DISSERTATION

# ANALYSIS OF RESERVOIR DREDGING IN TAIWAN – A CASE STUDY OF THE FEITSUI RESERVOIR

Submitted by

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In partial fulfillment of the requirements

for the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Spring, 2007

**COLORADO STATE UNIVERSITY**

February 28, 2007

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY TSU-KUANG HSIEH ENTITLED ANALYSIS OF RESERVOIR DREDGING IN TAIWAN – A CASE STUDY OF THE FEITSUI RESERVOIR BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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## ABSTRACT OF DISSERTATION


## ANALYSIS OF RESERVOIR DREDGING IN TAIWAN – A CASE STUDY OF THE FEITSUI RESERVOIR

The increase in annual sediment deposits in the Feitsui Reservoir is a serious problem. Reservoir dredging is a complementary to watershed management to extend the reservoir's life and eliminate the need for a new water storage project. A cost-benefit analysis was needed to estimate the benefit-cost ratio of dredging. Data and information from 5 reservoirs in Taiwan that were dredged were used to calculate the input variables for Program Dredge, a computer program to simulate the effects of dredging. The program was run to calculate the benefit-cost ratio for the 5 reservoirs. Values of the input variables from the 5 other watersheds and conservative assumptions were used to calculate the benefit-cost ratio for the Feitsui Reservoir. The benefit-cost ratio for dredging the Feitsui Reservoir was 1.440. The benefit-cost ratio was calculated without indirect costs and externalities. Various approaches to value externalities were presented.



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**ACKNOWLEDGEMENTS**

I wish to express my sincere and heart-felt gratitude to my adviser, Dr. Freeman M. Smith, Professor of the Geosciences Department, for his continuous guidance during my graduate study and research at Colorado State University.

I would also like to thank Dr. Ted C. Sheng, Professor of the Geosciences Department. Without his personal interest, sustained encouragement, and valuable assistance, this effort would never come to fruition.

A special note of appreciation goes to Dr. Chuen-Mei Fan, Professor of the Economics Department, for her continuous guidance during all my visits. She always made herself available and demonstrated a sincere interest in my endeavor.

Special appreciation goes to Dr. Stephen P. Mumme, Professor of the Political Sciences Department, for his fruitful support, guidance and valuable suggestions throughout my research work.

Additional appreciation is extend to my father, Prof. Hao-Lung Shieh, Soil and Water Conservation Department, National Chung Hsing University, Taiwan, for his encouragement , discussions and suggestions.

Special thanks are given to Dr. Yan Kuang Chang, Deputy Director of Taipei Watershed Management Bureau, Water Resources Agency, Ministry of Economic Affairs, for his useful discussion, encouragement and friendship and valuable data assistance.

Sincere gratitude goes to Cheng-Daw Hsieh, Division Director of Water Resources Bureau, Ministry of Economic Affairs, for his useful discussion, encouragement and friendship and valuable data assistance.

Finally, the deepest gratitude is given to my wife, Wan-Yu Lo and my son, Joseph Hsieh, for their patience, sacrifice, and continual support during my study at Colorado State University. Without their encouragement and understanding, the completion of my study might not have been achievable.

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# CHAPTER I
# INTRODUCTION

## 1.1 Background of Research

Taiwan is located in the subtropics with humid climates and high precipitation. The rivers are short and flow rapidly because of high mountains with steep slopes. Rainfall is abundant over the year but subject to great seasonal variations.

Because most of the watersheds are associated with poor geologic conditions and concentrated rainfall, though they are under care and protection, heavy sedimentation is unavoidable. Due to the difficulty of finding a new reservoir site near the Taipei metropolitan area, sedimentation is, therefore, a major concern of reservoir problem.

Feitsui Reservoir should consider sediment dredging as a supplementary measure to protect the reservoir. In this study, a cost-benefit analysis is applied to reservoir dredging, although limited information and data are available.

The Feitsui Reservoir is a long-term project which provides public water supply to the Taipei metropolitan area. Its construction began in August 1979 and was completed in June 1987. The Taipei City Government established the Taipei Feitsui

Reservoir Administration Bureau (TFRAB) to oversee operation, maintenance, and watershed work for the reservoir.

The existing watershed management plan for the Feitsui Reservoir includes a number of elements, among them :

1. Promoting comprehensive river basin planning and regulation.
2. Reinforcing management of the Feitsui watershed.
3. Safeguarding water resources development and management.
4. Ensuring a stable, high quality water supply for the Taipei metropolitan area.
5. Promoting comprehensive watershed conservation.

The purpose of reservoir dredging is to maintain a reservoir's capacity. Although the sediment problems have been quite serious, dredging has been minimal in the Feitsui Reservoir. Dredging, as a remedial measures, would greatly benefit the reservoir. Regaining the lost storage capacity by dredging the Feitsui Reservoir would extend the useful life of the reservoir.

## 1.2 Statement of Problem

The heavy sediment yield for the Feitsui Reservoir is a serious problem (see Table 1 for the rates). According to a reservoir profile survey of the Taipei Feitsui Reservoir Administration Bureau, the average sediment increment was 996,000 cubic meters from 1984 to 2005. The sedimentation trend of average increment rates have decreased to 313,000 cubic meters from 2003 to 2005, due to the implement of watershed management plans.

Table 1 : Sediment increments at Feitsui Reservoir (Taiwan) by year
( unit : thousand cubic meter )

| Types | Period | Yearly | Reservoir Capacity | Sediment Increments | Subsequent Increment | Average Increment |
|---|---|---|---|---|---|---|
| 1 | Jul,1984-Mar,1989 | 4.75 | 400,028 | 5,972 | 5,972 | 1257 |
| 2 | Apr,1989-Dec, 1989 | 0.75 | 399,007 | 1,021 | 6,993 | 1,361 |
| 3 | Jan,1990-Dec,1990 | 1 | 398,037 | 970 | 7,963 | 970 |
| 4 | Jan,1991-Dec,1991 | 1 | 397,056 | 981 | 8,944 | 981 |
| 5 | Jan,1992-Dec,1992 | 1 | 396,092 | 964 | 9,908 | 964 |
| 6 | Jan,1993-Dec,1993 | 1 | 395,686 | 405 | 10,313 | 405 |
| 7 | Jan,1994-Dec,1994 | 1 | 394,797 | 889 | 11,202 | 889 |
| 8 | Jan,1995-Dec,1995 | 1 | 394,311 | 486 | 11,688 | 486 |
| 9 | Jan,1996-Dec,1996 | 1 | 390,835 | 3,476 | 15,164 | 3,476 |
| 10 | Jan,1997-Dec,1997 | 1 | 390,058 | 777 | 15,942 | 777 |
| 11 | Jan,1998-Dec,1998 | 1 | 388,680 | 1,377 | 17,319 | 1,377 |
| 12 | Jan,1999-Dec,1999 | 1 | 388,196 | 484 | 17,803 | 484 |
| 13 | Jan,2000-Dec,2000 | 1 | 387,356 | 840 | 18,643 | 840 |
| 14 | Jan,2001-Dec,2001 | 1 | 386,003 | 1,354 | 19,997 | 1,354 |
| 15 | Jan,2002-Dec,2002 | 1 | 385,535 | 467 | 20,464 | 467 |
| 16 | Jan,2003-Dec,2003 | 1 | 385,320 | 214 | 20,678 | 214 |
| 17 | Jan,2004-Dec,2004 | 1 | 384,947 | 373 | 21,051 | 373 |
| 18 | Jan,2005-Dec,2005 | 1 | 384,596 | 351 | 21,040 | 351 |
| Total | | 21.5 | | 21,404 | | |
| Average | | | | | | 996 |

Source : http://www.feitsui.gov.tw ( Taipei Feitsui Reservoir Administration Bureau )

Because of the typhoons, the average increment of the years 1996, 1998, and 2001 are higher than the average increment. Reservoir dredging should be considered as an effective method to lessen the sediment increment problem and prolong the useful life of the Feitsui Reservoir.

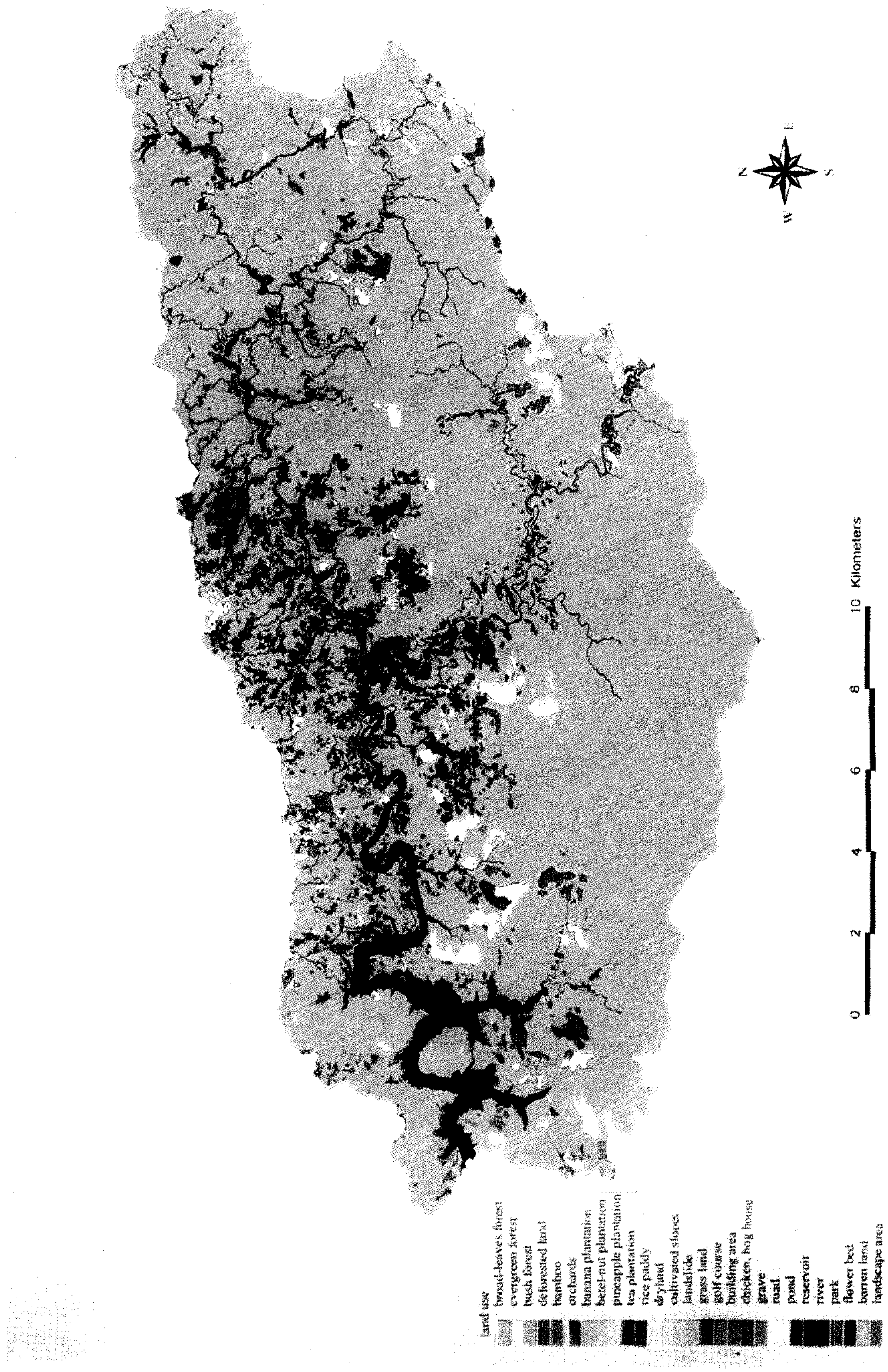
However, dredging would incur externality on resource allocation efficiency. A cost-benefit analysis of dredging for reservoir management should consider both external and internal benefits and costs. Although the external cost is a very important value to estimate in the cost-benefit analysis, unfortunately, sufficient data for the Feitsui Reservoir do not exist.

### 1.3 Study Area

The Feitsui Reservoir is about 30 kilometers east of Taipei, downstream of Peishih Creek which is a tributary of Hsintien Creek in Taipei County. The Feitsui Reservoir watershed is 303 $km^2$ of hilly terrain at an altitude ranging from 50 to 1200 meters. The southern elevation is higher than the northern.

The watershed's main stream, Peishih Creek, runs through the central part of the watershed from east to west. Land use classification of the Feitsui Reservoir watershed is shown on Map 1. It shows that forest covers about 88 % of the watershed (see Table A.2 in the Appendix for the statistic land use percentages). The watershed is southeast of the densely populated Taipei metropolitan area. The reservoir provides daily water to over 4,000,000 people and fulfills industrial water needs of the city.

Map 1 : Land Use Classifications of Feitsui Reservoir Watershed (Taiwan)



Reservoir administration is provided by the TFRAB and the Taipei Water Management Office of Water Resources Agency. The Taipei Feitsui Reservoir watershed's administrative area covers the following areas : the whole Pingling District and part of the Shihding District, Shuangshi District, and Hsintien City in Taipei County.

**1.4 Research Method**

The cost-benefit analysis is applied to this research by using Program Dredge, a computer simulation to estimate the benefit-cost ratio (Water Resource Bureau, Ministry of Economics Affairs & Department of Hydraulic and Ocean Engineering, National Cheng Kung University, 1994). Minor modifications were made to Program Dredge in order to smoothly and properly run the computer program. If the benefit-cost ratio is larger than 1.00, dredging is economically efficient. This is true only if there is no budgetary constraint. The greater the benefit-cost ratio, the greater the economic efficiency.

Due to limited data, some data obtained from Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoirs are used to estimate benefit-cost ratio for the Feitsui Reservoir. Reservoir dredging may result in different degrees of environmental impact caused by dredging itself, drying, transportation, and final handling of the sediments.

Environmental impacts could include water quality, air quality, noise, vibration, and traffic (Liang et al, 2002). These possible environmental impacts could be related to the externality of dredging. This research will explain the theories and applications limits of externalities.

### 1.5 Contribution of Research

Sedimentation rate determines the effective life of a reservoir. Preserving reservoir capacity through dredging can help extend a reservoir's ability to meet water demands over time. Morris and Fan (1998) state that with proper maintenance, the life of a reservoir is unlimited, but that most reservoirs are originally designed and operated upon the concept of a finite life which will ultimately be determined by annual sediment increment rather than structural obsolescence.

Therefore, reservoir dredging is important to water resource conservation and economic developments. The Feitsui Reservoir is the water resource for the Taipei municipal area and other communities in the Feitsui Reservoir watershed. To maintain a sustainable operation, the externality impacts of dredging processes are a very important issue for the Feitsui Reservoir.

The contribution of this research would be a methodology for calculating the cost-benefit for dredging the Feitsui Reservoir. The cost-benefit analysis would provide important information in a feasibility study. This research will also provide information and data that can be used in future studies.

**1.6 Objective of Study**

Based on gross initial storage capacity, the Feitsui Reservoir is the second largest among Taiwan's many reservoirs. Recognizing the problems of the Feitsui Reservoir and its watershed will help government authorities to determine appropriate methods to extend reservoir life.

Applying a cost-benefit analysis for reservoir dredging needs to identify the beneficiary by stating the multi-purpose nature of the project. For example, the beneficiary would include the city water users, the tourists who use the reservoir and water facilities, etc. Meanwhile, the beneficiary would be responsible on the cost (supply) side. It is very important to describe cost-benefit analysis by tax / subsidy measures to correct the externalities during reservoir dredging process.

This study considers a methodology for determining the cost-benefit of dredging of the Feitsui Reservoir and, to the extent possible, evaluating the impacts of externalities. Hopefully, this reservoir dredging plan may serve as a model for managing reservoirs throughout Taiwan.

The purpose of this study is to develop a methodology that can be used to analyze the costs and benefits of ongoing reservoir dredging projects. The Feitsui

Reservoir study includes the major tasks below :

1. Review of Paiho, Tapu, Mingte, Chingmien, Shihmen Reservoirs' reservoir dredging projects.
2. Estimate benefit-cost ratio for dredging Feitsui Reservoir, using data and information of reservoir dredging of five reservoirs in Taiwan.
3. Apply a sensitivity analysis for the input variables for Program Dredge.
4. Review the economic tools for evaluating externalities.

Applying a benefit-cost ratio to reservoir watershed dredging is the most important objective of this research. Environmental impact is the primary externality of reservoir dredging that must be controlled. Resource allocation efficiency (for example, the project is economically viable) calls for a positive net economic effect. Therefore, reservoir dredging is an alternative for reducing the loss of storage.

**1.7 Methodology**

The methodology of this study is for determining whether cost-benefit of dredging can be carried out, utilizing data from other reservoirs in Taiwan as basis of this study. Originally the Feitsui Reservoir was expected to last for at least 43 years, until 2030 (Water Resource Bureau, Ministry of Economics Affairs, 2002). However, dredging could feasibly increase the reservoir's life and eliminate the need for a new water storage project. In terms of time framing, generally speaking, this situation will depend on its original reservoir capacity and sediment yield.

This research analyzes the costs and benefits of hydraulic and mechanical dredging practices using data from other reservoirs in Taiwan that have used dredging to increase storage. Because dredging data collection is not yet institutionalized in Taiwan, this study also bases its conclusions on some reasonable assumptions.

In this study, unit dredging costs are assumed to be similar among reservoirs, although in reality there is some variation in labor and transportation costs by location. The total dredging costs would include dredging operations, transportation, handling and disposition of dredged material. Costs are figured using the March 2006 foreign exchange rate of approximately NT $ 32 dollars for US $ 1. Consequently, the total hydraulic dredging costs was NT $ 460-500 (approximately US $ 14.375-15.625) per cubic meter, and total mechanical dredging costs was NT $ 272-410 (approximately US $ 8.5-12.813) per cubic meter (Tsu and Cheng, 2002 A).

The economics of the Feitsui Reservoir can be measured by a cost-benefit analysis. This study analyzes past successes and failures, considers the existing economic and social characteristics of the Feitsui Reservoir watershed area, and builds a framework that can be used when evaluating alternative strategies during the future decisions making.

# CHAPTER II
# COST-BENEFIT ANALYSIS FOR RESERVOIR DREDGING

## 2.1 Introduction

Because sites suitable for new reservoirs are rare, preserving existing reservoirs is of utmost important. Sustainable development and management of existing reservoirs may help extend a reservoir's long-term utilization. An economic analysis of both costs and benefits is important in choosing a strategy for extending the usefulness of a reservoir.

In the past, reservoir dredging as a means to achieve long-term sustainability was rarely incorporated into reservoir management projects. The externality impact of dredging the Feitsui Reservoir to maintain its sustainable operation and economic efficiency, should consider the costs and benefits of internal and external factors.

Internal benefits of dredging include increased reservoir capacity and water quality improvement, and consistent city water supply. Water quality at Feitsui Reservoir, as measured by the Carlson Trophic State Index by year and its standard, are presented in Table A.1 in Appendix A. Internal costs include direct costs such as labor, drying, transportation, and final handing of sediments.

On the other hand, external benefits of dredging include downstream recreation such as swimming and recreational fishing and activity, while external costs include noise, air pollution, vibration, sediment disposal, ecosystem damage, traffic problems, and road maintenance. Bromley state that an external cost exists when either a production activity or a consumption activity causes a direct loss of utility to another consumer, or an increase in production cost to another producer, which does not enter the decision calculus of the controller of the activity (1995).

Basically, the internal benefits and costs can be estimated by quantitative analysis for management. On the other hand, the external benefits and costs can be approached by valuing external social benefits and costs methods. Hedonic Pricing Method (HPM), Travel Cost Method (TCM), and Contingent Valuation Method (CVM) are the methods of estimating the non-marketables, the intangibles, and to correct market imperfection. Unfortunately, the external benefits and costs, in this study, do not have ready market prices to use as guideline. Finally, the internal benefits and costs and external benefits and costs for reservoir dredging can be summarized in the following Table 2 :

Table 2 : External benefits and costs for reservoir dredging

| Internal benefits | Internal costs | External benefits | External costs |
|---|---|---|---|
| Reservoir capacity increased | dredging itself (such as labor) | Swimming | air pollution |
| water quality improvement | drying | recreational fishing | water pollution |
| Consistent city water supply | transportation | recreational activity | noise |
| | final handing of sediments | | vibration |
| | | | sediment disposal |
| | | | ecosystem damage |
| | | | traffic problems |
| | | | road maintenance |

In terms of reservoir sedimentation, regaining the lost storage capacity of water resources supply reservoirs for Feitsui Reservoir is not only a watershed management issue, but also a reservoir conservation issue. Both of them can extend reservoir life to attain economic efficiency. The sediment deposited in the reservoir is caused by the sediment yields of the entire watershed. Reservoir planning must consider the probable rate of sedimentation to determine how long the reservoir will have capacity to meet demand. Reservoir sedimentation is caused by soil erosion, the detachment and transportation of soil particles. Soil erosion is caused by precipitation, runoff, wind, and human activities. Jain and Singh (2003) state that the accumulation of sediment deposition through time is the major factor that threatens the longevity of reservoir capacity.

While Feitsui Reservoir has not been dredged fruitfully in the past, dredging operations at other reservoirs provide appropriate data for a representative cost-benefit analysis of the likely economic benefits of dredging the Feitsui Reservoir. Reservoirs in Taiwan that have used dredging include : Shihmen, Hsiszu, Hsinshan, and Tapu reservoirs in northern Taiwan; Wushtuo and Mingte reservoirs in central Taiwan; and Paiho, Wushuantou, Lunyintuan, and Akungtien reservoirs in southern Taiwan.

## 2.2 Cost-benefit Analysis

The cost-benefit analysis measures present value (PV) of benefit flow relative to PV of cost flow over the entire economic life span of a public project. Levin and McEwan (2001) indicate that a cost-benefit analysis is useful in evaluating dredging's economic advantages. Theoretically speaking, cost-benefit analysis should measure the monetary values of all benefits and costs involved.

However, Taiwan's water resource government authorities in the past have not considered the external effect of reservoir dredging operations. Failing to fully recognize the social component of benefits and costs of pollution abatement programs, reservoir dredging will provide less than the optimal level of environmental protection.

In terms of cost-benefit analysis for environmental projects, the relevant benefits and costs in particular were assumed to be capable of being measured and compared in dollar terms. However, when the output of a project is undefined or cannot be measured in monetary units, cost-benefit analysis is of limited use. In this study, unfortunately, the external impacts of reservoir dredging project are hardly to be measured in monetary units. Nevertheless, the cost-benefit analysis can still be offered as the theoretical foundations for welfare change measurement and for government budget decision purpose. The most important obstacle in the cost-benefit analysis of the present reservoir dredging project is that many costs and benefits do not have ready competitive market prices to serve as measurement of their values.

In this study, the external effects of reservoir dredging could be calculated through reasonable assumptions by analyzing economic theory in order to fulfill the purpose of resource allocation efficiency for Feitsui Reservoir. If the benefit-cost ratio is larger than 1.00, a reservoir dredging project may considered economically viable, provided that the government does not have a budget constraint. The greater the benefit-cost ratio, of course, the greater the economic efficiency.

The benefit-cost ratio (BCR) is defined as :

$$\mathrm{BCR} = \sum_{t=0}^{T}[B_t/(1+r)^t]/\sum_{t=0}^{T}[C_t/(1+r)^t] = \sum_{t=0}^{T}[Bt - Ct/(1+r)^t]$$

where Bt = benefits in time period t for t = 0,…, T; Ct = costs in time period t for t = 0,…, T; r = the social discount rate. Since BCR is by definition a ratio, it will always be a positive number. If the discounted benefits exceed the costs, then BCR will be greater than 1.00 (Loomis and Helfand, 2001).

### 2.2.1 Net Present Value (NPV)

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows by comparing the value of a dollar today to the value of that same dollar in the future, taking inflation and returns into account. If the NPV of a prospective project is positive, it should be accepted. However, if NPV is negative, the project should probably be rejected because cash flows will also be negative. NPV is used in capital budgeting to analyze the profitability of an investment or project. NPV analysis is also sensitive to the reliability of future cash inflows that an investment or project will yield.

In this study, for example, if a reservoir dredging company makes a bid for government authorities' dredging project, the company would first estimate the future cash flows that project would generate and then discount those cash flows into one lump-sum present value amount. Therefore, if the reservoir dredging company is willing to bid for this government project, the company must have estimated a positive NPV.

### 2.2.2 Social Discount Rate

Social time preference and opportunity cost are the two approaches to the choice of appropriate social discount rate. Social discount rate is crucial in the calculation of NPV of a project. The real rate of interest which means the social time preference is the appropriate social discount rate for cost-benefit analysis. Market interest rates are often used for discounting because they reflect the opportunity cost in reality, given the imperfection in the market and the presence of taxes.

In addition, the social rate of time preference refers to society as a whole and concerns the rate at which society will trade off present and future outcomes. Due to the social rate of time preference is not likely to coincide with the (risk-adjusted) social rate of return from investment. The implication is that investments can't be ranked in an order of preference using a rate of interest equal to the opportunity cost of capital.

Applying a discount rate to reservoir dredging operations, in this study, can be used to assume that a reservoir ecosystem is threatened by internal and external pollutions. The convergence of these environmental destructive activities threatens the viability of this reservoir watershed. As a result of government intervention, there would be both direct economic benefits (for example, reservoir capacity increased, water quality improvement, and consistent city water supply) and indirect benefits including swimming, recreational fishing, and recreational activity, as well as economic costs.

The costs associated with government intervention could include productivity losses incurred by reservoir dredging as a result of the controlling externalities. Finally, the city water users and the tourists who use the reservoir and water facilities should share the burden of the water costs due to comply with new regulations related to the reservoir dredging operations. This share the burden of the water costs are a form of abatement cost. An abatement cost is a cost borne by city water users to mitigate the damaging impact of an environmental externality that the reservoir dredging operation has created.

Generally speaking, investment of resources today generates a larger quantity of resources available for future consumption and investment. Thus, the future return from today's project investment is essentially a source of future flow of consumption and further investment. The interest rate, and thus the discount rate, should reflect the opportunity cost of relinquishing present consumption. For example, an investor expects $100 dollars in one year's time. To determine the present value of this $100 (what it is worth to this investor today), it needs to discount by a particular rate of interest (often the risk-free rate but not always). Assuming a discount rate of 10%, the $100 in a year's time would be the equivalent of $90.909 to this investor today

(100/[1.00 + 0.10]) for a given set of future benefits and costs. Benefits accrued in remote future contribute less to NPV than benefits accrued in the near future.

### 2.2.3 Shadow Price

Brent (1996) indicates that the shadow price can be defined as the social welfare improvements which are caused by any marginal change in the availability of commodities or factors of production. Shadow price (social value) determination is central to cost-benefit analysis and public policy.

If a public investment output of good g is denoted by $Yg$, then $Sg$ (a shadow price) can be presented as $Sg = \Delta$ social welfare / $\Delta$ output of good $Yg$, the shadow price should reflect social evaluation of the input and output. It may or may not equal the market price. Also, it is called a shadow price as it does not have an existence apart from its use in the social evaluation. Furthermore, while calculating cost-benefit analysis, shadow prices should also be used because market prices in the economy do not reflect the true social benefits and social costs. The objective function of cost-benefit analysis is to establish net social benefit, where costs and benefits are measured in terms of shadow prices of inputs and outputs instead of in actual market prices.

In this study, a shadow price should be applied in estimating the external costs and benefits of reservoir dredging rather than considering only internal costs and benefits such as labor, drying, transportation, final handing of sediments, reservoir capacity increased, water quality improvement, and consistent city water supply. If the shadow pricing is used, the economic valuation of a reservoir dredging would be seen as more accurate. Levin and McEwan (2001) make the following comments about the difficulty regarding shadow pricing :

> Unfortunately, it is not always the only source of ingredients in the competitive markets. Alternatively, there may be no obvious market for a particular ingredient. Moreover, no market exists for this type of facility. When the value of a good does not have a competitive market price, it is called a shadow price. Both market and shadow prices can be used to ascertain the values of the ingredients for purposes of cost estimation.

Due to the increase in social welfare which will be caused by any marginal change, in this study, shadow prices will be applied to the measurement of external costs and benefits of reservoir dredging. Three methods of estimating the non-marketables, the intangibles, and to correct market imperfection would be discussed below : Hedonic Pricing Method (HPM), Travel Cost Method (TCM), and Contingent Valuation Method (CVM). For example, in this study, the shadow interest rate or shadow price of capital would include 0.06 as annual interest rate. This number is in accordance with the past average interest rate of the banking systems and past issuing of the government bonds.

### 2.3 External Impacts of Reservoir Dredging Project

The existing Feitsui Reservoir watershed management plan has a comprehensive watershed conservation component. In this study, it is assumed that watershed management inclusive of reservoir dredging will have sizable external costs and benefits.

#### 2.3.1 Environmental Influences

Reservoir dredging may negatively impact water and air quality, noise levels, vibration, traffic, and the ecosystem. The possible environmental impacts would be related to the externalities of dredging operations.

##### 2.3.1.1 Water Quality

Because water quality is unavoidably affected by dredging, its physical and chemical characteristics should be monitored during and after operations, to establish guidelines for variables such as turbidity and odor.

The internal benefits of a dredging project include improved water quality, decreasing eutrophic phenomenon by diminishing plants' nutrient. Reservoir dredging may be an effective way to improve water quality because it changes an oligotrophic – mesotrophic phenomenon to a mesotrophic – eutrophic phenomenon.

In terms of calculating the external cost of water pollution after enforcing reservoir dredging operations, it could be calculated by the additional costs of wastewater treatment and sewerage treatment plants without considering the influences of flood or typhoon season. Brown and Barnwell (1985) state that a model attempts to simulate the quality and contamination of the water of a river must be able to adequately represent the physical, chemical and biological phenomena. With a view to the planning of sewerage and treatment of wastewater discharges in a hydrographic catchments area, various models or structural theories have been developed. The model of QUAL – II from Brown and Barnwell have been used of the United States Environment Protection Agency (US – EPA).

#### 2.3.1.2 Air Quality

Air quality inevitably declines during reservoir dredging operations, due to the transportation of dredged material to disposal sites. The effect on surrounding environments and ecosystems can be minimized by periodically cleaning up roads and wetting them down.

