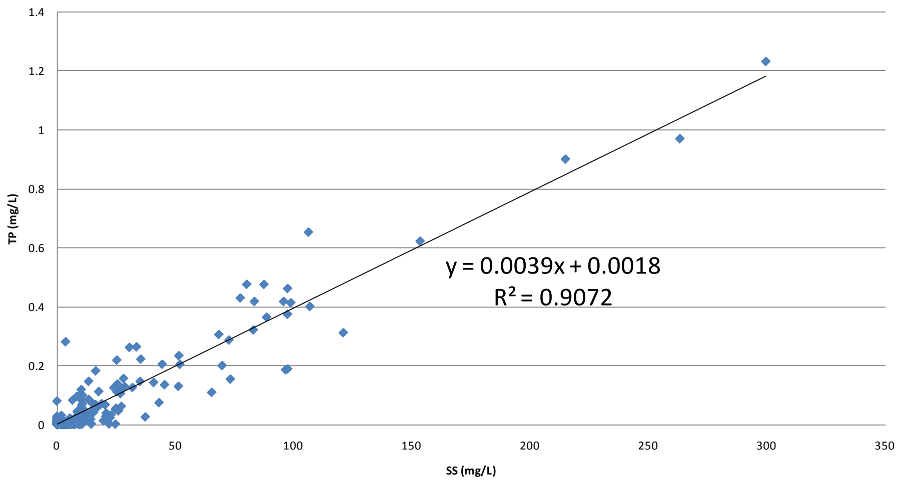
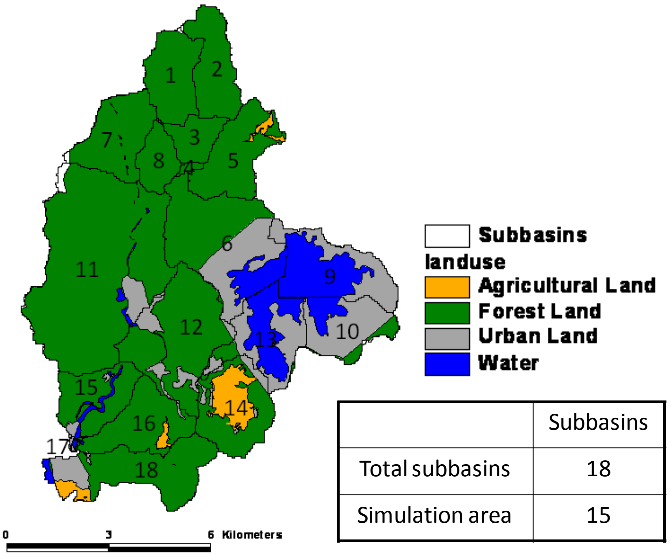


Fig. 7 The regression analysis between phosphate and suspended solid

This study illustrated the comparison between phosphate and suspended solid in figure 6 and their result of regression analysis in figure 7. The high relationship between those two parameters was demonstrated and R^2 = 0.9072 was calculated. According to the results of comparison, this study further proved that the sediment transport was very important in the total load simulation of phosphorus.

