A STRATEGY FOR IMPLEMENTING BMPs FOR CONTROLLING NONPOINT SOURCE POLLUTION: THE CASE OF THE FEI-TSUI RESERVOIR WATERSHED IN TAIWAN[1]

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ABSTRACT: This paper describes a concerted effort by the Taiwan Water Resources Bureau, the City of Taipei, and the Bureau of Fei-tsui Reservoir Management to protect the water quality in the Fei-tsui Reservoir.The reservoir is the major source of water supply for over two million people in the metropolitan area of Taipei. Over the years the reservoir has suffered from siltation and more recently eutrophication. The sources of the pollution are traced to the hundreds of tea gardens, rice fields and other agricultural areas in the watershed and to urban sources such as construction sites. Large amounts of nutrients enter the reservoir by way of storm water runoff during storm or typhoon events. Since 1999, various agencies have worked to initiate an effort to reduce nonpoint pollution in the Fei-Tsui Reservoir watershed. Practices being considered include nonstructural measures such as nutrient management, and structural measures such as swales, detention basins, and wetlands, in addition to erosion and sediment control methods. A number of field tests have been completed on the performance of selected best management practices (BMPs). A strategy for implementing the BMPs at the watershed scale has been developed based on a total maximum daily load (TMDL) analysis that is reported in this paper.

(KEY TERMS: watershed management; agriculture runoff; best management practices.)

Lin, Jen-Yang and Cheng-Daw Hsieh, 2003. A Strategy for Implementing BMPs for Controlling Nonpoint Source Pollution: The Case of the Fei-tsui Reservoir Watershed in Taiwan. J. of the American Water Resources Association (JAWRA) 39(2):401-412.

INTRODUCTION

Taiwan is an island nation with a land area of 36,002 km^2 and a 2000 population of almost 23 million. The topography is characterized by mountainous regions, with many peaks over 3,000 m covering two-thirds of the island. The annual precipitation averages more than 2,500 mm (about 98 inches) but has a very uneven monthly distribution pattern. Because of the steep terrain and short river length, on average almost 80 percent of the runoff is lost to the sea. Therefore, reservoirs are necessarily the major sources of water supply. There are currently more than 60 major and minor reservoirs in Taiwan. Fei-tsui Reservoir is a very important one among them.

Fei-tsui Reservoir is located in northern Taiwan on Pei-Shi Creek, which is a tributary to the largest river in northern Taiwan, the Tamsui River (see Figure 1). Fei-tsui (emerald in Chinese) Reservoir has a watershed area of 303 km^2 and a total storage volume of 406 million m^3 at its normal maximum water level. Land uses in the watershed are mainly forest (84 percent), agricultural (8.2 percent), and other (villages and towns, campsites, highways, etc.) (7.7 percent). Fei-tsui supplies drinking water to more than 2 million people in the metropolitan area of the capital city Taipei. Historically, water quality of the reservoir has been good; however, in recent years, urban growth and agricultural activities such as tea and rice farming have affected the reservoir. The Carlson's Trophic State Index (TSI) has been hovering between 40 and 50, which indicates a near eutrophic state, for the past ten years, with one reading of 54 (eutrophic state) in late 1987. Excessive nutrients have been cited as the reason for increasing occurrences of algae blooms at a few locations within the reservoir. Other water quality problems or concerns include sediment loading from construction sites and landslides caused by earthquakes and typhoons and occasional fish kills from chemical spills, etc.

In 1999, the Bureau of Fei-tsui Reservoir Management (BFRM) commissioned the National Taipei University of Technology to implement a total

[1]Paper No. 01152 of the *Journal of the American Water Resources Association.* **Discussions are open until October 1, 2003.**

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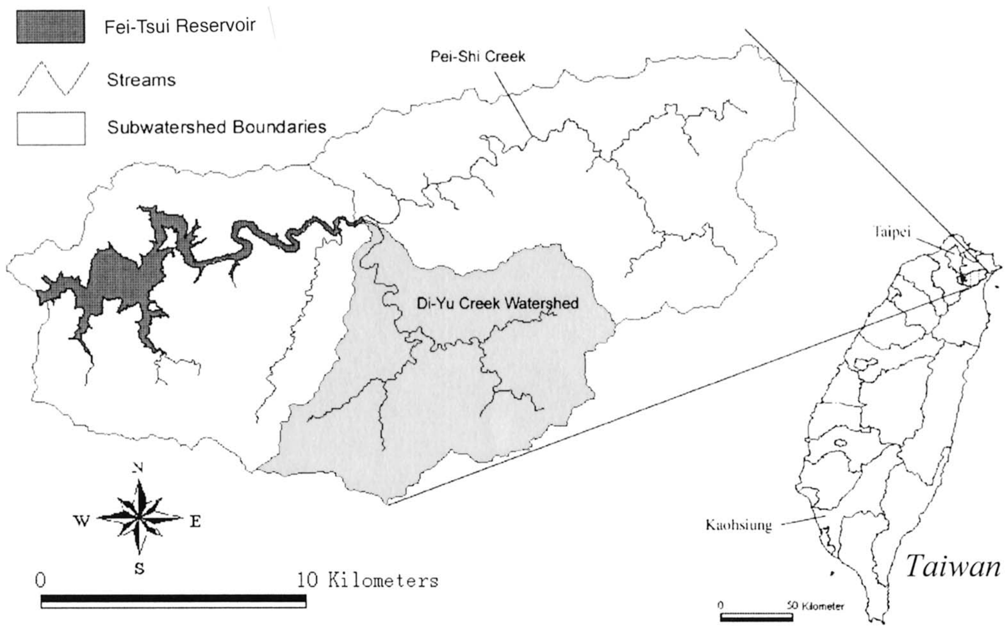

Figure 1. Fei-tsui Reservoir Watershed and Study Area.

maximum daily load (TMDL) study for the Fei-tsui Reservoir watershed. The objectives of the study were to: (1) quantify the various sources of pollution to the reservoir, specifically phosphorus in this case; (2) to determine the scenarios for allocating point and nonpoint source (NPS) loads; and (3) to recommend a strategy for controlling nonpoint pollution, especially those from agricultural sources. The results of the study (Lin *et al.,* 2000) are reported in the present paper.