Weber (1982) states that air quality management system is the consistent assembly of :

1. The assessment of present ambient air quality, emissions and related factors.

2. The comparison with existing standards, criteria and guidelines.

3. Projection of future emissions and ambient air quality.

4. The development, implementation, and revision of a control strategy including economic aspects and interactions with other environmental media.

In terms of calculating the external cost of air pollution from transport, Maddison, et al. (1996) state that the following model, taken from Ostro (1994), has been adopted. It involves two stages : firstly, identifying the effect of the pollutants from fuels on human health; secondly, placing a money value on those changes in health. Calculating the damage done to human health by these emissions require identifying the amount of the ambient concentration of pollution that has been generated by exhaust pipe emissions, the number of people exposed to these concentrations, and the effect of a unit of pollution on any exposed person. It can be expressed as : $\Delta H_{ij} = b_{ij} * POP_j * \Delta A_{jt}$

where $\Delta$ = change in, $H_i$ = health impact *i* per year, j = a particular pollutant *j* emitted from exhaust pipes, t = transport fuel type – diesel, petrol, or unleaded, $b_{ij}$ = slope of Dose-Response function of health effect *i* per year with respect to pollutant *j*, POP = population exposed to pollutant *j*, $A_{jt}$ = ambient concentration of pollutant *j* in 1993 attributable to emissions of specific fuel types.

The second stages of the technique requires placing an economic value on the change in health impact. It can be expresses as :

$P_i * \Delta H_{ij} = P_i * b_{ij} * POP_j * \Delta A_{jt}$

where $P_i$ = a price or economic value for the change in health impact *i*.

### 2.3.1.3 Noise and Vibration

Both mechanical and hydraulic dredging increase noise and vibration levels in dredging disposal areas, but appropriate management techniques can reduce the environmental impact. Mostly, no villages or residences are around the dredging areas.

Measuring noise pollution generated by dredging operations include transportations and operational equipments. Irwin and Graf (1979) state that a system can be used for an environmental noise analysis such as a plant boundary noise study. The microphone and data-acquisition system are portable and environmentally protected for outdoor use. Furthermore, measuring quantities and systems for vibration should be made to produce the data to minimize or eliminate the vibration. There are also examples where the noise is not the controlling parameter, but rather the quality of the product produced by the system. For example, in process control equipment, excessive vibration can damage the product, limit processing speeds, or even cause catastrophic machine failure.

In terms of aggregate noise costs for the United Kingdom, Maddison et al, (1996) state that the following model, taken from Lamure (1990), has been suggested for the relationship between vehicle flow and noise levels (1996). It can be expressed as :

$$L_{eq} [\ d\, \mathrm{B(A)}\ ] = a + 20 \log s - 10 \log d + 10 \log q$$

where : $a$ is a constant, $s$ is speed, $d$ is distance from the road, $q$ is traffic flow per hour.

### 2.3.1.4 Traffic

Dredged material transportation to disposal sites will increase the traffic burden on local roads. The situation may raise the reservoir dredging costs due to traffic congestion and delays. In addition, during transportation of dredging material, trucks need to be covered to reduce the dust and falling rocks. Roads need to be maintained periodically. The costs of road maintenance needs to be considered as external costs, if the distance is long.

In terms of empirical estimates of congestion costs, Maddison et al, (1996) state that the following model, taken from Walters (1961), has been suggested. It can be expressed as the following steps :

1. To establish for a representative road user a relationship describing marginal private cost (MPC) per kilometer traveled as a function of speed $s$ measured in

kilometers per unit of time, the value of a unit of time to the occupants of a vehicle *b* and *a* fixed cost a per kilometer. MPC = average social cost (ASC) = a + b/s.

2. To establish a speed flow relationship where F is traffic flow per unit of time. s = $\alpha - \beta F$.

3. To substitute this relationship into the expression for MPC and ASC to make them purely a function of F and a few parameters. MPC = ASC = a * b /($\alpha - \beta F$).

4. To multiply point 3 through by traffic flow gives total social cost (TSC). TSC = $aF + bF/(\alpha - \beta F)$.

5. To differentiate point 4 to traffic flow gives marginal social cost (MSC). MSC = a + $\alpha b/(\alpha - \beta F)^2$.

6. To subtract MPC from MSC (point 3 from point 5) and multiply by *F* yields the marginal externality charge (MEC = marginal environmental cost = marginal damage). MEC = (MSC – MPC)*F*.

Moreover, In terms of road damage costs, Maddison et al, (1996) state that a tax appears to give a fair reflection of the variable costs of heavy goods vehicle (HGV) road traffic – the kilometer tax. Odometers have been successfully used in some countries, such as New Zealand, Finland, Sweden and Norway.

#### 2.3.1.5 Ecosystem

Handling of dredged material may have a large influence on ecosystems. Material dredged from a reservoir's upper end may be recycled and used in construction projects, but material dredged from the lower reservoir is usually too muddy for any such re-use. Some dredged material can be used to fill gullies and create retaining walls at drainage facilities, thus offsetting the economic effects of dredging on the ecosystems.

In terms of ecological science and conservation values, three categories can be classified : professional fascination or curiosity, ecosystem or resource management, and conservation or crisis. Lautensach (2005) states that professional fascination or curiosity is the most abstract as it is virtually universal among scientists of all fields. This category include :

1. Attempting to confirm or refute a hypothesis or model.
2. Documenting ecologist's ignorance on a specific mechanism or situation.
3. Referring to a specific mechanism or situation as fascinating, intriguing, or similar attribute.

#### 2.3.1.6 Others

The uncertainty of dredging operations and procedures also need to be considered into the total costs issue. Other variable costs associated with dredging operations include traffic risks caused by transportation of dredged material, field drainage and the side slope stabilization, erosion control and ongoing management of the disposal site. Finally, the future following observation controlling plan of disposal dredged material is going to be observed continuously.

#### 2.3.1.7 Controlling Pollution in Transition Economics

Bluffstone and Larson (1997) state that these assumptions can be used to generate demand functions for pollution and to define an optimal supply of environmental services. Applying the economics of pollution control in transition economies on reservoir dredging operations include :

1. Pollution is generated by a set of dredging operation processes.

2. Dredging companies are able to measure pollution without excessive costs either through direct monitoring or indirect estimation methods.

3. Dredging companies understand the relationship between dredging operation and pollution.

4. Dredging companies try to optimize some objective function.

5. Pollution creates social costs through environmental damages that can be translated into the same units (for example, monetary) as the benefits of pollution.

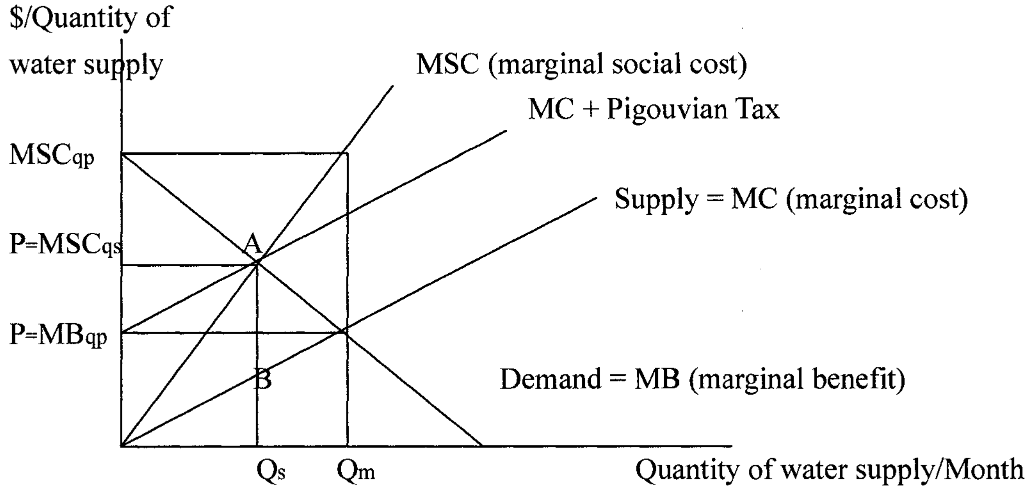
6. Water resource government authorities can observe pollution without excessive costs either through direct monitoring or through indirect estimation methods.

Assumptions one to four are needed to make the link between inputs, outputs and emissions that define the demand for pollution in an economy. Alternatively, assumption five adds the cost element and defines a social cost function (environmental damages), as well as a marginal social cost function that is the social willingness to allow pollution (the pollution supply function). Thirdly, assumption six allows enforcement of some chosen environmental policy approach, and in important respects defines the ability of water resource government authorities to achieve or approximate ideal policies.

### 2.3.2 Externalities and Allocative Inefficiency

Externality can be defined as "whenever some individuals' utility in consumption or production relationships are affected by real (physical) variables whose quantities are chosen by other entities without regard for the effects on others" (Loomis, 2002), therefore bypass the market price mechanism. Market economics tend to consume too many goods with negative externalities and too few with positive externalities. Externalities can be internalized through the use of taxes and subsidies.

To illustrate, the demand curve represents consumer's maximum willingness to pay for the service provided by the water from the reservoir. The supply curve represents the opportunity cost of providing the water. Without externality, social benefit equals social opportunity cost at equilibrium, and the quantity provided is socially optimal at Qm (quality market level). The following Graph 1 illustrates the economic theory :



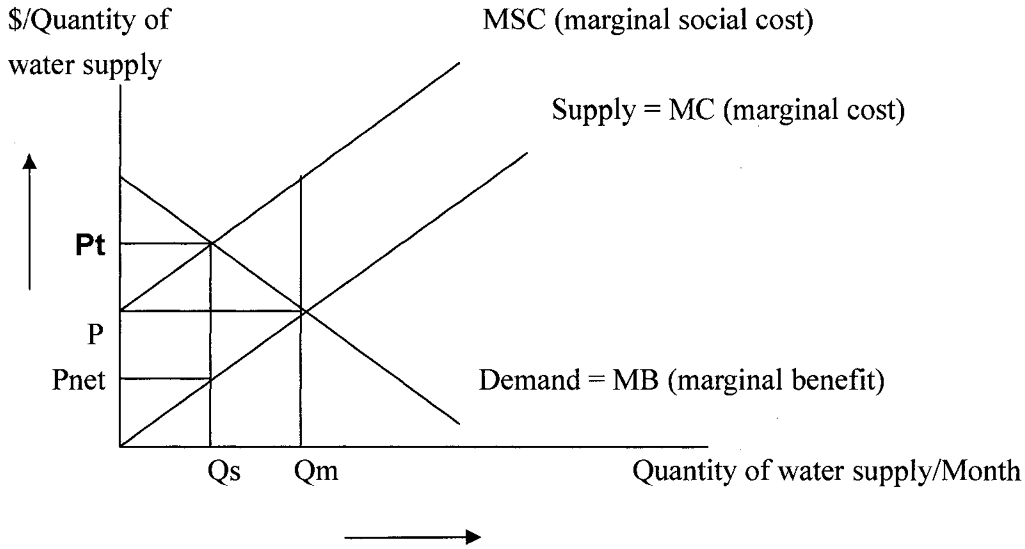

The vertical $ / Quantity of water supply presents value of a project involving multiple periods. The marginal benefit curve includes all social (internal plus external) benefits, just as marginal social cost curve is inclusive of all internal plus external costs. However, with externality, marginal social opportunity cost is greater than marginal benefit and Qm is larger than social optimal. In order to achieve resource allocation efficiency, the Pigouvian per unit tax (AB) can be used as one of the means to internalize the externality so that the true social optimal is attained at Qs (social optimal level).

For this watershed management project, the technological externality is associated with production externality. Production externality will consist of non-point sources (NPS) involved in the processing of reservoir dredging. Without externality, true value of water will equal marginal cost [ P(price paid by consumer) = MC ]. Alternately, with externality, true value of water will be smaller than marginal social cost. Therefore, the price the consumer pays should be equal to MSC by means of the Pigouvian tax equals MEC at Qs. Diagrammatically, the marginal environmental cost is the vertical distance between MSC and MC at socially optimal output level Qs.

In terms of marginal environmental cost, Pearce (1976) states that MPC gives marginal private costs which differ from MSC by an amount equal to marginal environmental costs (marginal external costs), for example, the marginal costs of pollution. In theory, environmental taxation could improve the market efficiency of the environmental goods and services by imposing a price on such goods equal to the marginal costs of their use (marginal environmental cost).

Evaluate private values versus social values, it is necessary to evaluate externality on consumption for the utility side or on production for factor productivity. Theorically speaking, if all external benefits and costs are correctly reflected in the MSC curve and MB curve, then tax (or subsidy) should be exactly equals MEC. Besides, Diamond (1975) comments, "social marginal utility of income can be defined as the sum of gains from individual consumption and from the marginal propensity to pay taxes out of income". This comment is meaning that social marginal utility of income will equal marginal utility of income plus taxes pay out of income.

Moreover, the marginal social cost (MSC) equals the marginal private cost (MPC) plus the marginal damage. Assuming a constant marginal damage for all quantities, diagrammatically, the marginal environmental cost (MEC) is the vertical distance between MSC and MC. If either the MSC or MC curve goes up or down, the marginal damage will not maintain a constant status. The following Graph 2 illustrates the economic theory :




The fundamental theorem of welfare economics states that the market mechanism operating in a perfectly competitive environment produces a Pareto optimal solution (Nas, 1996). Equilibrium is attained when the marginal benefit equals the price of the good, which equals marginal cost (MC). The point of intersection of the demand curve and the supply curve is the Pareto optimal solution.

### 2.3.3 Methods for Valuing External Social Benefits and Costs

The purposes of valuation and regulation of the environment are both correcting environmental externalities and identifying efficient development paths. Hedonic Pricing Method (HPM), Travel Cost Method (TCM) and Contingent Valuation Method (CVM) are three major methods to value external social benefits and costs. Therefore, these 3 methods are not limited to the cost side evaluation, they can also be used in evaluating the benefits.

Both HPM and TCM are revealed-preference methods. On the other hand, the CVM is a stated-preference method. The difference between revealed-preference method and stated-preference method is indirect techniques and direct techniques. For example, the revealed-preference method is likely to housing preference or recreational demand. However, the stated-preference method is likely to value solicited from hypothetical questions.

#### 2.3.3.1 Hedonic Pricing Method (HPM)

The Hedonic Pricing Method (HPM) evaluates an improvement in water quality in a stream that passes through a residential area (but is not used for drinking water). Due to the demand of drinking water is necessary for everybody, assumptions necessary to interpret the results as measures of WTP are restrictive and, in many real world settings are unrealistic.

Besides, HPM is a regression technique which calculates the value placed on the environment. It is behavior-based and works well for urban environmental quality and to monitor health and safety in the work place. Its disadvantages include resident's use value, it is used only in urban areas, and the usual perception problems associated with regression analysis in general (Loomis, 2002). Results are sensitive to the econometric assumptions adopted – empirical results depend on form selected. Full HPM studies require a considerable amount of data, which may be difficult and expensive to collect.

Use noise pollution created in reservoir dredging as an example, the technique of HPM is based on direct observation of consumer behavior. The basic idea is that willingness to pay (WTP) for noise environment quality around the reservoir dredging area is revealed in the market price for reservoir dredging effects. The government authorities of reservoir dredging need to compensate the resident for enduring the noise from the reservoir dredging operation.

An assumption of HPM is that changes in one of several types of attributes – including environmental quality – can affect the sale price of a property. To isolate the effects of specific environmental attributes on the price of reservoir dredging, the price needs to estimate a hedonic property price (or implicit price) function. HPM also needs to identify site characteristics which are related to the resources. The price of reservoir dredging can be represented as :

$P_H = f(L, T, M, E, EC, IB, EB)$

where $L$ : labor, $T$ : transportation, $M$ : dredging material disposal,

$E$ : expense of operation and management, $EC$ : external costs,

$IB$ : internal benefit, $EB$ : external benefit.

### 2.3.3.2 Travel Cost Method (TCM)

Another tool, the Travel Cost Method (TCM) is a method for estimating WTP for use values. TCM is based on the premise that WTP is a function of the costs of getting to the location and placing a value on recreational uses of the environment. For example, it may be used to calculate the value of recreation loss due to closure of swimming and water sport facilities for dredging operation or the value of recreation gains associated with improved water volume in a reservoir.

TCM is commonly applied in cost-benefit analysis and in natural resource damage assessments in which recreation values play a role. It is a good tool because it measures actual behavior and applies to rural and public land areas. On the other side, it measures only recreation use value and does not work well in urban areas (Loomis, 2002). Due to the standard TCM does not account for the quality of the experience, for example, crowding effects. Therefore, it does not work well in urban areas.

Furthermore, Hanley and Spash (1993) state that the basic problems of TCM are : 1. the choice of dependent variable, 2. multipurpose trips, 3. holiday-maker versus residents, 4. calculation of distance costs, 5. the value of time, and 6. statistical problems.

The basic approach of TCM indicates that information on visitors' total expenditure to visit a site is used to derive their demand curve for the site. If a consumer wants to use a site they must visit it. The travel cost to reach the site is considered as the implicit or surrogate price of the visit. Moreover, changes in travel cost should cause the number of visits to vary. The basic travel cost of recreational function, in this study, can be expressed as :

$V = f(W, S, F, O)$

where $W$ : water sport facilities, $S$ : swimming, $F$ : fishing,

$O$ : other types of recreation, all expressed in dollar value.

#### 2.3.3.3 Contingent Valuation Method (CVM)

The Contingent Valuation Method (CVM) is one of the most common techniques used to value non-market natural resource goods and services. The non-market natural resource goods and services can be given in the care of the watershed management and conservation plan or even if dredging operation. CVM can also be used to elicit values about very specific changes in the provision of goods and services, since it does not rely on observed data. In addition, it can be used to value any change in environmental quality. Nas (1996) states that CVM is used when no observation behavior exists to reveal individual preferences for proposed public actions.

CVM can be applied to non-users and has a wide range of other benefits. Again, CVM applying to non-users and having a wide range of other benefits can be given in the care of the watershed management and conservation plan or even if dredging operation. However, its disadvantages include hypothetical or intended behavior, it is expensive and time consuming, and non-users are not likely to monitor the outcome (Loomis, 2002). In terms of hypothetical or intended behavior, the CVM is systematic over or understatement of true value.

It focused on a welfare change by measuring willingness to pay or willingness to accept types of questions. For instance, CVM can put a value on environmental improvement or damage circumstance. The individual's maximum WTP to obtain the improvement (avoid the damage); or the individual's minimum willingness to accept (WTA) compensation to forgo the improvement (consent the damage). According to Boardman et al. (1996) the characteristics of CVM include :

1. A survey which measures an individual's willingness to pay.
2. Estimating willingness to pay by using information.

3. Responses are used to estimate the benefit which is affected by the policy or project.

Levin and McEwan (2001) make the following comment about contingent valuation : “because of the difficulty of estimating benefits, the contingent valuation method will need to rely on individuals to honestly approach their maximum willingness to pay. The CVM is a stated preference. Measuring consumer preferences for environmental amenities in hypothetical situations, by asking individuals to directly state their preferences. Moreover, the basic idea behind CVM is to ask individuals questions which provide information about their WTP for an environmental improvement (noise for example). This method involves observing responses to a controlled hypothetical situation.

Finally, All mechanized equipment makes noise, but the majority of dredging activities are relatively quiet and compare favorably with many other construction activities. Valuing noise annoyance is almost always based on the willingness to pay concept. WTP reflects the awareness by individuals of noise effects and the community or individuals’ willingness to pay to reduce or prevent transportation noise. Noise from traffic is considered by many to be the most serious road transport external impact. The external noise costs are typically estimated by Hedonic prices or by survey methods such as the CVM (Soguel, 1995).

### 2.3.4 Applying HPM, TCM, and CVM to Environmental Influences

After introducing the 3 approaches to the measurement of intangible and non-marketable costs and benefits, it is critically important to apply on the internal benefits and costs and external benefits and costs for reservoir dredging. These 3 methods have its advantages and disadvantages, reservoir dredging operations can be used to apply them to environmental influences.

General speaking, the internal benefits and costs can be measured by quantitative analysis for management. The external benefits will relate to public goods issue. The pricing mechanism should be different from Pigouvian tax / subsidy. The characteristics of public goods are as following : 1. consumption is non rival, 2. non excludable, and 3. non rejectable. In the previous diagram, the Pigouvian per unit tax (AB) indicates that Taipei water users and recreational users need to pay the tax. However, in terms of the non excludable characteristic of public goods, the tax paying should be financed by green tax revenue, not by user's fee. Moreover, the external costs of reservoir dredging operations occur lots of environmental influences which include water quality, air quality, noise and vibration, traffic, ecosystem and others.

First, the HPM is a market approach, attempting to assess the value attributed by buyers to the environmental attributes of a dwelling (Gilpin, 2000). Thus, in this study, the difference in reservoir dredging operations' price can be used as an estimate of city water users' and the tourists' who use the reservoir and water facilities willingness to pay for a better environment. Furthermore, the assumption of HPM including environmental quality which can affect the sale price of a property. Therefore, HPM is suitable for the evaluation of all the external benefits and costs.

Second, the basic approach of TCM is that information on visitor's total expenditure to visit a site is used to derive their demand curve for the site. Furthermore, TCM is based on the premise that WTP is a function of the costs of getting to the location and pricing a value on recreational uses of the environment. TCM is also particularly useful for assessing the economic value of natural areas or recreational areas where no price is directly charged (Gilpin, 2000). In this study, the willingness to pay for an environmental amenity is assumed to be measured in the costs incurred by visitors when traveling to chosen locations. Therefore, TCM is suitable for the evaluation of all the external benefits such as swimming, recreational fishing, and recreational activity. TCM is also suitable for the evaluation of some external costs such as road maintenance, traffic problems, and ecosystem damage.

Third, the CVM is valuing of an environmental improvement (damage) to set the individual's maximum WTP to obtain (avoid) the improvement (damage) or the individual's minimum WTA to compensation to forgo (consent) the improvement (damage). Gilpin (2000) states that CVM is a method of establishing a monetary value for a good or service by asking people what they are prepared to pay for it. Therefore, in this study, CVM is suitable for the evaluation of all the external benefits and costs.

Finally, in terms of the environmental influences on noise and vibration issue, the HPM and CVM are both suitable for the evaluation. Due to the CVM is measuring consumer preferences for environmental amenities in hypothetical situations, this method can be used by asking individuals to directly state their preferences. The CVM is the most suitable for the evaluation of the value of noise and vibration.

## 2.4 Dredging by Mechanical and Hydraulic Methods

There are two main methods of dredging : mechanical and hydraulic dredging. Mechanical dredging typically uses a bucket to scoop up material. It easily removes large pieces of material. Hydraulic dredging, on the other hand, uses a vacuum to suck up the bottom sediment. Basically, the best method for a particular project depends on the sediment material, season, disposal place, and environmental characteristics of reservoir.

Palermo (2000) lists three sediment disposal alternatives

1. Open-water disposal : the placement of dredged material into rivers, lakes, estuaries, or oceans via pipeline or release from hopper dredges or barges.

2. Confined disposal : the placement of dredged material within disked island, nearshore or upland confined disposal facilities, via pipeline or other means.

3. Beneficial use or recycling : the placement or use of dredged material for some productive purpose, such as used by building materials.

### 2.4.1 Mechanical Dredging

Low water levels in the dry season make mechanical dredging effective at most of the reservoirs in Taiwan. The method has been used in the Paiho, Tapu, Mingte, Chingmien, and Shihmen reservoirs.

Hadihardaja (2000) explains that the mechanical approach utilizes buckets to excavate and move up sediment with insignificant water entrapment to the surface (Morris and Fan, 1998). Several types of mechanical dredges are used, however, dipper and clam shell dredges are the two most common.

Mechanical dredges are ideal for removing hard-packed materials or debris. The mechanical dredges can be worked in confined areas and efficiently place the material onto barges for transport to a disposal site via land carriers. Mechanical dredging guidelines and standards are available at http://www.epa.gov.tw.

### 2.4.2 Hydraulic Dredging

Hydraulic dredging works well in those reservoirs where fine sediment is the primary deposit. This dredging method has been used in the Paiho and Shihmen reservoirs. Hadihardaja (2000) states that the hydraulic approach excavates sediment which is blended with a significant quantity of water and moved from the point of removal to the designated replacement such as sediment-water slurry (Morris and Fan, 1998).

There is one thing in common for all kinds of hydraulic dredging. Having a centrifugal pump discharging either into the hold of the dredge itself, into barges alongside, or ashore. In addition, they also all have a suction line through which the pump is supplied with material.

### 2.4.3 Dredging Cost

Randall (2000) states that dredge cost components include fuel, lubricants, dredge crew, land support crew, routine maintenance and repairs, major repairs and overhauls. The possibility of financial benefit from recycling will vary. For instance, the dredged material from the topset bed of the reservoir could be used in building projects. However, the dredged material from the buttomset bed of the reservoir near the dam site would likely be muddy, without any recycling potential.

The total dredging costs not only include dredging operations and transportation, but also include handling and disposition of dredged material. The dredging costs just include estimation of internal costs only. In Taiwan, generally speaking, the average hydraulic dredging costs are NT $ 480 (approximately US $

15.00 per cubic meter, and the mechanical dredging costs are NT $ 341 (approximately US $ 10.66) per cubic meter (Tsu and Chun, 2002 B). In the United States, the hydraulic dredging costs are US $ 5-15 per cubic yard, and the mechanical dredging costs are US $ 8-30 per cubic yard. Theoretical speaking, cost-benefit analysis should compare all costs (internal plus external), not just the internal costs only. Finally, it is inappropriate to compare only the internal costs to do the cost-benefit analysis. More information about hydraulic and mechanical dredging costs are available at

http://www.epa.state.il.us/water/conservation-2000/lake-notes/lake-dredging.

**2.5 Internalization (Controlling) of Externalities**

In terms of economic instruments for environmental regulation, the purpose is to use estimated environmental values to improve the free-market allocation of environmental resources. Moreover, economic instruments for pollution control can be divided into command and control instruments (technology-based regulations, emissions-based regulations) and market based instruments (pollution charges, tradable permits). Externalities can be internalized (controlled) by a tax on the party that generate pollution, levied by the government. Alternatively, externalities can be resolved by voluntary solutions that involve trading of property rights. Thirdly, government command and control and economic incentives can also be used to internalize externalities.

In terms of governmental funding issue, this study assumes that the Feitsui Reservoir dredging project is not going to compete with other government projects for the funding. The beneficiary from Taipei Water Department would pay the water fees to correct the externalities after enforcing reservoir dredging project. Again, the beneficiary would include the city water users, the tourists who use the reservoir and water facilities should share the burden of the tax.

### 2.5.1 Economic Incentives

Economic incentives are likely to be market based instruments. For example, pollution charges on environmental taxes, tradable emissions permits and tradable catch quotas. Tradable emissions permits mean the issue of permits to produce a given level of emissions. Tradable emissions permits also can determine target environmental quality, then allowable emissions to achieve emissions permits. Besides, auction and grandfathering are the normal methods during allocate permits procedure.

In this study, the government reservoir dredging authorities allow trade in permits. However, the reservoir dredging companies will demand permits if abatement costs are greater than market price of permits and vice versa. Thus, at equilibrium, marginal cost of all the reservoir dredging companies is equal. This situation will meet the total pollution reduction achieved at lowest cost.

The advantage of tradable emissions permits is reflected in the achievement of the target level of pollution reduction at lowest total cost. However, the problems of tradable emissions permits include transaction costs, competitive problems, and unknown costs. Optimal pollution level is difficult to estimate, resulting in large costs to polluters (internal and external costs), and different traders would come up with different estimates of cost. In addition, an optimum standard is difficult to determine, especially with non-marketable goods, such as air. Finally, economic incentives might include the Pigouvian tax.

### 2.5.2 Pigouvian Tax

Pigouvian tax can be defined as a tax enacted to correct the effects of a negative externality. Pigouvian tax should approximate MEC. A Pigouvian tax on the output of a polluting good, gasoline or electricity will be an example. The Pigouvian tax will give firms incentives to reduce the bad, without reducing the good we want. It would be an incentive to reduce pollution per unit output in short run. In addition, Baumol and Oates (1998) comment that Pigouvian tax provides the proper incentive for the supplier of the externality while leaving its consumer with a zero price. Therefore, a polluter can be taxed or bribed into reducing emission.

Most important of all, the beneficiary from Taipei Water Department would pay the water fees to correct the externalities after enforcing reservoir dredging project. The beneficiary would include the city water users, the tourists who use the reservoir and water facilities should share the burden of the tax as dictated by the objectives of the project. Meanwhile, if the people who enjoy the reservoir and water facilities and different from the general city water users, they should also pay for the benefit received the reservoir dredging operations. Finally, if the reservoir and water facilities are better treated as a public good, then the water resource government authorities should share that part of the costs and finance through general tax revenue. This would mean that water users from Taipei Water Department would not pay the full Pigouvian tax.

On the other hand, the shortcoming for a Pigouvian tax is that the government needs a lot of information to choose the right amount to tax because marginal environmental costs (the damage function, the marginal benefit function, and the private marginal cost function, as well as the external costs of resource use that could be saved by recycling) are difficult to measure correctly.

### 2.5.3 Subsidies

Generally speaking, taxes and subsidies on the generation of externalities are symmetrical. Taxes reduce the polluters' emission, and a subsidy is an incentive to induce the reductions of pollution. (a company will receive more subsidy for more pollution reduced.) For the Feitsui Reservoir management authorities [Taipei Feitsui Reservoir Administration Bureau (TFRAB) and Taipei Watershed Management Bureau of Water Resources Agency, Ministry of Economic Affairs (WRATB)] who will receive government funds in lieu of subsidies from Taipei City Government and Water Resources Agency, Ministry of Economic Affairs to promote reservoir watershed conservation and management.

Subsidies could be used to strengthen water utilization management, raise water utilization efficiency, and properly allocate of water resources. In addition to empowering the water resources authorities, directions and rules are needed for private firms to prevent and protect water quality. Some argue that government subsidies, in general, are a satisfactory substitute for taxes. Compensating the private companies can distort choices involving defensive activities by themselves to reduce the damages they suffer. For example, the tea farmers tend to rely on doing watershed conservation in order to reduce sedimentation to receive the government's subsidies.

