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MANAGING TAIWAN'S RESERVOIR WATERSHEDS BY THE ZONING APPROACH[1]

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ABSTRACT: For many years, a commonly used strategy for source water protection in Taiwan has been setting up arbitrary, fixed-width buffer zones near sensitive waters, such as water-supply reservoirs, and prohibiting any development in their watersheds. However, such regulations are now often viewed as infringing by the government on landowners' property rights, a situation that has led to citizen protests. This paper describes a proposed strategy that is water-quality based and uses a quantitative zoning approach. A reservoir's watershed is divided into several zones beginning from the normal water line to the divide. Different levels of best management practices (BMPs) are required for controlling runoff pollution in different zones. The layout of the management zones is based on a number of factors such as reservoir classification, water quality conditions, and physical characteristics of the watershed. The goal of promoting such an approach is to try to balance the needs of watershed development and water quality protection. A case study using the Tapu Reservoir Watershed in Northern Taiwan as an example for illustrating the proposed zoning approach is presented.
(KEY TERMS: watershed management; water quality; land use planning; nonpoint source pollution; zoning; best management practices; buffer strips; reservoirs.)

INTRODUCTION

There are currently more than 60 reservoirs in Taiwan, an island nation of 21 million people and a land area of approximately 36,000 km^2 (14,000 mi^2). Figure 1 shows the locations of 30 major reservoirs in Taiwan (Wu, 1993). Reservoirs are the main source of water, supplying close to 70 percent of the total national drinking water consumption. Because of rapid agricultural and industrial growth and urban development, many reservoir watersheds have been for years under heavy build-up pressure, which has led to serious water quality problems for the reservoirs. To protect the water quality in these reservoirs, arbitrary "buffer zone" setbacks and strict development limitations have been imposed by the government on the residents living in the reservoir watersheds. For example, there are regulations which prohibit any development within 1,000m from a water intake, and in the "source water protection zones," often meaning the entire reservoir watershed. These "basin-wide" restrictions have led to citizen complaints and even organized protests in recent years. Since the amount of reservoir watershed areas account for almost 30 percent of the total island land, enforcing such regulations has always been a formidable task. Besides, many watershed residents do need to use their lands for more "profitable" ventures to sustain their livelihood, making it more difficult to enforce laws and regulations.

Realizing that there is an urgent need to review and revise the land use policy for reservoir watersheds, the government is contemplating the implementation of a "management oriented" policy instead of a "strict control" policy for land use planning in water-supply reservoir watersheds. A "balance" needs to be reached between land development and hence economic growth on the one hand, and the protection of natural resources on the other, even though it is a very difficult task for a developing country such as Taiwan.

Many developed countries have instituted the "zoning" approach for watershed management. For example, in Germany and in the United States where "zoning" management methods have long been applied in source water watersheds (Lundqvist *et al.*,

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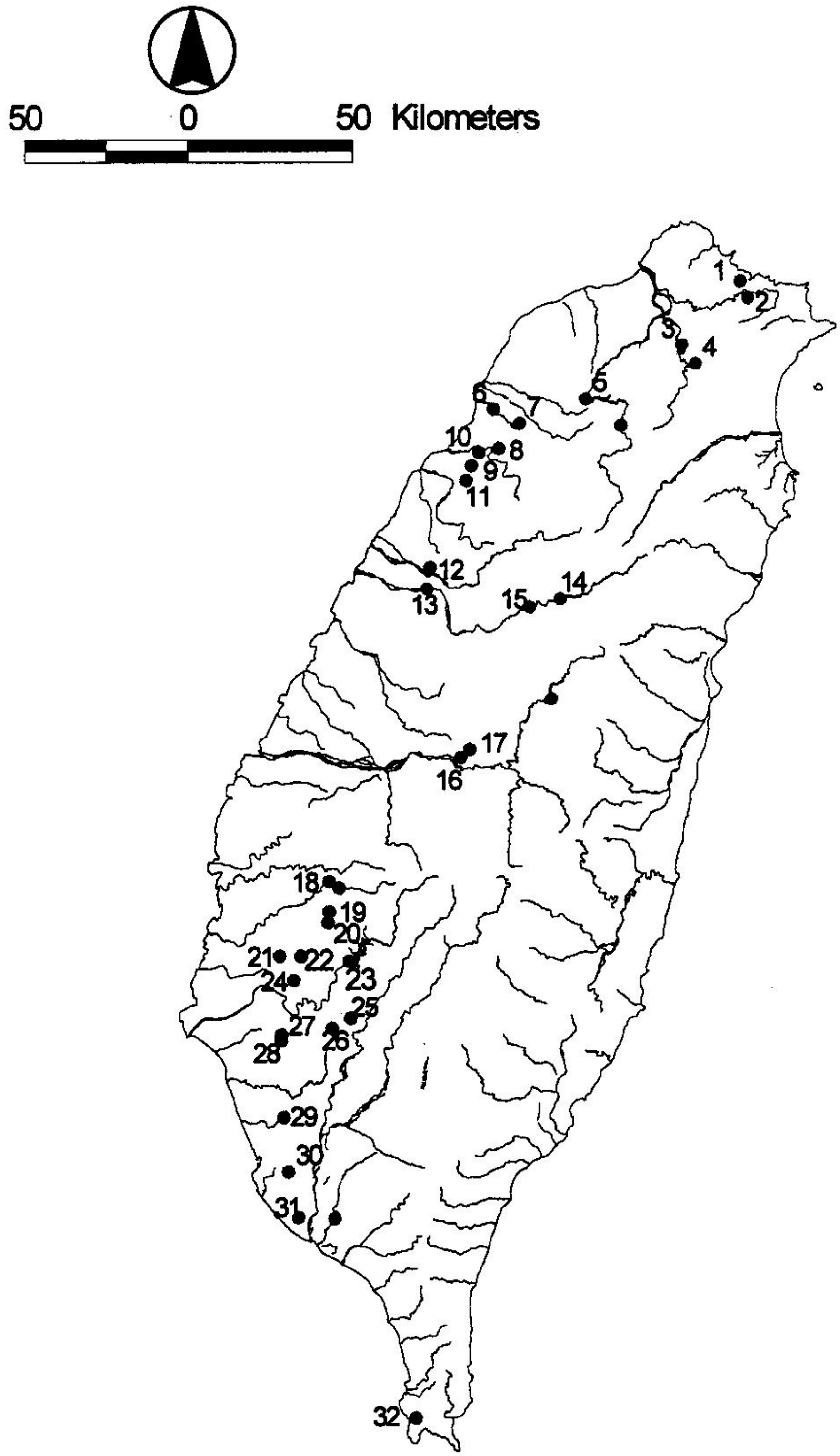