SOURCES OF FEI-TSUI WATERSHED POLLUTION

Although the Fei-tsui watershed is mostly forested (84 percent), there are many tea gardens and some rice fields, many of which are on the waterfront of the reservoir. Figure 2 shows an example of such a tea garden. There are also many tea gardens located on the banks of tributaries that feed into the reservoir or on upland areas with slopes that can exceed 50 percent. Runoff from these gardens can enter into the reservoir in a very short period of time. Because of the subtropical climate, tea farmers in Taiwan make multiple harvests in a year, and fertilizers and pesticides are applied on average five to six times in a year. The amount of fertilizers and pesticides carried by storm water runoff into the Fei-tsui Reservoir could be quite significant.

Highway and other types of construction are another major source of pollution, especially in terms of sediment. Erosion control measures at most construction sites are not very well implemented because of the lack of clearly defined storm water management regulations as well as weak enforcement efforts of existing erosion control laws. Previous studies (Hwang *et al.,* 2001; Yu *et al.,* 1996) have indicated that the major sources of pollution entering the Fei-tsui Reservoir are: (1) nonpoint sources (NPS), including agricultural, construction sites, highways, etc.; and (2) point sources, including wastewater from small towns and camp sites.

The NPSs listed above were identified through synthesizing results from a number of previous small scale field monitoring efforts conducted by the BFRM and by several researchers. These documents are summarized in Lin *et al.* (2000)

INTEGRATED WATERSHED POLLUTION CONTROL

The Taiwan Environmental Protection Administration (TEPA) has been promoting an integrated point and nonpoint source pollution control strategy that is similar to the TMDL approach in the United States. A subbasin of the Fei-tsui Reservoir watershed, the Di-yu watershed (see Figure 1), was chosen as the first one in Taiwan to demonstrate the strategy.

Figure 2. Tea Gardens at Reservoir Edge.

The TMDL Process (USEPA, 1991)

The TMDL of a water body is defined as the total allowable loading of a pollutant from all sources, point and nonpoint, entering the water body so that the water quality standards are not violated. For a water body, the TMDL can be expressed as:

$$TMDL = LC = WLA + LA + MOS$$

In the above equation, TMDL = total maximum daily load; LC = loading capacity of the water body; WLA = portion of the TMDL allocated to point sources; LA = portion of the TMDL allocated to NPSs; and MOS = margin of safety or uncertainty factor.

The necessary components of a TMDL process should include the following:

- Selection of the pollutant or pollutants to consider.
- Estimation of the waterbody assimilative capacity.
- Estimation of the pollution from all sources, including background.
- Simulation of the fate and transfer of pollutants in the waterbody and the determination of total allowable load under critical or design conditions.
- Allocation of the allowable load among all sources in a manner that water quality standards are achieved
- Consideration of seasonal variations and uncertainties
- Inclusion of public and stakeholder participation.

In a report to the U.S. Environmental Protection Agency (USEPA), the National Advisory Council for Environmental Policy and Technology (NACEPT) stressed that the implementation of TMDLs is the key to the success of protecting the nation's water bodies (NACEPT, 1998). The NACEPT report also pointed out that in a TMDL analysis, communication with the public is crucial and that the involvement of all "stakeholders" in the TMDL development is required for the program to succeed.

Case Study: The Di-yu Watershed

Watershed Description. Di-yu Creek is a tributary to Pai-Shi Creek, which is the main tributary to the Fei-tsui Reservoir (Figure 1). The Di-yu watershed has a drainage area of 78 km^2, about one-fourth of the total area that drains into the Fei-tsui Reservoir. The land use pattern is 84 percent forest, 10 percent tea gardens, 3 percent rice fields, less than 2 percent pasture land, 1 percent structures (such as farm houses), and the rest is water surfaces, roads, etc. Figure 3 is a GIS based land use map of the Di-yu watershed. The locations of the rain gage, flow gaging, and the seven water quality stations are also shown in Figure 3.

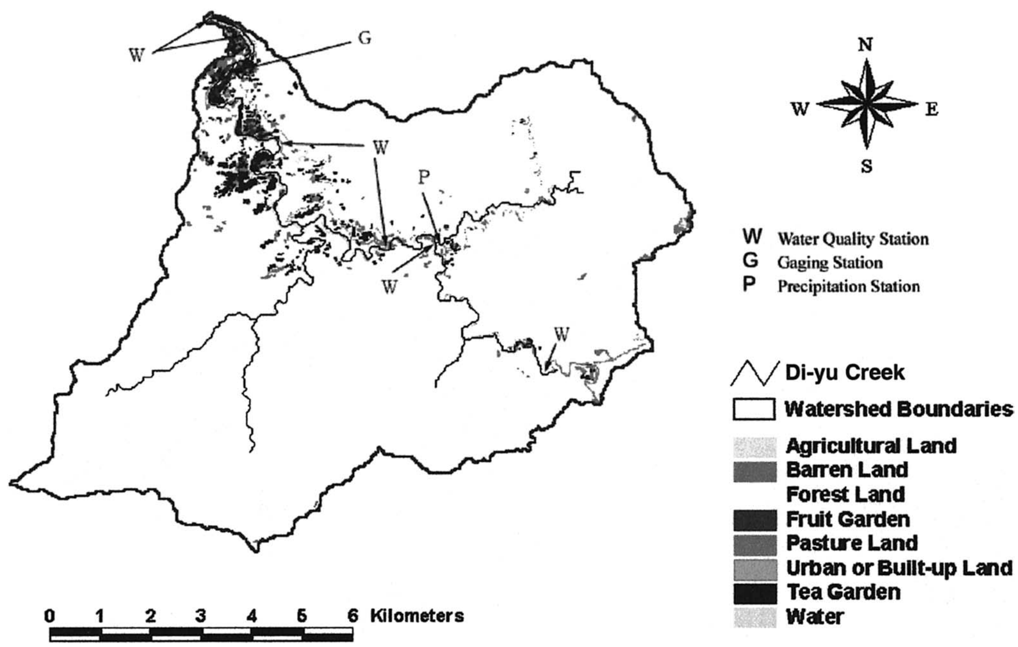

Figure 3. Land use in the Di-yu Watershed and Watershed Monitoring Stations.

