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Planning for Implementation of Riparian Buffers in the Feitsui Reservoir Watershed

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Abstract The Feitsui reservoir is a major water supply source for more than five million people in Northern Taiwan. The reservoir water quality has been good, but is threatened by eutrophication due to excessive nutrient input and siltation due to sediment loads. Recently, the water authorities in Taiwan have made considerable efforts to devise strategies using watershed conservation practices for the protection of Feitsui reservoir water quality. The control of non-point source pollution (NPS) represents one of the major strategies and the use of best management practices (BMPs) is under careful consideration. The objective of this study was to assess the effectiveness and cost of a full Feitsui watershed implementation of riparian buffer strips and other appropriate conservation practices. Based on the use of watershed simulation models and a statistical relationship between pollution reduction rate and the width and slope of a buffer strip, a methodology for the planning and design of riparian buffer strips was addressed. Data from field experiments were used to calibrate the coefficients of the regression equations. Several planning scenarios were evaluated by means of cost-benefit analysis coupled with net present value method. Data on local construction and maintenance costs for the selected design and location of buffer strips were used in the analysis. Based on several cost-benefit analyses, the scenario for installing buffer strips with 30 m width and 5% slope along both sides

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of tributary streams in the sub-watersheds with high nutrient (phosphorus) loadings was found to be most cost effective.

Keywords Cost-benefit analysis · Implementation strategy · Riparian buffer zone · Watershed model · WinVAST · Soil/water conservation practices

1 Introduction

The Feitsui reservoir watershed has an area of 303 km^2 with mostly forested land. It is a major water supply source for more than five million people in Northern Taiwan. The reservoir water quality has been good. However, human activities in the watershed have gradually increased, particularly in the form of road building and tea farming. The water quality of Feitsui reservoir is threatened by siltation due to sediment loads and eutrophication due to excessive nutrient input. In recent years the water authorities have initiated many programs for the protection of the Feitsui reservoir water quality. The control of pollution from nonpoint sources represents one of the major strategies. This paper reports on efforts made by the water authorities in Taiwan to devise a strategy using watershed conservation practices for the protection of Feitsui reservoir.

Riparian buffer strips are strips of natural or constructed vegetation that grow along stream and concentrated flow channels. They can protect a stream from the impact of neighboring human activities. The function of a filter strip is to trap sediment, nutrients, organic matter and chemicals when runoff passes through the vegetated zone (Chesapeake Bay Program 1995). Filter strips are generally more effective in trapping particulate pollutants such as sediment and sediment-bound nutrients than soluble pollutants. Since uniform and shallow flows provide more contact time for the removal of pollutants by several physical processes, including deposition, infiltration, biological and chemical process, filter strips are more effective when runoff passes through the vegetation in the form of uniform sheet flow compared to conditions where the flow is concentrated in small channels (Leeds et al. 1994).

Environmental planners realize the importance of maintaining existing or newly constructed riparian buffers when land is developed for urban purposes (McKague et al. 1996; Norman 1996). With the degeneration of numerous aquatic ecosystems due to human activities, riparian buffer strips have become a very common conservation practice aimed at protecting water quality (Barling and Moore 1994; Osborne and Kovacic 2006). Guo et al. (2009) studied the impacts of land use coupled with various buffer area on water quality and concluded that effective design of buffer zone will impose significant impacts on water quality. This study discusses the planning and design of riparian buffer strips in the Feitsui reservoir watershed in Taiwan.

In recent study, Holvoet et al. (2007) proposed a modeling approach to simulate the effectiveness of different management scenarios, including buffer strips, dealing with both point and diffuse pollution. In this study, a methodology for the planning and design of riparian buffer strips was addressed, based on the use of watershed simulation models and a quantitative relationship between pollution reduction rate and the width and slope of a buffer strip. The objective of this study was to assess the effectiveness and cost of a full Feitsui watershed implementation of riparian buffer strips and other appropriate conservation practices.

2 Materials and Methods

2.1 Quantitative Relationships

The design and placement of strips are important in the planning of riparian buffer zones, since they can have a large influence on the control efficiency of water quality and water quantity. Besides watershed protection efficiency, the costs and benefits of watershed conservation practices should be carefully considered. The methodology for evaluating the control efficiency under different designs of riparian buffer strips has usually been based on empirical or semi-empirical relationships linking efficiency to certain design parameters.