NORTH REGION

NO	NAME OF DAM
1	Hsin Shan
2	His Shin
3	Csin Tan
4	Fei Tsui
5	Shin Men
6	Ching Sao Hu
7	Pao Shan
8	Ta Pu

CENTRAL REGION

NO	NAME OF DAM
9	Yung Ho San
10	Chien Tan
11	Ming Ted
12	Li Yu Tan
13	Shin Kang
14	The Chi
15	Ku Kuan
16	Tou shin
17	Wu Shen

SOUTH REGION

NO	NAME OF DAM
18	Lan Tan
19	Lu Liao Chi
20	Pai Ho
21	Te Yuen Pei
22	Chien Shan Pei
23	Tseng Wen
24	Wu San Tou
25	Nan Hua
26	Ching Mien
27	Yen Shui Pei
28	Hu Tou Pei
29	A Kung Tien
30	Cheng Chin Lake
31	Fung Shan
32	Lung Luan Tan

Figure 1. Location of Existing Reservoirs.

1985) An example of the zoning approach can be illustrated as shown in Figure 2. The zoning approach involves the division of a source water watershed into several zones. A prescribed degree of development is allowed in each zone based on its characteristics in land, water, etc. Different levels of "control" measures may be required for the protection of water quality in different zones. If properly designed and executed, the zoning approach should bring about a balance between development and economic growth. However, the implementation of the zoning approach in Taiwan, where land resources are very limited and the pressure for development is extremely high, the zoning approach as used in other countries needs to be first carefully evaluated and analyzed. The delineation of the various zones must be based on sound scientific and also social/economical considerations. The rationale behind establishing certain limitations on development and other men's activities in the watershed should be clearly explained and subject to stakeholders' scrutiny. This paper uses "reservoir classification" as the basis for zoning delineation and uses soil/water conservation and environmental protection concepts in determining the proper buffer widths that separate the water bodies and the land areas that drain into them. Finally, this paper will describe a case study conducted on the Tapu Reservoir Watershed in Northern Taiwan as an example of showing the feasibility of applying the zoning approach in managing water-supply watersheds in Taiwan.

In the following paragraphs two examples of comprehensive zoning regulations that may be suitable for Taiwan are described in more detail.

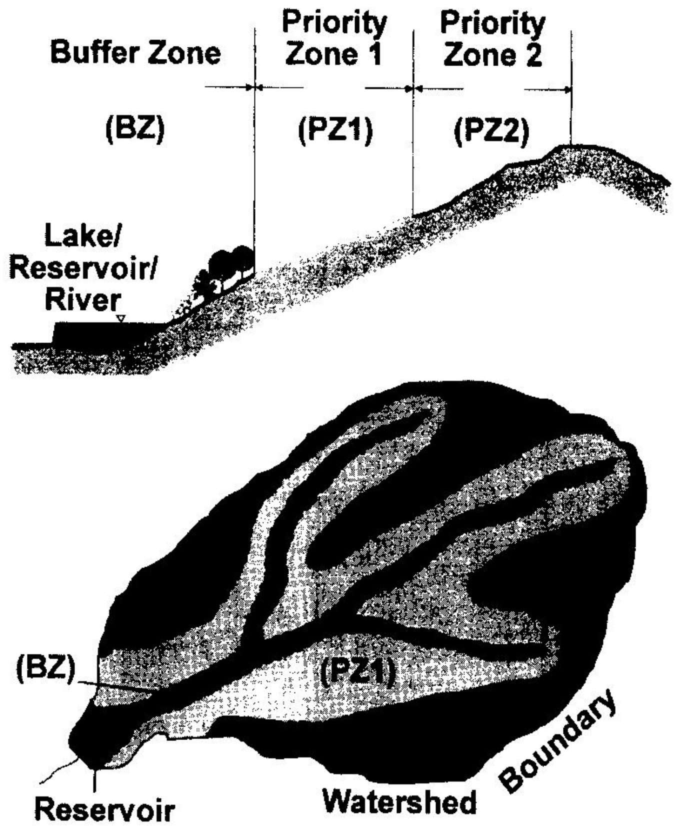

Figure 2. The Concept of the Zoning Approach.

The North Carolina Watershed Management Plan

North Carolina classified its water supply watershed zones into different classes based on its surface water classification system. The surface water classification system divided watershed zones into five classes, WS-I through WS-V, with different degrees of development and waste material control systems, and stormwater BMP requirements imposed for each class (see Table 1).

Watershed Management Strategy for New Jersey

Nieswand *et al.* (1989) described the New Jersey watershed management strategy, which divides a watershed into five zones from the water's edge to a certain distance beyond the watershed boundary (see Figure 3). For each zone a specific control or regulatory requirement is imposed.

Water Zone. The most important part of the watershed area, the water zone consists of the reservoir and its tributaries. Activities permitted in the water zone are dictated by the amount of pollution generated in the watershed and the pollutant load assimilative capacity of the water bodies involved.