Hydrology and Water Quality Monitoring. Daily hydrologic data are collected by a rain gage and a stream flow gaging station in the Di-yu watershed. Annual average rainfall for this area is about 3,300 mm and runoff about 1,000 mm. There are seven water quality monitoring stations on Di-yu Creek as shown in Figure 3. The BFRM has collected monthly grab sample water quality data manually since 1995, usually on the same day of the month. Water quality parameters measured include specific conductance, dissolved oxygen, nitrogen and phosphorus, pH, temperature, and turbidity. The data are presented each year in the BFRM's annual report (BFRM, 1995-1999).

Current Water Quality Conditions. Water quality monitoring for Di-yu Creek began in January 1995. A review of the water quality data showed that significant natural or manmade events such as typhoons and major road construction contributed to spikes in the water quality parameters. Figures 4 and 5 illustrate the variation in reactive phosphorus and turbidity, respectively, during the period 1995 to 1999. It can be seen from these figures that certain sharp rises of water quality parameters occurred at times following typhoons or construction activities. However, there are also other times at which elevated levels of phosphorus and turbidity were observed, indicating potential contribution from point sources such as the town of Pinling. Similar trends were found with the other water quality parameters.

In Figures 4 and 5, it can also been seen that the peak values of an observed water quality parameter do not necessarily coincide exactly with the occurrences of typhoons. One possible reason for this is the timing of sampling. The BFRM takes samples once every month manually and sampling is usually not done during typhoons due to safety concerns. Therefore the peak readings may have passed the sampling locations by the time samples are taken. The other reason might be the attenuation effect due to the transport of pollutants in the watershed. One thing, however, is certain – the BFRM has for years observed huge rises in turbidity levels (tenfold to a hundred-fold) in the reservoir following typhoon events.

Modeling Analysis for the TMDL Study

The first step of a TMDL analysis is to select the key pollutant that contributes to the impairment of the waterbody in question. In this case the pollutant is phosphorus, since it is the limiting nutrient for the eutrophication problem of the Fei-tsui Reservoir, as reported by Lin *et al.* (2000). The next step is to select an appropriate analytical tool for pollutant load generation and comparison of allocation scenarios. The model used in the present study is BASINS, or "Better Assessment Science Integrating Point and Nonpoint Sources" (USEPA, 1996). The BASINS model is

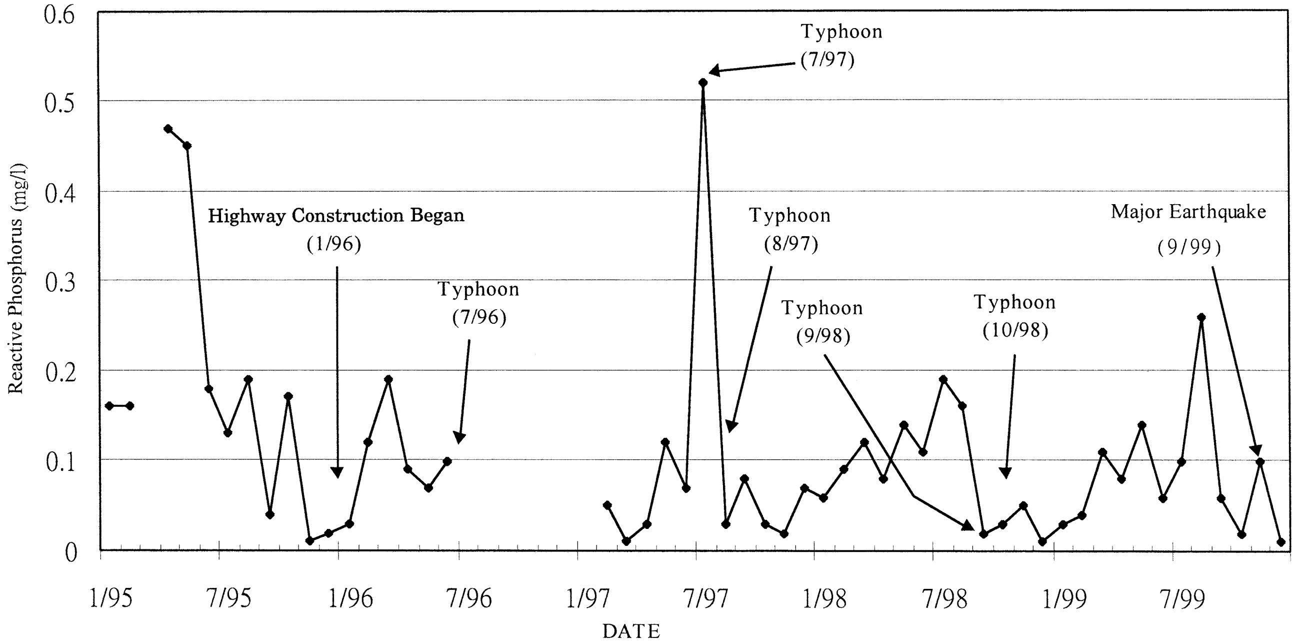

Figure 4. Reactive Phosphorus Variations at Di-yu Creek Outlet.