The factors that influence the performance of riparian buffer strips include width, slope, soil properties, vegetation and flow rate, etc. This study examines only two factors: slope and width of buffer strips. For pollutant trapping simulation of riparian buffer strips, a simplified method used in SWAT was implemented (Neitsch et al. 2002). This method estimates the pollutant trapping efficiency by Eq. 1.

$$E_t = a \times W^b \times S^c \tag{1}$$

where E_t is the trapping efficiency for the pollutant; a, b and c are coefficients varied under different forms of vegetation, various widths and slopes of buffer strips; W is the width of buffer strip; S is the average slope of buffer strip. The data from numerous field experiments, as shown in Table 1, were used to calibrate the coefficients of these regression equations, i.e. a, b and c. SWAT model has good potential for application in water environmental studies (Jayakrishnan et al. 2005). This study applied the quantitative relationships to determine suitable designs of riparian buffer strips in the Feitsui reservoir watershed.

2.2 Watershed Simulation Model

WinVAST model was developed by University of Virginia in 2003. It combines several computation modules in a single windows interface. WinVAST model is friendlier for model users than its former version “VAST”. It is an event-based model. It can connect with the Geographic Information Systems (GIS) (Chang et al. 2006). WinVAST model uses a binary-tree structure to describe the stream distribution in a watershed. It provides various methods for calculating rainfall abstraction, runoff, flow routing and pollutant transport. Model users can choose different computation algorithms depending on the complexity of problems and availability of data.

Table 1 Field data of buffer strip experiments

W (m)	*S* (%)	*Et_SS* (%)	*Et_TP* (%)	*Et_TN* (%)
5.5	6	27	22	6
15.2	6	67	22	8
45.7	6	68	33	9

Data source: Yu and Kaighn (1992)

W width of buffer strip; *S* average slope of buffer strip; *Et_SS* trapping efficiency for suspended solids; *Et_TP* trapping efficiency for total phosphorous; *Et_TN* trapping efficiency for total nitrogen

Since WinVAST model has these advantages, this study applied it to predict the potential pollutant loadings from the sub-watersheds in the Feitsui reservoir watershed without any watershed conservation practices. "SCS unit hydrograph method" was used to calculate surface runoff. The peaking factor for SCS unit hydrograph was 484. "The Muskingum method" was applied to describe flow routing. The Muskingum parameters, involving weight factor, X, and routing constant, K, were 2 h and 0.2 respectively.

The algorithms for calculation of pollutant accumulation, transportation and decay in WinVAST are similar to those of the STORM model (Tisdale et al. 1996; Yu et al. 2003). The pollutant wash-off from the land surface during a storm event can be calculated by the following formula:

$$M(p,l) = A(p) \times P(p,l) \times (1.0 - \exp[-k(p) \times R]) + FSUS(p) \times M(sus) + FSET(p) \times M(set) \quad (2)$$

where $M(p,l)$ is the wash-off rate of pollutant p from land use l; $A(p)$ is the fraction of pollutant p available for wash-off from the land surface; $P(p,l)$ is the accumulation of pollutant p on land use l just prior to storm event;$K(p)$ is wash-off decay coefficient for pollutant p; R is surface runoff; *FSUS(p)* is the fraction of suspended solids that is pollutant p; *M(sus)* is the wash-off rate of suspended solids; *FSET(p)* is the fraction of settleable solids that is pollutant p; *M(set)* is the wash-off rate of settleable solids. $A(p)$ is determined by surface runoff. $K(p)$ was given by 0.2. *FSUS(p)* and *FSET(p)* were given by 0.0045 and 0.001 respectively in this study.

Since the land-use conditions and pollutant loadings are spatially variable in the Feitsui reservoir watershed, the potential impact on reservoir water quality from each sub-watershed would be different. The simulation results can be a significant basis for the planning of riparian buffer strips, particularly for prioritizing buffer strips placement.

2.3 Study Area and Planning Scenarios

The location of the Feitsui reservoir watershed and its 25 sub-watersheds are shown in Figs. 1 and 2, respectively. The geographic properties, land-use conditions and pollutant loads are listed in Table 2. This study collected rainfall records from 1999–2005, calculated average rainfall intensity, precipitation and rainfall duration, compared all rainfall events to the average rainfall in the case area, and selected one representative rainfall event for simulation. The selected representative rainfall event occurred from September 2 to September 4 in 1999. The total precipitation was 79.8 mm and the duration was 33 h, similar to the average rainfall properties in the study area. This study addressed four planning scenarios. The width and slope of riparian buffer strips determined by quantitative relationships were fixed, but the placement locations of buffer strips were different in each scenario. In scenario 1, the riparian buffer strips were set along both sides of all tributary streams in all the sub-watersheds. In scenario 2, the riparian buffer strips were limited to a length of 300 m along both sides of the tributary streams in all the sub-watersheds. In scenario 3, the riparian buffer strips were implemented along both sides of tributary streams in the selected 10 sub-watersheds, which contribute more pollutant loadings than other sub-watersheds. In scenario 4, the riparian buffer strips were set only in the sub-watersheds having more agriculture activities and more pollutant loadings than other