No-Development Buffer Zone. Also referred to as buffer strips, transition areas, and riparian corridors or zones, it starts from the edge of the water zone and includes "land transitional between aquatic and upland habitats that is characterized by hydro soil and distinctive vegetation requiring free or unbound water" (Bureau of Land Management, 1986). It serves as a buffer that mitigates the pollutants as they are transported into the water body from upstream lands. No development is permitted in this zone.

Restricted Zone. Extending from the buffer zone to a designated upland point, the restricted zone is one within which development is allowed but limited. Limitations may be made in terms of the type of

TABLE 1. The North Carolina Watershed Classification and List of Restrictions (Source: Lin *et al.*, 1997).

Land Classification	Waste Water Effl.	Type of Land Development	Non-Residential Land Development	Sludge Utilization	Sanitary Land-Fill Sites	Hazardous Materials	Farm BMPs	Forest BMPs	Road BMPs	Buildings in Low-Density Develop. Zone	Ratio of Const'n. in High Density Develop. Zone (percent)	Avg. Size (mile)
WS-I watershed	Banned	Development Banned	Banned	Banned	Banned	Banned	Essential	Essential	Essential			2
WS-II Watershed	Regular	Development Banned	Permitted	Condition I Permission	Seepage Banned	Survey Classification	Not Necessary	Essential	Essential	1	30	30
Key Zone	Regular	Development Banned	Conditional Permission	Permitted	New Construction Banned	Survey Classification	Essential	Essential	Essential			
WS-III Watershed	Household and Non-Industrial	Low to Moderate	Permitted	Condition I Permission	Seepage Banned	Survey Classification	Not Necessary	Essential	Essential	1/2	30	60
Key Zone	Regular	Low to Moderate	Conditional Permission	Permitted	New Construction	Survey Classification	Essential	Essential	Essential			
WS-IV Key Zone	Household and Industrial	Low to Moderate	Permitted	Condition I Permission	New Construction Banned	Survey Classification	Essential	Essential	Essential	1/2	70	75
Protection Zone	Household and Industrial	Low to Moderate	Permitted	Permitted	Permitted	Survey Classification	Not Necessary	Essential	Essential			
WS-V Basin	Household and Industrial	All restrictions are based on the regular wastewater effluent standards.										

Notes:
1. All lands within a 1/2 mile radius of water supply watersheds are classified as key zones.
2. All lands within a five-mile radius of water supply watersheds or within a 10-mile radius of reservoir upstream areas are classified as protection zones.
3. In low-density development zones, land along a 30-feet radius of a water body should be classified as buffers, in high-density zones it should be 100 feet.
4. The survey classification of hazardous materials should include the use, manufacturing and storage of hazardous materials.
5. Farm enterprises should comply with the 1985 Food Security Act, farm enterprises in watershed zones should maintain a minimum of 10-feet buffer.
6. Logging activities in water supply watersheds should comply with the water quality protection provisions.
7. Road constructions should follow the Best Management Practices (BMPs) of water supply watershed zones.

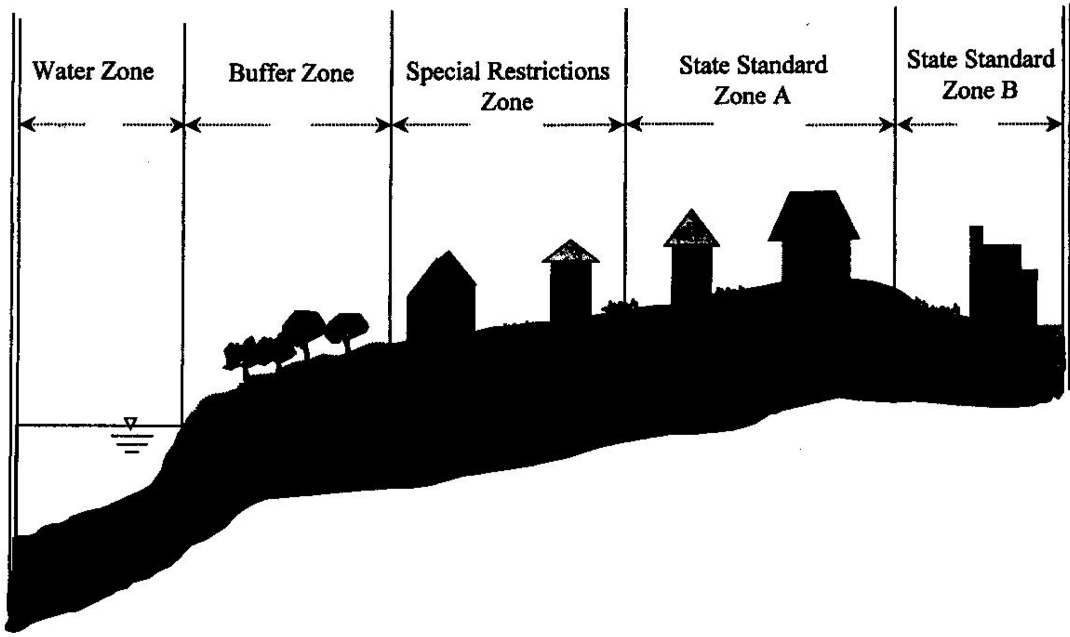

Figure 3. Layout of the New Jersey Watershed Management Zones.

development permitted and the specific control measures (BMPs) required.

State Standard Zone A. This zone includes the rest of the watershed area outside the restricted zone. In this zone development in general is permitted, provided that regular erosion and pollution control practices are implemented.

State Standard Zone B. This zone is the area outside the watershed boundary, but adjacent to the watershed. Since airborne contamination such as acid rain could originate from this area and then impact water quality within the watershed, it is important to institute appropriate controls in this zone if a regulatory framework is established.

PROPOSED ZONING APPROACH FOR TAIWAN

In a developing country such as Taiwan, balancing economic growth and environmental protection is always a challenge. The task is even more complicated now that the government encourages citizen's participation in decision-making processes for water resources projects. Current land-use laws prohibiting logging, mining, hog and duck raising, and golf course construction in the watersheds often prove to be ineffective. Another difficulty is how to deal with residents, sometimes aborigines, in the watershed whose livelihood depend on utilizing the land. Monetary compensations are offered in some cases, but more often than not the asking price is too high for the government to afford. The present paper proposes a "zoned" approach, which is similar to the New Jersey Model (Nieswand *et al.,* 1989) and is modified to suit Taiwan's situation.