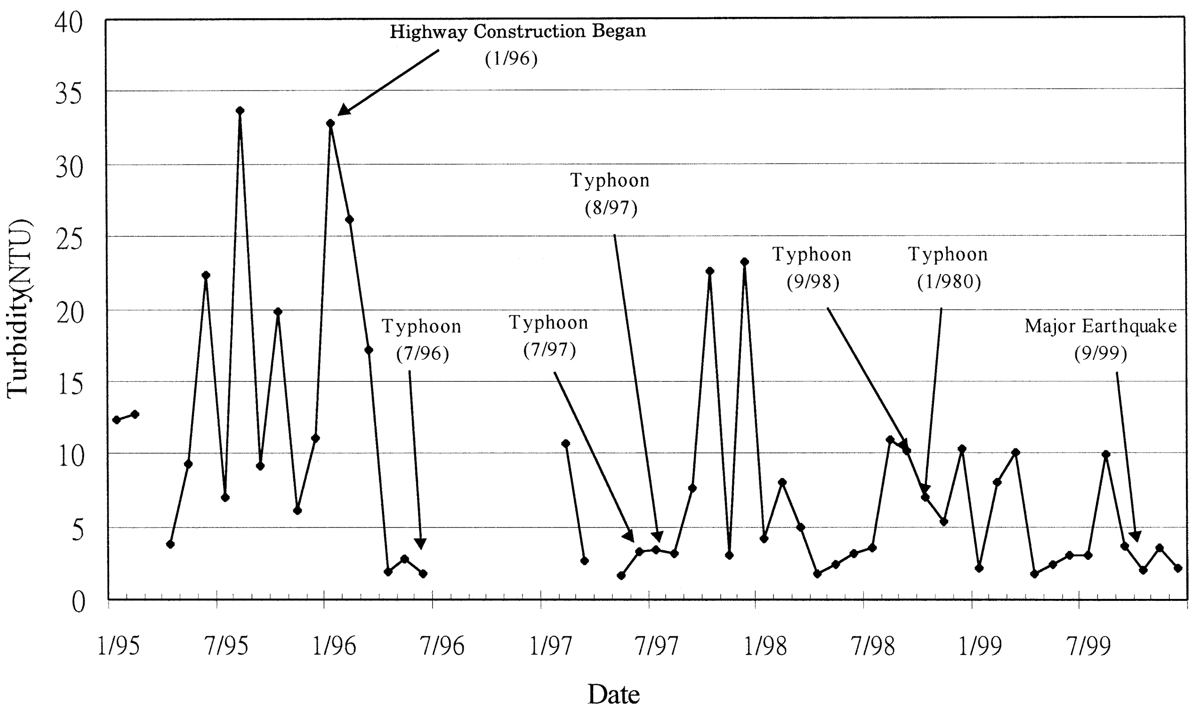

Figure 5. Turbidity Variations at Di-yu Creek Outlet.

an integrated GIS, data analysis, and modeling system designed to support watershed based analysis and TMDL development.

In the Di-yu Creek TMDL analysis, the nonpoint source model (NPSM) within BASINS was used for watershed nonpoint phosphorus loading computations. NPSM estimates NPS loads at the watershed scale based on various land uses. Continuous simulations are used by the model to create a time series of water quality variations.

Hydrologic Calibration. Stream flow data for Di-yu Creek are available at the gaging station near the confluence with Pei-Shi Creek (Figure 1). The March 1999 flow data were selected at random for calibrating BASINS hydrologic parameters. It was felt that the 30 plus points would provide a statistically significant data set for the calibration. Ranges of parameter values as recommended in BASINS Technical Notes (USEPA, 1999) were checked before final selection was made of the parameters for Di-yu Creek. Figure 6 shows the flow calibration. The hydrologic parameters were later successfully verified by using the flow data for April 1999. The RMS (root-mean-square) error for the fit was found to be quite small (about 0.2). The correlation, measured by the R-square value, was calculated as 0.85, indicating a fairly good fit. The calibrated hydrologic model was then used to generate continuous flow data for the remaining months of 1999. The results are shown in Figure 7.

Water Quality Calibration. The water quality model calibration and verification were done by using the PQUAL and GQUAL subroutines in BASINS. Data on total phosphorus collected near the mouth of Di-yu Creek for January through June 1999 were used in the calibration. The results show a reasonable fit between the observed and simulated values, with an RMS error of 13.3. The verification was performed by using the data for July through December 1999 and the results were poor, with an RMS of 26.5. The water quality model calibration and verification was hindered by the fact that too few observations were available. Although the model is capable of generating daily values, actual field data were only available on a monthly basis. A more rigorous statistical analysis of the goodness of fit could not be done at this time due to the scarcity of field observations. The lack of storm water runoff quality data in Taiwan in general, and in the Fei-tsui watershed in particular, prevented a more detailed phosphorus generation and transport analysis using the more comprehensive Hydrologic Simulation Program-Fortran (HSPF) model. Figure 8 depicts results of the verification run for total phosphorus using water quality data collected during July through December of 1999.