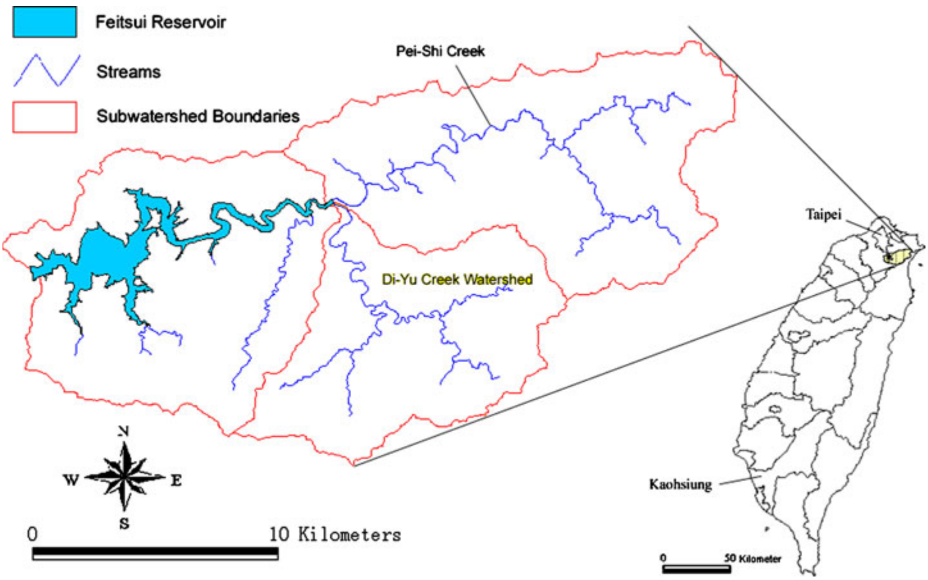


Fig. 1 Location of the Feitsui reservoir watershed in Taiwan

sub-watersheds. The identification of sub-watersheds with high pollution loadings was assessed by using the WinVAST model.

2.4 Cost-Benefit Analysis

Cost-benefit analysis is widely used to determine whether the project or scenario is worthwhile. For example, the cost effectiveness of planting grass buffer strips was