The proposed zoning model divides the watershed into three management zones, including a buffer strip that separates the water body from the rest of the watershed area. The model attempts to "quantify" the dimensions of all three zones, and also of the buffer strip, based on water quality and other factors such as local social-economical considerations. Such a land-use control policy should be received favorably by all the "stakeholders" in reservoir watersheds because it allows "controlled" developments in the watershed and provides needed protection for the reservoir and its tributaries. Since the width of the buffer and all three zones are determined by sound reasoning, there should be less controversy compared to a policy with arbitrarily selected widths. Water quality is protected by prohibiting development in the buffer and restricted zones. In the zones where development is permitted, certain BMPs are required. A scheme similar to one proposed by Whipple (1992) can be used for setting BMP requirements.

Quantification of the Buffer Zone Width

Buffer width determination tends to be most controversial since areas in the proximity of water attracts development and provides accessibility for recreational and many other activities. It is therefore imperative to determine buffer width based on as much scientific and logical considerations as possible. The rationale behind the selection of a certain buffer width should be defensible at public forums, and eventually verifiable with actual field data showing the buffer's effectiveness.

For water-supply reservoir protection, Nieswand *et al.* (1989) reported that a U.S. national survey showed buffer widths varied between 20 to 90 m, and that another study on 44 reservoirs in the Eastern and Midwest U.S. resulted in buffer widths ranging from around 20 m to 650 m. They also reported that watershed managers in North Carolina, trying to use a functional approach, determined the buffer width by calculating the width required to provide a 1-hour travel time for a spill to reach the reservoir in question.

A comprehensive review of buffer width determination was given in Johnson and Ryba (1992). As shown in Table 2, Johnson and Ryba (1992) summarized recommended buffer widths for maintaining various buffer functions in the literature.

The wide range of the recommended buffer widths listed in Table 2 attests to the fact that many factors contribute to the buffer width determination. For a specific buffer function, such as water quality protection, the most important factors are the type of pollutant of concern and the slope and surface roughness of the terrain. As the slope increases, the buffer width should be increased to maintain the total travel time desired. In the present study, the pollutant to be considered is total suspended solids (TSS), and the method proposed by Wong and McCuen (1982) is used for computing the buffer widths.

Based on extensive laboratory tests, Wong and McCuen (1982) developed a nomograph (Figure 4) for designing buffer strips. The chart shows that given the slope(s) of the terrain, the Manning roughness coefficient (n) and the TSS removal rate desired, one can obtain the corresponding required buffer width from the chart. For example, if slope = 2 percent, n = 0.20, and TSS removal rate = 95 percent, then the required buffer width was found to be 200 feet.

For pollutants other than solids, a similar approach can be used. For example, for organic matters, a first-order decay model can be used:

$$BOD_x = BOD_0 \cdot e^{-k_r t} \quad (1)$$

where BOD_x = Biochemical Oxygen Demand remaining at x-distance, or t-day travel time downstream; BOD_0 = Initial Biochemical Oxygen Demand; k_r = decay coefficient, and t = travel time (i.e., t = x/velocity). It should be noted that the BOD decay rate for overland flow may be quite different from that found in open channels. Therefore, before actual implementation of the zoning approach, water quality data must be collected and analyzed for determining applicable decay rates for specific pollutants of concern.

By considering how much the assimilative capacity of the reservoir is with respect to biochemical oxygen demand, the "allowable" amount of BOD_x can be determined and therefore the required travel time t. Knowing t, by using the Manning's Equation (Equation 2, in metric) one can compute the required buffer width using Equation (3):

TABLE 2. Recommended Buffer Widths to Maintain Various Functions (Source: Johnson and Ryba, 1992).

Function	Recommended Buffer Width
1. Miscellaneous Functions	
a. System Stability	Minimum 20-38 m
b. Noise Reduction	6-15 m
c. Maintenance of Benthic Communities	30 m
2. Reduce Fecal Coliforms	20-90 m
3. Nutrient Reduction	4-45 m
4. Sediment Removal	5-120 m
5. Water Temperatures – Control	10-45 m
6. Wildlife Habitat	10-200 m

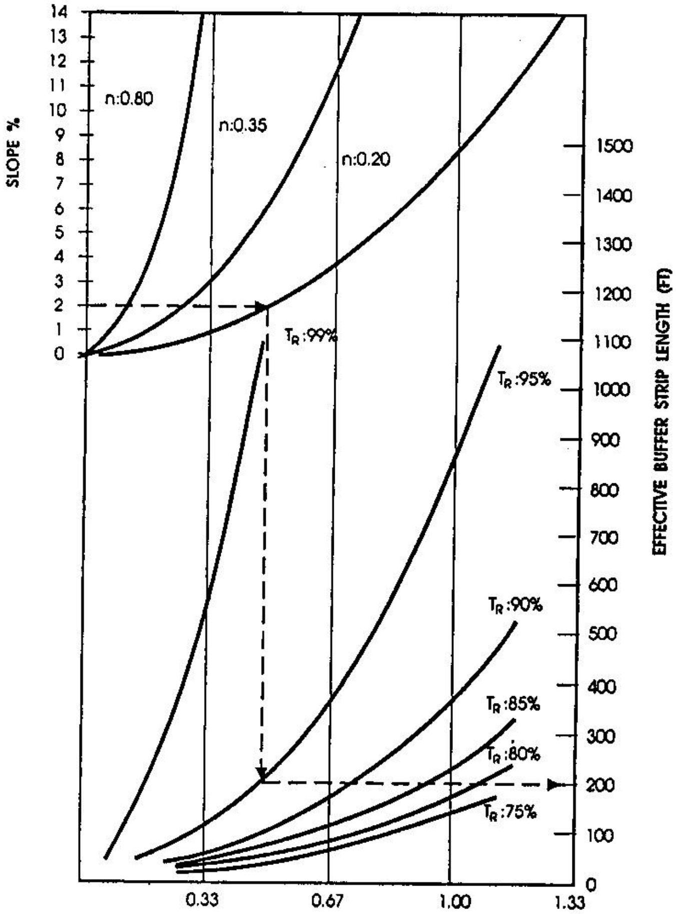

Figure 4. Nomograph for Buffer Width Determination.