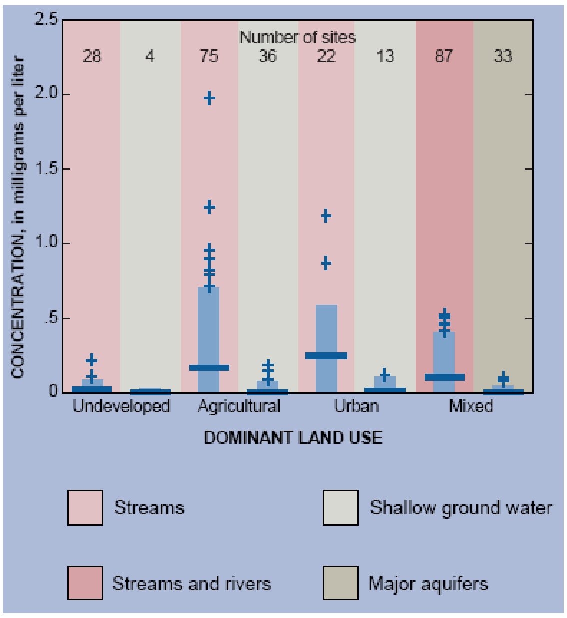
Management efficiency simulation

Since land use management is one of the most important strategies of total load management (Chan and Tsai, 2009; Hu, 2006), the efficiency simulation of different land use alternatives was studied. The distribution of land use in this watershed was expressed as figure 8. Totally 18 subbasins were divided and No. 1 to 15 were chosen as study boundary because the water quality station was set in the No. 15. The major type of land use was forest, the second was agriculture and the third was urban. For the management purpose, the main source of phosphate should be concerned first. According to USGS (1999) and Litke (1999), agricultural and urban utilizations are usually the major sources shown as figure 9. Therefore, this paper focused on those two types of land use. The agricultural utilization was concentrated on No. 5 and No. 14 subbasins and the proportion was 12% and 88%, respectively. The biggest urban area was around Sun-moon Lake and thus No. 6, 10, 13 subbasins were selected as a model for the effect of urban area.



	Subbasins
Total subbasins	18
Simulation area	15

Fig. 8 The distribution of land use in the watershed



Source: USGS, 1999.
Fig. 9 Total phosphorus in streams and orthophosphate in ground water

The strategy for reducing total load in this study was to apply reforestation in agricultural or urban area. There were 2 agricultural and 3 urban subbasins in the simulations which could form 10 possibilities of alternatives shown in table 5. Each alterative was evaluated and the results could be shown in table 6. The results showed that the best efficiency was performed in the alternative 3 which applied reforestation on agricultural land. The amount of reduced total load was up to 3.43 ton/year and equilibrium to 19.05 ton/year phosphorus fertilizer. The reduction rate, peak reduction rate and reduced load of alternative 3 were calculated as 9.43%, 2.61% and 18.53 kg/ha · year, respectively. One thing was interesting that the highest reduced load was presented in alternative 1. The reason might be the No. 5 subbasin located at the upstream and more erosion in that area. Comparing the results of the efficiency assessments, the better alternative is concluded on agricultural land than urban area. Although high reduction rate was concluded, the managed water body still cannot fit the national standard yet (Taiwan EPA, 1998). Therefore, it might need to do the further reduction plan on it.

Table 5 All the alternatives in this study

Alternative	Content
1	Reforestation in No. 5 subbasin
2	Reforestation in No. 14 subbasin
3	Reforestation in No. 5 & 14 subbasin
4	Reforestation in No. 6 subbasin
5	Reforestation in No. 10 subbasin
6	Reforestation in No. 13 subbasin
7	Reforestation in No. 6 & 10 subbasin
8	Reforestation in No. 6 & 13 subbasin
9	Reforestation in No. 10 & 13 subbasin
10	Reforestation in No. 6 & 10& 13 subbasin

Table 6 The efficiency in each alternative

Management target	Alternative	Total Load (kg/year)	Reduction Rate (%)	Peak Reduction Rate (%)	Reduced Load (kg/ha・yr)
	Current	36356	-	-	-
agriculture	Alt1	35884	1.30	0.58	20.81
	Alt2	33399	8.13	2.02	18.22
	Alt3	**32928**	**9.43**	**2.61**	**18.53**
urban area	Alt4	36526	-0.47	-2.88	-0.58
	Alt5	36072	0.78	-5.00	1.08
	Alt6	36041	0.87	-3.50	1.44
	Alt7	36210	0.40	-8.20	0.26
	Alt8	36179	0.48	-6.69	0.34
	Alt9	35753	1.66	-8.87	1.25
	Alt10	35930	1.17	-12.40	0.55

CONCLUSIONS

In the processes of total load estimation, the wash-off parameter is the most effective factor to calibrate. The results of land-use alternatives simulation demonstrate the TMDL could efficiently reduce total phosphorus load. We hope those processes could help to establish better policy for watershed management in Taiwan.

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