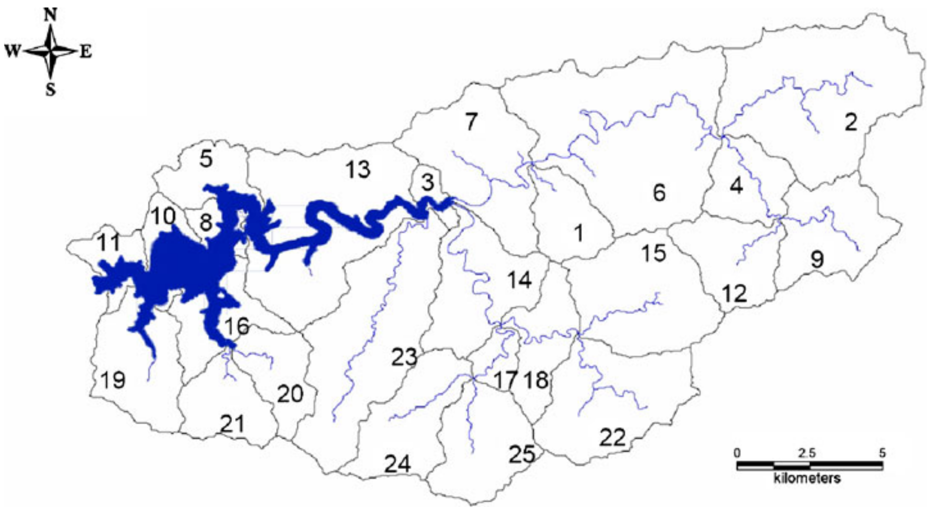


Fig. 2 Feitsui reservoir watershed with 25 sub-watersheds

Table 2 Data for each sub-watershed in the Feitsui reservoir watershed

Sub-watersheds no.	Area (km^2)	Perimeter (m)	Slope (%)	Stream length (m)	CN	Pollutant loads_TP (g/ha/day)
1	6.41	14,623	14.6	874	66	1.209
2	28.10	30,290	2.7	7,430	45	0.978
3	3.53	9,609	5.0	2,878	66	1.910
4	6.83	13,996	9.2	3,826	45	1.307
5	6.34	14,414	8.7	366	66	0.685
6	33.70	34,885	4.3	11,286	45	0.955
7	15.20	24,858	8.2	3,800	45	2.008
8	1.73	9,400	3.3	1,409	66	1.073
9	9.65	18,383	4.7	2,682	77	0.540
10	4.46	11,907	10.3	3,087	45	0.779
11	3.61	10,445	20.1	1,083	45	0.536
12	10.50	18,174	8.9	2,178	45	0.395
13	28.20	30,290	3.9	11,747	66	1.636
14	12.40	20,054	5.8	6,992	66	3.647
15	16.60	21,725	9.0	3,460	66	0.554
16	9.04	19,218	9.2	3,844	66	0.977
17	2.73	8,565	12.3	2,947	45	1.420
18	7.81	18,174	11.2	3,869	66	1.155
19	13.10	21,098	10.2	3,474	45	1.123
20	6.60	15,040	12.9	852	45	0.493
21	7.48	15,249	15.2	1,270	45	0.767
22	16.50	22,143	7.1	5,391	45	1.029
23	24.00	33,005	7.5	7,260	66	2.024
24	10.90	20,681	10.1	2,473	66	0.733
25	11.10	17,756	15.1	1,752	45	0.741

analyzed by Morschel et al. (2004) and, in their study, the reduction in sediments cleanup fees was considered as an annual benefit. The costs and benefits of their study were then calculated based on several slope and length combinations. Hsieh and Yang (2007) developed an optimization model for nonpoint source pollution control for the Feitsui Reservoir using localized cost functions for several structured BMPs, including buffer strips.

In general, the total cost of constructing buffer strips includes land cost, construction cost and operation and management (O&M) cost (USEPA 2004). The land cost is variable and could be substantial depends on the ownership of the land, e.g. private land or public land. However, as a rule of thumb, the land cost of the private land can be estimated based on the annual land present value announced by local government. The public land could be deemed to be free of charge for public construction. On the other hand, the construction cost of the buffer strips is normally a function of the planned area which is recommended to be: (WERF 2003; USEPA 2004)

$$C_{construction} = (0.3 \sim 0.7) \times Area\left(ft^2\right) \tag{3}$$

The coefficient in Eq. 3, 0.3∼0.7, largely depends on the living standards, material price and is also varied from site to site. With respect to the operation and maintenance (O&M) cost, filter strips can last for 10 to 20 years with proper conditions and regular maintenance. Proper maintenance is defined as those operations needed to ensure that uniform sheet flow and dense vegetation are maintained (Shoemaker et al. 2002). The maintenance cost is usually proportional to the construction cost, which is:

$$C_{O\&M} = k \times C_{construction} \tag{4}$$

where k stands for the O&M coefficient and is 1∼6% recommended by USEPA (2004). Since the transportation fee for routine maintenance is an important consideration, the coefficient k in Eq. 4 should depend on the distance between the location of buffer strips and downstream metropolitan area, that is, the farther the distance, the greater the O&M coefficient k.

Based on the above information, the total costs and benefits can be estimated and cost-benefit analysis can then be applied to evaluate the economic viability of the above four scenarios. Once the preliminary cost-benefit analysis is done, further decision-making analysis, such as incremental analysis and net present value method (NPVM), can be applied to determine which scenario is the most cost effective (Hansen et al. 1998).

3 Results and Discussion

3.1 Design of Riparian Buffer Strips

This study used literature field test data (Table 1) for buffer strip performance to develop regression equations, as shown in Eqs. 5, 6 and 7. These equations represent the quantitative relationship between pollution reduction rates and the width and slope of a buffer strip.

$$E_t\_SS = 2.8 \times W^{0.1} \times S^{-1} \tag{5}$$

$$E_t\_TP = 0.35 \times W^{0.2} \times S^{-0.5} \tag{6}$$

$$E_t\_TN = 0.4 \times W^{0.1} \times S^{-1.1} \tag{7}$$

where E_t_SS, E_t_TP and E_t_TN are trapping efficiency of suspended solid (SS), total phosphorous (TP) and total nitrogen (TN) respectively under the planning of riparian buffer strips with W(m) width and S(%) slope. The width of buffer strip is measured by the vertical distance outside the stream channel.