$$v = \frac{1}{n} R^{2/3} S^{1/2} \qquad (2)$$

where v = flow velocity; n = roughness coefficient; R = hydraulic radius, and S = slope.

$$B_W = v \cdot t \qquad (3)$$

in which B_W = buffer width required.

Figure 5 illustrates the relationship of the ratio BOD_x/BOD_0 and travel time t for various values of the decay rate.

Determining the Dimension of the Proposed Three- Zone Layout

Based on reviewing the zoning approaches used in the U.S. and other countries, and considering the situation in Taiwan, this paper proposes the following quantitative equations for the determination of the three management zones outside the buffer zone:

$$B_{W0} = F(X_1, X_2, X_3, X_4, \ldots.) \qquad (4)$$

$$B_{W1} = X_f \times B_{W0} \qquad (5)$$

$$B_{W2} = S_f \times B_{W0} \qquad (6)$$

$$B_{W3} = B_T - B_{W2} - B_{W1} - B_{W0} \qquad (7)$$

where B_{W0} = buffer width, a function of factors X's, which represent pollutant of concern, slope, etc.; B_{W1}

TABLE 3. Removal Rate of Vegetated Buffer Strips on TSS and TP.

Reference	Buffer Width (m)	Removal Rate (percent) TSS	TP
Doyle *et al.*, 1977	4.0	–	62
Thompson *et al.*, 1978	12.0	–	55
	36.0	–	70
Young *et al.*, 1980	21.3	73	67
	27.0	79	83
Edwards *et al.*, 1983	30.5	50	49
Dillaha *et al.*, 1986	4.6	81	58
	9.1	91	69
Yu, S. L. *et al.*, 1987)	24~31	70	40
Lee *et al.*, 1989	4.6	70	61
	9.1	84	79
Magette *et al.*, 1989	4.6	66	27
	9.2	83	44

= restricted development zone width; B_{W2} = conditional development zone width; B_{W3} = permissible development zone width; W_f = weighting factor, depending on soil erodibility; S_f = reservoir water use index; and B_T = distance between the water edge and watershed boundary. The proposed three-zone layout is depicted in Figure 6.

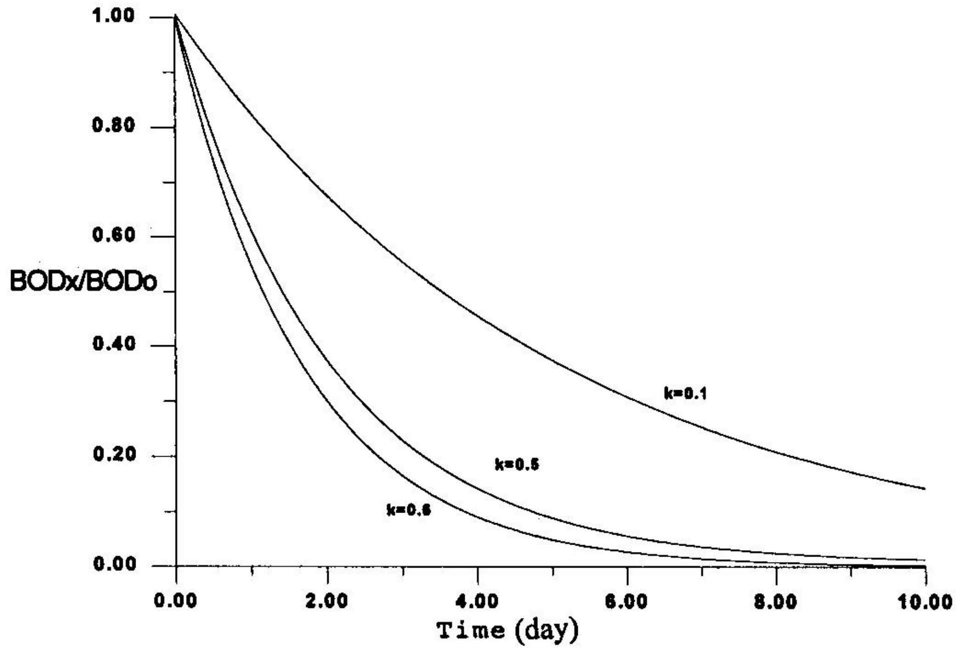

Figure 5. BOD_x/BOD_0 vs. Travel Time for Various Decay Rates.