## 2.6 Water Administration and Policy Setting

Water resources policy manages the environmental impact of distributing water use. Dredging projects, hydraulic or mechanical, are subject to approval of the Taipei City Government. Both TFRAB and Taipei Watershed Management Bureau are responsible for protecting and maintaining the safety and purity of the water supply for the Taipei metropolitan area.

Because Feitsui Reservoir and watershed are located in Taipei County, the administrative management belongs to Taipei City Government. The city and the reservoir administration, therefore, do not always agree on policies. De Mooij (2000) states that political discussions about environmental policy instruments are often dominated by distributional concerns, rather than efficiency concerns.

In June 1987, the Taipei City Government established the TFRAB to administer reservoir operation, maintenance, and watershed management. The detailed responsibilities of the group are listed on its website at http://www.feitsui.gov.tw. Water resources management is complicated because it involves legal, environmental and political decisions about water resources use. For example, water resources management depends on the government's ability to establish an appropriate legal, regulatory and administrative framework.

Brent (1996) states that when an externality exists, the recommended public policy instrument for bringing about the social optimum is the Pigouvian taxes or subsidies. Nas (1996) also states that externalities could be internalized by mutual agreement among the parties involved or corrected through government intervention. Negotiation provides an efficient solution when the parties involved in an externality problem are few and negotiation costs are small.

Finally, policy setting should consider sustainable development. Langston (2001) states that understanding and connecting environmental and economic issues contributes to sustainable development. Therefore, public participation plays an important role in the policy setting process. Governments can internalize external effects by setting production standards, imposing taxes and subsidies, or auctioning marketable pollution permits.

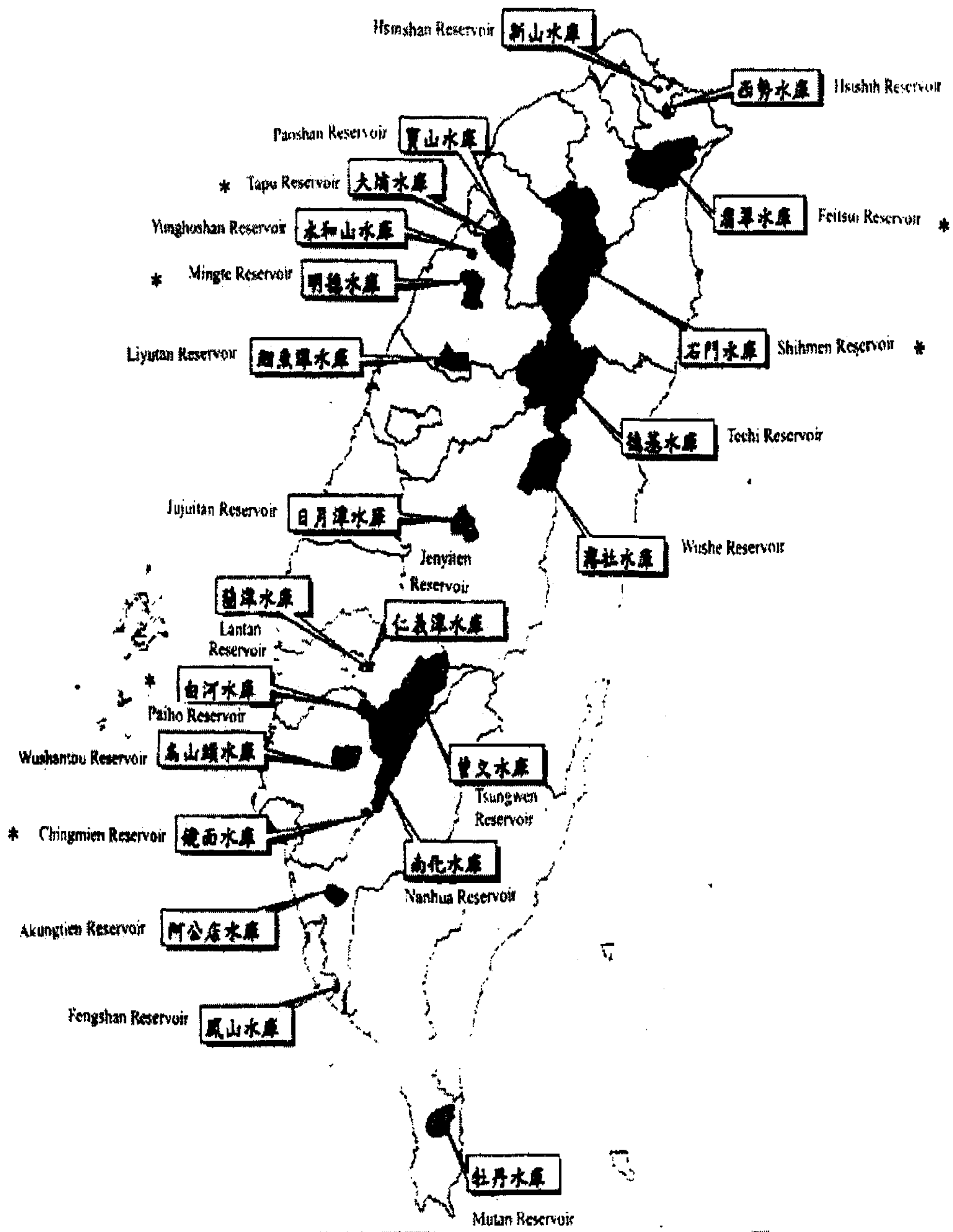
# CHAPTER III
# CASE STUDIES ON RESERVOIR DREDGING

## 3.1 Introduction

Watershed sedimentation has significantly decreased the effective storage capacities of many reservoirs in Taiwan. Dredging has been used in many of the island's reservoirs to mitigate this problem : Paiho, Tapu, Mingte, Chingmien, Shihmen, Wushantou, Hutoupi and Teyuanpi Reservoirs, and Shihkang Dam (see Map 2 for the locations of the reservoirs studies).

This study examines the dredging operations at the five reservoirs with the most complete data : Paiho, Tapu, Mingte, Chingmien and Shihmen (see Table A.2 for comprehensive data). The benefits, costs, environmental impact and policies for on-site dredging operations and material disposition are considered for each reservoir. Costs for each reservoir are determined based on a wholesale water price of NT $ 7 per cubic meter and an annual interest rate of 6 % (Water Resource Bureau, Ministry of Economics Affairs, 1994, p.45).

Map 2 : Location of Taiwan's reservoirs




Source : Water Resource Bureau, Ministry of Economics Affairs (2000 B)

Table A.2 : Data for Paiho, Tapu, Mingte, Chingmien, Shihmen, Feitsui Reservoir watersheds

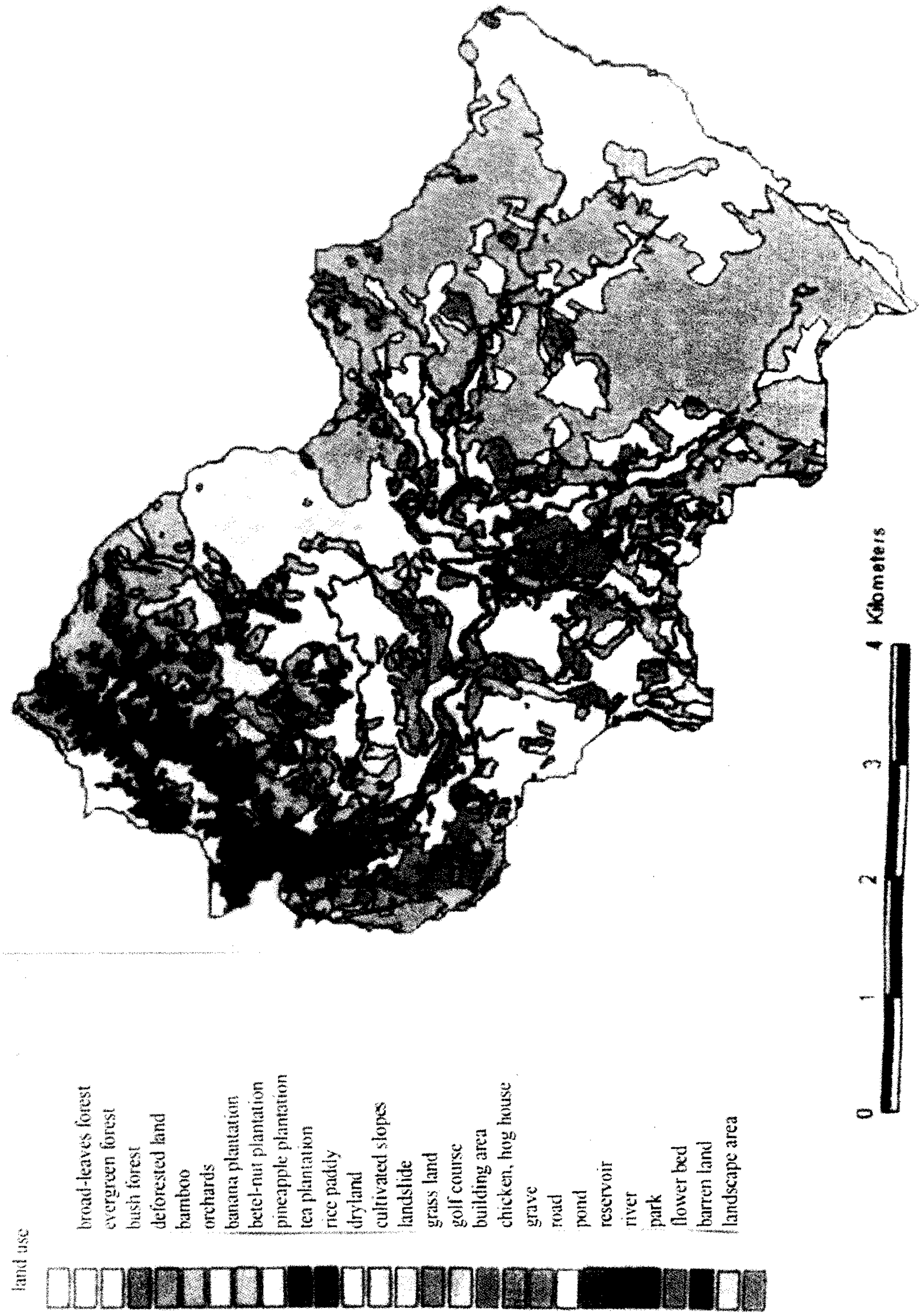
| | Paiho | Tapu | Mingte | Chingmien | Shihmen | Feitsui |
|---|---|---|---|---|---|---|
| Watershed area($km^2$) | 26.6 | 100 | 61.1 | 2.73 | 763.4 | 303 |
| Reservoir capacity($1000m^3$) | 25093 | 5499.4 | 17700 | 1150 | 309120 | 406000 |
| Average steepness(%) | 40.15 | 40.25 | 54.13 | 34.54 | 66.99 | 51.69 |
| Average annual precipitation(mm) | 2843.3 | 2047.4 | 1731.3 | 2559.9 | 2378.8 | 3524.5 |
| Land use(%) | | | | | | |
| Forest | 41.57 | 64.73 | 63.35 | 21.9 | 93.89 | 87.23 |
| Tea plantation | 0.02 | 1.23 | 0.88 | | | 3.84 |
| Reservoir | 5.17 | 0.12 | 2.24 | | 0.99 | 2.8 |
| Grass land | 2.78 | 1.89 | 2.19 | 1.18 | 1.46 | 1.19 |
| Barren land | 2.72 | 4.25 | 1.65 | 2.09 | | 1.07 |
| Orchards | 3.62 | 9.06 | 2.15 | 65.93 | 3.05 | 0.28 |
| Landslide | 0.64 | 0.01 | 0.02 | 0.12 | 0.58 | 0.04 |
| Bamboo | 3.3 | 6.44 | 21.12 | 0.79 | | 0.25 |
| Betel-nut plantation | 34.97 | 0.46 | 0.09 | 1.14 | | 0.15 |
| Pond | 0 | 0.78 | 0.27 | 4.13 | | 0.01 |

Source : Water Resource Bureau, Ministry of Economics Affairs & Department of Hydraulic and Ocean Engineering, National Cheng Kung University (1998)

### 3.2 Paiho Reservoir

The Paiho Reservoir is located upstream of Paishuei Creek which is a tributary of Jishuei Creek in Paiho, Tainan County. The dam site of the Paiho Reservoir is upstream of Paishuei Creek, about 20 kilometers from Hsinying, Tainan County. Land use classifications are shown on Map 3.

Map 3 : Land Use Classifications of Paiho Reservoir Watershed (Taiwan)




Source : Water Resource Bureau, Ministry of Economics Affairs (2000 B)

Reservoir capacity of Paiho Reservoir was 25,093,000 cubic meters when it was completed in 1965. The Paiho Reservoir serves a number of purposes, including irrigation, domestic water supply, and flood prevention and is administered by Chianan Irrigation Association.

Between June 1965 and March 1992, the average deposit of sediment for Paiho Reservoir was 353,800 cubic meters per year. The largest source of this sediment was from landslides in the watershed (Water Resource Bureau, Ministry of Economics Affairs, 1994). Other sources include poor land use, new slope cultivation without proper conservation measures.

### 3.2.1 Dredging Operation

In order to recover reservoir capacity, both mechanical and hydraulic dredging have been used at Paiho Reservoir since 1991. Only hydraulic dredging costs are available for this site. The volume removed was 679,250 cubic meters of sediment at the Paishuei Creek intake. The average hydraulic dredging per unit costs were NT$ 171.429 (approximately US$ 5.357)/cubic meter, and the total average mechanical dredging per unit costs were NT$ 143.25 (approximately US$ 4.477)/cubic meter.

In 1992, the total average hydraulic dredging per unit costs were NT$ 36.667 (approximately US$ 1.146)/ cubic meter, and the mechanical dredging per unit costs were NT$ 110 (approximately US$ 3.438)/ cubic meter (Water Resource Bureau, Ministry of Economics Affairs & Department of Hydraulic and Ocean Engineering, National Cheng Kung University, 1994).

This study indicated that mechanical dredging could best be conducted during the dry seasons from November through March when the water level is lowest at the Paishuei Creek intake. Hydraulic dredging could be done year round at the Hsientankeng Creek intake.

### 3.2.2 Cost-Benefit Analysis and Mechanical Dredging

In terms of economic efficiency, a benefit-cost ratio is one of the best methods for evaluating a reservoir dredging project. Reservoir dredging costs include dredging operations and material disposal. According to the records of dredging data and information for Paiho Reservoir, the mechanical dredging project for Paiho Reservoir removed 283,194 cubic meters of bottom sediment at a cost of NT$ 32,000,000 between 1993 and 1994. Unfortunately, there is insufficient data for hydraulic dredging for this reservoir.

Dredging benefits, in this case, only considered the income increased by selling more water; without considering agricultural and industrial benefits. The dredging benefit was calculated to be NT$ 48,075,000. The resulting of benefit-cost ratio was 1.502 (see Appendix C for comprehensive data).

### 3.2.3 Environmental Impact and Public Policy

It is important to minimize dredging's effects on the surrounding environment. Generally speaking, reducing impacts on the surrounding environment will internalize the externalities. Dredged material was used to stabilize a near by slope.

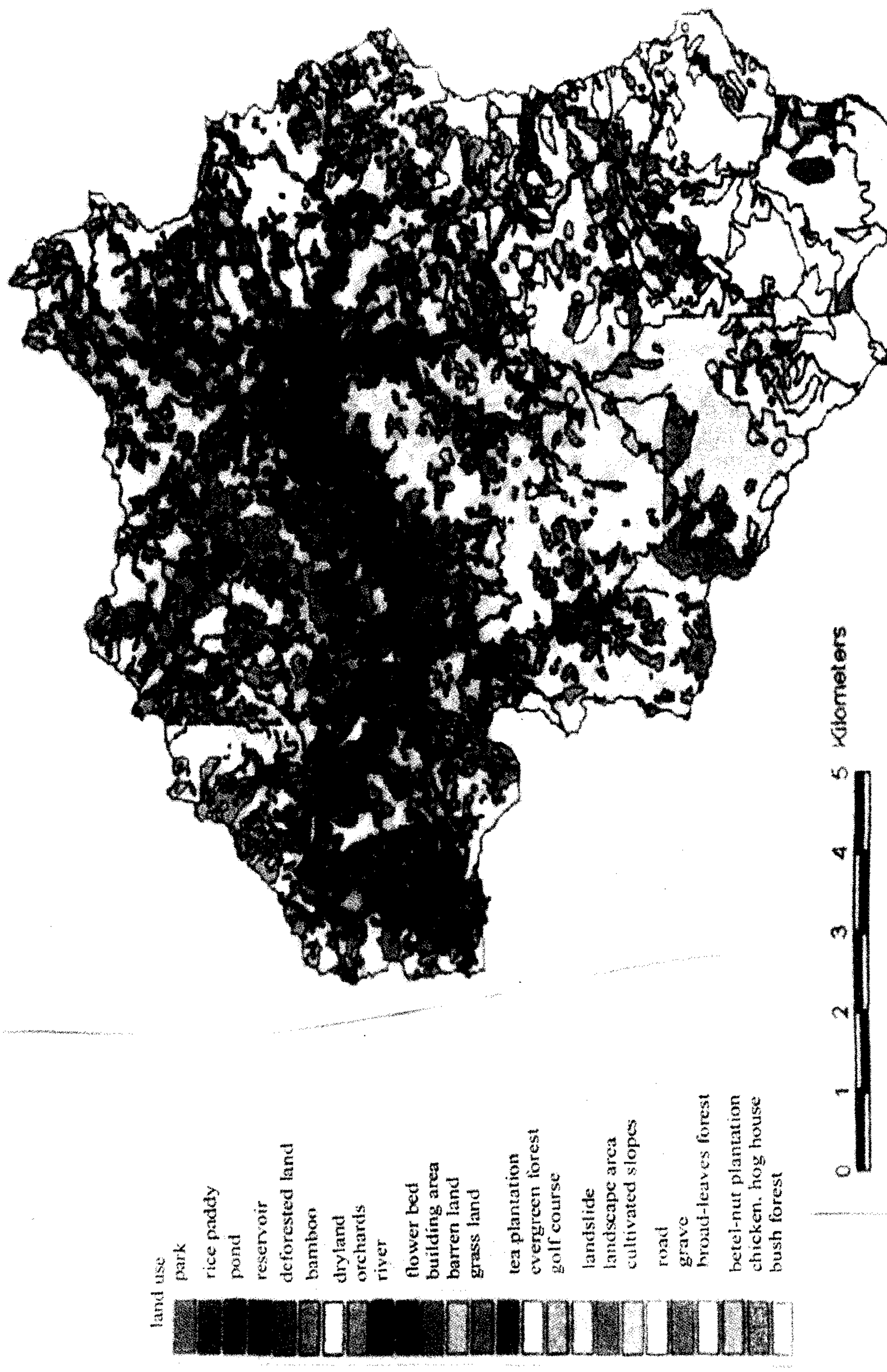
Dredged material was also disposed of in a vacant field. The disposal area was within two kilometers of the dredging area, and no significant environmental impacts resulted from the deposition.

## 3.3 Tapu Reservoir

The Tapu Reservoir is located in the middlestream of Emei Creek which is a tributary of Jhonggang Creek in Emei, Hsinchu County. The Tapu Reservoir is about six kilometers from Tunglo, Miaoli County. The land use classifications are shown on Map 4.

When the reservoir was completed in 1960, the capacity of the Tapu Reservoir was 9,000,000 cubic meters. It is administered by the Miaoli Irrigation Association and serves a number of purposes, including irrigation, domestic water supply, and flood prevention.

Map 4 : Land Use Classifications of Tapu Reservoir Watershed (Taiwan)




Source : Water Resource Bureau, Ministry of Economics Affairs (2000 B)

A large amount of sediment diminished the reservoir's original storage capacity. This has a particularly direct effect on the water supply during dry seasons, especially in supplying water for the rapidly growing population and industry demand downstream of the reservoir. With no other water storage in this area, the demand on Tapu Reservoir will likely continue to increase.

### 3.3.1 Dredging Operation

The reservoir administrators had attempted to use a flushing and emptying method to drain sediment through the dam gates and thereby recover reservoir storage. Unfortunately, the effort was not successful because of the damage caused in downstream area.

Mechanical dredging at the Tapu Reservoir during the dry seasons from 1993 through 1994 removed 638,000 cubic meters of bottom sediment. The total average mechanical dredging per unit costs was NT$ 53.292 (approximately US $ 1.665)/ cubic meter (Water Resource Bureau, Ministry of Economics Affairs, 1994).

The dredged material was used to improve a flood-damaged farm field. This farm suffered frequent flood damages from Emei Creek. The dredged material reduced the flood damage. This case study indicated that mechanical dredging could best be conducted from November through December at the upper intake, while hydraulic dredging was effective year round in the lower reservoir area.

### 3.3.2 Cost-Benefit Analysis

Again, the economic efficiency of reservoir dredging is best evaluated by analyzing its benefit-cost ratio. Reservoir dredging costs include dredging itself, material transportation, disposal handling, and clean up. The total costs was NT $ 34,000,000 from 1993 to 1994. However, there is not sufficient data for the cost of hydraulic dredging at this reservoir.

Dredging benefits only considered the income increased by selling water without considering agricultural, industrial production, and flood reduction . The dredging benefit was calculated at NT $ 359,460,000, with a benefit-cost ratio of 9.906 (see Appendix C for comprehensive data).

The benefit came from additional income revenue generated from increased water sales after the 1994 dredging. Agricultural and industrial production were not calculated.

### 3.3.3 Environmental Impact and Public Policy

Dredged material was used to improve a flood-damaged farm field in the upper watershed of Hulutu. It is about seven kilometers from the dredging area. During transportation of dredging material, trucks were covered to reduce the dust and falling soils. Periodically, the roads were sprinkled with water and cleaned up to minimize air pollution. Unfortunately, these activities of reservoir dredging were not counted as external costs.

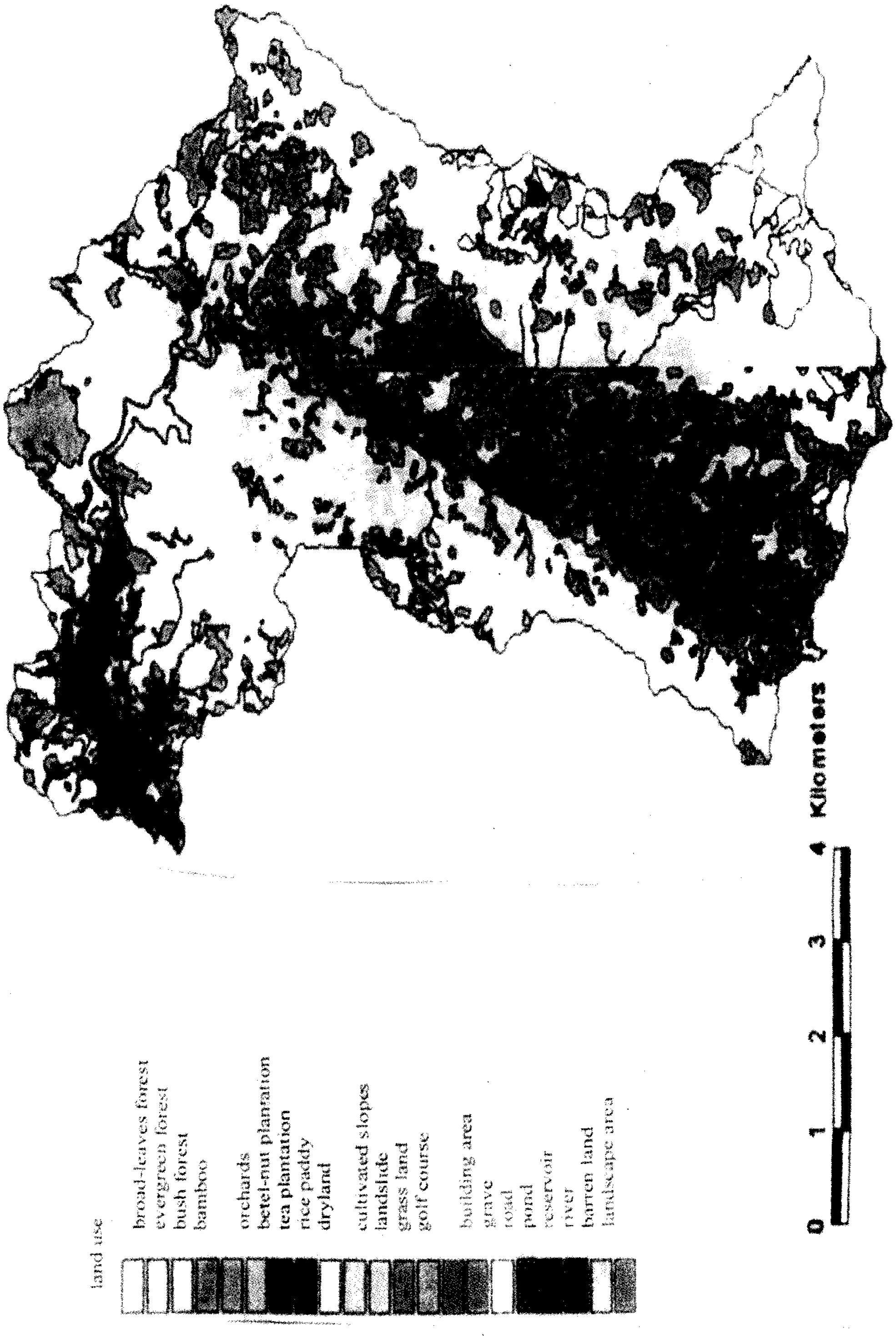
The Tapu Reservoir has lost 49 % of its original capacity since it was completed in 1960. Water shortages occurred from 1961 to 1987 for the Tapu Reservoir (Water Resource Bureau, Ministry of Economics Affairs & Department of Hydraulic and Ocean Engineering, 1994). With the rapid population growth and increasing industrialization in downstream of Toufen, Chunuan districts, the reservoir's capacity needs to be increased. Dredging is on-going.

### 3.4 Mingte Reservoir

The Mingte Reservoir is located at the mid-point of the Laotienliao Creek watershed. The dam site of Mingte Reservoir is about eight kilometers from the Miaoli City. Land use classifications are shown on Map 5.

Mingte Reservoir had a capacity of 17,700,000 cubic meters when it was completed in 1970. The reservoir is managed by the Miaoli Irrigation Association and serves a number of purposes, primarily irrigation, but also for domestic and industrial water supply and flood prevention.

Map 5 : Land Use Classifications of Mingte Reservoir Watershed (Taiwan)




Source : Water Resource Bureau, Ministry of Economics Affairs (2000 B)

Annual water demand is around 46,497,000 cubic meters. Available water falls short of that demand by about 22 percent. Since the reservoir was built, the communities it supplies have suffered serious water shortages annually except in 1979 and 1988 (Water Resource Bureau, Ministry of Economics Affairs, 1994).

### 3.4.1 Dredging Operation

Mingte Reservoir administrators have been experimenting with hydraulic dredging to reduce sediment and thereby recover reservoir capacity. However, dredging operations were stopped shortly after they began due to costs and material handling issues. Fortunately, these problems have been resolved and dredging has resumed.

Mechanical dredging at the upper end of Mingte Reservoir could best be conducted from October through December and during low-flow periods. Hydraulic dredging is possible year round at the lower end, and during high-flow seasons in the middle reservoir area.

### 3.4.2 Cost-Benefit Analysis

In terms of economic efficiency, the analysis is one of the best methods for evaluating a reservoir dredging project. Reservoir dredging costs include the dredging itself, material transportation, disposal handling, and clean up of the operational field.

The dredging benefit was calculated to be NT $ 195,567,000, resulting with a benefit-cost ratio of 4.008 (see Appendix C for comprehensive data). This benefit is from additional income from increased water sales after the 1994 dredging. Unfortunately, agricultural and industrial production issues were not calculated.

### 3.4.3 Environmental Impact and Public Policy

Dredged material was used for landfill in a gully about one kilometer to the watershed. A water resources researcher suggested that the designs of the retaining wall and drainage facility at the disposal site be reviewed by a certified civil engineer. No significant environmental impact resulted from this dredging project.

The trucks carrying the dredged material were covered to reduce the dust and falling soils. Periodically roads were sprinkled with water and cleaned up to minimize air pollution. Unfortunately, these activities for reservoir dredging were not counted as external costs.

## 3.5 Chingmien Reservoir

The Chingmien Reservoir is located upstream of Chialai Creek which is a tributary of Shengwen Creek in Naihu, Tainan County. The dam site of Chingmien Reservoir is at the lower end of the Chigmien Creek watershed. The dam site of

Chingmien Reservoir is about thirty kilometers from Tainan City. Land use classifications are show on Map 6.