The coefficients in the regression equations (Eqs. 5–7) were calibrated by the field experiment data according to the measure of the R-squared value (R^2) and relative error between measured and predicted pollutant trapping efficiency. The R^2 between measured and predicted trapping efficiency of SS by Eq. 5 is about 0.72. The R^2 between measured and predicted trapping efficiency of TP by Eq. 6 is about 0.82. The R^2 between measured and predicted trapping efficiency of TN by Eq. 7 is about 0.94. In addition, the average relative error between measured and predicted pollutant trapping efficiency is less than 5% except for few special events.

Taiwan's soil and water conservation laws recommend that buffer strips be 30 to 50 m wide. Figure 3 shows the relationship between the removal rate of pollutants and the design of buffer strips with various widths and slopes. The results show that

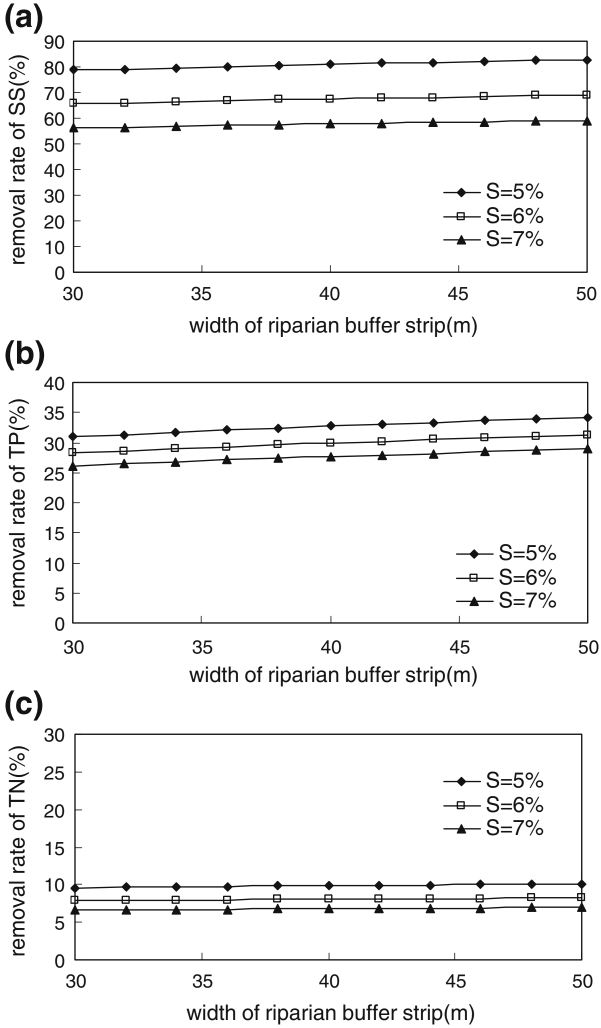


Fig. 3 Removal rates of pollutants under various designs of riparian buffer strips. **a** Removal rates of SS under various designs of riparian buffer strips. **b** Removal rates of TP under various designs of riparian buffer strips. **c** Removal rates of TN under various designs of riparian buffer strips

the reduction rate of SS is always more than 50% as the buffer strip has a width of 30–50 m. However, the removal rates of nutrients, e.g. phosphorus and nitrate, are not as efficient as sediment reduction rate. The average removal rate of TP and TN are 32.7% and 9.8% respectively when the buffer strip has a slope of 5% with 30–50 m width. The efficiency of pollutant reduction rate can improve when decreasing the slope and/or increasing the width of a buffer strip. However, the design of riparian buffer strip needs to accommodate terrain and space limitations. In addition, the construction cost of a buffer strip having a width of 50 m is much higher than it is with 30 m width. It is with no economic effectiveness to increase the width of a buffer strip to only slightly improve pollutant removal rates. Therefore, this study suggested that a typical design of the riparian buffer strip with 30 m and 5% slope can be adopted in the case area. The water authorities in the Feitsui reservoir watershed should consider other conservation practices where buffer strips are deemed inappropriate.