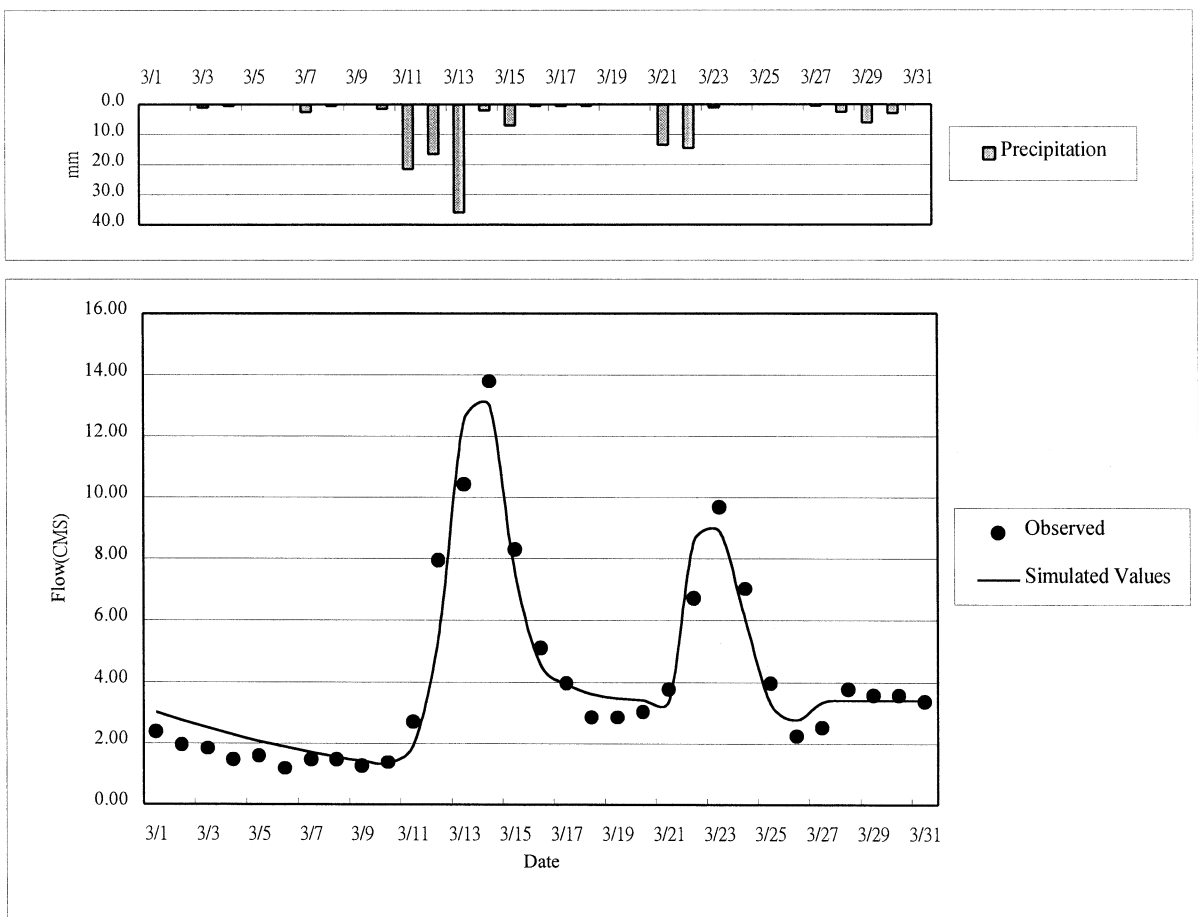

Figure 6. Di-yu Creek Flow Model Calibration (March 1999 data).

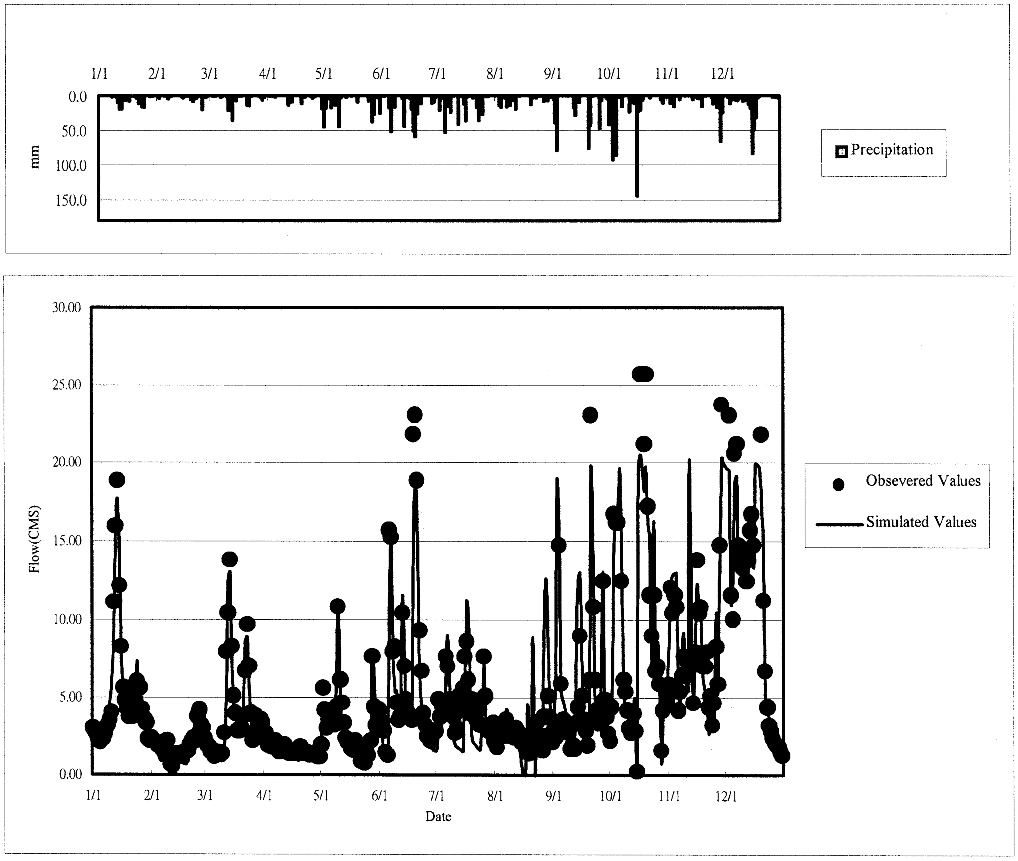

Figure 7. Di-yu Creek Flow Model Verification (1999 data).

TMDL Analysis for Di-yu Creek Watershed. Using the calibrated BASINS model, the total phosphorus loading generated from the Di-yu Creek watershed for an average year was estimated as 4,034 kg, of which only 12 percent are from point sources such as camp sites, etc. Compared to a preliminary estimate made by the Taiwan Environmental Protection Administration (TEPA, 1999), the 4,034 kg/yr loading represents roughly 25 percent of the total phosphorus loading entering the Fei-tsui Reservoir from its entire watershed.