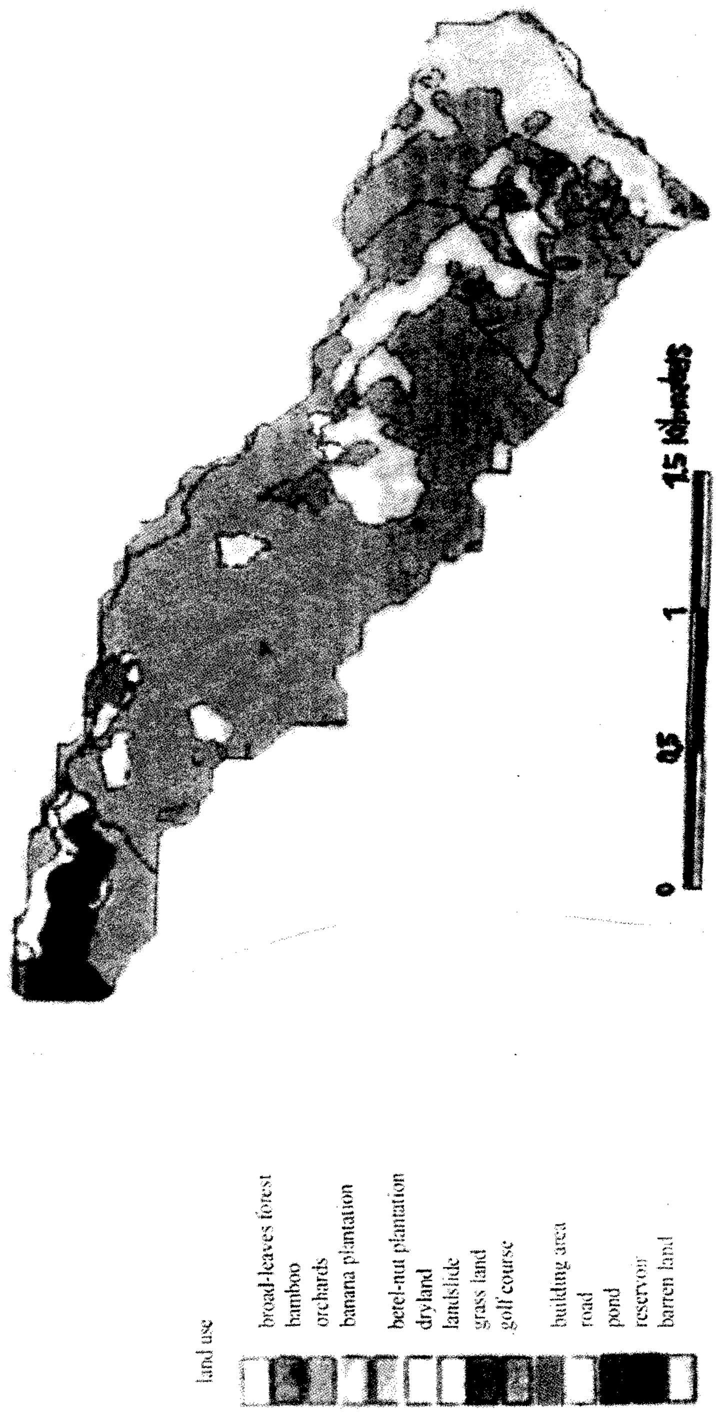
When built in June 1980, the Chingmien Reservoir capacity was 1,150,000 cubic meters. The reservoir is administered by the Taiwan Water Supply Corporation and its primary function is to provide domestic water to residents of Naihu, Tainan County. It also provides water for agricultural production.

The Taiwan Water Supply Corporation had planned two stages to remove the total of 100,000 cubic meters of sediment between March and June in 1994 and 1995, in order to maintain normal reservoir operations and prolong reservoir life. Unfortunately, this project lacked sufficient funding for implementation (Water Resource Bureau, Ministry of Economics Affairs, 1994).

### 3.5.1 Dredging Operation

According to 1994 Water Resource Bureau report, Chingmien Reservoir had one sediment measurement in November 1988, the only one since the dam was completed. Calculations showed that total reservoir storage had diminished from 1,150,000 cubic meters to 1,041,463 cubic meters, a decrease of 9.4 percent over eight years. Moreover, the live storage above dead storage had diminished from 987,000 cubic meters to 947,000 cubic meters, a loss of about 4.1 percent. Total reservoir storage in January 1994 was estimated to be about 981,165 cubic meters.

Map 6 : Land Use Classifications of Chingmien Reservoir Watershed (Taiwan)




Source : Water Resource Bureau, Ministry of Economics Affairs (2000 B)

The plan called for two phases of sediment removal by mechanical dredging. In the first phase, 50,000 cubic meters of sediment would be removed between March and June on one side of the reservoir's upper end in 1994. In the second phase, an additional 50,000 cubic meters would be removed between March and June on the other side of the reservoir's upper end in 1995. The plan was not carried out due to unknown reason.

### 3.5.2 Cost-Benefit Analysis

Generally speaking, the economic efficiency of reservoir dredging could be evaluated by analyzing the benefit-cost ratio. Reservoir dredging costs include dredging, transportation and handle of disposal material, and clean up the operational field (Water Resource Bureau, Ministry of Economics Affairs, 1994).

The estimation of reservoir dredging benefits, in this case, only considered the income increase of selling more water after sediment measurements in1988. Without considering agricultural and industrial production, the total dredging cost from the simulation of program was estimated to be NT $ 5,830,189 and the dredging benefit was predicted to be NT $ 8,480,000, both in 1994 currency values. The calculation assumed a unit mechanical dredging cost at NT $ 60 per cubic meter. The resulting benefit-cost ratio was 2.102 (see Appendix C for comprehensive data).

### 3.5.3 Environmental Impact and Public Policy

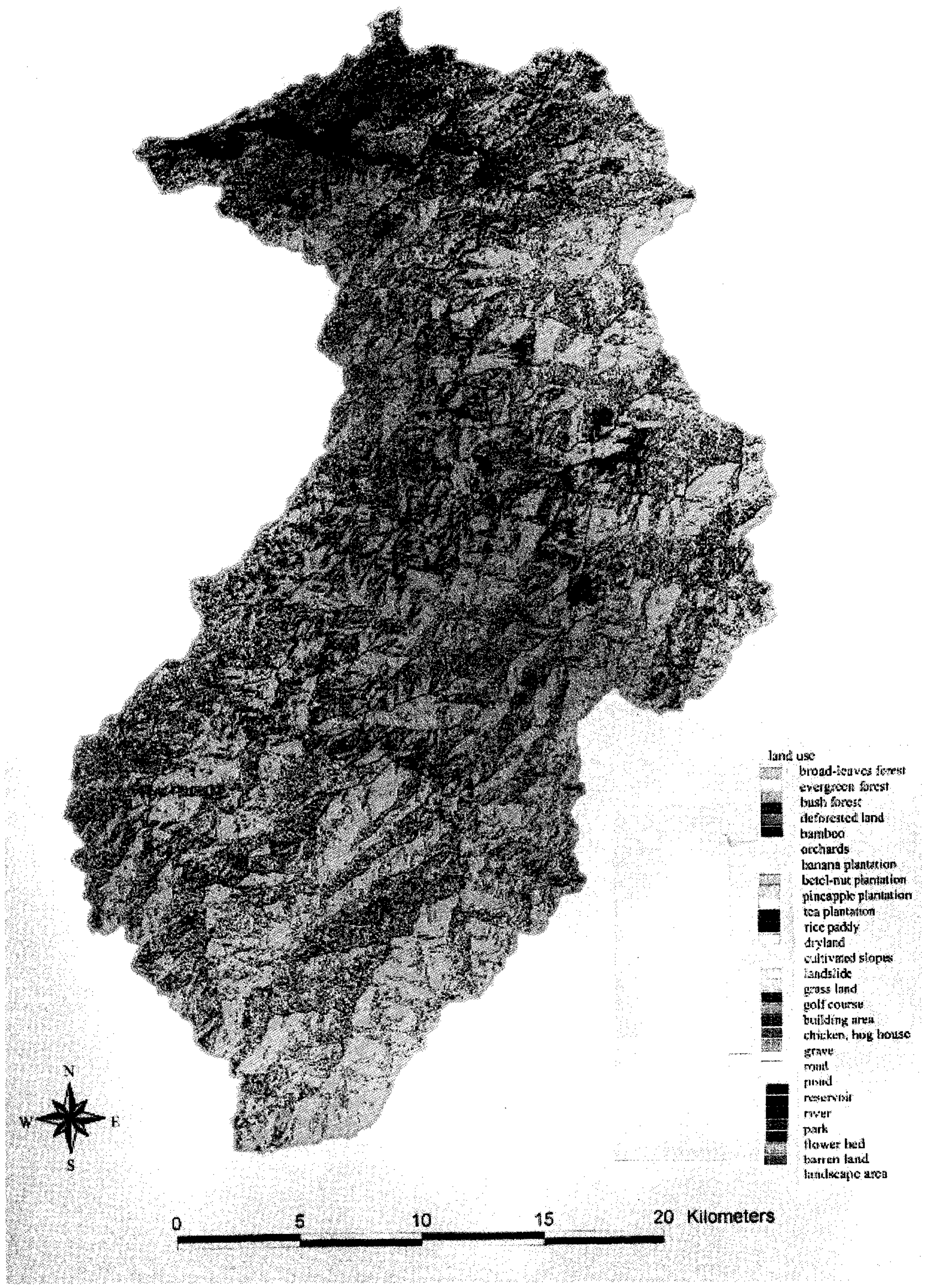
Because no water shortage has been experienced or anticipated for Chingmien Reservoir region, the proposed dredging was postponed until a need developed.

## 3.6 Shihmen Reservoir

The Shihmen Reservoir is located in the middle portion of the Tahan Creek watershed which is a tributary of Tanshui River in Lungtan, Taoyuan County. It is the third largest reservoir in Taiwan, supplying water to about 3.4 million people in 28 districts, as well as industrial customers in the region. Land use classifications are shown on Map 7.

Shihmen Reservoir's capacity was 309,120,000 cubic meters when it was completed in June 1964. It is administered by the Northern Region Water Resources Office, Water Resources Agency, Ministry of Economic Affairs (Water Resource Bureau, Ministry of Economics Affairs & Nungpang Technical Adviser Limited Corporation, 2002). The Shihmen Reservoir provides water for irrigation, hydroelectric power, domestic water use, flood prevention and tourism. The irrigation service area includes Taoyuan and Taipei, and covers 36,500 hectares.

Map 7 : Land Use Classifications of Shihmen Reservoir Watershed (Taiwan)




Source : Water Resource Bureau, Ministry of Economics Affairs (1998 B)

### 3.6.1 Dredging Operation

Sedimentation has significantly decreased the effective storage capacity of the reservoir in spite of tremendous efforts have been invested in Shihmen Reservoir watershed management work. To recover capacity, the Shihmen Reservoir has been dredging since 1976. In one year (November 1993 to November 1994), for example, dredging removed 395,000 cubic meters of sediment (Water Resource Bureau, Ministry of Economics Affairs & Department of Soil and Water Conservation, National Chung Hsing University, 1998).

Between 1977 and 1994, hydraulic dredging removed 6,000,000 cubic meters of sediment from the mid-section of the reservoir. In 1984, sediment was also removed from the lower end of the reservoir. The total average hydraulic dredging unit costs was NT$ 271 (approximately US$ 8.469)/ cubic meter (Water Resource Bureau, Ministry of Economics Affairs & Nungpang Technical Adviser Limited Corporation, 2002).

### 3.6.2 Cost-Benefit Analysis

By assessing past reservoir dredging of the Shihmen Reservoir and the 2003 - 2007 yearly data of dredging planning estimation, dredging could maintain the hydropower function of the reservoir through hydraulic excavation. Annually, this project would remove about 300,000 cubic meters sedimentation near the intakes.

According to 2003 - 2007 yearly dredging project costs of dredging planning estimation, the benefit-cost ratio was calculated to be about 1.961 (see Appendix C for comprehensive data). These ratios demonstrate the economic efficiency of the Shihmen Reservoir dredging project (Water Resource Bureau, Ministry of Economics Affairs & Nungpang Technical Adviser Limited Corporation, 2002).

### 3.6.3 Environmental Impact and Public Policy

Reservoir dredging generally affects environment quality. Dredged material was dumped in a vacant field just a few kilometers from the dredging area. Trucks were covered to reduce dust and spills. The road was sprinkled with water and cleaned up periodically to minimize air pollution. No significant environmental impact resulted from this reservoir dredging project. Consequently, these activities for reservoir were not counted as external costs.

## 3.7 Conclusions

Dredging is important to maintain and recover reservoir capacity. The choice between mechanical excavation and hydraulic dredging will depend on the conditions of the reservoir itself, including incoming water and sediments flow, sediment size and physical characteristics, location of sediment, reservoir operation strategy, and the opportunity for recycling (Water Resource Bureau, Ministry of Economics Affairs &

Department of Hydraulic and Ocean Engineering, National Cheng Kung University, 1994).

The dredging operations at the reservoirs reviewed here – Paiho, Tapu, Mingte, Chingmien, and Shihmen – all had cost-benefit ratios in excess of 1.502. Collectively, these case studies provide information and data that can be used to calculate a benefit-cost ratio for dredging the Feitsui Reservoir.

Public policy associated with water resource development and public water supply needs to be carefully assessed. Even if a reservoir dredging program is not justified by cost-benefit analysis, public policy could dictate its implementation. The influences of public policy may affect water supply, future water demand, water resource economics and social issues.

# CHAPTER IV
# RESERVOIR DREDGING SIMULATION

## 4.1 Introduction

In order to maintain the functions of a reservoir, dredging is used to recover effective reservoir capacity and its efficiency. Efficiency is measurable by measuring storage capacity after a dredging program. Although not all reservoir are used for the same purposes, typical uses are :

1. Domestic water supply.
2. Hydroelectric power.
3. Irrigation.
4. Flood prevention.

The ability of a reservoir to fulfill its various demands can be estimated by simulating reservoir operations.

The increase in annual sediment deposits in the Feitsui Reservoir is a serious problem. Reservoir dredging is an alternative to extend the reservoir's life and thereby eliminate the need for a new water storage project. A cost-benefit analysis was needed to estimate the benefit-cost ratio of dredging for Feitsui Reservoir by using data and information of reservoir dredging of Paiho, Tapu, Mingte, Chingmien, and Shihmen reservoirs in Taiwan. The sensitivity analysis of Feitsui Reservoir uses logical assumptions for varying the increase and decrease all input values (+/-) change of 5% and 10 % at the same time by running a simulation computer program.

### 4.2 Methodology for Program Dredge

The purpose of a model is to save money, time, effort, or some other valuable commodity. A computer program called Program Dredge (see Appendix B) was developed to assist in the cost-benefit analysis of the dredging (Water Resource Bureau, Ministry of Economics Affairs & Department of Hydraulic and Ocean Engineering, National Cheng Kung University, 1994). In this study, the Program Dredge was modified slightly to perform related cost-benefit analysis. The program includes :

1. Simulation of reservoir storage after dredging.
2. Calculation of annual residuals of the dredging volume.
3. Calculation of annual benefits from increased water sales.
4. Conversion of annual benefits to the present value.
5. Calculation of benefit-cost ratio.

### 4.2.1 Input Variables of Program Dredge

The program computes annual reservoir storages with and without dredging, and performs the related cost-benefit analysis with the reservoir dredging program. The input variables include :

1. Annual interest rate.
2. Wholesale water price (NT $ /cubic meter).
3. Reservoir storage utilization frequency.
4. Unit dredging cost (NT $ /cubic meter).
5. Reservoir storage at beginning of simulation.
6. Annual runoff volume for the simulation period.
7. Average reservoir storage for the record period (year).
8. Annual runoff volume for the record period (year).
9. Annual sedimentation rate for the record period (year).
10. Brune's trap efficiency curve (1 = fine, 2 = median, 3 = coarse).
11. Simulation period in years.
12. Stages of dredging.
13. Dredge volume.

Besides, the above input variables can be explained. For instance, reservoir storage utilization frequency at point 3 = annual water supply / live storage.

Moreover, the trap of Brune's trap efficiency curve (1 = fine, 2 = median, 3 = coarse) can be expressed as clastic sediment yield by using Brune's clastic sediment yield curve. Julien (1995) states that the class name of sediment grade scale can be divided as fine, median, and coarse which the size range are 0.016 – 0.008 mm (fine), 0.031 – 0.016 mm (median), 0.062 – 0.031 mm (coarse).

The trap efficiency is the proportion of the sediment in the water inflow to the reservoir which is trapped in the pool of the reservoir. Moreover, the trap efficiency is an important factor in the amount of sediment that accumulates in a reservoir over the design life. McCuen (2005) states, "Brune trap efficiency relationship for (1) primary highly flocculated and coarse-grained sediments, (2) median-grained sediments, and (3) primary colloidal and dispersed fine-grained sediments" (p.828). The Brune-type curve is shown on Table A.6.

### 4.2.2 Output Variables of Program Dredge

The program output includes the following :

1. Reservoir storage at the beginning year.
2. Sedimentation volume.
3. Reservoir storage at the ending year.
4. Dredging residual volume at the beginning and end of the year.
5. Present value of wholesale water efficiency.

6. Present dredging cost.

7. Benefit-cost ratio of reservoir watershed dredging.

The output variables are defined as follows :

1. YEAR : each year for the simulation period.

2. B STOR C.M. : reservoir storage at the beginning year in cubic meters.

3. C/I : reservoir storage / annual runoff volume.

4. TRAP : clastic sediment yield by using Brune's clastic sediment yield curve.

5. SEDIMENT C.M. : annual sedimentation for the record period in cubic meters.

6. E STOR C.M. : reservoir storage at the ending year in cubic meters.

7. DREDGING RESIDUAL/BEG : dredging residual volume at the beginning of the year.

8. DREDGING RESIDUAL/ END : dredging residual volume at the end of the year.

9. BENEFIT : present value of wholesale water efficiency volume for the record period.

10. COST : present value of dredging cost for the record period.

11. B/C Ratio : benefit-cost ratio.

**4.3 Reservoir Dredging Program**

Implementing reservoir dredging program is one of the effective methods which can approach the economic efficiency of reservoir storage increment. In terms of reservoir storage simulation, it should be known that whether reservoir is dredged or not, the reservoir will lose some effective storage by natural sedimentation. A dredging program can recover most of a reservoir's original capacity, but some sediment will naturally remain. A simulation should also project a reservoir's water capacity in the future with a continued dredging program.

The simulation, annual sedimentation volume can be estimated using data of trapped sediment by annual sediment inflow. Variability for the simulated period can be estimated by repeating this calculation.

Sediment yield can be simulated with and without dredging program situation in order to calculate the variety of reservoir storage after implementing reservoir dredging. In terms of Brune's theory, analyzing the relationship value of Brune's theory [ C/I ratio (reservoir storage / annual runoff volume) and clastic sediment yield ] can predict average reservoir sedimentation yearly between the average of annual sedimentation rate and the average of C/I ratio.

**4.4 Computer Simulation of Reservoir Storage**

In order to calculate the benefit-cost ratio, the reservoir dredging program needs to be simulated after carrying out reservoir dredging program. The reservoir capacity for the Feitsui Reservoir was shown in Table 1 (sediment increments at Feitsui Reservoir by year) on page 3.

Reservoir capacity in the absence of a dredging program can be simulated. Clastic sediment yield of the first year can be calculated by C/I ratio (beginning reservoir storage for simulation / annual runoff volume for simulation). The sediment volume of the first year will be calculated using data of clastic sediment yield and annual sediment volume.

Reservoir capacity can also be simulated for reservoirs with dredging programs. The reservoir storage volume of the first beginning year will be the sum of beginning reservoir storage and hypothetic dredging volume during simulation period in years.

The reservoir storage volume after simulated dredging operations will be equal to the sum of the initial reservoir storage capacity and the hypothetical dredging volumes during the simulation period. Clastic sediment yield can be estimated using the Brune's median curve C/I ratio.

The sediment volume for the first year will be calculated using annual sediment yield. The reservoir storage at the end of the first year will be calculated by subtracting annual sediment volume from the initial reservoir storage capacity. Repeating this calculation will yield predictions of future reservoir storage with and without dredging programs.

## 4.5 Examples of Input Data for Reservoir Watersheds

In this study, Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoirs have different decision variables as input values. Variables for the Paiho, Tapu, Mingte, Chingmien Reservoir watersheds are based on a 1994 Water Resource Bureau, Ministry of Economics Affairs report. Variables for the Shihmen Reservoir come from a 2002 report from the Water Resource Bureau, Ministry of Economics Affairs and Nungpang Technical Adviser Limited Corporation. See Table A.3 and for the complete list of variables used in the simulation.

Data and information for Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoirs come from Water Resource Bureau, Ministry of Economics Affairs reports. Although the data and information of the 5 reservoirs come from different reports, they are both available and supported by water resource government authorities.

Table A.3 : Input variables for Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoirs

| | Paiho | Tapu | Mingte | Chingmien | Shihmen |
|---|---|---|---|---|---|
| Annual interest rate | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| Wholesale water price (NT$/cubic meter) | 7 | 7 | 7 | 7 | 10 |

Table A.3 : Input variables for Paohi, Tapu, Mingte, Chingmien, and Shihmen Reservoirs continued

| | Paiho | Tapu | Mingte | Chingmien | Shihmen |
|---|---|---|---|---|---|
| Reservoir storage utilization frequency | 1.6 | 5 | 2.5 | 1.15 | 2.491 |
| Unit dredging cost (NT$/cubic meter) | 112.99435 | 53.29 | 68.16 | 60 | 200 |
| Reservoir storage at beginning of simulation | 15519000 | 4525000 | 13874800 | 981165 | 309120000 |
| Annual runoff volume for the simulation period | 43475000 | 174330000 | 86580000 | 2929000 | 535567369.4 |
| Average reservoir storage for the record period | 20529000 (1965-1992) | 5148000 (1972-1987) | 15000000 (1973-1989) | 1095730 (1980-1988) | 234000000 (2000) |
| Annual runoff volume for the record period | 43370000 (1965-1992) | 230137000 (1972-1987) | 85247000 (1973-1989) | 3139000 (1980-1988) | 534273877.2 (2000) |
| Annual sedimentation rate for the record period | 353800 (1965-1992) | 44500 (1972-1987) | 93800 (1973-1989) | 12060 (1980-1988) | 1860000 (2000) |

Table A.3 : Input variables for Paohi, Tapu, Mingte, Chingmien, and Shihmen Reservoirs continued

| | Paiho | Tapu | Mingte | Chingmien | Shihmen |
|---|---|---|---|---|---|
| Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) | 2 | 2 | 2 | 2 | 2 |
| Simulation period in years | 51 | 300 | 300 | 300 | 100 |
| Stages of dredging | 1 | 1 | 1 | 1 | 1 |
| Dredge volume | 283200 | 638000 | 679250 | 638000 | 300000 |

Note : stages of dredging means each stage for a whole year as the assumption for modeling; dredge volume means total dredge volume as the assumption for modeling
Source : Water Resource Bureau, Ministry of Economics Affairs

### 4.6 Estimate Benefit-cost Ratio for Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoir Watersheds

Projecting the results of one reservoir's dredging program onto another reservoir must take into consideration possible variations in their circumstances, including the use of the best dredging method based on season, mechanical dredging being most appropriately used during the dry season, while hydraulic dredging works with normal water levels. Also, costs for items such as labor and transportation may differ by location.

The benefit-cost ratio estimates after running the dredge computer software (see Appendix B for the details) does not include externalities. Estimates of the benefit-cost ratio for the 5 selected reservoirs are shown in the following table. The Paiho Reservoir has the lowest benefit-cost ratio. The Tapu Reservoir has the highest benefit-cost ratio.

Because of the Shihmen Reservoir is nearby the Taipei metropolitan area, the reservoir has the higher dredging cost by using both hydraulic and mechanical methods. Finally, the following Table 3 also shows that the higher the dredging cost, the lower the benefit-cost ratio.

Table 3 : Dredging cost and B/C ratio for 5 reservoirs

| Reservoir | B/C Ratio | Dredging Cost ( NT $ ) | Hydraulic Dredging Cost ( NT $ ) | Mechancial Dredging Cost ( NT $ ) |
|---|---|---|---|---|
| Paiho | 1.502 | 112.99 | 110.00 | 112.80 |
| Tapu | 9.906 | 53.29 | | 53.29 |
| Mingte | 4.008 | 68.16 | | 68.16 |
| Chingmien | 2.102 | 60.00 | | 60.00 |
| Shihmen | 1.961 | 200.00 | 400.00 | 130.00 |

Sources : Water Resource Bureau, Ministry of Economics Affairs & Department of Hydraulic and Ocean Engineering, National Cheng Kung University (1994) & Water Resource Bureau, Ministry of Economics Affairs & Nungpang Technical Adviser Limited Corporation (2002).

This study assumes a simulation period of 50 years for Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoir. These 5 reservoirs dredging benefit-cost ratios are 1.502, 9.906, 4.008, 2.102, and 1.961. See Appendix C for the complete analysis.

### 4.7 Data Collection for Feitsui Reservoir Watershed

The analysis of the Feitsui Reservoir watershed in this study uses the following variables from the annual report of the Feitsui Reservoir (2000) and Taipei Water Department (see Table A.4) as well as other variables assumed by calculating simulation input variables and listed below :

1. Annual interest rate = 0.06.

2. Wholesale water price (NT$/cubic meter) = 7.213.

3. Reservoir storage utilization frequency = 3.806.

   Note : annual water supply / live storage = 329,586,560 + 1,603,258,704 / 507,841,635 = 3.806 (annual water supply from Feitsui Reservoir plus Nanshih Creek by reservoir capacity in 2000)

4. Unit dredging cost (NT$/cubic meter) = 300.

5. Reservoir storage at beginning of simulation = 400,028,000.

   Note : reservoir storage at beginning of simulation = 400,028,000 (see Table 1 for the data from July, 1984 to Mar, 1989)

6. Annual runoff volume for the simulation period = 990,000,000.

7. Average reservoir storage for the record period (1987-2000) = 391,474,000.

   Note : average reservoir storage = 5,480,636,000 / 14 = 391,474,000

8. Annual runoff volume for the record period (1987-2000) = 990,141,770.

   Note : 13,861,984,786 / 14 = 990,141,770

9. Annual sedimentation rate for the record period (1984-2005) = 996,000.

   Note : average increment = 996,000 (see Table 1 for the rate)

10. Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) = 2.

11. Simulation period in years = 50.

12. Stages of dredging = 1.

13. Dredge volume = 600,000.

### 4.8 Estimated Benefit-cost Ratio for Hypothetical Dredging of Feitsui Reservoir Watershed

This study assumes a simulation period of 50 years for Feitsui Reservoir. The Feitsui Reservoir dredging benefit-cost ratio is 1.44. See Appendix C for the complete analysis.

The results of dredging simulation and cost-benefit analysis were divided into three parts : without dredging, with dredging, and dredging residual. Appendix C for the Feitsui Reservoir is divided into 14 columns to interpret each result. For explaining the calculations, only the first and the second row are used as examples :

WITHOUT DREDGING

(1). B STOR C.M. : reservoir storage at the beginning year in cubic meters

The number of 400,028,000 for the first row comes from the beginning storage for simulation. The number of 399,031,200 for the second row comes from the fifth column [E STOR C.M. (reservoir storage at the ending year in cubic meters) ] of the first row.

(2). C/I : reservoir storage / annual runoff volume

The decision variables of reservoir storage and annual runoff volume come from the simulations. The number of 0.4041 for the first row comes from dividing [ reservoir storage (400,028,000) ] by [ annual runoff volume (990,000,000) ]. The number of 0.4031 for the second row comes from the first column 399031200 [ B STOR C.M. (reservoir storage at the beginning year in cubic meters) ] dividing by 990,000,000.

(3). TRAP : clastic sediment yield by using Brune's clastic sediment yield curve

The numbers of third column (TRAP) can be calculated by following the dredge computer software in Appendix B. The average trap efficiency (XSQ) equals [ STORP (average reservoir capacity for the record period) ] by [ QAP (average annual runoff for the record period in cubic meter) ]. The formula presents the average trap efficiency under without dredging circumstance, XSQ equals [ STOR1 (storage without dredging at the beginning of a year) ] by [ Q (Q=QA) ]. Applying the linear interpolation method to estimate the range in reservoir capacity-inflow ratio (SQ) and trap efficiency for median curve.

Therefore, the XSQ equals STORP by QAP [ 400,028,000 by 990,141,760 equals 0.404 ]. The number of 0.404 ranges between 0.40 to 0.50 in reservoir capacity-inflow ratio. Moreover, the number of 0.404 ranges between 0.975 to 0.983 in trap efficiency for the median curve. Estimating the trap efficiency for the median curve is done by applying the linear interpolation. The linear interpolation method shows 0.404-0.40 / 0.50-0.40 = 0.004 / 0.10 = 0.04. Then 0.04% (see Table A.6 for the percentage) plus 0.975 equals 0.975. The number of 0.9754 for the first row is the trap efficiency.

The number of 0.9753 for the second row comes from the XSQ equals STOR1 by QA [ 399,031,200 by 990,141,760 equals 0.403 (ranges between 0.40 to 0.50) in reservoir capacity-inflow ratio and ranges between 0.975 to 0.983 in trap efficiency for median curve ]. Again, the linear interpolation method shows 0.403-0.40 / 0.50-0.40 = 0.003 / 0.10 = 0.03. Then 0.03% (see Table A.6 for the percentage) plus 0.975 equals 0.975. The number of 0.9753 for the second row is the trap efficiency.

(4). SEDIMENT C.M. : annual sedimentation for the record period in cubic meters

According to the formula, the annual sedimentation rate equals annual sediment inflow by trap efficiency. The QSA (average annual sediment inflow) equals [ QSED (average annual reservoir sedimentation rate for the record period) ] by [ TRAP (column 3) ]. The XSQ equals STORP by QAP [ 391,473,984 by

990,141,760 equals 0.395 ]. The number of 0.395 ranges between 0.30 to 0.40 in reservoir capacity-inflow ratio. The number of 0.395 ranges between 0.965 to 0.975 in trap efficiency for the median curve.

The linear interpolation method shows 0.395-0.30 / 0.40-0.30 = 0.095 / 0.10 = 0.95. Then 0.95% (see Table A.6 for the percentage) plus 0.965 equals 0.975 (YTRAP). QSA equals [ 996,000 (average annual sedimentation rate for calibration) ] by 0.975 [ = 1,021,538 ]. Finally, the number of 996,784 comes from the 1,021,538 by 0.9754 equals 996,409. This value is approximately 996,784 for the first row in forth column.

The second row of XSQ equals STORP by QAP [ = 400,028,000 by 990,141,760 = 0.404 ]. The number of 0.404 ranges between 0.40 to 0.50 in reservoir capacity-inflow ratio. Moreover, the number of 0.404 ranges between 0.975 to 0.983 in trap efficiency for the median curve. Estimating the trap efficiency for the median curve was by linear interpolation. The linear interpolation method shows 0.404-0.40 / 0.50-0.40 = 0.004 / 0.10 = 0.04. Then 0.04% (see Table A.6 for the percentage) plus 0.975 equals 0.9754 (YTRAP). QSA equals 996,000 (average annual sedimentation rate for calibration) by 0.9754 [ = 1,021,120 ]. Finally, the number of 996,693 comes from the 1,021,120 by 0.9754 equals 996,000. This value is approximately 996,693 for the second row in forth column.

(5). E STOR C.M. : reservoir storage at the ending year in cubic meters

[ B STOR C.M. in first column (reservoir storage at the beginning year in cubic meters) ] minus [ SEDIMENT C.M. in forth column (annual sedimentation for the record period in cubic meters) ] equals [ E STOR C.M. in fifth column (reservoir storage at the ending year in cubic meters) ].