3.2 Prior Locations for Riparian Buffer Strip Placement

Based on the simulation results of WinVAST model, the potential pollutant loadings from the sub-watersheds in the Feitsui reservoir watershed can be evaluated. The pollutant loadings can result from natural loadings and agriculture activities. The natural loadings are related to soil properties. Figure 4 shows the sub-watersheds with dense agricultural activities and high nutrient (phosphorus) loadings, which could be priority locations for the placement of riparian buffer strips. In addition, the placements of buffer strips should be based on cost-benefit analysis. When the design of buffer strip such as width and slope and the buffer strip length along the stream channel are fixed, the construction cost per unit area is constant. However, the placement of riparian buffer strips can influence the efficiency of watershed protection. Therefore, the locations for buffer strip placements are significant in the planning of riparian buffer zone.

3.3 Cost-Benefit Analysis of Planning Scenarios

This study provided four planning scenarios. Each one has different buffer strip placements, but the design of grass buffer strips was fixed as 5% slope and 30 m width based on the analysis results of quantitative relationships between buffer strips design and pollutant reduction rate. Although the design of buffer strips was the same in these four scenarios, the total costs and the pollutant reduction rate would be different when the placement and/or the length of riparian buffer strip changes.

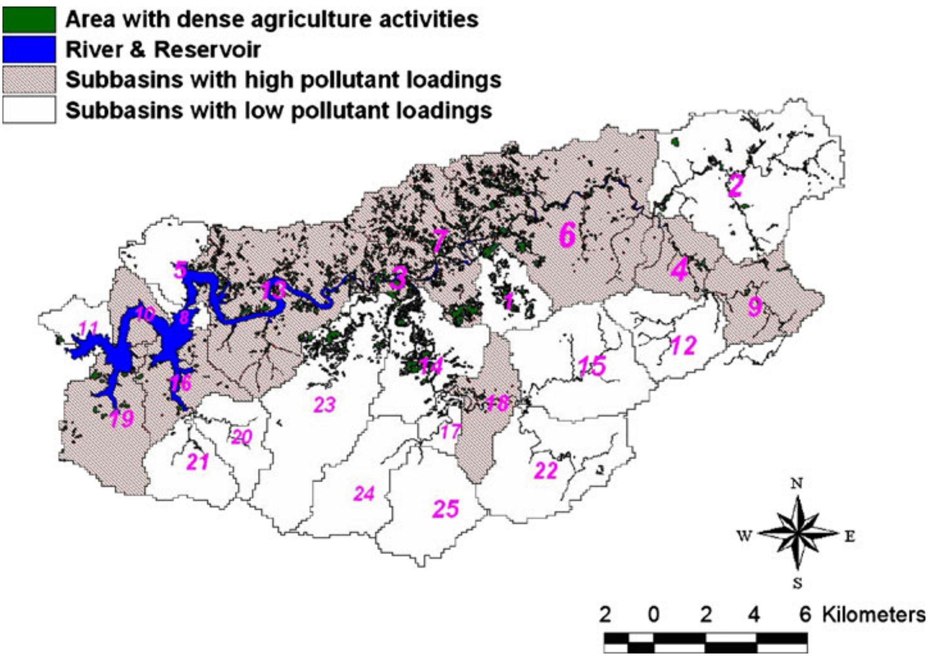


Fig. 4 Sub-watersheds with dense agriculture activities and high pollutant loadings (phosphorus)

Once the placement including the location and the length of buffer strips are known, the land costs, construction costs, and O&M costs with respect to each scenario can be estimated by the aforementioned cost functions. The total cost and the removal rate of SS in these scenarios with different planning of riparian buffer strips are summarized in Table 3.

Under the planning of riparian buffer strips in scenario 1, the SS reduction rate can reach 80%. However, the total cost in scenario 1 is the highest one among these four scenarios. The length of buffer strips in each sub-watershed is only 300 m in scenario 2, so the removal rate of SS is very low, only 6.4%. The SS removal rate under the planning of riparian buffer strips in scenario 3 and 4 are 48.8% and 30% respectively. Although they are not as good as the SS reduction rate in scenario 1, the costs in these two scenarios are less than half of the costs in scenario 1.

The pollutant removal rate, cost and benefit should be carefully assessed based on cost-benefit analysis for selecting a suitable planning of riparian buffer strips. Table 4 shows the benefit cost ratio, i.e. B/C, for these scenarios with different planning of riparian buffer strips. The annual amount of silt deposits can decrease and the annual cleaning silt fee can consequently reduce under the planning of riparian buffer strips. Therefore, the annual reduction fee for cleaning silt deposits can be regarded as the benefits of the planning of riparian buffer strips. Moreover, the present value (PV) of the annual benefit can be obtained by multiplying annual cleaning silt fee(benefit) by annularity factor. The B/C ratio is then calculated by dividing the PV of the annual benefit by the total cost. The procedure is detailed on the Table 4.