To devise a pollutant load reduction strategy, it was decided as an initial approach to employ a "uniform reduction" scheme (i.e., all subwatersheds of the Fei-tsui Reservoir would be given the same percentage reduction requirement). This is similar to the 40 percent nonpoint phosphorus load reduction requirement set forth for the Chesapeake Bay Watershed in the United States. The maximum phosphorus load permitted to enter the Fei-tsui Reservoir, obtained from a study by Kuo and Yang (2000), is described below.

Using a completely mixed water body modeling analysis (CE-QUAL-W2), Kuo and Yang (1999) estimated the tributary phosphorus load reduction required to lower the phosphorus concentration in the Fei-tsui Reservoir (Figure 9). The study concluded that to keep the TSI below 50, the total phosphorus concentration should be kept below 10 parts per billion (ppb), which corresponds to the load reduction requirement of 50 percent.

Load Allocation Scenarios. Based on the 50 percent load reduction requirement, a TMDL of 2,017 kg P/yr was assigned for the Di-yu Creek watershed. Assuming an MOS) term of 100 kg/yr (about 5 percent of the TMDL), the permitted total phosphorus load was determined as 1,917 kg/yr from the Di-yu Creek watershed. The following allocation recommendations were used to create seven different scenarios: (1) point source reduction is either 50 or 100 percent; and (2) nonpoint source reduction from three subwatersheds of Di-yu Creek watershed ranged from 0 to 70 percent.

The BASINS model was used to compute total phosphorus loads under each of the seven allocation scenarios. The results are presented in Table 1, where it can be seen that except for Scenarios A and B, all other allocation scenarios meet the 1,917 kg/yr maximum load requirement.

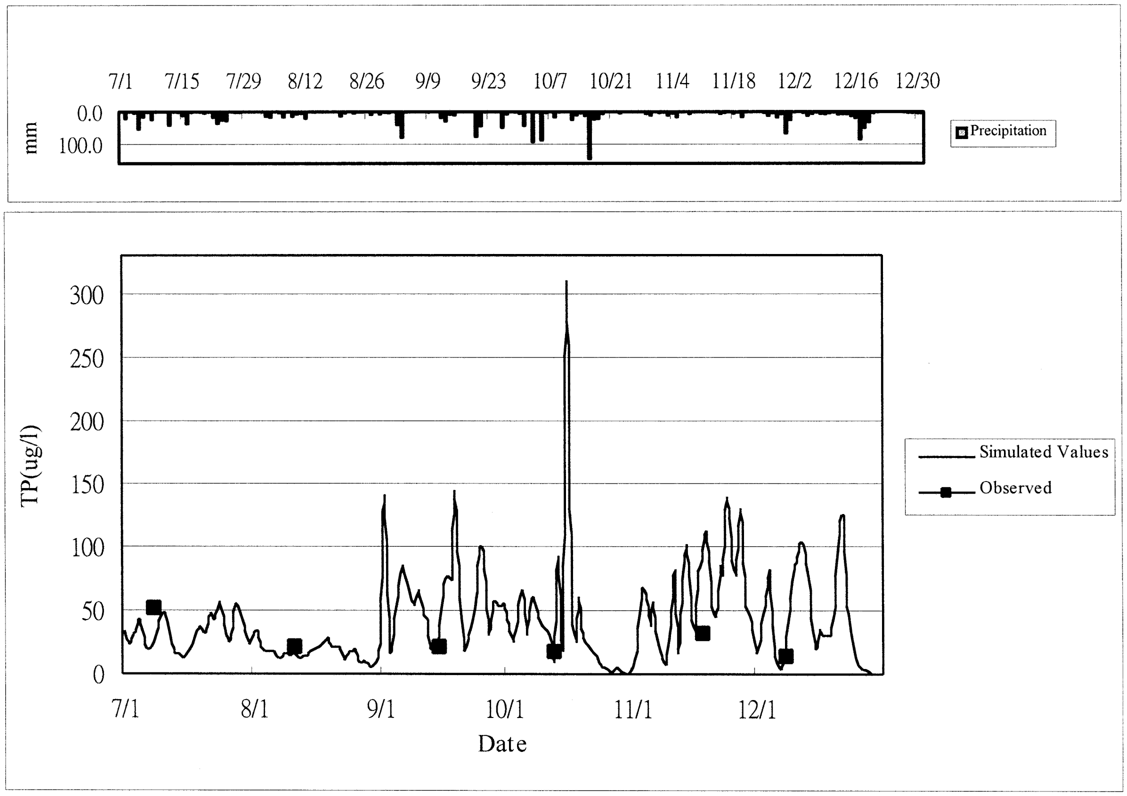

Figure 8. Di-yu Creek Total Phosphorus Verification (1999 data).

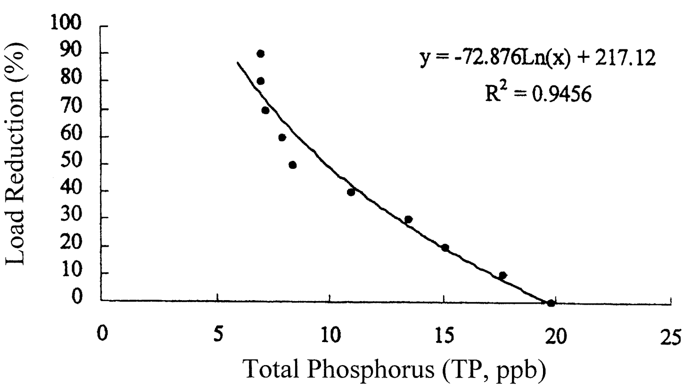

Figure 9. Relationship Between Tributary Load Reduction and Fei-tsui Reservoir TP Level (Source: Kuo *et al.,* 1999).