The number of 399,031,200 for the first row in fifth column comes from 400,028,000 minus 996,784 equals 399,031,216. This value is approximately 399,031,200 for the first row in fifth column. Moreover, the number of 398,034,496 for the second row in fifth column comes from 399,031,200 minus 996,693 equals 398,034,507. This value is approximately 398,034,496 for the second row in fifth column.

WITH DREDGING

(6). B STOR C.M. : reservoir storage at the beginning year in cubic meters

The number of 400,628,000 for the first row in sixth column comes from [ 400,028,000 (beginning storage for simulation) ] plus [ 600,000 (stage No. 1 volume) ] equals 400,628,000. Moreover, the number of 399,631,168 for the second row in sixth column comes from the tenth column for the first row [ E STOR C.M. (reservoir storage at the ending year in cubic meters).

(7). C/I : reservoir storage / annual runoff volume

The decision variables of reservoir storage and annual runoff volume come from the simulations. The number of 0.4047 for the first row comes from 400,628,000 by 990,000,000. The number of 0.4037 for the second row comes from dividing 399,631,168 by 990,000,000.

(8). TRAP : clastic sediment yield by using Brune's clastic sediment yield curve

The numbers of the eighth column (TRAP) can be calculated by following the dredge computer software in Appendix B. The average trap efficiency (XSQD) equals [ STORD1 (storage with dredging at the beginning of a year) ] by [ Q (annual runoff for simulation) ].

The formula presents the average trap efficiency under with dredging circumstance, XSQD equals STORD1 (storage with dredging at the beginning of a year). Applying the linear interpolation method to estimate the range in reservoir capacity-inflow ratio (SQ) and trap efficiency for median curve. Therefore, the XSQD equals STORD1 by Q [ = 400,628,000 by 990,141,760 equals 0.405 ]. The number of 0.405 ranges between 0.40 to 0.50 in reservoir capacity-inflow ratio. The number of 0.405 ranges between 0.975 to 0.983 in trap efficiency for median curve.

Estimating the trap efficiency for the median curve was by linear interpolation. The linear interpolation method shows 0.405-0.40 / 0.50-0.40 = 0.005 / 0.10 = 0.05.

Then 0.05% (see Table A.6 for the percentage) plus 0.975 equals 0.975. The number of 0.9754 for the first row is the trap efficiency.

The number of 0.9753 for the second row comes from the XSQD equals STORD1 by Q [ = 399,631,168 by 990,141,760 equals 0.404 (ranges between 0.40 to 0.50) in reservoir capacity-inflow ratio and ranges between 0.975 to 0.983 in trap efficiency for median curve) ]. Again, the linear interpolation method shows 0.404-0.40 / 0.50-0.40 = 0.004 / 0.10 = 0.04. Then 0.04% (see Table A.6 for the percentage) plus 0.975 equals 0.975. The number of 0.9753 for the second row is the trap efficiency.

(9). SEDIMENT C.M. : annual sedimentation for the record period in cubic meters

According to the formula, the annual sedimentation rate equals annual sediment inflow by trap efficiency. The QSA (average annual sediment inflow) equals [ QSED (average annual reservoir sedimentation rate for the record period) ] by [ TRAP (column 8) ]. The XSQD equals STORD1 by Q [ = 400,628,000 (400,028,000 plus 600,000) by 990,141,760 equals 0.405 ]. The number of 0.405 ranges between 0.40 to 0.50 in reservoir capacity-inflow ratio. Moreover, the number of 0.405 ranges between 0.975 to 0.983 in trap efficiency for the median curve.

Estimating the trap efficiency for the median curve was by linear interpolation. The linear interpolation method shows 0.405-0.40 / 0.50-0.40 = 0.005 / 0.10 = 0.05.

Then 0.05% (see Table A.6 for the percentage) plus 0.965 equals 0.9655 (YTRAP). QSA equals [ 996,000 (average annual sedimentation rate for calibration) ] by 0.9655 = 1,031,590 ]. Finally, the number of 996,839 comes from the 1,031,590 by 0.9754 equals 1,006,213. This value is approximately 996,839 for the first row in ninth column.

The second row of XSQD equals STORD1 by Q [ = 399,631,168 by 990,141,760 equals 0.404 ]. The number of 0.404 ranges between 0.40 to 0.50 in reservoir capacity-inflow ratio. Moreover, the number of 0.404 ranges between 0.975 to 0.983 in trap efficiency for median curve. Estimating the trap efficiency for the median curve was by linear interpolation. The linear interpolation method shows 0.404-0.40 / 0.50-0.40 = 0.004 / 0.10 = 0.04. Then 0.04% (see Table A.6 for the percentage) plus 0.975 equals 0.9754 (YTRAP). QSA equals [ 996,000 (average annual sedimentation rate for calibration) ] by 0.9754 [ = 1,021,120 ]. Finally, the number of 996,748 comes from the 1,021,120 by 0.9754 equals 996,000. This value is approximately 996,748 for the second row in ninth column.

(10). E STOR C.M. : reservoir storage at the ending year in cubic meters

[ B STOR C.M. in sixth column (reservoir storage at the beginning year in cubic meters) ] minus [ SEDIMENT C.M. in ninth column (annual sedimentation for the record period in cubic meters) ] equals [ E STOR C.M. in tenth column (reservoir storage at the ending year in cubic meters) ].

The number of 399,631,168 for the first row in tenth column comes from 400,628,000 minus 996,839 equals 399,631,161. This value is approximately 399,631,168 for the first row in tenth column. Moreover, the number of 398,634,432 for the second row in tenth column comes from 399,631,168 minus 996,748 equals 398,634,420. This value is approximately 398,634,432 for the second row in tenth column.

DREDGING RESIDUAL

(11). BEG. C.M. : dredging residual volume at the beginning of the year

[ B STOR C.M. in sixth column (reservoir storage at the beginning year in cubic meters) ] minus [ B STOR C.M. in first column (reservoir storage at the beginning year in cubic meters) ] equals [ BEG. C.M. in eleventh column (dredging residual volume at the beginning of the year) ]. The number 600,000 for the first row in eleventh column comes from 400,628,000 minus 400,028,000 equals 600,000. Moreover, the number of 599,968 for the second row in eleventh column comes from 399,631,168 minus 399,031,200 equals 599,968.

(12). END C.M. : dredging residual volume at the end of the year

[ SEDIMENT C.M. in ninth column (annual sedimentation for the record period in cubic meters) ] minus [ SEDIMENT C.M. in forth column (annual sedimentation for the record period in cubic meters) ] equals A. Then [ BEG. C.M. in eleventh column (dredging residual volume at the beginning of the year) ] minus A equals [ END C.M. in twelfth column (dredging residual volume at the end of the year) ]. The number of 599,968 for the first row in twelfth column comes from 996,839 minus 996,784 equals 55. Then 600,000 minus 55 equals 599,945. This value is approximately 599,968 for the first row in twelfth column. Moreover, the number of 599,936 for the second row in twelfth column comes from 996,748 minus 996,693 equals 55. Then 599,968 minus 55 equals 599,913. This value is approximately 599,936 for the second row in twelfth column.

(13). BENEFIT NT $ : present value of wholesale water efficiency volume for the record period

[ BEG. C.M. in eleventh column (dredging residual volume at the beginning of the year) + END C.M. in twelfth column (dredging residual volume at the end of the year) / 2 * reservoir storage utilization frequency * wholesale water price ] / (1+r)t = BENEFIT NT $ in thirteenth column (present value of wholesale water efficiency volume for the record period).

The number of 15,538,838 for the first row in thirteenth column comes from [ (600,000 + 599,968) / 2 * 3.81 * 7.2 ] / 1.06 = 16,458,761 / 1.06 = 15,527,133. This value is approximately 15,538,838 for the first row in thirteenth column. Moreover, the number of 14,658,500 for the second row in thirteenth column comes from

[ (599,968 + 599,936 ) / 2 *3.81 * 7.2 ] / 1.124 = 16,457,883 / 1.124 = 14,642,245.

This value is approximately 14,658,500 for the second row in thirteenth column.

(14). COST NT $ : present value of dredging cost for the record period

There is a controversial column for all reservoirs' dredging cost-benefit analysis. All reservoir dredging cost-benefit analysis show zero in the cost column after the second year (row). Because this is a one operation cost without subsequent maintenance. According to the BCR equation, this can be attributed to a natural change in net present value (NPV) over time. Because of fluctuation costs, benefits and interest rates, the NPV for the first year will differ from the NPV for the following year; therefore the second year cost be represented with a zero.

**4.9 Conclusion**

The results of dredging simulation and cost-benefit analysis is presented in Appendix C by following above instructions step by step. The numbers calculated after the third row until 50 years used the same formulas from the first row and the second row. The sensitivity analysis for these 6 reservoir watersheds used logical assumptions for varying the decision variables. All the input variables were increased and decreased 5% and 10%.

## CHAPTER V
## RESULTS AND DISCUSSIONS

### 5.1 Introduction

Traditional cost-benefit analysis is a useful tool in assessing the social desirability of many programs or projects that impact the environment, but for some decisions other information is required.

### 5.2 Cost-benefit Analysis for Feitsui Reservoir Watershed Dredging

In this study, the methodology for reservoir watershed dredging cost-benefit analysis for the six reservoirs does not include externalities issues. The benefit-cost ratio can be expected to change if externalities are included. In the absence of external costs and benefits for the Feitsui Reservoir dredging project simulation, this study used the limited data to estimate the approximate benefit-cost value. It is difficult, for instance, to measure the value of external costs such as noise, air pollution, vibration, and ecosystem impact.

In the situations which do not consider externality, price will equal marginal cost (P=MC). With externality, the price will be smaller than the marginal social cost ($P < MSC = MC + MEC$). On the other hand, without externality, the price will equal the marginal benefit (P=MB). However, in the circumstance with externality, price will be smaller than marginal social benefit (P < MSB = MB + MEB).

To attain resources allocation efficiency, the marginal social cost equals the marginal private cost plus the marginal damage. The external costs charge, for example, that achieves efficiency sets the marginal social cost equal to the marginal social benefit – the marginal benefit enjoyed by the consumer of the good plus the marginal external benefit.

### 5.3 Sensitivity Analysis for Paiho, Tapu, Mingte, Chingmien, Shihmen Reservoir Watersheds

This sensitivity analysis uses logical assumptions for varying most of the decision variables under both increases and decreases of input values by 5% and 10% to calculate the benefit-cost ratios for Paiho,Tapu, Mingte, Chingmien, and Shihmen Reservoir watersheds by running the dredge computer software – Program Dredge.

Assuming the decision variables of Brune's trap efficiency curve (1=fine, 2=median, 3=coarse ), simulation period in years, and stages of dredging have not changed at the same time, the results are shown in Table A.5 (5.1 – 5.5). The reservoir capacity-inflow ratio (SQ) determines sediment trap efficiency of a reservoir from Brune's curves by using trap efficiency for the median curve. (see Appendix B of dredge computer software for complete details).

The decision variable of simulation period in years will be divided into interval years to estimate the benefit-cost ratio. The decision variable of stages of dredging means that the water resources government authorities enforce the reservoir dredging project in stages to finish during one year. For example, the reservoir dredging project can be divided into months, seasons, and quarters to complete the reservoir dredging.

Table A.5 (5.1) is shown in below, others are shown in Table A.5 (5.2 – 5.5).

Table A.5 (5.1) Paiho Reservoir watershed dredging cost-benefit analysis
Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|
| Annual interest rate | 0.05 | 0.057 | 0.06 | 0.063 | 0.07 |
| Wholesale water price (NT$/cubic meter) | 6.3 | 6.65 | 7 | 7.35 | 7.7 |
| Reservoir storage utilization frequency | 1.44 | 1.52 | 1.6 | 1.68 | 1.76 |
| Unit dredging cost (NT$/cubic meter) | 101.695 | 107.345 | 112.99435 | 118.644 | 124.294 |
| Reservoir storage at beginning of simulation | 13967100 | 14743050 | 15519000 | 16294950 | 17070900 |

Table A.5 (5.1) Paiho Reservoir watershed dredging cost-benefit analysis continued
Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|
| Annual runoff volume for the simulation period | 39127500 | 41301250 | 43475000 | 45648750 | 47822500 |
| Average reservoir storage for the record period (1965-1992) | 18476100 | 19502550 | 20529000 | 21555450 | 22581900 |
| Annual runoff volume for the record period (1965-1992) | 39033000 | 41201500 | 43370000 | 45538500 | 47707000 |
| Annual sedimentation rate for the record period (1965-1992) | 318420 | 336110 | 353800 | 371490 | 389180 |
| Dredge volume | 254880 | 269040 | 283200 | 297360 | 311520 |
| B/C ratio | 1.553 | 1.486 | 1.502 | 1.517 | 1.456 |

| | | | |
|---|---|---|---|
| Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) | 1 | 2 | 3 |
| B/C ratio | 1.491 | 1.502 | 1.511 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Simulation period in years | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 51 |
| B/C ratio | 0.417 | 0.727 | 0.956 | 1.126 | 1.251 | 1.343 | 1.409 | 1.455 | 1.486 | 1.502 | 1.502 |

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Stages of dredging | 1 | 2 | 3 | 4 |
| B/C ratio | 1.502 | | | |

The original benefit-cost ratio for the Paiho Reservoir was 1.502. Examining Table A.5 (5.1), the changes of +/– 5% of the input variables resulted in marginal changes in the benefit-cost ratios (1.517 and 1.486, respectively). For a –10% change in the input variables, the benefit-cost ratio increased to 1.553. For a +10% change in the input variables, the benefit-cost ratio decreased to 1.456. Considering the sensitivity to the simulation period in 5 – year increments, the benefit-cost ratio for the Paiho Reservoir reached a value of 1.126 after 20 years and reached a value of 1.502 after 50 years. The progressive increase of the benefit-cost ratio in 5 – years increments suggests that the benefit-cost ratio will not exceed 1.00 until after 20 years of dredging. These results are similar for the sensitivity analysis of the Tapu, Mingte, Chingmien, and Shihmen Reservoirs.

### 5.4 Sensitivity Analysis for Feitsui Reservoir Watershed

The sensitivity analysis of Feitsui Reservoir watershed also uses logical assumptions for varying most of all the decision variables under both increases and decreases of +/ – 5% and +/ – 10%, to calculate the benefit-cost ratios with Program Dredge.

Assuming the decision variables of Brune's trap efficiency curve (1=fine, 2=median, 3=coarse ), simulation period in years, and stages of dredging have not changed at the same time, the results are shown in Table A.5 (5.6). The reservoir capacity-inflow ratio (SQ) determines the sediment trap efficiency from Brune's median curve. (see Appendix B of dredge computer software for complete details).

The benefit-cost ratio of the Feitsui Reservoir watershed varies from 1.388 to 1.501 with the decision variables changed minus 5%, 10% and plus 5%, 10% of the original decision variables, without concerning Brune's trap efficiency curve (1=fine, 2=median, 3=coarse ), simulation period in years, and stages of dredging.

The decision variable of stages of dredging means that the water resources government authorities enforce the reservoir dredging project in stages to finish during a one year time period. For example, the reservoir dredging project can be divided into months, seasons, and quarters to complete the reservoir dredging.

Table A.5 (5.6) Feitsui Reservoir watershed dredging cost-benefit analysis

5.6 Feitsui Reservoir watershed dredging cost-benefit analysis
Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|
| Annual interest rate | 0.05 | 0.057 | 0.06 | 0.063 | 0.07 |
| Wholesale water price (NT$/cubic meter) | 6.492 | 6.852 | 7.213 | 7.574 | 7.934 |
| Reservoir storage utilization frequency | 3.425 | 3.616 | 3.806 | 3.996 | 4.187 |
| Unit dredging cost (NT$/cubic meter) | 270 | 285 | 300 | 315 | 330 |
| Reservoir storage at beginning of simulation (1984-1989) | 360025200 | 380026600 | 400028000 | 420029400 | 440030800 |

5.6 Feitsui Reservoir watershed dredging cost-benefit analysis continued

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|
| Annual runoff volume for the simulation period | 891000000 | 940500000 | 990000000 | 1039500000 | 1089000000 |
| Average reservoir storage for the record period (Taiwan Year 1987-2000) | 352326600 | 371900300 | 391474000 | 411047700 | 430621400 |
| Annual runoff volume for the record period (Taiwan Year 1987-2000) | 891127593 | 940634681.5 | 990141770 | 1039648859 | 1089155947 |
| Annual sedimentation rate for the record period (Taiwan Year 1984-2005) | 896400 | 946200 | 996000 | 1045800 | 1095600 |
| Dredge volume | 540000 | 570000 | 600000 | 630000 | 660000 |
| B/C ratio | 1.501 | 1.428 | 1.44 | 1.451 | 1.388 |

| Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) | 1 | 2 | 3 |
|---|---|---|---|
| B/C ratio | 1.439 | 1.44 | 1.442 |

| Simulation period in years | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B/C ratio | 0.385 | 0.673 | 0.888 | 1.049 | 1.169 | 1.258 | 1.325 | 1.375 | 1.413 | 1.44 | 1.523 |

| Stages of dredging | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| B/C ratio | 1.44 | | | |

The original benefit-cost ratio for the Feitsui Reservoir was 1.440. Examining Table 5.6, the changes of +/ – 5% of the input variables resulted in marginal changes of the original benefit-cost ratio. However, a + 10% change in the input variable resulted in a benefit-cost ratio of 1.388 and a – 10% change resulted in a benefit-cost ratio of 1.501. Considering the simulation period in years as an input variable, it is interesting that the benefit-cost ratio after 5 years of simulation is only 0.385. As the simulation period increases by 5 – year increments, the benefit-cost ratio is 1.049 after 20 years and is 1.44 after 50 years.

**5.5 In the Absence of Externalities**

The reservoir dredging cost-benefit analysis for Paiho, Tapu, Mingte, Chingmien, Shihmen, and Feitsui Reservoir watersheds did not consider externalities. According to environmental policy, externalities introduce distortions in resource use because they are circumstances for which society fails to set a positive or negative cost. No normal price can adequately capture the value of externalities. This result in a price asymmetry : a nonzero price to the supplier of the externality (positive price for an external benefit and a negative price or tax for a detrimental externality), and a zero price for the consumption of the externality.

An ordinary price is symmetrical between supplier and consumer, and an asymmetrical price will probably not include efficient behavior. Pigouvian tax can be used to measure MEC (marginal environmental cost). However, the Pigouvian tax (subsidy) can provide the appropriate incentive for the supplier of the externality while leaving consumer with a zero price (Baumol, 1988).

For externality characteristics, externality for third party interaction will not be reflected in the market, nor will the externality spillover effect on a third party. Moreover, externality could be divided by positive and negative externalities. Rao (2003) states that approaching externality can prevail whenever there is a divergence between the social and the private costs of an activity if the Pigouvian social welfare model is used.

### 5.5.1 Benefits

The benefits are both direct and indirect. Direct benefits are likely to be internal, including increased reservoir capacity and water quality, decreased reservoir nutrients and aquatic life, and steady water supply to city residents. In terms of internal benefits, Program Dredge does not take these factors into account. However, indirect benefits are likely to be external, including improved swimming, fishing, and other forms of recreation. However, in terms of external benefits, Program Dredge doesn't take these factors into account.

The disposal of dredged material requires close management. In urban areas it may be difficult to find a proper site nearby to place sediments. Besides, dredged material with recyclable and economic value can be viewed as part of reservoir dredging efficiency. This situation causes decreasing the manipulative cost of original water. This cost-benefit analysis will consider benefits derived from dredging including the recycling value of dredged material, and improvements to irrigation, agricultural, industry and recreation brought about by the recovered water supply. In this study, dredged material does not count into this cost-benefit analysis, although it would influence the benefit-cost ratio.

### 5.5.2 Costs

Direct and indirect costs are very important decision variables to estimate cost-benefit analysis. However, the indirect costs and some direct costs are not included in this results and discussions due to lacking of basic information. Direct costs are likely to be internal costs such as dredging, labor, transportation, dredging material disposal and the expense of operation and management. Indirect costs are likely to be external costs such as noise, air pollution, vibration, ecosystem impact, traffic, and road maintenance.

The environmental cost must be sufficiently large to outweigh the investment and operational system costs (Sterner, 1999). Bray, et al. (1997) state that air quality is generally judged by a medium to a long-term monitoring of total suspended particulates (TSP), respirable suspended particulates (RSP), sulfur dioxide and nitrogen dioxide. Unfortunately, such dioxide data are usually lacking.

### 5.6 Dredging Methods and Environmental Impacts

Various aspects of reservoir dredging affect the environment, including the dredging itself, drying of dredged material, transportation, and final handling. Removing sediments by dredging methods can both remove nutrient-rich sediments and toxic substances.

Mechanical dredging is extremely disruptive to the aquatic ecosystem because in the course of removing sediment and organic matter, it also removes the plants and organisms of the bottom community. Hydraulic dredging, however, has a lower impact on the environment because it vacuums material from the reservoir bottom with little disruption to the ecosystem.

Hydraulic dredging can actually benefit the environment. By removing eroded soil and plant overgrowth. Water-based species return to the area and usually thrive in the restored conditions. Also, dredged material can be used in wetlands construction, beach enhancement, or as a supplement on agricultural land.

## 5.7 Conclusions

Economic analysis can help in making resource allocation decisions. Welfare economics may be applied to reach the status of equilibrium : willingness to pay (WTP) = willingness to accept (WTA). WTP and WTA are both measures of valuation. WTP is likely to equivalent variation which maximum payment a consumer would spend over and above the current cost of using the resource. On the other hand, WTA is likely to compensate variation which minimum payment accepted by a consumer to do without a given resource. In addition, externalities may be controlled by using economic solutions. For instance, taxing pollution will increase net economic efficiency.

Policy makers frequently hope to maximize the economic benefits of production, such as maximizing profits or minimizing costs, while at the same time, preserving or enhancing environmental quality.

This input-output model (cost-benefit analysis) was derived from a reliable data system. Setting up a model forces analysts to obtain an accurate historical record and a consistent set of estimates for major economic and natural-systems flows and their interconnections. This should lead to systematic monitoring, estimating, and data collecting to provide a framework for cost-benefit analysis. Once the model is established, it could be used to simulate different economic scenarios.

# CHAPTER VI
# RECOMMENDATIONS

## 6.1 General

Reservoir watershed management plays an important role to reduce sediment yield. It is also important to include control of sediment sources in the upper watershed when creating a reservoir operational strategy. Such controls might include watershed conservation, sediment interception, and sediment bypass.

Generally speaking, the source of a reservoir's pollution (including sediment) comes from the watershed's point source and non-point sources (NPS). The point source includes domestic and industrial wastewater from sources such as construction sites, abusive agricultural and forestry land, landslides, residential and industrial areas.

The major pollution source of Feitsui Reservoir watershed comes from the sewage of the Pingling community. Non-point sources come from landslides, runoff from tea farms and the Peiyi Highway. Controlling point sources and non-point sources effectively can improve the reservoir as well the residential quality of life for residents of the Taipei Water Source District.

Reservoirs in Taiwan are subject to severe sedimentation and require periodic dredging in order to maintain their functionality. Reservoir dredging requires not only careful planning of the dredging operation but also proper disposal of dredged material to avoid potential environmental impact.

For effective utilization of water resources, reservoirs must regulate stream flows. Meeting demand for water in a timely manner has become more challenging in Taiwan in recent years because of rapid economic development. Maintenance to reduce sediment will help keep reservoir capacity high which is vital to ensure sustainable use of existing reservoirs.

### 6.2 Valuing of Input Variables with Conservative Assumptions for 5 Reservoirs

Reservoir sedimentation rates determine the effective life of a reservoir. In terms of reservoir sedimentation rates, soil erosion and sediment transport dynamics in the upstream watershed must be known to manage the throughput of sediment-laden waters. It is helpful to estimate the input variables of Feitsui Reservoir by review of the Paiho, Tapu, Mingte, Chingmien, Shihmen Reservoirs' reservoir dredging projects.

Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoirs have different decision variables as input variables. Although the data and information of 5 reservoirs come from different reports, they are both available and valuable and are supported by government authorities of water resources. The analysis of the Feitsui Reservoir uses most input variables from the annual report of the Feitsui Reservoir. However, some additional input variables of the Feitsui Reservoir are derived from analysis of these 5 reservoirs.

### 6.3 Methodology for Estimating Benefit-Cost Ratio

Sedimentation in reservoirs is a natural, unavoidable process. It is recommended that reservoir dredging be considered as part of regular reservoir maintenance. Program Dredge can be used to determine the cost-benefit of dredging. This study can be used to build a high-efficiency dredging operation and present planning guidelines to the government authorities of water resources.

A computer program called Program Dredge (see Appendix B) was used to assist in the cost-benefit analysis of the dredging. In this study, the Program Dredge was modified slightly from its original computer program to perform related cost-benefit analysis. The program includes :

1. Simulation of reservoir storage after dredging.
2. Calculation of annual residuals of the dredging volume.
3. Calculation of annual benefits from increased water sales.

4. Conversion of annual benefits to the present value.

5. Calculation of benefit-cost ratio.

Program Dredge has some limitations and shortages to run benefit-cost ratio completely. It is recommended that cost-benefit analysis should consider externalities issues for further improvements in the future.

### 6.4 Applying A Sensitivity Analysis to Estimate Benefit-Cost Ratio

In terms of the Feitsui Reservoir watershed, Program Dredge computer software can calculate the increase in effectiveness of water sale by reservoir dredging. The benefit-cost ratio of 1.44 (see Appendix A.5 (5.6) for comprehensive data) can be directly calculated without considering externalities. The benefit-cost ratio is greater than 1.00 which means that the reservoir dredging project does achieve efficiency. However, if Program Dredge could include externalities, the benefit-cost ratio may or may not be greater than 1.00.

Sensitivity analysis can be more accurate by using logical assumptions for varying most of all the decision variables with both increases and decreases of 5% and 10%. This done, the benefit-cost ratio is ranged from 1.388 to 1.501 (see Appendix A.5 (5.6) for comprehensive data) for the Feitsui Reservoir. The benefit-cost ratio remained greater than 1.00, which means that the reservoir dredging project can attain efficiency after applying a sensitivity analysis in the absence of externalities.

## 6.5 Evaluating the External Costs of Reservoir Dredging

Cost-benefit analysis can help decision makers to achieve economic efficiency of reservoir dredging. Reservoir dredging costs may equal the market price plus including external cost. Marginal damage can also be taken into account. The marginal social cost could be estimated by the marginal private cost plus the marginal damage. Hopefully, the future researcher would have more data to determine the indirect costs and benefits and estimate the cost-benefit analysis more accurately.

During the processing of reservoir dredging in the constructional area, non-point source control should be focused on externalities. The control method will need to internalize externalities impact on environmental ecosystems. Therefore, environmental impact from reservoir watershed dredging needs to be investigated, including the impacts on water quality, air quality, noise and vibration, and ecosystem damage.

Most of the point sources and non-point sources are caused by “human activity.” Therefore, a study of the planning and management of a reservoir watershed needs to consider the human factor. For example, the Hedonic Pricing Method (HPM), Travel Cost Method (TCM), and Contingent Valuation Method (CVM) are associated with the human behavior issue. These methods also can help the decision makers to manage externalities associated with a watershed dredging program. If the data for external costs for reservoir dredging are available, the cost-benefit analysis of Program Dredge simulate more accurately.

### 6.6 Beneficial Reuse of Dredged Material

Sediments in reservoirs, being mostly silt and clay, are too fine to be used as aggregates for concrete. Sediments near the dam, containing a lot of organic matter and clay, should be disposed of properly to prevent environmental pollution. However, dredged material from the upper end of reservoir contains renewable and recyclable material.

The government authorities can handle dredged material with a proper policy during reservoir dredging. A proper policy not only can reduce the sediment volume to be disposed of, but also reduce the net cost of sediment removal as a result of the economic value of the renewable materials.

It is recommended that government water resource authorities manage dredged material to achieve maximum benefits and minimum costs. The company who dredged the reservoir material should be allowed to harvest building material or coarse sediment from upstream to offset the dredging cost. This kind of dredged material policy could be considered by the government water resource authorities in future reservoir dredging projects.

### 6.7 Best Management Practices (BMPs)

According to recent observations by international and domestic studies, it is important to reduce the effect of non-point sources pollution of the watershed by using control methods known as Best Management Practices (BMPs). BMPs can be defined as any action, technique, equipment plan or operational method that can reduce, eliminate, prevent, and control non-point source pollution. BMPs can be divided into : “structural” and “non-structural”.

Structural BMPs refers to building equipment to control non-point source pollution. The ecological engineering method would be one of the BMPs. According to America National Academy of Sciences seminar, ecological engineering can be defined as “the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both” (Mitsch, 1988).

Ecological management can be interpreted as :

1. Respecting the original variety of the natural environment.
2. Following the existing natural rules to create the best water cycle and creek environmental safety.
3. Aggressively making a renewable natural environment to create water and a green ecological net (Water Environment Research Center, National Taipei University of Technology, 2002).

Besides a study of the ecological engineering field, the wider definition of a restorative plan for the environment should consider safety, protection, restoration, and economy.

Therefore, the conservation work of reservoir watersheds becomes the long-term management practices. To develop the sustainable management of reservoirs and the best effect of limited water resources, it is necessary to evaluate the effectiveness of the conservation work of reservoir watersheds (see Table A.8 in Appendix A for complete watershed management plan). Moreover, optimum strategies for management and control of the reservoir watershed are fundamental tasks for water resources development, management and conservation.

### 6.8 Public Participation and Funding Sources

Reservoir dredging can be driven by the Build, Operate, Transfer (BOT) method. The BOT method also can meet the Coase theorem in which voluntary negotiated settlements will optimally internalize the externality, as long as the property rights to the resource are assigned to one party, which doesn't matter which party assigned. The BOT method applied to reservoir dredging will help reach economic efficiency.

Because the wholesale water price is regulated by the government, it should be lower than the market price. This does not reflect the costs of water resource development appropriately. In this situation, the government authorities should consider the reservoir dredging program as a substitution for water resource development and set aside funds to supplement and support the work of reservoir watershed conservation and reservoir dredging program.