By definition, the scenario is worth investing if the B/C ratio exceeds 1. We found, from Table 4, that all four scenarios are worth investing, while scenario 3 presents the highest B/C ratio and is the best option in the preliminary B/C analysis.

Since the benefit cost ratios in these four scenarios are similar, this study applied "Incremental Analysis" coupled with "Net Present Value Method, NPVM" to

Table 3 Removal rate of SS and total cost in the scenarios with different planning of riparian buffer strips

Scenarios no.	Planning of riparian buffer strips	Total SS reduction rate (%)	Total cost (NTD$ × 1000)
1	Along both sides of tributary streams in all sub-watersheds	80	4,275,394
2	Along both sides of tributary streams in all sub-watersheds with "the length of 300 m"	6.4	332,283
3	Along both sides of tributary streams in the sub-watersheds with high pollutant loadings. (sub-watershed 3, 4, 6, 7, 9, 10, 13, 16, 18 and 19)	48.8	2,136,893
4	Along both sides of tributary streams in the sub-watersheds with high pollutant loadings and dense agriculture activities. (sub-watershed 3, 6, 7, 10, 13, 16 and 19)	30	1,527,271

Table 4 Cost-benefit analyses of these scenarios for the planning of riparian buffer strips

Scenarios no.	Total cost (NTD$ × 1000)	Annual reduction amount of silt deposits (m^3/year)	Annual cleaning silt fee (NTD$ × 1000/year)	Annularity factor (4%, 20 years)	Present value (PV) of annual benefit (NTD$ × 1000)	B/C
1	4,275,394	583,120	349,872	13.59	4,754,760	1.112
2	332,283	46,650	27,990	13.59	380,384	1.050
3	2,136,893	355,703	213,422	13.59	2,900,405	1.245
4	1,527,271	218,670	131,202	13.59	1,783,035	1.071

4% in annularity factor represents the recent loan rate with collateral announced by local Central Bank

B/*C* benefit cost ratio

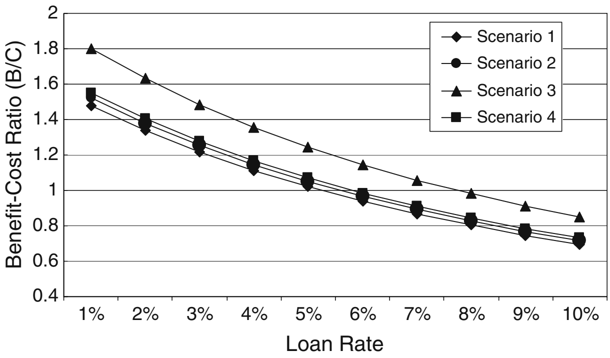
evaluate the economic effectiveness of these scenarios. Incremental analysis is used to assess the expected impact of the alternative on future income for decision-making purposes. When the planning of riparian buffer strips changes from scenario 2 to scenario 4, the increased cost and benefit are $1,194,988 \times 10^3$ and $1,402,651 \times 10^3$ NTD respectively, and the change of benefit cost ratio, i.e. $\Delta B/\Delta C$, is 1.174 higher than it in scenario 2, i.e. 1.050. Thus, the economic effectiveness in scenario 4 is larger than it in scenario 2. When the planning of riparian buffer strips shifts from scenario 4 to scenario 3, the added cost and benefit are $609,622 \times 10^3$ and $1,117,370 \times 10^3$ NTD respectively, and the variation of benefit cost ratio, i.e. $\Delta B/\Delta C$, is 1.832 larger than it in scenario 4, i.e. 1.071. Thus, the economic effectiveness in scenario 3 is higher than it in scenario 4. When the planning of riparian buffer strips changes from scenario 3 to scenario 1, the increased cost and benefit are $2,138,501 \times 10^3$ and $1,854,355 \times 10^3$ NTD respectively, and the change of benefit cost ratio, i.e. $\Delta B/\Delta C$, is 0.867 lower than it in scenario 3, i.e. 1.245. Thus, the economic effectiveness in scenario 1 is less than it in scenario 3. According to the results of incremental analysis, scenario 3 has the highest economic effectiveness among these four scenarios.