Best Management Practice (BMP) Tested in Taiwan

A report by Yu *et al.* (1993) to the National Science Council promoted the implementation of best management practices (BMPs) for controlling NPS pollution. Beginning in 1994, the TEPA initiated a five-year comprehensive study on NPS pollution and its control. The main objectives of the project were to collect additional wet weather data, test selected BMPs in the field, and prepare guidebooks for BMP implementation. Other than TEPA, the Water Resources Bureau, under the Ministry of Economic Affairs, has also sponsored a number of studies on BMP testing.

Under the TEPA project, the following BMPs have been tested:

Silt Fence (Wen *et al.,* 1997). Reported sediment removal efficiency ranging from 50 to 90 percent through field tests in Southern Taiwan.

Vegetative Buffer Strips (VBS) (Fan, 1998). Reported results from testing vegetative buffer strips at an agriculture experiment farm near Taipei. VBS's with length ranging from 4 m to 16 m and slope from 5 to 20 percent were tested. Preliminary results showed maximum removal rates of 81 percent for total suspended solids (TSS), 72 percent for chemical oxygen demand (COD), 66 percent for total phosphorus (TP), 58 percent for ammonia nitrogen, and 34 percent for nitrate nitrogen.

Swales (Kuo *et al.,* 1997). Reported testing results of a swale 30 m long with a 1 percent slope. A check dam was installed at the midpoint of the swale for

TABLE1. Scenario Assessment for Point and Nonpoint Source Reduction of TP.

Scenario	Rate of PS Reduction (percent)	Rate of NPS Reduction (percent)*			Loading			
		I	II	III	Simulation Loading (kg/yr)	Assimilative Capacity (kg/yr)	MOS** (ky/yr)	TMDL*** (kg/yr)
A	50	0	50	50	2,230	1,917	100	2,017
B	50	50	50	50	2,099	1,917	100	2,017
C	50	60	60	60	1,652	1,917	100	2,017
D	50	50	50	60	1,866	1,917	100	2,017
E	50	70	50	55	1,884	1,917	100	2,017
F	50	70	55	50	1,917	1,917	100	2,017
G	100	70	55	50	1,902	1,917	100	2,017

*Rate of NPS reduction (percent) in Subwatershed I, II, and III, respectively.
**Margin of Safety.
***Total Maximum Daily Load.

part of the experiments. Water mixed with prescribed pollutant concentrations was fed to the swale from two storage tanks. Results show a 70 to 86 percent removal for TSS, 46 to 63 percent for COD, 14 to 24 percent for total nitrogen (TN), and 34 to 77 percent for TP.

Porous Pavement (Hwang, 1997). Has been conducting a field test of porous pavement at a parking lot in Kaoshiung County, Taiwan. The design followed those reported in the Japanese and U.S. literature. Structural testing has shown that the pavement could sustain loads from large buses. Water quality tests are currently being conducted.

Detention Pond (Kuo *et al.,* 1997). Performed field tests of a small, wet detention pond (about 15 m by 5 m by 1.5 m in size) in the Fei-tsui Reservoir watershed near Taipei. Results obtained for four storm events showed average removal rates of 60 percent for TSS, 45 percent for COD, 28 percent for TP, and negligible removal for TN.

Integrated BMP System (Wen and Yu, 1997). Described results of monitoring an innovative BMP system for a recreational farm in southern Taiwan. The system consists of a number of BMPs placed in a series. The BMPs include a grassed strip, a swale, wetland vegetation, two check dams, a shallow lotus pond, and two wet detention basins (see Figure 10). Results show that the system is capable of reducing flood peaks by 50 to 75 percent. As for pollutant removal, the system achieved the following removal rates: TSS, -14 to 99 percent; COD, -90 to 88 percent; biochemical oxygen demand, 72 to 85 percent; Total Kjeldahl Nitrogen, 23 to 72 percent, and TP, 20 to 80 percent. Although the system was originally not designed for water quality purposes, the results show that BMPs placed in a series could provide good pollutant removal efficiency.

Guidebooks for Construction and Recreational Activities (Wen and Yu, 1999)**.** In 1999, Wen and Yu developed the first draft of the BMP Guidebooks for construction and recreational activities. During the spring of 2000, TEPA was considering the promulgation of the first phase of nonpoint pollution regulations which would target selected industrial and construction activities. Wen and Yu offered several workshops for representatives from the targeted activities to explain the requirements under the proposed regulations.

BMP Implementation Strategy for Fei-tsui Reservoir Watershed

Currently, there is no regulation under the Taiwanese Clean Water Act specifically addressing the NPS pollution problem. There are, however, various regulations dealing with NPS pollution. For example, under the Environmental Impact Statement Regulation, NPS pollution can be covered if it can be determined to cause significant impact to the environment from major construction or development projects. There are also erosion and sediment control regulations under the Soil and Water Conservation Act, and many regulations addressing development within "sensitive" areas (e.g., water source protection zones). Many experts believe, however, that the NPS control program will be more effective if the Clean Water Act