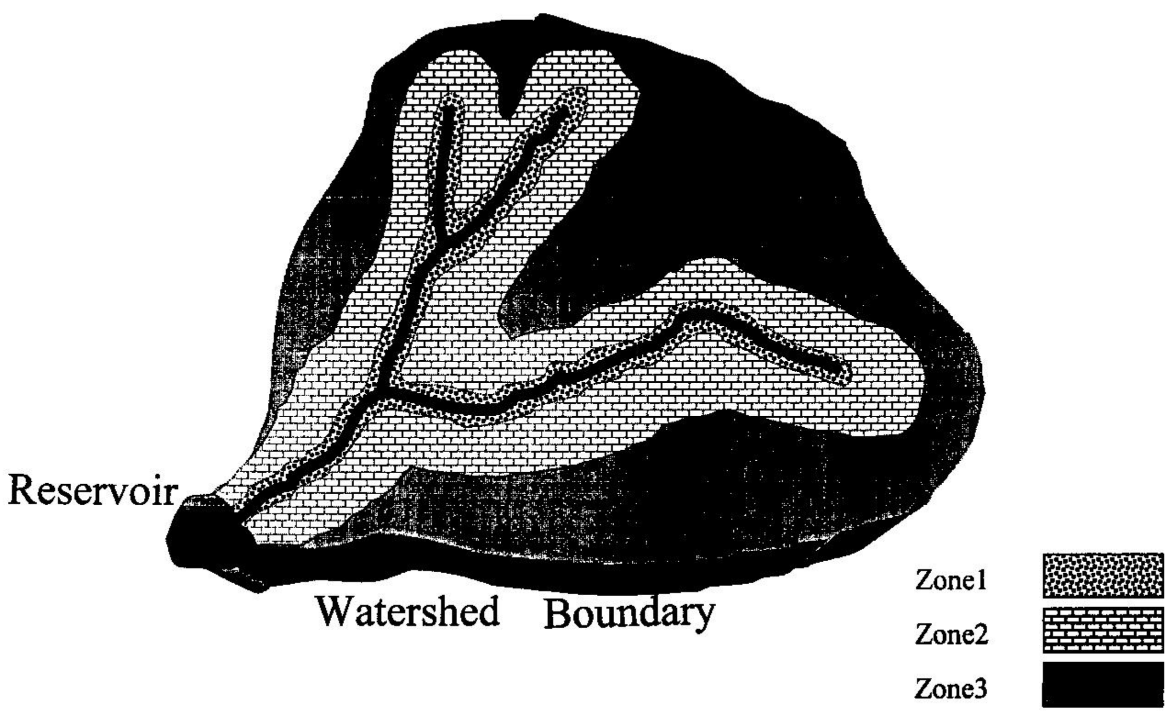

Figure 6. Proposed Three-Zone Watershed Management Scheme.

The rationale behind the computational scheme proposed in Equations (4) through (7) is as follows. After the buffer zone width is determined from Equation (4), the widths of the restricted and conditional development zones are determined by applying a "multiplier" to the buffer zone width, or B_{W0}. The multiplier W_f, called weighting factor for B_{W1}, is assumed to be dependent upon the prevailing soil property in the watershed. Soil property is considered very important because siltation has been a major problem for reservoirs in Taiwan due to the steep terrain and lack of conservation practices. Values proposed for W_f are listed in Table 4. The numerical values of between 2.0 to 4.0 for W_f were selected based on the practical consideration of allowing a "safety factor," which would set a buffer width two to four times of the calculated value, with higher numbers for more erosive type of soil. It is expected that the actual selection of the safety factor will be determined by the governing authorities, with input provided by concerned citizens and other stakeholders.

TABLE 4. Proposed W_f Values for Various Soil Properties.

Soil Properties	W_f (proposed value)
Less Erosive Soil (soil erodibility, k < 0.026)	2.0
Moderately Erosive Soil (soil erodibility, 0.026< k<0.052)	2.0~3.0
Highly Erosive Soil (soil erodibility, k > 0.052)	3.0~4.0

Note: Soil erodibility, k, is an index, which is related to the potential amount of soil eroded due to detachment and transport by rainfall and runoff. [Defined in the Universal Soil Loss Equation and with units of (t-ha-y)/(ha-mj-mm)].

The conditional development zone width (B_{W2}) is determined based on the designated use, or purpose, of the reservoir water. Reservoirs are classified into the following four types based on their purposes: domestic, industrial, agricultural, and others (power generation, etc.). Water quality requirement is classified also into the following classes: domestic, industrial, agricultural, and others (power generation, etc.). Domestic demand is ranked the highest, followed by industrial, then agricultural and other demands. The conditional development zone width (B_{W3}) was then defined as the buffer zone width times the reservoir purpose parameter (S_f). The reservoir purpose parameter is based on the classification of a particular reservoir. Proposed values of S_f for different water uses are listed in Table 5. In assigning the numerical values for S_f, consideration was given to the existing land use laws and regulations. As reported earlier, currently an arbitrary width of 1,000 meters is set for the "restricted zone" (i.e., the zone with no development allowed). The 1,000-meter width roughly corresponds to about 15 times of the calculated buffer zone width of 70 meters. Therefore, the S_f factor was given a numerical value of between 3 and 15. Again, when the zoning concept is actually implemented in Taiwan, the selection of both the W_f and the S_f factors should be made based on water quality considerations and suggestions from stakeholders.

TABLE 5 Proposed S_f Values for Different Water Uses.

Purpose	Reservoir Type*	S_f (proposed value)
Domestic	On-Channel	15
	Off-Channel	12
Irrigation	On-Channel	10
	Off-Channel	8
Industrial (others)	On-Channel	5
	Off-Channel	3

*An on-channel reservoir is one built on the main stem of a river. An off-channel reservoir is one built on a small tributary, with water transported into the reservoir from an adjacent larger river.

The permissible development zone is the land outside the restricted and conditional development zones. In this zone development is permitted as long as requirements under the normal erosion and runoff control regulations are met. There is no requirement for "special" or high-performance type of best management practices (BMPs), as in the cases of the other two zones. A schematic diagram of the three-zone layout is shown in Figure 6.

THE TAPU RESERVOIR CASE STUDY

The present study chose the Tapu Reservoir (No.8 in Figure 1) for a case study since it is a water body impacted mainly by nonpoint pollution, which is typical for many reservoirs in Taiwan. Tapu reservoir possess the following characteristics: (1) being a typical small, single purpose (irrigation) reservoir; (2) having a small watershed and a progressive management agency; and (3) with a simple land use pattern of mainly forest and agriculture. With less current development pressure compared to many larger reservoirs, Tapu serves as a good case study for testing the proposed zoning concept.