Net present value method is a widely used approach for evaluating an investment project. The annual benefit can be discounted back to its present value (PV). The initial value (I) is the total cost for the planning of riparian buffer strips. The rate and number of years in this study were given by 4% and 20 respectively. When the net present value (NPV) is minus, i.e. (PV-I) < 0, the project is with no value

Table 5 Net present value method for evaluating these scenarios

Scenarios no.	Total cost (I) (NTD$ × 1000)	Annual benefit (A) (NTD$ × 1000/year)	Annularity factor (F) (4%, 20 years)	Present value (PV) of annual benefit (NTD$ × 1000)	Net present value (NPV) (NTD$ × 1000)
1	4,275,394	349,872	13.59	4,754,760	479,366
2	332,283	27,990	13.59	380,384	48,101
3	2,136,893	213,422	13.59	2,900,405	763,512
4	1,527,271	131,202	13.59	1,783,035	255,764

Fig. 5 Benefit-cost ratios of each scenario with loan rates between 1% and 10%



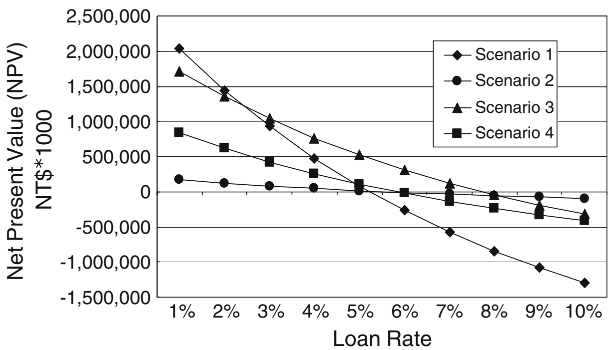
for investment. The evaluation of these scenarios with different planning of riparian buffer strips by net present value method was shown in Table 5. The net present value in scenario 3 is 763,512 $\times$ 10^3 NTD, which is the highest one among these scenarios. According to the results in cost-benefit analysis, incremental analysis and net present value method, the planning of riparian buffer strips in scenario 3 has the highest economic effectiveness for investment. Therefore, this study suggested that the sub-watersheds with high nutrient pollutant loadings should be the priority locations of buffer strip placements. Some other suitable watershed conservation practices should also be adopted in the case area to reach complete pollution reduction goals.

3.4 The Impact of Interest Rates on the Cost-Benefit Analysis

In the previous analysis, 4% interest rate with collateral was selected to perform cost-benefit and net present value analyses. To investigate the impacts of interest rates on the investing scenarios, various benefit-cost ratios and net present values were calculated with loan rates from 1% to 10%. The results of calculation of benefit-cost ratios and net present values were shown in Figs. 5 and 6, respectively.

As shown in Fig. 5 that, the benefit-cost ratio of scenario 3 is definitely higher than those of the other three scenarios at any arbitrarily loan rates between 1% and 10%. However, it should be noted that a project is not worth investing if its B/C ratio

Fig. 6 Net present values of each scenario with loan rates between 1% and 10%



less than 1. Therefore, a beneficial project such as scenario 3 of this study will not be accepted for investing in case the loan rate is greater than about 8%.

On the other hand, Fig. 6 shows the net present values (NPVs) of each scenario with loan rate between 1% and 10%. As stated previously that scenario 3 is the best pick among four scenarios at loan rate 4%. Nevertheless, as shown in Fig. 6, scenario 3 will be superseded by scenario 1 for its higher net present value at loan rate less than 2%. However, the NPVs of scenario 1 will drop sharply as loan rates increase compared with those of the other three scenarios. Comparatively, scenario 3 is still the better selection at loan rates between 2% and 8%.

4 Conclusions

Riparian buffer strips have been an important conservation practices for watershed management for a long time. The planning of riparian buffer strips should consider many aspects rather than only the control effectiveness of runoff and pollutant loadings. This study evaluated several planning scenarios for different placements with the same width, 30 m, and 5% slope of riparian buffer strips derived from quantitative relationship analysis. Based on several cost-benefit analyses, the scenario for installing buffer strips along both sides of tributary streams in the sub-watersheds with high nutrient (phosphorus) loadings was found to be most effective. The impacts of varying interest rates on the selection of better scenario were also discussed. From our study, the selection of the best scenario for planning buffer strips would depend on the interest rates and analysis methods such as cost-benefit analysis, incremental analysis, and net present value method, NPVM.

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