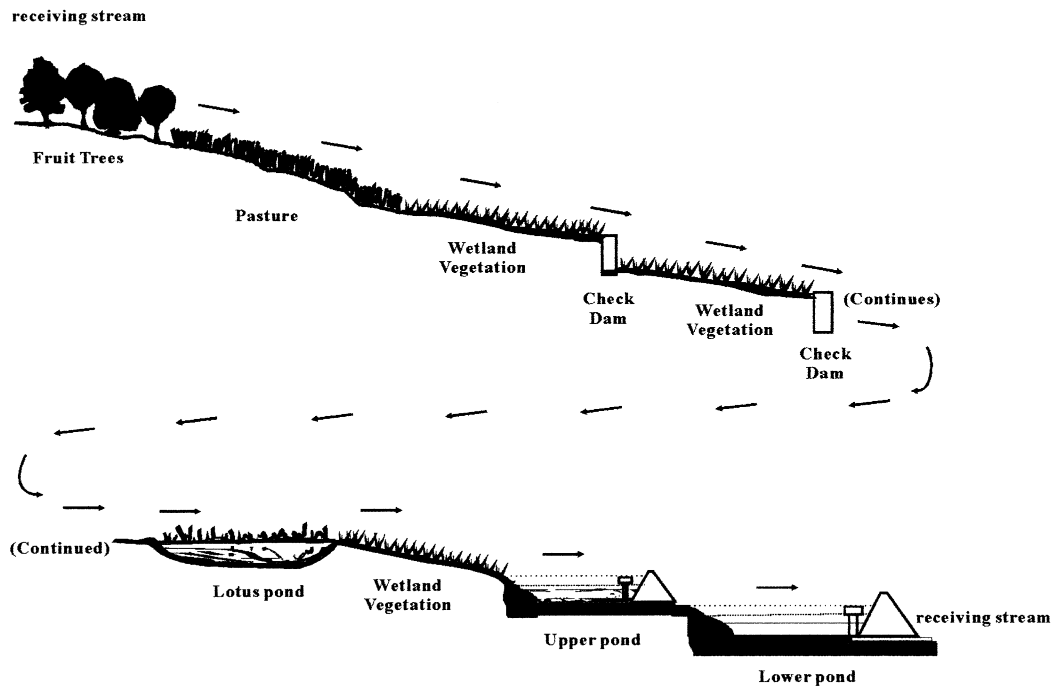

Figure 10. BMP in Series on a Taiwan Farm.

can be amended to include NPS pollution. This is a complicated process because controlling NPS pollution will affect all sectors of society and will need blessing from the general public. The legislature is unlikely to amend the Clean Water Act without strong public support. The notion that protecting the environment will "hurt" the economy still remains a myth that needs to be clarified.

To ensure an effective control of NPS in the Fei-tsui Reservoir watershed, a three-prong approach is proposed and described as follows.

1. Continue and expand collection of basic data, especially in terms of NPS pollution characteristics and loading. Data on BMP efficiencies are also needed. Data based on monitoring of BMPs used in other countries may not be applicable in Taiwan, due to the humid, sub-tropical climate and very steep terrain.

2. Initiate immediately BMP demonstration projects, which should target the most important sources such as tea gardens and highway construction sites.

3. Establish the necessary regulatory framework and institutional/organizational structures needed for the full scale watershed implementation of BMPs. An aggressive public education campaign is also needed so that the general public, especially the farmers in the watershed, understands the importance of implementing the various control measures.

To exemplify potential BMP demonstration projects, the following two cases have been recommended to the BFRM (Lin *et al.,* 2000).

1. For tea gardens that are on the "water front," as illustrated in Figure 2, it is proposed to install an "interception trench," which will carry runoff from the tea garden to a swale or detention basin for treatment. Since a minimum amount of land is involved, there should be a better chance of the BFRM reaching agreement with the farmers for the installation. The swale or detention pond can be built at nearby, flatter locations on public land.

2. For tea gardens situated on the hills, vegetative filter strips could be constructed at downstream, milder slope locations, as shown in Figure 11. Other BMPs, such as detention ponds or constructed wetlands, could also be considered when the situation is favorable for them.

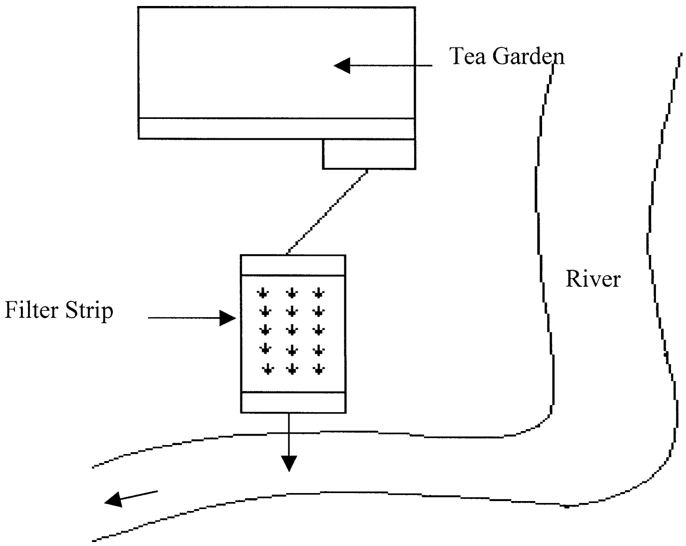

Figure 11. Filter Strip Installation at Tea Gardens (Source: Fan, 1998).

CONCLUSIONS

The Fei-tsui Reservoir is one of the most important drinking water sources in Taiwan. The present study investigated the pollution sources of the reservoir and determined that the water quality in the reservoir is impacted significantly by NPS pollution such as runoff from tea gardens and highway construction sites. A TMDL analysis using the BASINS model was performed for a subwatershed to provide an example of the allocation strategy between point and NPS pollution loads. A number of phosphorus control allocation strategies were developed that would achieve water quality goals. Using the Carlson's TSI as a reference, the paper generated phosphorus load reduction plans so that, when implemented, the TSI in the Fei-tsui Reservoir will be kept below the threshold value of 50. These plans call for the reduction of phosphorus loads of 50 to 100 percent for point sources, and 50 to 70 percent for NPSs. The final selection of a plan for implementation should be made based on cost, engineering, and political/social considerations.

It is imperative that the authorities initiate a comprehensive control strategy that includes BMP implementation, public education, etc., for protecting the reservoir and ensuring sustainable use of the valuable water resource for the millions of people living in the Taipei Metropolitan Area on Taiwan.

ACKNOWLEDGMENTS

The writers would like to express their sincere appreciation to the Bureau of Fei-tsui Reservoir Management for its financial support for this research. The assistance of Mr. Edward Y. C. Lin, former graduate assistant at National Taipei University of Technology, is also acknowledged. Special thanks are given to Mr. Tsu-Chuan Lee and Miss Yiwen Chiu, who provided much needed help in the preparation of the manuscript. Last, but not the least, the writers appreciate greatly the assistance of Professor Shaw L. Yu, Department of Civil Engineering, University of Virginia, during the preparation of the manuscript.

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