Raising the water price per unit could pay for dredging. Raising the water price per unit is likely to set a Pigouvian tax which can be used to measure marginal environmental cost. This kind of government project for reservoir dredging can consider that water users be taxed. A Pigouvian tax not only considers the externality of reservoir dredging, but also the supporting of the reservoir management and dredging budget as well.

### 6.9 Summary and Recommendations

With limited sites for constructing reservoirs, dredging existing reservoirs becomes an attractive measure. The purpose of this study was to develop a methodology that could be used to analyze the costs and benefits for dredging the Feitsui Reservoir. The methodology included identifying and analyzing reservoirs in Taiwan where dredging was carried out.

Data and information from 5 reservoirs were used to calculate the benefit-cost ratios of dredging with Program Dredge, an existing computer program. Input variables derived from these 5 reservoirs were used to calculate the B/C ratio for the Feitsui Reservoir. The B/C ratio calculated for the Feitsui Reservoir was 1.440.

The sensitivity analysis of the benefit-cost ratio to the input variables was carried out by varying the input variables + / –5% and + / –10%. Input variable changes of + / –5% resulted in marginal changes of the original benefit-cost ratio (1.451 and 1.428, respectively). Changes in the input variables of + / –10% resulted in benefit-cost ratios of 1.388 and 1.501, respectively. After sensitivity analysis it was found that the longer the beneficial years, the greater the B/C ratio. Whether one operation of dredging could last 50 years is a subject of future study.

Program Dredge does not include indirect costs and benefits and does not include the effect of externalities. Various economic tools for valuing costs, benefits, and externalities are discussed in detail and recommended for future cost-benefit studies. If externalities are considered, Program Dredge could be more useful in planning reservoir dredging operations.

Finally, it is recommended that a comprehensive reservoir conservation plan should include both dredging operations and watershed management practices to reduce erosion and sedimentation. Best Management Practices (BMPs) should be incorporated in watershed conservation practices to control point and non-point erosion. Dredging and sound watershed management should complement each other.

# BIBLIOGRAPHY

Baumol, W. J., & Oates, W. E. ( 1988 ). *The theory of environmental policy* ( 2th ed.). Cambridge : Cambridge University Press.

Boardman, A. E., Greenberg, D. H., Vining, A. R., & Weimer, D. L. ( 1996 ). *Cost-benefit analysis : Concepts and practice.* Upper Saddle River, NJ : Prentice Hall.

Bluffstone, R., & Larson, B. A. ( Eds. ). (1997 ). *Controlling pollution in transition economies : Theories and methods*. Lyme : Edward Elgar Publishing, Inc.

Bray, R. N., & Bates, A. D., & Land, J. M. ( Eds. ). ( 1997 ). *Dredging : A handbook for engineers.* New York : John Wiley & Sons, Inc.

Brent, R. J. ( 1996 ). *Applied cost-benefit analysis.* Vermont, Edward Elgar Publishing Company.

Bromley, D. W. ( Eds. ). ( 1995 ). *Handbook of environmental economics*. Cambridge : Blackwell Publishers Inc.

Brown, L., & Barnwell, T. ( 1985 ). *Computer program documentation for the stream quality model QUAL II : Version Quel2e*. U. S. Environmental Protection Agency.

Chang, Y. ( 2001 ). *Problem analysis and management policy of important water resource districts in Twiwan*. Unpublished doctoral dissertation, National Chung-Hsing University, Taichung, Taiwan.

Chinese Soil and Water Conservation Academy. ( 2000 ). *Law of soil and water conservation and related laws : Technical criteria of soil and water conservation.* Taipei : Author.

De Mooij, R. A. ( 2000 ). *Environmental taxation and the double dividend.* New York : North-Holland Press.

Diamond, P. A. ( 1975 ). A many-person Ramsey tax rule, *Journal of Public Economics*, 4 , 335-342.

Environmental Protection Administration, the Executive Yuan. ( 2000 ). *Panhsin water resource protection district, survey on nitrogen, phosphorus pollution, analysis and management planning of Feitsui reservoir water source watershed area – fist work report*. Taipei : Author.

Environmental Protection Administration, the Executive Yuan. ( 2000 ). *The non-point source pollution analytic investigation and management planning on Tahan creek, Hsintien creek of Tanshui river basin –Panhsin water resource district, survey on nitrogen, phosphorus pollution, analysis and management planning of Feitsui reservoir water source watershed area.* Taipei : Author.

Feitsui Reservoir Administration Bureau. ( 2001 ). *A year report of Feitsui Reservoir.* Taipei : Author.

Gilpin, A. ( 2000 ). *Environmental economics : A critical overview*. England : John Wiley & Sons Ltd.

Hadihardaja, I. ( 2000 ). *Modeling of reservoir operation with sedimentation control.* Unpublished doctoral dissertation, Colorado State University, Fort Collins, USA.

Hammond, R. ( 1969 ). *Modern dredging practice.* Letchworth : The Garden City Press.

Hanley, N., & Spash, C. L. (1993). *Cost-benefit analysis and the environment.* Vermont : Edward Elgar Publishing Company.

Hsiaotao, C. ( 1984 ). *Water quality prediction and preventive pollution policy of Feitsui Reservoir*. Taipei : Taipei Feitsui reservoir Administration Bureau.

Hsu, Y. ( 2002 ). *A study on renewable resource technique of reservoir silt*. Paper presented at the seminar of the Department of Soil and Water Conservation of National Chung Hsing University, Taichung, Taiwan.

Huston, J. ( 1970 ). *Hydraulic dredging : Theoretical and applied.* Maryland : Cornell Maritime Press.

Irwin, J. D., & Graf, E. R. ( 1979 ). *Industrial noise and vibration control.* London : Prentice-Hall International, Inc.

Jaegar, W. K. ( 2001 ). *Double dividend reconsidered.* Agricultural and Resource Economic Department Working Paper, Oregon State University.

Jain, S. K., & Singh, V. P. ( 2003 ). *Developments in water science : Water resources systems planning and management.* Amsterdam, The Netherlands : Elsevier Science B. V.

Julien, P. Y. ( 1995 ). *Erosion and sedimentation.* Australia : Cambridge University Press.

Kuo, C., Yu, H., Lo, S., & Lin, C. ( 1996 ). *The best operational management research on non-point pollution source control of reservoir watershed ( I ).* Taipei : Author.

Lamure ( 1990 ) cited in Mayeres ( 1993 ) op cit.

Langston, C. A., & Ding, G. K. ( 2001). *Sustainable practices in the built environment* ( 2th ed. ). Woburn, MA : Reed Educational and Professional Publishing Ltd.

Lautensach, A. K. ( 2005 ). The values of ecologists. *Environmental Values*, 14, 241 - 250.

Levin, H. M., & McEwan, P. J. ( 2001 ). *Cost-effectiveness analysis* ( 2th ed.). Thousand Oaks, CA : Sage Publications, Inc.

Liang, W., Yang, F., & Hsu, S. ( 2002 ). *Reservoir dredge on environmental affection.* Paper presented at the seminar of the Department of Soil and Water Conservation of National Chung Hsing University, Taichung, Taiwan.

Liu, K., & Huang, C. ( 1989 ). *English Chinese dictionary of hydrology*. Taipei : Center for WuChou.

Loomis, J. ( 2002 ). *Environmental economics.* Lecture notes. Colorado State University, Fort Collins, Colo. USA.

Loomis, J., Helfand, G. ( 2001 ). *Environmental policy analysis for decision making.* Dordrecht, The Netherlands : kluwer Academic Publishers.

Maddison, D., Pearce, D., Johansson, O., Calthrop, E., Litman, T., & Verhoef, E. ( 5th Eds.). ( 1996 ). *The true costs of road transport.* London : Earthscan Publications Limited.

Management committee of Taipei Watershed Management Bureau. ( 1995 ). *A whole planning on watershed land utility of Taipei Watershed Management Area.* Taipei : Author.

McCuen, R. H. ( 2005 ). *Hydrologic analysis and design.* ( 3rd ed.). New Jersey : Pearson Education, Inc.

Mitsch, W. J. ( 1988 ). Ecological engineering and ecotechnology with wetlands : Applications of systems approaches. *In Advances in Environmental Modelling : Proceedings of Conference on State of the Art of Ecological Modelling, June, 1987, Venice, Italy.* Elsevier, Amsterdam.

Mitsch, W. J., & Jorgensen, S. E. ( 1989 ). *Ecological engineering : an introduction to ecotechnology.* New York : John Wiley & Sons, Inc.

Mooij De, R. A. ( 2000 ). *Contributions to economics analysis : Environmental taxation and the double dividend.* Amsterdam, The Netherlands : Elsevier Science B. V.

Morris, G. L., & Fan, J. ( 1998 ). *Reservoir sedimentation handbook : Design and management of dams, reservoirs, and watersheds for sustainable use.* New York : McGraw-Hill Companies.

Nas, T. F. ( 1996 ). *Cost-benefit analysis : Thoery and application.* Thousand Oaks, CA : Sage Publications, Inc.

Ng, Y. ( 2004 ). *Welfare economics : Towards a more complete analysis.* Australia : Monash University Press.

O'connell, J. F. ( 1982 ). *Welfare economics theory.* Boston : Auburn House Publishing Company.

Ostro, B. ( 1994 ). *Estimating the health effects of air pollution : A methodology with an application to Jakarta policy.* World Bank, Washington DC.

Palermo, M. R. ( 2000 ). Handbook of dredging engineering. (Ed.), *Disposal and placement of dredged material* ( pp. 11.1-11.52 ). New York : McGraw- Hill Companies.

Pearce, D. ( 1998 ). *Economics and environment : Essays on ecological economics and sustainable development.* Massachusetts : Edward Elgar Publishing, Inc.

Pearce, D, W. ( Eds. ). ( 1976 ). *Environmental economics.* New York : Longman Inc.

Prasifka, D. W. ( 1994 ). *Water supply planning.* Malabar, FL : Krieger Publishing Company.

Pugner, P. E., & Hughes, T. C. ( 1976 ). *User oriented systems analysis for regional municipal water supply planning.* Logan, Utah : Utah State University Press.

Randall, R. E. ( 2000 ). Handbook of dredging engineering. (Ed.), *Dredging costs and cost estimating* ( pp. A9.1-A9.22 ). New York : McGraw- Hill Companies.

Rao, P. K. ( 2003 ). *The economics of transaction costs : Theory, methods and applications.* New York : Palgrave Macmillan.

Rice, T. L. ( 1981 ). *Reservoir sedimentation modeling.* Unpublished doctoral dissertation, Colorado State University, Fort Collins, USA.

Roberts, B. R. ( 1993 ). *Water management in desert environments : A comparative analysis.* Berlin : Springer-Verlag.

Russell, C. S. ( 2001 ). *Applied economics to the environment.* New York : Oxford University Press.

Shieh, H. ( 1997 ). Sediment related disasters on slopeland and their control methods. *Journal of Soil and Water Conservation*, 29, 125-135.

Soguel, N. ( 1995 ). Contingent valuation of traffic noise reduction benefits. *Swiss Statistical and Political Economic Review*, 132, 109-123.

Soil and Water Conservation Bureau, Council of Agricultural, Executive Yuan. ( 2001 ). *Soil and water resources, conservative talking.* Taipei : Author.

South Region Water Resources Office, Water Resources Agency, Ministry of Economic Affairs & Cultural and Educational Foundation of Hydraulic and Ocean Study and Development, Cheng Kung University. ( 2002 ). *Tsengwen Reservoir desilting and post-processing feasibility study.* Taipei : Author.

Sterner, T. ( Eds. ). ( 1999 ). *The market and the environment.* Massachusetts : Edward Elgar.

Taipei Feitsui Reservoir Administration Bureau. ( 2001 ). *A study on planning and management of the Feitsui Reservoir Watershed ( II ).* Taipei : Author.

Taipei Water Department. ( 2001 ). *Taipei's water.* Taipei : Author.

Taipei Water Resource District Management Committee. ( 1985 ). *A management plan on recreational activities of Taipei Water Resource District.* Taipei : Author.

Tsu, W., & Cheng, C. ( 2002 A ). *Benefit-cost analysis of reservoir sediment dredging.* Paper presented at the seminar of the Department of Soil and Water Conservation of National Chung Hsing University, Taichung, Taiwan.

Tsu, W., & Chun, C. ( 2002 B ). *Benefit-cost analysis on reservoir sediment dredging.* Paper presented at the seminar of the Department of Soil and Water Conservation of National Chung Hsing University, Taichung, Taiwan.

Turner, T. M. ( 1996 ). *Fundamentals of hydraulic dredging* ( 2th ed. ). New York : American Society of Civil Engineers Press.

Votruba, L. ( 1988 ). *Analysis of water resource systems.* Amsterdam : Elsevier Science Publishing Company. Inc.

Walter, A. ( 1961 ). The theory and management of private and social costs of highway congestion. *Econometrica*, 29, 676 – 699.

Water Environment Research Center, National Taipei University of Technology. ( 2002 ). *Ecological working method manual.* Taipei : Author.

Water Resource Bureau, Ministry of Economics Affairs. ( 2000 A ). *Annual report of Feitsui Reservoir.* Taipei : Author.

Water Resource Bureau, Ministry of Economics Affairs. ( 1998 A ). *Implementation plan for promoting citizen's participation in reservoir watershed management.* Taipei : Author.

Water Resource Bureau, Ministry of Economics Affairs. ( 2000 B ). *The project for water resources database establishment and conservation program of the major reservoir watersheds in Taiwan.* Taipei : Author.

Water Resource Bureau, Ministry of Economics Affairs. ( 1998 B ). *YuanWaiLiuChang : graphs on Taiwan area reservoirs.* Taipei : Author.

Water Resource Bureau, Ministry of Economics Affairs & Department of Hydraulic and Ocean Engineering, National Cheng Kung University. ( 1998 ). *A seminar on research plan results of reservoir sustainable management : dissertations.* Taipei : Author.

Water Resource Bureau, Ministry of Economics Affairs & Department of Hydraulic and Ocean Engineering, National Cheng Kung University. ( 1994 ). *An analysis on reservoir sedimentation dredging.* Taipei : Author.

Water Resource Bureau, Ministry of Economics Affairs & Department of Hydraulic and Ocean Engineering, National Cheng Kung University. ( 2002 ). *Tseng-Wen reservoir desilting and post-processing feasibility study ( I ).* Taipei : Author.

Water Resource Bureau, Ministry of Economics Affairs & Department of Hydraulic and Ocean Engineering, National Cheng Kung University. ( 2002 ). *Tseng-Wen reservoir desilting and post-processing feasibility study ( II ).* Taipei : Author.

Water Resource Bureau, Ministry of Economics Affairs & Department of Soil and Water Conservation, National Chung Hsing University. ( 1998 ). *The influence of land use in reservoir sedimentation ( III )*. Taipei : Author.

Water Resource Bureau, Ministry of Economics Affairs & Nungpang Technical Adviser Limited Corporation. ( 2002 ). *An assessment of the benefits and costs of reservoir dredging*. Taipei : Author.

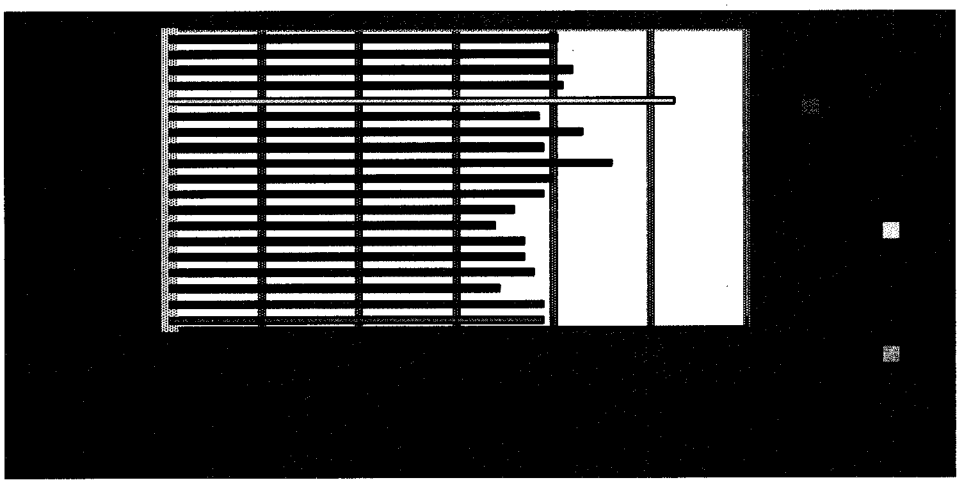
Weber, E. ( Eds ). (1982 ). *Air pollution : Assessment methodology and modeling*. New York : A Division of Plenum Publishing Corporation.

Wen, C., & Yu, H. ( 1998 ). A best management and operational criteria on non-point source pollution of recreational activity. Taipei : Author.

Wrobel, L. C., & Brebbia, C. A. ( Eds. ). ( 1993 ). *Water pollution II : Modeling, measuring and prediction*. Billerica : Computational Mechanics Inc.

## APPENDIX A
## TABLES AND CHARTS

Table A.1 : Carlson indices at Feitsui Reservoir by year



Note : Carlson's TSI ( Carlson Trophic State Index )

| Degree | Carlson's TSI |
|---|---|
| Oligotrophic | < 40 |
| Mesotrophic | 40-50 |
| Eutrophic | > 50 |

Source : Taipei Feitsui Reservoir Administration Bureau

Table A.2 : Data for Paiho, Tapu, Mingte, Chingmien, Shihmen, Feitsui Reservoir watersheds

| | Paiho | Tapu | Mingte | Chingmien | Shihmen | Feitsui |
|---|---|---|---|---|---|---|
| Watershed area($km^2$) | 26.6 | 100 | 61.1 | 2.73 | 763.4 | 303 |
| Reservoir capacity($1000m^3$) | 25093 | 5499.4 | 17700 | 1150 | 309120 | 406000 |
| Average steepness(%) | 40.15 | 40.25 | 54.13 | 34.54 | 66.99 | 51.69 |
| Average annual precipitation(mm) | 2843.3 | 2047.4 | 1731.3 | 2559.9 | 2378.8 | 3524.5 |
| Land use(%) | | | | | | |
| Forest | 41.57 | 64.73 | 63.35 | 21.9 | 93.89 | 87.23 |
| Tea plantation | 0.02 | 1.23 | 0.88 | | | 3.84 |
| Reservoir | 5.17 | 0.12 | 2.24 | | 0.99 | 2.8 |
| Grass land | 2.78 | 1.89 | 2.19 | 1.18 | 1.46 | 1.19 |
| Barren land | 2.72 | 4.25 | 1.65 | 2.09 | | 1.07 |
| Orchards | 3.62 | 9.06 | 2.15 | 65.93 | 3.05 | 0.28 |
| Landslide | 0.64 | 0.01 | 0.02 | 0.12 | 0.58 | 0.04 |
| Bamboo | 3.3 | 6.44 | 21.12 | 0.79 | | 0.25 |
| Betel-nut plantation | 34.97 | 0.46 | 0.09 | 1.14 | | 0.15 |
| Pond | 0 | 0.78 | 0.27 | 4.13 | | 0.01 |

Source : Water Resource Bureau, Ministry of Economics Affairs

Table A.3 : Input variables for Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoirs

| | Paiho | Tapu | Mingte | Chingmien | Shihmen |
|---|---|---|---|---|---|
| Annual interest rate | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| Wholesale water price (NT$/cubic meter) | 7 | 7 | 7 | 7 | 10 |
| Reservoir storage utilization frequency | 1.6 | 5 | 2.5 | 1.15 | 2.491 |
| Unit dredging cost (NT$/cubic meter) | 112.99435 | 53.29 | 68.16 | 60 | 200 |
| Reservoir storage at beginning of simulation | 15519000 | 4525000 | 13874800 | 981165 | 309120000 |
| Annual runoff volume for the simulation period | 43475000 | 174330000 | 86580000 | 2929000 | 535567369.4 |
| Average reservoir storage for the record period | 20529000 (1965-1992) | 5148000 (1972-1987) | 15000000 (1973-1989) | 1095730 (1980-1988) | 234000000 (2000) |
| Annual runoff volume for the record period | 43370000 (1965-1992) | 230137000 (1972-1987) | 85247000 (1973-1989) | 3139000 (1980-1988) | 534273877.2 (2000) |

Table A.3 continued

| | Paiho | Tapu | Mingte | Chingmien | Shihmen |
|---|---|---|---|---|---|
| Annual sedimentation rate for the record period | 353800 (1965-1992) | 44500 (1972-1987) | 93800 (1973-1989) | 12060 (1980-1988) | 1860000 (2000) |
| Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) | 2 | 2 | 2 | 2 | 2 |
| Simulation period in years | 51 | 300 | 300 | 300 | 100 |
| Stages of dredging | 1 | 1 | 1 | 1 | 1 |
| Dredge volume | 283200 | 638000 | 679250 | 638000 | 300000 |

Source : Water Resource Bureau, Ministry of Economics Affairs

Table A.4 : Water pricing data

monthly counting expense of water volume (thousand cubic meter), monthly income of water expense (thousand NT$), monthly income of water supply, monthly income of selling water per degree, and monthly cost of selling water per degree for East, West, South, North, and Yangming office

| Item | East office | West office | South office | North office | Yangming office |
|---|---|---|---|---|---|
| Counting expense of water volume (thousand cubic meter) | 125,539 | 179,372 | 121,839 | 72,240 | 76,760 |
| income of water expense (thousand NT$) | 1,070,469 | 1,323,778 | 1,049,147 | 566,522 | 586,594 |

| item | unit | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|
| counting expense of water volume (thousand cubic meter) | thousand cubic meter | 565,811 | 573,659 | 582,443 | 560,105 | 575,751 |
| income of water supply | thousand NT$ | 4,444,093 | 4,490,220 | 4,593,861 | 4,459,474 | 4,596,511 |
| income of selling water per degree | NT$ | 7.854 | 7.827 | 7.887 | 7.962 | 7.984 |
| cost of selling water per degree | NT$ | 7.222 | 7.690 | 7.163 | 7.475 | 7.213 |

Source : Taipei Water Department

Table A.5 : Sensitivity analysis

5.1 Paiho Reservoir watershed dredging cost-benefit analysis

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|
| Annual interest rate | 0.05 | 0.057 | 0.06 | 0.063 | 0.07 |
| Wholesale water price (NT$/cubic meter) | 6.3 | 6.65 | 7 | 7.35 | 7.7 |
| Reservoir storage utilization frequency | 1.44 | 1.52 | 1.6 | 1.68 | 1.76 |
| Unit dredging cost (NT$/cubic meter) | 101.695 | 107.345 | 112.99435 | 118.644 | 124.294 |
| Reservoir storage at beginning of simulation | 13967100 | 14743050 | 15519000 | 16294950 | 17070900 |
| Annual runoff volume for the simulation period | 39127500 | 41301250 | 43475000 | 45648750 | 47822500 |
| Average reservoir storage for the record period (1965-1992) | 18476100 | 19502550 | 20529000 | 21555450 | 22581900 |
| Annual runoff volume for the record period (1965-1992) | 39033000 | 41201500 | 43370000 | 45538500 | 47707000 |
| Annual sedimentation rate for the record period (1965-1992) | 318420 | 336110 | 353800 | 371490 | 389180 |
| Dredge volume | 254880 | 269040 | 283200 | 297360 | 311520 |
| B/C ratio | 1.553 | 1.486 | 1.502 | 1.517 | 1.456 |

| Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) | 1 | 2 | 3 |
|---|---|---|---|
| B/C ratio | 1.491 | 1.502 | 1.511 |

Table A.5 : Sensitivity analysis

5.1 Paiho Reservoir watershed dredging cost-benefit analysis continued

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | | minus 5% | | original | | plus 5% | | plus 10% | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Simulation period in years | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 51 |
| B/C ratio | 0.417 | 0.727 | 0.956 | 1.126 | 1.251 | 1.343 | 1.409 | 1.455 | 1.486 | 1.502 | 1.502 |

| Stages of dredging | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| B/C ratio | 1.502 | | | |

5.2 Tapu Reservoir watershed dredging cost-benefit analysis

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|
| Annual interest rate | 0.05 | 0.057 | 0.06 | 0.063 | 0.07 |
| Wholesale water price (NT$/cubic meter) | 6.3 | 6.65 | 7 | 7.35 | 7.7 |
| Reservoir storage utilization frequency | 4.5 | 4.75 | 5. | 5.25 | 5.5 |
| Unit dredging cost (NT$/cubic meter) | 47.961 | 50.626 | 53.29 | 55.955 | 58.619 |
| Reservoir storage at beginning of simulation | 4072500 | 4298750 | 4525000 | 4751250 | 4977500 |
| Annual runoff volume for the simulation period | 156897000 | 165613500 | 174330000 | 183046500 | 191763000 |
| Average reservoir storage for the record period (1972-1987) | 4633200 | 4890600 | 5148000 | 5405400 | 5662800 |
| Annual runoff volume for the record period (1972-1987) | 207123300 | 218630150 | 230137000 | 241643850 | 253150700 |
| Annual sedimentation rate for the record period (1972-1987) | 40050 | 42275 | 44500 | 46725 | 48950 |
| Dredge volume | 574200 | 606100 | 638000 | 669900 | 701800 |
| B/C ratio | 11.000 | 10.298 | 10.337 | 10.371 | 9.842 |

| Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) | 1 | 2 | 3 |
|---|---|---|---|
| B/C ratio | 10.083 | 10.337 | 10.495 |

5.2 Tapu Reservoir watershed dredging cost-benefit analysis continued

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | | minus 5% | | original | | plus 5% | | | plus 10% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Simulation period in years | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 300 |
| B/C ratio | 2.749 | 4.773 | 6.264 | 7.36 | 8.166 | 8.757 | 9.19 | 9.507 | 9.738 | 9.906 | 10.337 |

| Stages of dredging | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| B/C ratio | 10.337 | | | |

5.3 Mingte Reservoir watershed dredging cost-benefit analysis

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|
| Annual interest rate | 0.05 | 0.057 | 0.06 | 0.063 | 0.07 |
| Wholesale water price (NT$/cubic meter) | 6.3 | 6.65 | 7 | 7.35 | 7.7 |
| Reservoir storage utilization frequency | 2.25 | 2.375 | 2.5 | 2.625 | 2.75 |
| Unit dredging cost (NT$/cubic meter) | 61.344 | 64.752 | 68.16 | 71.568 | 74.976 |
| Reservoir storage at beginning of simulation | 12487320 | 13181060 | 13874800 | 14568540 | 15262280 |
| Annual runoff volume for the simulation period | 77922000 | 82251000 | 86580000 | 90909000 | 95238000 |
| Average reservoir storage for the record period (1973-1989) | 13500000 | 14250000 | 15000000 | 15750000 | 16500000 |
| Annual runoff volume for the record period (1973-1989) | 76722300 | 80984650 | 85247000 | 89509350 | 93771700 |
| Annual sedimentation rate for the record period (1973-1989) | 84420 | 89110 | 93800 | 98490 | 103180 |
| Dredge volume | 611325 | 645287.5 | 679250 | 713212.5 | 747175 |
| B/C ratio | 4.545 | 4.220 | 4.224 | 4.228 | 3.992 |

| Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) | 1 | 2 | 3 |
|---|---|---|---|
| B/C ratio | 4.208 | 4.224 | 4.244 |

5.3 Mingte Reservoir watershed dredging cost-benefit analysis continued

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | | minus 5% | | original | | plus 5% | | plus 10% | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Simulation period in years | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 300 |
| B/C ratio | 1.08 | 1.885 | 2.485 | 2.931 | 3.263 | 3.51 | 3.694 | 3.831 | 3.932 | 4.008 | 4.224 |

| Stages of dredging | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| B/C ratio | 4.224 | | | |

5.4 Chingmien Reservoir watershed dredging cost-benefit analysis

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|
| Annual interest rate | 0.05 | 0.057 | 0.06 | 0.063 | 0.07 |
| Wholesale water price (NT$/cubic meter) | 6.3 | 6.65 | 7 | 7.35 | 7.7 |
| Reservoir storage utilization frequency | 1.035 | 1.093 | 1.15 | 1.208 | 1.265 |
| Unit dredging cost (NT$/cubic meter) | 54 | 57 | 60 | 63 | 66 |
| Reservoir storage at beginning of simulation | 883048.5 | 932106.75 | 981165 | 1030223.25 | 1079281.5 |
| Annual runoff volume for the simulation period | 2636100 | 2782550 | 2929000 | 3075450 | 3221900 |
| Average reservoir storage for the record period (1980-1988) | 986157 | 1040943.5 | 1095730 | 1150516.5 | 1205303 |
| Annual runoff volume for the record period (1980-1988) | 2825100 | 2982050 | 3139000 | 3295950 | 3452900 |
| Annual sedimentation rate for the record period (1980-1988) | 10854 | 11457 | 12060 | 12663 | 13266 |
| Dredge volume | 574200 | 606100 | 638000 | 669900 | 701800 |
| B/C ratio | 2.366 | 2.205 | 2.208 | 2.212 | 2.090 |

| Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) | 1 | 2 | 3 |
|---|---|---|---|
| B/C ratio | 2.203 | 2.208 | 2.216 |

5.4 Chingmien Reservoir watershed dredging cost-benefit analysis continued

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | | | minus 5% | | original | | plus 5% | | plus 10% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Simulation period in years | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 300 |
| B/C ratio | 0.565 | 0.986 | 1.3 | 1.535 | 1.709 | 1.839 | 1.936 | 2.008 | 2.062 | 2.102 | 2.208 |

| Stages of dredging | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| B/C ratio | 2.208 | | | |

5.5 Shihmen Reservoir watershed dredging cost-benefit analysis

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|
| Annual interest rate | 0.05 | 0.057 | 0.06 | 0.063 | 0.07 |
| Wholesale water price (NT$/cubic meter) | 9 | 9.5 | 10 | 10.5 | 11 |
| Reservoir storage utilization frequency | 2.242 | 2.366 | 2.491 | 2.616 | 2.74 |
| Unit dredging cost (NT$/cubic meter) | 180 | 190 | 200 | 210 | 220 |
| Reservoir storage at beginning of simulation | 278208000 | 293664000 | 309120000 | 324576000 | 340032000 |
| Annual runoff volume for the simulation period | 482010632.5 | 508789000.9 | 535567369.4 | 562345737.9 | 589124106.3 |
| Average reservoir storage for the record period (2000) | 210600000 | 222300000 | 234000000 | 245700000 | 257400000 |
| Annual runoff volume for the record period (2000) | 480846489.5 | 507560183.3 | 534273877.2 | 560987571.1 | 587701264.9 |
| Annual sedimentation rate for the record period (2000) | 1674000 | 1767000 | 1860000 | 1953000 | 2046000 |
| Dredge volume | 270000 | 285000 | 300000 | 315000 | 330000 |
| B/C ratio | 2.219 | 2.063 | 2.066 | 2.068 | 1.952 |

| | | | |
|---|---|---|---|
| Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) | 1 | 2 | 3 |
| B/C ratio | 2.063 | 2.066 | 2.069 |