Geographical Setting

The Tapu Reservoir is located in Hsinchu County in Northern Taiwan, on the Omei Creek, a tributary of the Chungkang River. Omei Creek originates in the Ekungchih Mountain of the Snow Mountain range (see Figure 7). The Tapu Reservoir was completed in 1960, with an original storage volume of 9 million cubic meters and a watershed area of 100 km^2. Tapu supplied water for domestic, irrigation, and industrial uses, until domestic supply was discontinued in 1987 due to poor water quality.

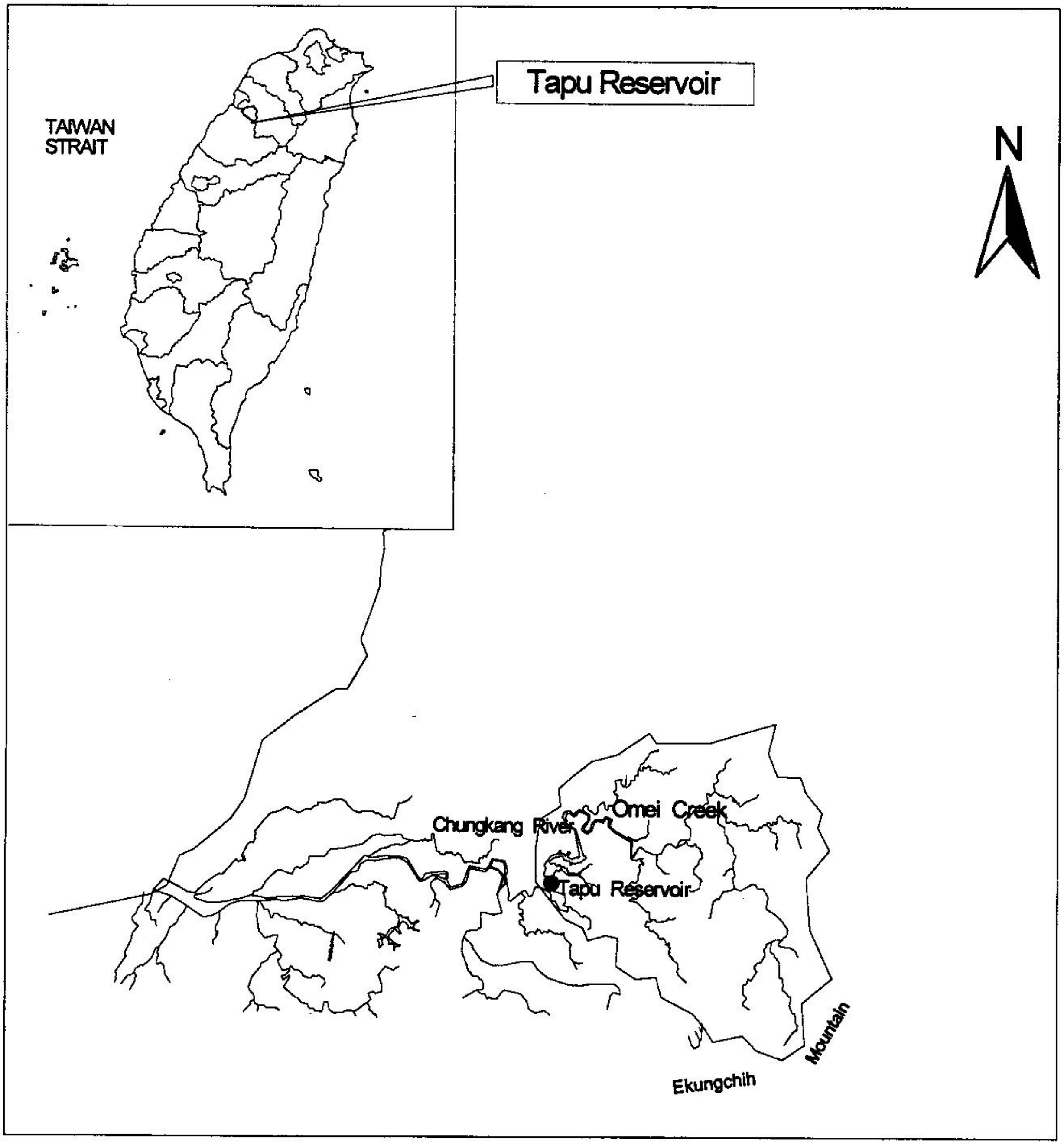

Figure 7. Tapu Reservoir Watershed Geographical Setting.

Siltation is a serious problem for the Tapu Reservoir. In 1994, a survey found the total storage volume was down to 5.44 million cubic meters, or about only 60 percent of the original volume due to siltation. Other water quality problems include eutrophication and the potential of toxicity impacts due to pesticide and heavy metal in the runoff.

Quantification of the Management Zones

Buffer Zone Width. As mentioned earlier, siltation is the major threat to Tapu Reservoir because of the steep terrain and lack of conservation measures. Therefore sediment was used as the pollutant for calculating the buffer width. A removal rate of 90 percent was selected because of the severity of the current siltation situation. Based on information regarding the average slope and Manning's roughness coefficient, the required buffer width was obtained using Figure 4 (Wong and McCuen, 1982) for all the sections of land around Tapu Reservoir. The results are listed in Table 5.

Computation of the Widths of the Three Management Zones. After the buffer width was determined, the widths of the three management zones were computed using Equations (5) through (7). Information gathered for Tapu Watershed suggested Wf values of 2.0 and 2.5, and an S_f value of 10. Results of the computations are listed in Table 6 (see Figure 8).

Expected Water Quality Benefits

As shown in Table 6, the calculated buffer widths for Tapu Reservoir ranged from 43 m (140 ft) to 171m (560 ft). These widths are comparable to those (150 ft to 400 ft) recommended by Nieswand *et al.* (1989) for protecting New Jersey water supply reservoirs against pollution from sediment and other constituents. As mentioned earlier in this paper, Johnson and Ryba (1992) reported that buffer widths of 30 m to 120 m were recommended for sediment and water quality control.