5.5 Shihmen Reservoir watershed dredging cost-benefit analysis continued

Decision variable minus 5%, 10% and plus 5%, 10%

| | | minus10% | | minus 5% | | original | | plus 5% | | plus 10% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Simulation period in years | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 100 |
| B/C ratio | 0.525 | 0.917 | 1.209 | 1.428 | 1.592 | 1.714 | 1.805 | 1.873 | 1.923 | 1.961 | 2.066 |

| Stages of dredging | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| B/C ratio | 2.066 | | | |

5.6 Feitsui Reservoir watershed dredging cost-benefit analysis

Decision variable minus 5%, 10% and plus 5%, 10%

| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|
| Annual interest rate | 0.05 | 0.057 | 0.06 | 0.063 | 0.07 |
| Wholesale water price (NT$/cubic meter) | 6.492 | 6.852 | 7.213 | 7.574 | 7.934 |
| Reservoir storage utilization frequency | 3.425 | 3.616 | 3.806 | 3.996 | 4.187 |
| Unit dredging cost (NT$/cubic meter) | 270 | 285 | 300 | 315 | 330 |
| Reservoir storage at beginning of simulation (1984-1989) | 360025200 | 380026600 | 400028000 | 420029400 | 440030800 |
| Annual runoff volume for the simulation period | 891000000 | 940500000 | 990000000 | 1039500000 | 1089000000 |
| Average reservoir storage for the record period (Taiwan Year 1987-2000) | 352326600 | 371900300 | 391474000 | 411047700 | 430621400 |
| Annual runoff volume for the record period (Taiwan Year 1987-2000) | 891127593 | 940634681.5 | 990141770 | 1039648859 | 1089155947 |
| Annual sedimentation rate for the record period (Taiwan Year 1984-2005) | 896400 | 946200 | 996000 | 1045800 | 1095600 |
| Dredge volume | 540000 | 570000 | 600000 | 630000 | 660000 |
| B/C ratio | 1.501 | 1.428 | 1.44 | 1.451 | 1.388 |

5.6 Feitsui Reservoir watershed dredging cost-benefit analysis continued

Decision variable minus 5%, 10% and plus 5%, 10%

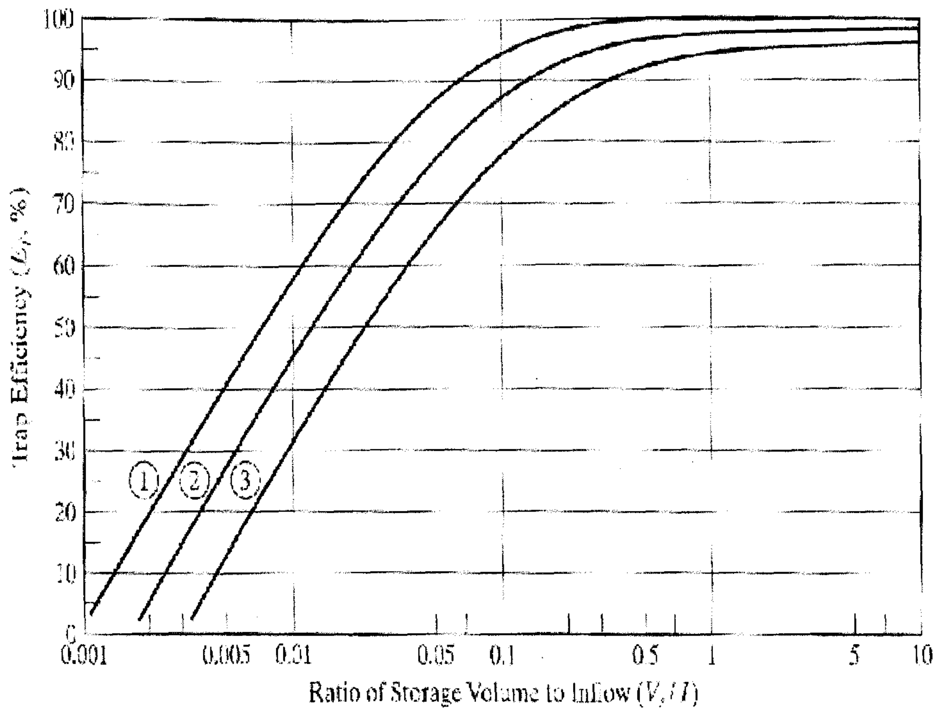
| | minus10% | minus 5% | original | plus 5% | plus 10% |
|---|---|---|---|---|---|

| Brune's trap efficiency curve (1=Fine, 2=Median, 3=Coarse) | 1 | 2 | 3 |
|---|---|---|---|
| B/C ratio | 1.439 | 1.44 | 1.442 |

| Simulation period in years | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B/C ratio | 0.385 | 0.673 | 0.888 | 1.049 | 1.169 | 1.258 | 1.325 | 1.375 | 1.413 | 1.44 | 1.523 |

| Stages of dredging | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| B/C ratio | 1.44 | | | |

Table A.6 : A Brune-type curve



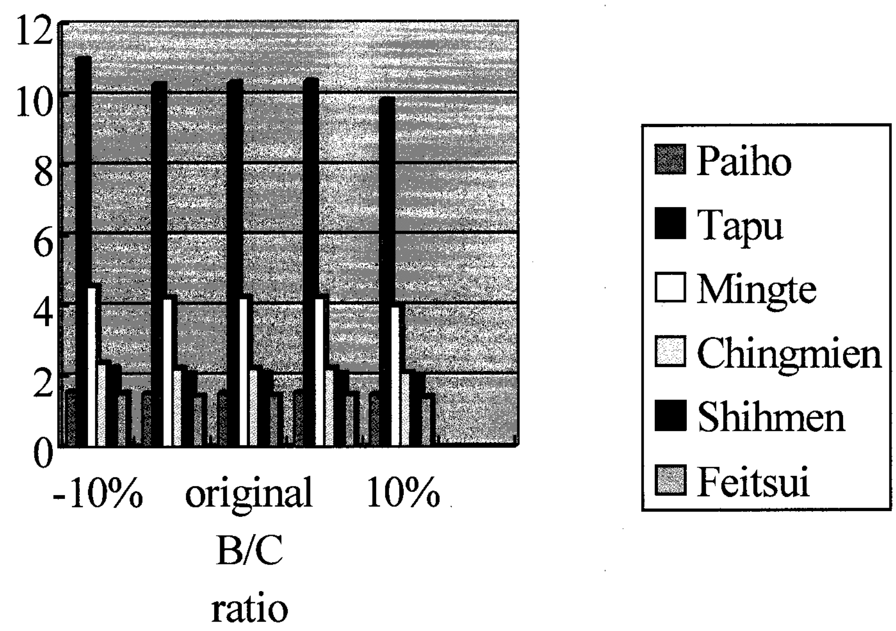

Ef : trap efficiency

Vs : estimate the expected storage volume in the reservoir

*I* : estimate the average water inflow into the reservoir

Source : McCuen, R. H. ( 2005 ). *Hydrologic analysis and design.* ( 3rd ed.). New Jersey : Pearson Education, Inc.

Table A.7 : Sensitivity analysis of benefit-cost ratio for 6 reservoirs




| | -10% | -5% | original | +5% | +10% |
|---|---|---|---|---|---|
| Paiho | 1.553 | 1.486 | 1.502 | 1.517 | 1.456 |
| Tapu | 11.000 | 10.298 | 10.337 | 10.371 | 9.842 |
| Mingte | 4.545 | 4.220 | 4.224 | 4.228 | 3.992 |
| Chingmien | 2.366 | 2.205 | 2.208 | 2.212 | 2.090 |
| Shihmen | 2.219 | 2.063 | 2.066 | 2.068 | 1.952 |
| Feitsui | 1.501 | 1.428 | 1.44 | 1.451 | 1.388 |

Table A.8 : Watershed management plan

<table>
<tr><td>road dig</td><td colspan="6">recreation</td><td colspan="6">water quality</td><td colspan="6">forest</td><td colspan="6">business</td><td colspan="6">agriculture</td><td>housing</td></tr>
<tr><td>water supply</td><td colspan="30" rowspan="6"><u>Watershed Management Plan</u><br><br>Let's work whole puzzles done</td><td>sewerage</td></tr>
<tr><td>beneficiary group</td><td>land use planning</td></tr>
<tr><td>private business</td><td>urban runoff</td></tr>
<tr><td>community group</td><td>central government</td></tr>
<tr><td>pasture</td><td>flood control</td></tr>
<tr><td>environmental problem</td><td>local government</td></tr>
<tr><td>public health</td><td colspan="5">soil and water conservation</td><td colspan="5">terrestrial protection</td><td colspan="5">dairy</td><td colspan="5">industry</td><td colspan="5">resident</td><td colspan="5">mining</td><td>rainstorm</td></tr>
</table>

Source : Water Resource Bureau, Ministry of Economic Affairs (1998 A)

## APPENDIX B
## DREDGE COMPUTER SOFTWARE

```
      PROGRAM DREDGE
C       This program computes annual reservoir storages with and
C       and without dredging and performs related benefit-cost
C       analysis.

        DIMENSION DRED(300)
        REAL IRATE
        CHARACTER*12 FILE5,FILE6
        CHARACTER*80 TITLE

        WRITE(*,*)'Enter the input file name:'
        READ(*,'(A)') FILE5
        OPEN(15,FILE=FILE5,STATUS='OLD')
        WRITE(*,*)'Enter the output file name:'
        READ(*,'(A)') FILE6
        OPEN(16,FILE=FILE6,STATUS='NEW')

C       IRATE = Annual interest rate
C       PWATER = Wholesale water price
C       FREQ = Reservoir storage utilization frequency
C       STORO = Initial reservoir capacity for simulation
C       QA = Average annual runoff in cubic meters

C       STORP = Avarage reservoir capacity for the record period
C       QAP = Average annual runoff for the record period in cubic meters
C       QSED = Average annual reservoir sedimentation rate for the record
C                 period
C       Brune's sediment trap efficiency for reservoir:
C       ICURVE = 1    Fine sediment
C       ICURVE = 2    Median curve
C       ICURVE = 3    Coarse sediment

C       NYR = Simulation period in years
C       NSTAGE = Number of stages for reservoir dredging in years
C       DRED(I) =Dredge amount for ith stage in cubic meters,I = 1,NSTAGE
```

```
C       Read data from FILE5:

C       Enter job title
        READ(15,'(A)') TITLE
        READ(15,*) IRATE
        READ(15,*) PWATER
        READ(15,*) FREQ
        READ(15,*) UCOST
        READ(15,*) STORO
        READ(15,*) QA
        READ(15,*) STORP
        READ(15,*) QAP
        READ(15,*) QSED
        READ(15,*) ICURVE
        READ(15,*) NYR
        READ(15,*) NSTAGE

C       Read in annual dredge volumes for the NSTAGE stages

        DO 10 I=1,NSTAGE
        DRED(I)=0.
        READ(15,*) DRED(I)
10      CONTINUE

C       Set the initial value of DRED for each stages
        DO 15 I=2,300
        DRED(I)=0
15      CONTINUE

C       Determine the average trap efficiency,YTRAP,for the record period
C       using Brune's curve:

        XSQ=STORP/QAP
        CALL TRAP(ICURVE,XSQ,YTRAP)
C       Compute average annual sediment inflow, QSA, based on the trap
C       efficiency and annual sedimentation rate for the record period:
```

```
      IF(YTRAP.NE.0.) QSA=QSED/YTRAP
      GO TO 40
      IF(YTRAP.EQ.0.) WRITE(16,30)
30    FORMAT(1X,'Zero trap efficiency for the past record period')
      GO TO 500

40    CONTINUE

      WRITE(16,42) TITLE
42    FORMAT(1X,A60)

WRITE(16,43)IRATE,PWATER,FREQ,UCOST,STORO,QA,STORP,QAP,QSED
43    FORMAT(/1X,'Bases for Analysis:'/
     1           1X,' Annual interest Rate =',F7.3/
     1           1X,' Wholesale Water Price =',F5.1,' NT$/C.M.'/
     2           1X,' Reservoir Storage Utilization Frequency =',F5.2/
     3           1X,' Unit Dredging Cost = ', F12.6,' NT$/C.M.'/
     4           1X,' Begining Storage for Simulation =',F14.0,' C.M.'/
     5           1X,' Annual Runoff for Simulation = ',F14.0,'C.M.'/
     6           1X,' Average Past Storage for Calibration =',F14.0,'C.M.'/
     7           1X,' Average Annual Runoff for Calibration =',F14.0,'C.M.',
     8           1X,' Average Annual Sedimentation Rate for Calibration =',
     9           F14.0,' C.M.')

       IF(ICURVE .EQ.1 ) WRITE(16,44)
       IF(ICURVE .EQ.2 ) WRITE(16,45)
       IF(ICURVE .EQ.3 ) WRITE(16,46)
44     FORMAT(2X,'Trap Efficiency determined from Brune''s curve for fine
      1sediment')
45     FORMAT(2X,'Trap Efficiency determined from Brune''s median curve')
46     FORMAT(2X,'Trap Efficiency determined from Brune''s curve for coar
      1se sediment')

       WRITE(16,52) NSTAGE
52     FORMAT(/1X,' Number of Dredging Stages =',I5)

       DO 54 I=1,NSTAGE
       WRITE(16,53) I,DRED(I)
```

```
53          FORMAT(1X,'Stage No.',I2,'       Volume = ',F14.0,'C.M.')
54          CONTINUE
             WRITE(16,55)
55          FORMAT(//)

             WRITE(16,57)
57          FORMAT(1X,'Results of Dredging Simulation and Benefit-Cost Analysi
           1s')

             WRITE(16,58)
58          FORMAT('.......................................................
           1...............................................................
           2...............................')

             WRITE(16,60)
60          FORMAT(18X,'    WITHOUT DREDGING     ',21X,'              WITH
DREDG
           1ING',22X,'DREDGING RESIDUAL'/1X,'YEAR',' ........................
           2.......................     ......................................
           3........     ......................')
             WRITE(16,70)
70          FORMAT(5X,4X,'B STOR',5X,'C/I',4X,'TRAP',
           1           3X,'SEDIMENT',6X,'E STOR',6X,'B STOR',5X,
           2           'C/I',3X,'TRAP',3X,'SEDIMENT',6X,'E STOR',
           3           10X,'BEG.',9X,'END',6X,'BENEFIT',9X,
           4           'COST')

             WRITE(16,72)
72          FORMAT(11X,'C.M.',23X,'C.M.',9X,'C.M.',7X,'C.M.',23X,'C.M.',
           1           7X,'C.M.',10X,'C.M.',8X,'C.M.',10X,'NT$',10X,'NT$')

             WRITE(16,58)

C            Simulations with and without dredging

C            STOR1 = Storage without dredging at the begining of a year
             STOR1=STORO
C            STORD1 = Storage with dredging at the begining of a year
```

```
      STORD1=STORO+DRED(1)
C     Residual dredging from the previous year
      RESIDE=0

      Q=QA

      SUMBFT=0.

      DO 100 I=1,NYR
C     Dredging residual, RESIDB, at the begining of a year
      RESIDB=RESIDE+DRED(I)

C     Without dredging

      XSQ=STOR1/Q
      CALL TRAP(ICURVE,XSQ,YTRAP)
      QS=QSA*YTRAP
      STOR2=STOR1-QS

C     With dredging

      XSQD=STORD1/Q
      CALL TRAP(ICURVE,XSQD,YTRAPD)
      QSD=QSA*YTRAPD
      STORD2=STORD1-QSD

C     Dredging residual at the end of a year

      RESIDE=STORD2-STOR2
      IF(QS.LE.20. .OR. QSD.LE.20.) GO TO 400

C     Compute dredging benefit from water sale

      RESID=(RESIDB+RESIDE)/2.
      BENEFIT=RESID*FREQ*PWATER/(1+IRATE)**I
      SUMBFT=SUMBFT+BENEFIT

C     Dredging cost spent at the begining of a year
```

```
      COST=DRED(I)*UCOST
      PCOST=COST/(1+IRATE)**(I-1)
      SUMCOST=SUMCOST+PCOST

C     Write computational results:

      WRITE(16,80) I,
STOR1,XSQ,YTRAP,QS,STOR2,STORD1,XSQD,YTRAPD,
     1            QSD,STORD2,RESIDB,RESIDE,BENEFIT,PCOST
80    FORMAT(I4,F13.0,2F7.4,F11.0,F13.0,F13.0,2F7.4,F11.0,F13.0,2F12.0,
     1       2F13.0)

      STOR1=STOR2
      STORD1=STORD2

      IF(I.LT.NSTAGE) STORD1=STORD2+DRED(I+1)

100   CONTINUE
400   CONTINUE

      WRITE(16,58)

C     Benefit-cost ratio

      BC=SUMBFT/SUMCOST

      WRITE(16,120) SUMBFT,SUMCOST,BC
120   FORMAT(1X,'TOTAL BENEFIT (PRESENT WORTH) = NT$',F14.0/
     1       1X,'TOTAL COST (PRESENT WORTH) = NT$',F14.0/
     2       1X,'B/C RATIO = ',F6.3)

500   CONTINUE
      STOP
      END


      SUBROUTINE TRAP(ICURVE,XSQ,YTRAP)
```

```
C       This subroutine determines sediment trap efficiency of
C       a reservoir from Brune's curves (1952)

        DIMENSION SQ(28),TRAPF(28),TRAPM(28),TRAPC(28)

C       Reservoir capacity-inflow Ratio (SQ)

        DATA SQ/0.001, 0.0018, 0.002, 0.0025, 0.003, 0.0033, 0.005,
     1          0.007, 0.01,   0.015, 0.02,   0.03,  0.04,   0.05,
     2          0.06,  0.07,   0.08,  0.10,   0.15,  0.20,   0.30,
     3          0.40,  0.50,   0.60,  0.70,   0.80,  1.0,    10.0/

C       Trap efficiency for coarse sediment

        DATA TRAPC/0.0,  0.175, 0.2,  0.262, 0.318, 0.338, 0.45,
     1             0.53, 0.60,  0.67, 0.715, 0.78,  0.82,  0.86,
     2             0.88, 0.90,  0.91, 0.938, 0.965, 0.98,  0.995,
     3             1.00, 1.00,  1.00, 1.00,  1.0,   1.0,   1.0/

C       Trap efficiency for median curve

        DATA TRAPM/0.0,   0.0,   0.03,  0.10,  0.15,  0.185, 0.29,
     1             0.37,  0.455, 0.545, 0.605, 0.68,  0.74,  0.78,
     2             0.80,  0.82,  0.84,  0.875, 0.918, 0.94,  0.965,
     3             0.975, 0.983, 0.985, 0.985, 0.985, 0.985, 0.985/

C       Trap efficiency for fine sediment

        DATA TRAPF/0.0,   0.0,   0.0,   0.0,   0.0,   0.,    0.12,
     1             0.218, 0.31,  0.41,  0.47,  0.56,  0.62,  0.663,
     2             0.70,  0.73,  0.76,  0.80,  0.855, 0.88,  0.91,
     3             0.925, 0.935, 0.938, 0.939, 0.94,  0.94,  0.945/

        IN=1
        IE=28
        ISX=1
        ISY=0
```

```
      XX=XSQ

C     Determine reservoir trap efficiency
      IF(ICURVE.EQ.1) CALL
INTP11(XX,YTRAP,SQ,TRAPF,ISX,ISY,IN,IE,IER)
      IF(ICURVE.EQ.2) CALL
INTP11(XX,YTRAP,SQ,TRAPM,ISX,ISY,IN,IE,IER)
      IF(ICURVE.EQ.3) CALL
INTP11(XX,YTRAP,SQ,TRAPC,ISX,ISY,IN,IE,IER)
      IF(XSQ.LE.SQ(1))    YTRAP=0

C     WRITE(16,*) ICURVE, XSQ, XX,YTRAP
      RETURN
      END

      SUBROUTINE INTP11(XX,YY,X,Y,ISX,ISY,IN,IE,IER)
C     For X array in ascending order
      DIMENSION X(IE),Y(IE)
      CALL ORDER(XX,X,IN,IE,IX,ISLINE,IER)
      IF(IER.NE.0) RETURN
      IF(ISLINE.NE.1) GO TO 100
100   CALL INTRP(XX,YY,X(IX),Y(IX),X(IX+1),Y(IX+1),ISX,ISY,IER)
      IF(IER.NE.0) IER=2
      RETURN
      END



      SUBROUTINE INTRP(XX,YY,X1,Y1,X2,Y2,ISX,ISY,IER)
      U1=X1
      U2=X2
      U=XX
      V1=Y1
      V2=Y2
      IER=0
      IF(ISX.NE.1) GO TO 120
      IF(U1.GT.0.    .AND. U2.GT.0.    .AND. U.GT.0.) GO TO 110
100   IER=1
```

```
      RETURN
110   U1=ALOG(U1)
      U2=ALOG(U2)
      U=ALOG(U)
120   IF(ISY.NE.1) GO TO 130
      IF(V1.LE.0.    .OR. V2.LE.0.) GO TO 100
      V1=ALOG(V1)
      V2=ALOG(V2)
130   YY=(U-U1)*(V2-V1)/(U2-U1)+V1
      IF(ISY.EQ.1) YY=EXP(YY)
      RETURN
      END


      SUBROUTINE ORDER(XX,X,IN,IE,IX,ISLINE,IER)
C     Array X(I) in ascending order
      DIMENSION X(IE)
      ISLINE=0
      IER=ISLINE
      DO 120 I=IN, IE
      IF (XX-X(I)) 100, 110, 120
100   IX=I-1
      IF(I.NE.IN) RETURN
      GO TO 130
110   IX=I
      ISLINE=1
120   CONTINUE
      RETURN
130   IER=1
      RETURN
      END
```

# APPENDIX C

## Paiho Reservoir Dredging Cost-benefit Aanlysis (50 years)

Paiho Reservoir Dredging Cost-benefit Analysis

Bases for Analysis:
Annual interest Rate = 0.060
Wholesale Water Price = 7.0 NT$/C.M.
Reservoir Storage Utilization Frequency = 1.60 per period
Unit Dredging Cost = 112.994347 NT$/C.M. per period
Beginning Storage for Simulation = 15519000. C.M.
Annual Runoff for Simulation = 43475000.C.M.
Average Past Storage for Calibration = 20529000.C.M.
Average Annual Runoff for Calibration = 43370000.C.M.
Average Annual Sedimentation Rate for Calibration = 353800. C.M.
Trap Efficiency determined from Brune's median curve

Number of Dredging Stages = 1
Stage No. 1 Volume = 283200.C.M.

Results of Dredging Simulation and Cost-benefit Analysis (in the absence of externalities)

| YEAR | WITHOUT DREDGING | | | | | WITH DREDGING | | | | | DREDGING RESIDUAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | BEG. C.M. | END C.M. | BENEFIT NT$ | COST NT$ |
| 1 | 15519000. | 0.3570 | 0.9710 | 350196. | 15168804. | 15802200. | 0.3635 | 0.9717 | 350423. | 15451777. | 283200. | 282973. | 2991103. | 31999998. |
| 2 | 15168804. | 0.3489 | 0.9702 | 349910. | 14818894. | 15451777. | 0.3554 | 0.9709 | 350142. | 15101635. | 282973. | 282741. | 2819508. | 0. |
| 3 | 14818894. | 0.3409 | 0.9694 | 349618. | 14469276. | 15101635. | 0.3474 | 0.9701 | 349854. | 14751781. | 282741. | 282505. | 2657713. | 0. |
| 4 | 14469276. | 0.3328 | 0.9686 | 349318. | 14119958. | 14751781. | 0.3393 | 0.9693 | 349561. | 14402220. | 282505. | 282262. | 2505152. | 0. |
| 5 | 14119958. | 0.3248 | 0.9678 | 349012. | 13770946. | 14402220. | 0.3313 | 0.9684 | 349260. | 14052960. | 282262. | 282014. | 2361296. | 0. |
| 6 | 13770946. | 0.3168 | 0.9669 | 348698. | 13422248. | 14052960. | 0.3232 | 0.9676 | 348952. | 13704008. | 282014. | 281760. | 2225656. | 0. |
| 7 | 13422248. | 0.3087 | 0.9660 | 348377. | 13073871. | 13704008. | 0.3152 | 0.9667 | 348637. | 13355371. | 281760. | 281500. | 2097761. | 0. |
| 8 | 13073871. | 0.3007 | 0.9651 | 348047. | 12725824. | 13355371. | 0.3072 | 0.9658 | 348314. | 13007057. | 281500. | 281233. | 1977169. | 0. |
| 9 | 12725824. | 0.2927 | 0.9635 | 347470. | 12378354. | 13007057. | 0.2992 | 0.9648 | 347956. | 12659101. | 281233. | 280747. | 1862758. | 0. |
| 10 | 12378354. | 0.2847 | 0.9618 | 346855. | 12031499. | 12659101. | 0.2912 | 0.9632 | 347353. | 12311748. | 280747. | 280249. | 1754242. | 0. |
| 11 | 12031499. | 0.2767 | 0.9600 | 346223. | 11685276. | 12311748. | 0.2832 | 0.9614 | 346735. | 11965013. | 280249. | 279737. | 1651965. | 0. |
| 12 | 11685276. | 0.2688 | 0.9582 | 345573. | 11339703. | 11965013. | 0.2752 | 0.9597 | 346099. | 11618914. | 279737. | 279211. | 1555569. | 0. |
| 13 | 11339703. | 0.2608 | 0.9564 | 344906. | 10994797. | 11618914. | 0.2673 | 0.9579 | 345447. | 11273467. | 279211. | 278670. | 1464717. | 0. |
| 14 | 10994797. | 0.2529 | 0.9545 | 344219. | 10650578. | 11273467. | 0.2593 | 0.9560 | 344776. | 10928691. | 278670. | 278113. | 1379089. | 0. |
| 15 | 10650578. | 0.2450 | 0.9525 | 343512. | 10307066. | 10928691. | 0.2514 | 0.9541 | 344085. | 10584606. | 278113. | 277540. | 1298387. | 0. |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 10307066. | 0.2371 | 0.9505 | 342783. | 9964283. | 10584606. | 0.2435 | 0.9521 | 343374. | 10241232. | 277540. | 276949. | 1222327. | 0. |
| 17 | 9964283. | 0.2292 | 0.9484 | 342031. | 9622252. | 10241232. | 0.2356 | 0.9501 | 342640. | 9898592. | 276949. | 276340. | 1150644. | 0. |
| 18 | 9622252. | 0.2213 | 0.9462 | 341254. | 9280998. | 9898592. | 0.2277 | 0.9480 | 341884. | 9556708. | 276340. | 275710. | 1083082. | 0. |
| 19 | 9280998. | 0.2135 | 0.9440 | 340451. | 8940547. | 9556708. | 0.2198 | 0.9458 | 341102. | 9215606. | 275710. | 275059. | 1019404. | 0. |
| 20 | 8940547. | 0.2056 | 0.9417 | 339620. | 8600927. | 9215606. | 0.2120 | 0.9436 | 340294. | 8875312. | 275059. | 274385. | 959389. | 0. |
| 21 | 8600927. | 0.1978 | 0.9392 | 338701. | 8262226. | 8875312. | 0.2041 | 0.9413 | 339457. | 8535855. | 274385. | 273629. | 902728. | 0. |
| 22 | 8262226. | 0.1900 | 0.9361 | 337593. | 7924633. | 8535855. | 0.1963 | 0.9386 | 338491. | 8197364. | 273629. | 272731. | 849059. | 0. |
| 23 | 7924633. | 0.1823 | 0.9329 | 336442. | 7588191. | 8197364. | 0.1886 | 0.9355 | 337375. | 7859988. | 272731. | 271797. | 798314. | 0. |
| 24 | 7588191. | 0.1745 | 0.9296 | 335246. | 7252945. | 7859988. | 0.1808 | 0.9323 | 336216. | 7523772. | 271797. | 270827. | 750493. | 0. |
| 25 | 7252945. | 0.1668 | 0.9261 | 334000. | 6918946. | 7523772. | 0.1731 | 0.9289 | 335011. | 7188761. | 270827. | 269816. | 705427. | 0. |
| 26 | 6918946. | 0.1591 | 0.9225 | 332699. | 6586246. | 7188761. | 0.1654 | 0.9255 | 333754. | 6855007. | 269816. | 268761. | 662954. | 0. |
| 27 | 6586246. | 0.1515 | 0.9188 | 331340. | 6254906. | 6855007. | 0.1577 | 0.9218 | 332443. | 6522563. | 268761. | 267658. | 622922. | 0. |
| 28 | 6254906. | 0.1439 | 0.9136 | 329472. | 5925434. | 6522563. | 0.1500 | 0.9180 | 331072. | 6191491. | 267658. | 266057. | 584701. | 0. |
| 29 | 5925434. | 0.1363 | 0.9078 | 327402. | 5598031. | 6191491. | 0.1424 | 0.9125 | 329082. | 5862409. | 266057. | 264378. | 548214. | 0. |
| 30 | 5598031. | 0.1288 | 0.9018 | 325228. | 5272803. | 5862409. | 0.1348 | 0.9067 | 326993. | 5535415. | 264378. | 262613. | 513825. | 0. |
| 31 | 5272803. | 0.1213 | 0.8955 | 322939. | 4949863. | 5535415. | 0.1273 | 0.9006 | 324798. | 5210617. | 262613. | 260754. | 481408. | 0. |
| 32 | 4949863. | 0.1139 | 0.8888 | 320522. | 4629341. | 5210617. | 0.1199 | 0.8942 | 322486. | 4888132. | 260754. | 258791. | 450841. | 0. |
| 33 | 4629341. | 0.1065 | 0.8817 | 317962. | 4311380. | 4888132. | 0.1124 | 0.8874 | 320042. | 4568090. | 258791. | 256710. | 422012. | 0. |
| 34 | 4311380. | 0.0992 | 0.8737 | 315087. | 3996292. | 4568090. | 0.1051 | 0.8802 | 317452. | 4250637. | 256710. | 254345. | 394691. | 0. |
| 35 | 3996292. | 0.0919 | 0.8618 | 310795. | 3685498. | 4250637. | 0.0978 | 0.8715 | 314285. | 3936352. | 254345. | 250855. | 368083. | 0. |
| 36 | 3685498. | 0.0848 | 0.8491 | 306215. | 3379283. | 3936352. | 0.0905 | 0.8594 | 309940. | 3626413. | 250855. | 247130. | 342289. | 0. |
| 37 | 3379283. | 0.0777 | 0.8357 | 301382. | 3077902. | 3626413. | 0.0834 | 0.8466 | 305301. | 3321112. | 247130. | 243211. | 317958. | 0. |
| 38 | 3077902. | 0.0708 | 0.8217 | 296336. | 2781566. | 3321112. | 0.0764 | 0.8331 | 300444. | 3020668. | 243211. | 239103. | 295050. | 0. |
| 39 | 2781566. | 0.0640 | 0.8083 | 291517. | 2490049. | 3020668. | 0.0695 | 0.8190 | 295376. | 2725293. | 239103. | 235244. | 273751. | 0. |
| 40 | 2490049. | 0.0573 | 0.7949 | 286673. | 2203376. | 2725293. | 0.0627 | 0.8057 | 290561. | 2434732. | 235244. | 231356. | 254038. | 0. |
| 41 | 2203376. | 0.0507 | 0.7815 | 281834. | 1921542. | 2434732. | 0.0560 | 0.7924 | 285784. | 2148948. | 231356. | 227406. | 235633. | 0. |
| 42 | 1921542. | 0.0442 | 0.7579 | 273326. | 1648216. | 2148948. | 0.0494 | 0.7779 | 280557. | 1868391. | 227406. | 220175. | 216877. | 0. |
| 43 | 1648216. | 0.0379 | 0.7288 | 262840. | 1385376. | 1868391. | 0.0430 | 0.7529 | 271513. | 1596879. | 220175. | 211503. | 197331. | 0. |
| 44 | 1385376. | 0.0319 | 0.6926 | 249773. | 1135602. | 1596879. | 0.0367 | 0.7222 | 260460. | 1336418. | 211503. | 200816. | 177813. | 0. |
| 45 | 1135602. | 0.0261 | 0.6544 | 235998. | 899605. | 1336418. | 0.0307 | 0.6851 | 247067. | 1089351. | 200816. | 189747. | 158897. | 0. |
| 46 | 899605. | 0.0207 | 0.6113 | 220457. | 679147. | 1089351. | 0.0251 | 0.6467 | 233224. | 856127. | 189747. | 176980. | 140754. | 0. |
| 47 | 679147. | 0.0156 | 0.5535 | 199602. | 479545. | 856127. | 0.0197 | 0.6018 | 217021. | 639106. | 176980. | 159561. | 121857. | 0. |
| 48 | 479545. | 0.0110 | 0.4768 | 171941. | 307604. | 639106. | 0.0147 | 0.5405 | 194934. | 444172. | 159561. | 136568. | 101155. | 0. |
| 49 | 307604. | 0.0071 | 0.3726 | 134358. | 173246. | 444172. | 0.0102 | 0.4598 | 165807. | 278365. | 136568. | 105118. | 77885. | 0. |
| 50 | 173246. | 0.0040 | 0.2327 | 83906. | 89340. | 278365. | 0.0064 | 0.3488 | 125791. | 152574. | 105118. | 63234. | 51182. | 0. |