The buffer widths computed for Tapu Reservoir was based on a required 90 percent removal of sediment. Tapu lost 40 percent of its original capacity (from 9.0 million cubic meters to 5.44 million cubic meters) in 34 years due to siltation. If the buffer is as effective as designed, the expected life expectancy of Tapu can be prolonged from 52 years to several hundred years. It is estimated that between 15 percent to 40 percent of total phosphorus will be removed by the buffers. The implementation of various best management practices in the other management zones will also help reduce watershed pollution significantly. [Note: There is no regulatory requirement for best management practice (BMP) installation at the present time. The integration of the zoning approach with stormwater management planning is discussed in more detail in the following section.)

TABLE 6. Computation of Management Zone Widths.

Section	Slope (percent)	n	T_R (percent)	B_{W0} (m)	B_{W1} (m)	B_{W2} (m)	Remarks
1-1	8	0.35	90	43	86	430	W_f = 2.0 under
1-2	24	0.35	90	109	218	1090	erosive soil
1-3	24	0.35	90	109	218	1090	S_f = 10
1-4	24	0.35	90	109	218	1090	
1-5	24	0.35	90	109	218	1090	
1-6	20	0.35	90	93	186	930	
2-1	31	0.35	90	143	286	1430	W_f = 2.5
2-2	27	0.35	90	127	318	1270	moderately
2-3	12	0.35	90	61	153	610	erosive soil
2-4	16	0.35	90	78	195	780	S_f = 10
2-5	35	0.35	90	171	428	1710	
2-6	31	0.35	90	143	358	1430	

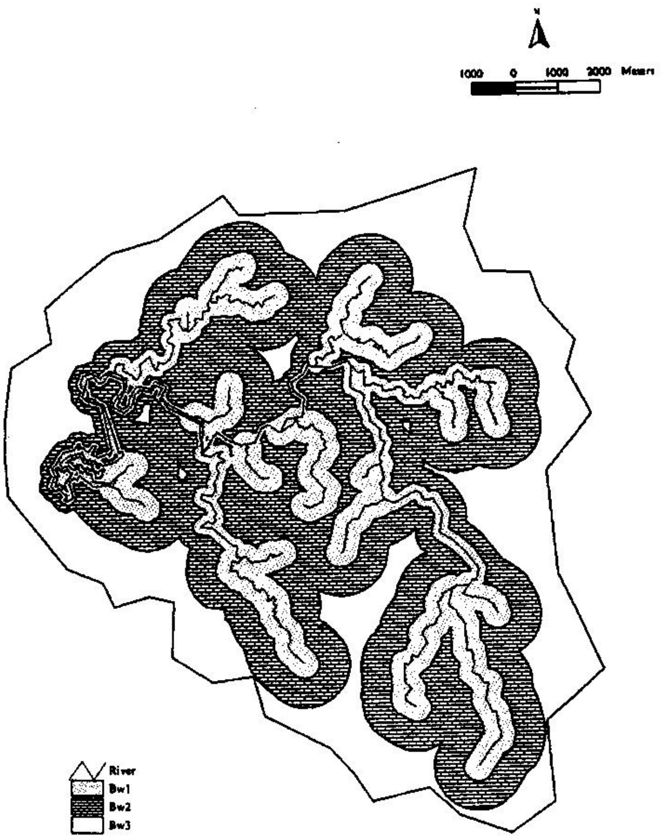

Figure 8. Layout of the Tapu Reservoir Watershed Management Zones.

ZONING AND STORMWATER MANAGEMENT SYSTEMS

The basic approach to integrating zoning and stormwater management, recommended in the present study, is a matrix type analysis proposed by Whipple (1992). In principle, an appropriate degree of best management practice (BMP) is prescribed for a certain zone. These BMPs can range from no action to low-level practices such as dry detention ponds and infiltration trenches, to high-level practices such as constructed wetlands and ultra-urban BMPs. The selection of appropriate BMPs will also depend on the specific "keystone" pollutant to be controlled.

For the Tapu Reservoir Watershed, high-level BMPs should be required for the conditional development zone, and lower-level BMPs for the permissible development zone. Since sediment and nutrients such as phosphorus are the keystone pollutants, wet ponds, for example, should be required for the conditional development zone and dry ponds or grassed swales for the permissible development zone. In case of pollution "hot spots," special BMPs such as BMP-in-series may be required (Wen and Yu, 1997).

CONCLUSIONS

1. For developing countries with limited land resources such as Taiwan, it is imperative to devise a strategy for balancing economic growth and environment protection. The zoning approach proposed in the present paper attempts to strike such a balance in that it provides a controlled development scheme with specific control measures required for the protection of water-supply reservoirs.

2. Under the proposed zoning approach, a reservoir watershed is divided into a buffer zone, and three management zones, i.e., a "restricted" development zone, a "conditional" development zone, and a "permissible" development zone. A water-quality based computational method is used to determine the buffer zone width. The widths of the other three zones are also determined quantitatively by applying "weighting factors" to the buffer zone width.

3. No development is permitted in the buffer zone, which should be vegetated. Development in the "restricted" zone is also prohibited, except for necessary types such as access roads. Those whose livelihood will be impacted are compensated by the government. High performance best management practices (BMPs) are required in this zone for any development activity. Certain types of development in the "conditional" zone can be made under a specified BMP requirement. In the "permissible" zone, most development types are permitted, provided that normal erosion and runoff control measures are implemented.

4. A case study example using the Tapu Reservoir Watershed in Northern Taiwan is described in this paper. According to computations made in this study, the maximum width in which development is prohibited is about 600 meters, which is significantly lower than the current 1,000 meters. The 1,000 meters was administratively selected and has been a major issue among governmental agencies, property owners, aborigines and developers.

5. It is expected that if the zoning approach is implemented, water quality of the Tapu Reservoir will improve significantly, with many more years added to its life of expectancy. It is recommended that a water quality-monitoring program be executed to examine the reservoir water quality before and after implementation.

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