TOTAL BENEFIT (PRESENT WORTH IN TERMS OF YEAR 1) = NT$ 48055056.
TOTAL COST (PRESENT WORTH) = NT$ 31999998.
B/C RATIO = 1.502

# Tapu Reservoir Dredging Cost-benefit Aanlysis (50 years)

Tapu Reservoir Dredging Cost-benefit Analysis

Bases for Analysis:
Annual interest Rate = 0.060
Wholesale Water Price = 7.0 NT$/C.M.
Reservoir Storage Utilization Frequency = 5.00 per period
Unit Dredging Cost = 53.290001 NT$/C.M. per period
Beginning Storage for Simulation = 4525000. C.M.
Annual Runoff for Simulation = 174330000.C.M.
Average Past Storage for Calibration = 5148000.C.M.
Average Annual Runoff for Calibration = 230136992.C.M.
Average Annual Sedimentation Rate for Calibration = 44500. C.M.
Trap Efficiency determined from Brune's median curve

Number of Dredging Stages = 1
Stage No. 1 Volume = 638000.C.M.

Results of Dredging Simulation and Cost-benefit Analysis (in the absence of externalities)

| YEAR | WITHOUT DREDGING | | | | | WITH DREDGING | | | | | DREDGING RESIDUAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | BEG. C.M. | END C.M. | BENEFIT NT$ | COST NT$ |
| 1 | 4525000. | 0.0260 | 0.6532 | 46457. | 4478544. | 5163000. | 0.0296 | 0.6776 | 48192. | 5114808. | 638000. | 636265. | 21037386. | 33999020. |
| 2 | 4478544. | 0.0257 | 0.6513 | 46321. | 4432223. | 5114808. | 0.0293 | 0.6759 | 48068. | 5066740. | 636265. | 634517. | 19792344. | 0. |
| 3 | 4432223. | 0.0254 | 0.6494 | 46184. | 4386039. | 5066740. | 0.0291 | 0.6741 | 47944. | 5018796. | 634517. | 632757. | 18620488. | 0. |
| 4 | 4386039. | 0.0252 | 0.6475 | 46046. | 4339992. | 5018796. | 0.0288 | 0.6724 | 47819. | 4970977. | 632757. | 630985. | 17517532. | 0. |
| 5 | 4339992. | 0.0249 | 0.6455 | 45907. | 4294085. | 4970977. | 0.0285 | 0.6706 | 47693. | 4923284. | 630985. | 629199. | 16479446. | 0. |
| 6 | 4294085. | 0.0246 | 0.6435 | 45768. | 4248317. | 4923284. | 0.0282 | 0.6688 | 47566. | 4875717. | 629199. | 627400. | 15502427. | 0. |
| 7 | 4248317. | 0.0244 | 0.6415 | 45627. | 4202691. | 4875717. | 0.0280 | 0.6670 | 47439. | 4828279. | 627400. | 625588. | 14582906. | 0. |
| 8 | 4202691. | 0.0241 | 0.6396 | 45485. | 4157206. | 4828279. | 0.0277 | 0.6652 | 47310. | 4780969. | 625588. | 623763. | 13717520. | 0. |
| 9 | 4157206. | 0.0238 | 0.6375 | 45341. | 4111865. | 4780969. | 0.0274 | 0.6634 | 47180. | 4733788. | 623763. | 621924. | 12903100. | 0. |
| 10 | 4111865. | 0.0236 | 0.6355 | 45197. | 4066667. | 4733788. | 0.0272 | 0.6616 | 47050. | 4686738. | 621924. | 620071. | 12136661. | 0. |
| 11 | 4066667. | 0.0233 | 0.6335 | 45052. | 4021616. | 4686738. | 0.0269 | 0.6597 | 46919. | 4639820. | 620071. | 618204. | 11415391. | 0. |
| 12 | 4021616. | 0.0231 | 0.6314 | 44905. | 3976710. | 4639820. | 0.0266 | 0.6579 | 46786. | 4593033. | 618204. | 616323. | 10736642. | 0. |
| 13 | 3976710. | 0.0228 | 0.6293 | 44757. | 3931953. | 4593033. | 0.0263 | 0.6560 | 46653. | 4546380. | 616323. | 614427. | 10097921. | 0. |
| 14 | 3931953. | 0.0226 | 0.6272 | 44609. | 3887344. | 4546380. | 0.0261 | 0.6541 | 46519. | 4499862. | 614427. | 612517. | 9496885. | 0. |
| 15 | 3887344. | 0.0223 | 0.6251 | 44458. | 3842886. | 4499862. | 0.0258 | 0.6522 | 46383. | 4453478. | 612517. | 610592. | 8931323. | 0. |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 3842886. | 0.0220 | 0.6230 | 44307. | 3798579. | 4453478. | 0.0255 | 0.6503 | 46247. | 4407231. | 610592. | 608653. | 8399153. | 0. |
| 17 | 3798579. | 0.0218 | 0.6209 | 44155. | 3754424. | 4407231. | 0.0253 | 0.6483 | 46110. | 4361122. | 608653. | 606698. | 7898418. | 0. |
| 18 | 3754424. | 0.0215 | 0.6187 | 44001. | 3710423. | 4361122. | 0.0250 | 0.6464 | 45971. | 4315150. | 606698. | 604727. | 7427269. | 0. |
| 19 | 3710423. | 0.0213 | 0.6165 | 43846. | 3666578. | 4315150. | 0.0248 | 0.6444 | 45832. | 4269318. | 604727. | 602741. | 6983971. | 0. |
| 20 | 3666578. | 0.0210 | 0.6143 | 43689. | 3622888. | 4269318. | 0.0245 | 0.6425 | 45691. | 4223627. | 602741. | 600738. | 6566889. | 0. |
| 21 | 3622888. | 0.0208 | 0.6121 | 43532. | 3579357. | 4223627. | 0.0242 | 0.6405 | 45550. | 4178077. | 600738. | 598720. | 6174482. | 0. |
| 22 | 3579357. | 0.0205 | 0.6099 | 43373. | 3535984. | 4178077. | 0.0240 | 0.6385 | 45407. | 4132669. | 598720. | 596685. | 5805300. | 0. |
| 23 | 3535984. | 0.0203 | 0.6076 | 43212. | 3492772. | 4132669. | 0.0237 | 0.6364 | 45264. | 4087406. | 596685. | 594634. | 5457979. | 0. |
| 24 | 3492772. | 0.0200 | 0.6053 | 43050. | 3449721. | 4087406. | 0.0234 | 0.6344 | 45119. | 4042287. | 594634. | 592566. | 5131232. | 0. |
| 25 | 3449721. | 0.0198 | 0.6028 | 42869. | 3406852. | 4042287. | 0.0232 | 0.6324 | 44973. | 3997315. | 592566. | 590463. | 4823777. | 0. |
| 26 | 3406852. | 0.0195 | 0.6002 | 42684. | 3364168. | 3997315. | 0.0229 | 0.6303 | 44825. | 3952489. | 590463. | 588321. | 4534406. | 0. |
| 27 | 3364168. | 0.0193 | 0.5975 | 42497. | 3321671. | 3952489. | 0.0227 | 0.6282 | 44677. | 3907812. | 588321. | 586141. | 4262059. | 0. |
| 28 | 3321671. | 0.0191 | 0.5949 | 42308. | 3279362. | 3907812. | 0.0224 | 0.6261 | 44528. | 3863285. | 586141. | 583922. | 4005751. | 0. |
| 29 | 3279362. | 0.0188 | 0.5922 | 42118. | 3237244. | 3863285. | 0.0222 | 0.6240 | 44377. | 3818908. | 583922. | 581664. | 3764549. | 0. |
| 30 | 3237244. | 0.0186 | 0.5895 | 41927. | 3195318. | 3818908. | 0.0219 | 0.6218 | 44225. | 3774683. | 581664. | 579366. | 3537578. | 0. |
| 31 | 3195318. | 0.0183 | 0.5868 | 41733. | 3153584. | 3774683. | 0.0217 | 0.6197 | 44072. | 3730612. | 579366. | 577027. | 3324010. | 0. |
| 32 | 3153584. | 0.0181 | 0.5841 | 41538. | 3112046. | 3730612. | 0.0214 | 0.6175 | 43917. | 3686695. | 577027. | 574649. | 3123067. | 0. |
| 33 | 3112046. | 0.0179 | 0.5813 | 41341. | 3070705. | 3686695. | 0.0211 | 0.6153 | 43761. | 3642933. | 574649. | 572229. | 2934014. | 0. |
| 34 | 3070705. | 0.0176 | 0.5785 | 41143. | 3029562. | 3642933. | 0.0209 | 0.6131 | 43604. | 3599329. | 572229. | 569768. | 2756158. | 0. |
| 35 | 3029562. | 0.0174 | 0.5757 | 40943. | 2988619. | 3599329. | 0.0206 | 0.6109 | 43446. | 3555883. | 569768. | 567265. | 2588847. | 0. |
| 36 | 2988619. | 0.0171 | 0.5729 | 40741. | 2947877. | 3555883. | 0.0204 | 0.6086 | 43286. | 3512597. | 567265. | 564720. | 2431467. | 0. |
| 37 | 2947877. | 0.0169 | 0.5700 | 40538. | 2907340. | 3512597. | 0.0201 | 0.6064 | 43125. | 3469472. | 564720. | 562133. | 2283437. | 0. |
| 38 | 2907340. | 0.0167 | 0.5671 | 40332. | 2867008. | 3469472. | 0.0199 | 0.6040 | 42954. | 3426518. | 562133. | 559511. | 2144227. | 0. |
| 39 | 2867008. | 0.0164 | 0.5642 | 40125. | 2826883. | 3426518. | 0.0197 | 0.6014 | 42769. | 3383749. | 559511. | 556866. | 2013358. | 0. |
| 40 | 2826883. | 0.0162 | 0.5613 | 39916. | 2786967. | 3383749. | 0.0194 | 0.5988 | 42583. | 3341166. | 556866. | 554199. | 1890358. | 0. |
| 41 | 2786967. | 0.0160 | 0.5583 | 39705. | 2747262. | 3341166. | 0.0192 | 0.5961 | 42395. | 3298771. | 554199. | 551509. | 1774758. | 0. |
| 42 | 2747262. | 0.0158 | 0.5553 | 39492. | 2707769. | 3298771. | 0.0189 | 0.5935 | 42206. | 3256565. | 551509. | 548796. | 1666117. | 0. |
| 43 | 2707769. | 0.0155 | 0.5523 | 39277. | 2668492. | 3256565. | 0.0187 | 0.5908 | 42015. | 3214550. | 548796. | 546058. | 1564022. | 0. |
| 44 | 2668492. | 0.0153 | 0.5492 | 39061. | 2629431. | 3214550. | 0.0184 | 0.5881 | 41822. | 3172728. | 546058. | 543297. | 1468083. | 0. |
| 45 | 2629431. | 0.0151 | 0.5462 | 38842. | 2590589. | 3172728. | 0.0182 | 0.5853 | 41628. | 3131100. | 543297. | 540511. | 1377931. | 0. |
| 46 | 2590589. | 0.0149 | 0.5429 | 38612. | 2551977. | 3131100. | 0.0180 | 0.5826 | 41432. | 3089668. | 540511. | 537691. | 1293211. | 0. |
| 47 | 2551977. | 0.0146 | 0.5396 | 38375. | 2513602. | 3089668. | 0.0177 | 0.5798 | 41234. | 3048433. | 537691. | 534832. | 1213585. | 0. |
| 48 | 2513602. | 0.0144 | 0.5362 | 38136. | 2475466. | 3048433. | 0.0175 | 0.5770 | 41035. | 3007398. | 534832. | 531933. | 1138744. | 0. |
| 49 | 2475466. | 0.0142 | 0.5328 | 37895. | 2437571. | 3007398. | 0.0173 | 0.5742 | 40834. | 2966564. | 531933. | 528993. | 1068407. | 0. |
| 50 | 2437571. | 0.0140 | 0.5294 | 37651. | 2399920. | 2966564. | 0.0170 | 0.5713 | 40631. | 2925933. | 528993. | 526013. | 1002308. | 0. |

TOTAL BENEFIT (PRESENT WORTH IN TERMS OF YEAR 1) = NT$ 336796864.
TOTAL COST (PRESENT WORTH) = NT$ 33999020.
B/C RATIO = 9.906

## Mingte Reservoir Dredging Cost-benefit Aanlysis (50 years)

Mingte Reservoir Dredging Cost-benefit Analysis

Bases for Analysis:
Annual interest Rate = 0.060
Wholesale Water Price = 7.0 NT$/C.M.
Reservoir Storage Utilization Frequency = 2.50 per period
Unit Dredging Cost = 68.160004 NT$/C.M. per period
Beginning Storage for Simulation = 13874800. C.M.
Annual Runoff for Simulation = 86580000.C.M.
Average Past Storage for Calibration = 15000000.C.M.
Average Annual Runoff for Calibration = 85247000.C.M.
Average Annual Sedimentation Rate for Calibration = 93800. C.M.
Trap Efficiency determined from Brune's median curve

Number of Dredging Stages = 1
Stage No. 1 Volume = 679250.C.M.

Results of Dredging Simulation and Cost-benefit Analysis (in the absence of externalities)

| YEAR | WITHOUT DREDGING | | | | | WITH DREDGING | | | | | DREDGING RESIDUAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | BEG. C.M. | END C.M. | BENEFIT NT$ | COST NT$ |
| 1 | 13874800. | 0.1603 | 0.9231 | 93079. | 13781721. | 14554050. | 0.1681 | 0.9267 | 93448. | 14460602. | 679250. | 678881. | 11210988. | 46297684. |
| 2 | 13781721. | 0.1592 | 0.9225 | 93027. | 13688694. | 14460602. | 0.1670 | 0.9262 | 93398. | 14367204. | 678881. | 678510. | 10570641. | 0. |
| 3 | 13688694. | 0.1581 | 0.9220 | 92975. | 13595719. | 14367204. | 0.1659 | 0.9257 | 93348. | 14273856. | 678510. | 678137. | 9966837. | 0. |
| 4 | 13595719. | 0.1570 | 0.9215 | 92922. | 13502797. | 14273856. | 0.1649 | 0.9252 | 93298. | 14180558. | 678137. | 677761. | 9397486. | 0. |
| 5 | 13502797. | 0.1560 | 0.9210 | 92869. | 13409928. | 14180558. | 0.1638 | 0.9247 | 93247. | 14087311. | 677761. | 677383. | 8860623. | 0. |
| 6 | 13409928. | 0.1549 | 0.9205 | 92816. | 13317112. | 14087311. | 0.1627 | 0.9242 | 93196. | 13994115. | 677383. | 677003. | 8354404. | 0. |
| 7 | 13317112. | 0.1538 | 0.9199 | 92763. | 13224349. | 13994115. | 0.1616 | 0.9237 | 93145. | 13900970. | 677003. | 676621. | 7877079. | 0. |
| 8 | 13224349. | 0.1527 | 0.9194 | 92709. | 13131640. | 13900970. | 0.1606 | 0.9232 | 93094. | 13807876. | 676621. | 676236. | 7426997. | 0. |
| 9 | 13131640. | 0.1517 | 0.9188 | 92655. | 13038985. | 13807876. | 0.1595 | 0.9227 | 93042. | 13714834. | 676236. | 675849. | 7002603. | 0. |
| 10 | 13038985. | 0.1506 | 0.9183 | 92600. | 12946385. | 13714834. | 0.1584 | 0.9222 | 92990. | 13621844. | 675849. | 675459. | 6602433. | 0. |
| 11 | 12946385. | 0.1495 | 0.9177 | 92536. | 12853849. | 13621844. | 0.1573 | 0.9216 | 92937. | 13528907. | 675459. | 675058. | 6225064. | 0. |
| 12 | 12853849. | 0.1485 | 0.9169 | 92459. | 12761390. | 13528907. | 0.1563 | 0.9211 | 92884. | 13436023. | 675058. | 674633. | 5869111. | 0. |
| 13 | 12761390. | 0.1474 | 0.9161 | 92382. | 12669008. | 13436023. | 0.1552 | 0.9206 | 92831. | 13343192. | 674633. | 674184. | 5533312. | 0. |
| 14 | 12669008. | 0.1463 | 0.9154 | 92304. | 12576704. | 13343192. | 0.1541 | 0.9201 | 92778. | 13250414. | 674184. | 673710. | 5216534. | 0. |
| 15 | 12576704. | 0.1453 | 0.9146 | 92226. | 12484478. | 13250414. | 0.1530 | 0.9195 | 92724. | 13157690. | 673710. | 673212. | 4917710. | 0. |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 12484478. | 0.1442 | 0.9138 | 92147. | 12392331. | 13157690. | 0.1520 | 0.9190 | 92670. | 13065020. | 673212. | 672689. | 4635832. | 0. |
| 17 | 12392331. | 0.1431 | 0.9130 | 92068. | 12300263. | 13065020. | 0.1509 | 0.9185 | 92615. | 12972405. | 672689. | 672142. | 4369950. | 0. |
| 18 | 12300263. | 0.1421 | 0.9122 | 91988. | 12208275. | 12972405. | 0.1498 | 0.9179 | 92557. | 12879848. | 672142. | 671573. | 4119173. | 0. |
| 19 | 12208275. | 0.1410 | 0.9114 | 91908. | 12116367. | 12879848. | 0.1488 | 0.9171 | 92481. | 12787367. | 671573. | 671000. | 3882710. | 0. |
| 20 | 12116367. | 0.1399 | 0.9106 | 91827. | 12024540. | 12787367. | 0.1477 | 0.9164 | 92403. | 12694964. | 671000. | 670424. | 3659799. | 0. |
| 21 | 12024540. | 0.1389 | 0.9098 | 91746. | 11932794. | 12694964. | 0.1466 | 0.9156 | 92326. | 12602638. | 670424. | 669844. | 3449666. | 0. |
| 22 | 11932794. | 0.1378 | 0.9090 | 91664. | 11841130. | 12602638. | 0.1456 | 0.9148 | 92248. | 12510390. | 669844. | 669260. | 3251575. | 0. |
| 23 | 11841130. | 0.1368 | 0.9082 | 91581. | 11749549. | 12510390. | 0.1445 | 0.9140 | 92169. | 12418221. | 669260. | 668672. | 3064840. | 0. |
| 24 | 11749549. | 0.1357 | 0.9074 | 91498. | 11658051. | 12418221. | 0.1434 | 0.9133 | 92090. | 12326131. | 668672. | 668080. | 2888808. | 0. |
| 25 | 11658051. | 0.1347 | 0.9066 | 91415. | 11566636. | 12326131. | 0.1424 | 0.9125 | 92011. | 12234120. | 668080. | 667484. | 2722869. | 0. |
| 26 | 11566636. | 0.1336 | 0.9057 | 91331. | 11475305. | 12234120. | 0.1413 | 0.9117 | 91930. | 12142190. | 667484. | 666885. | 2566446. | 0. |
| 27 | 11475305. | 0.1325 | 0.9049 | 91246. | 11384059. | 12142190. | 0.1402 | 0.9109 | 91850. | 12050340. | 666885. | 666281. | 2418993. | 0. |
| 28 | 11384059. | 0.1315 | 0.9040 | 91160. | 11292899. | 12050340. | 0.1392 | 0.9101 | 91769. | 11958571. | 666281. | 665672. | 2279993. | 0. |
| 29 | 11292899. | 0.1304 | 0.9032 | 91074. | 11201825. | 11958571. | 0.1381 | 0.9093 | 91687. | 11866884. | 665672. | 665059. | 2148963. | 0. |
| 30 | 11201825. | 0.1294 | 0.9023 | 90988. | 11110837. | 11866884. | 0.1371 | 0.9084 | 91605. | 11775279. | 665059. | 664442. | 2025450. | 0. |
| 31 | 11110837. | 0.1283 | 0.9015 | 90901. | 11019936. | 11775279. | 0.1360 | 0.9076 | 91522. | 11683757. | 664442. | 663821. | 1909023. | 0. |
| 32 | 11019936. | 0.1273 | 0.9006 | 90813. | 10929123. | 11683757. | 0.1349 | 0.9068 | 91438. | 11592319. | 663821. | 663196. | 1799275. | 0. |
| 33 | 10929123. | 0.1262 | 0.8997 | 90724. | 10838399. | 11592319. | 0.1339 | 0.9060 | 91354. | 11500965. | 663196. | 662566. | 1695824. | 0. |
| 34 | 10838399. | 0.1252 | 0.8988 | 90635. | 10747764. | 11500965. | 0.1328 | 0.9051 | 91270. | 11409695. | 662566. | 661931. | 1598308. | 0. |
| 35 | 10747764. | 0.1241 | 0.8979 | 90545. | 10657219. | 11409695. | 0.1318 | 0.9043 | 91184. | 11318511. | 661931. | 661292. | 1506387. | 0. |
| 36 | 10657219. | 0.1231 | 0.8970 | 90455. | 10566764. | 11318511. | 0.1307 | 0.9034 | 91099. | 11227412. | 661292. | 660648. | 1419742. | 0. |
| 37 | 10566764. | 0.1220 | 0.8961 | 90364. | 10476400. | 11227412. | 0.1297 | 0.9026 | 91012. | 11136400. | 660648. | 660000. | 1338070. | 0. |
| 38 | 10476400. | 0.1210 | 0.8952 | 90272. | 10386128. | 11136400. | 0.1286 | 0.9017 | 90925. | 11045475. | 660000. | 659347. | 1261087. | 0. |
| 39 | 10386128. | 0.1200 | 0.8943 | 90179. | 10295949. | 11045475. | 0.1276 | 0.9008 | 90837. | 10954638. | 659347. | 658689. | 1188523. | 0. |
| 40 | 10295949. | 0.1189 | 0.8934 | 90086. | 10205863. | 10954638. | 0.1265 | 0.9000 | 90749. | 10863889. | 658689. | 658026. | 1120124. | 0. |
| 41 | 10205863. | 0.1179 | 0.8924 | 89992. | 10115871. | 10863889. | 0.1255 | 0.8991 | 90660. | 10773229. | 658026. | 657358. | 1055653. | 0. |
| 42 | 10115871. | 0.1168 | 0.8915 | 89897. | 10025974. | 10773229. | 0.1244 | 0.8982 | 90571. | 10682658. | 657358. | 656684. | 994883. | 0. |
| 43 | 10025974. | 0.1158 | 0.8906 | 89802. | 9936172. | 10682658. | 0.1234 | 0.8973 | 90480. | 10592178. | 656684. | 656006. | 937603. | 0. |
| 44 | 9936172. | 0.1148 | 0.8896 | 89706. | 9846466. | 10592178. | 0.1223 | 0.8964 | 90389. | 10501789. | 656006. | 655323. | 883614. | 0. |
| 45 | 9846466. | 0.1137 | 0.8886 | 89609. | 9756857. | 10501789. | 0.1213 | 0.8955 | 90298. | 10411491. | 655323. | 654634. | 832726. | 0. |
| 46 | 9756857. | 0.1127 | 0.8877 | 89511. | 9667346. | 10411491. | 0.1203 | 0.8946 | 90205. | 10321286. | 654634. | 653940. | 784761. | 0. |
| 47 | 9667346. | 0.1117 | 0.8867 | 89412. | 9577934. | 10321286. | 0.1192 | 0.8936 | 90112. | 10231174. | 653940. | 653240. | 739552. | 0. |
| 48 | 9577934. | 0.1106 | 0.8857 | 89313. | 9488621. | 10231174. | 0.1182 | 0.8927 | 90019. | 10141155. | 653240. | 652534. | 696940. | 0. |
| 49 | 9488621. | 0.1096 | 0.8847 | 89213. | 9399408. | 10141155. | 0.1171 | 0.8918 | 89924. | 10051231. | 652534. | 651823. | 656778. | 0. |
| 50 | 9399408. | 0.1086 | 0.8837 | 89112. | 9310296. | 10051231. | 0.1161 | 0.8908 | 89829. | 9961402. | 651823. | 651106. | 618923. | 0. |

TOTAL BENEFIT (PRESENT WORTH IN TERMS OF YEAR 1) = NT$ 185554704.
TOTAL COST (PRESENT WORTH) = NT$ 46297684.
B/C RATIO = 4.008

**Chingmien Reservoir Dredging Cost-benefit Aanlysis (50 years)**

Chingmien Reservoir Dredging Cost-benefit Analysis

Bases for Analysis:
- Annual interest Rate = 0.060
- Wholesale Water Price = 7.0 NT$/C.M.
- Reservoir Storage Utilization Frequency = 1.15 per period
- Unit Dredging Cost = 60.000000 NT$/C.M. per period
- Beginning Storage for Simulation = 981165. C.M.
- Annual Runoff for Simulation = 2929000.C.M.
- Average Past Storage for Calibration = 1095730.C.M.
- Average Annual Runoff for Calibration = 3139000.C.M.
- Average Annual Sedimentation Rate for Calibration = 12060. C.M.
- Trap Efficiency determined from Brune's median curve

Number of Dredging Stages = 1
Stage No. 1 Volume = 638000.C.M.

Results of Dredging Simulation and Cost-benefit Analysis (in the absence of externalities)

| YEAR | WITHOUT DREDGING | | | | | WITH DREDGING | | | | | DREDGING RESIDUAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | BEG. C.M. | END C.M. | BENEFIT NT$ | COST NT$ |
| 1 | 981165. | 0.3350 | 0.9688 | 12042. | 969123. | 1619165. | 0.5528 | 0.9841 | 12232. | 1606933. | 638000. | 637810. | 4844469. | 38280000. |
| 2 | 969123. | 0.3309 | 0.9684 | 12037. | 957086. | 1606933. | 0.5486 | 0.9840 | 12231. | 1594702. | 637810. | 637616. | 4568878. | 0. |
| 3 | 957086. | 0.3268 | 0.9680 | 12031. | 945055. | 1594702. | 0.5445 | 0.9839 | 12230. | 1582472. | 637616. | 637418. | 4308937. | 0. |
| 4 | 945055. | 0.3227 | 0.9675 | 12026. | 933029. | 1582472. | 0.5403 | 0.9838 | 12229. | 1570243. | 637418. | 637215. | 4063755. | 0. |
| 5 | 933029. | 0.3185 | 0.9671 | 12020. | 921008. | 1570243. | 0.5361 | 0.9838 | 12228. | 1558016. | 637215. | 637008. | 3832498. | 0. |
| 6 | 921008. | 0.3144 | 0.9666 | 12015. | 908993. | 1558016. | 0.5319 | 0.9837 | 12227. | 1545789. | 637008. | 636796. | 3614375. | 0. |
| 7 | 908993. | 0.3103 | 0.9662 | 12009. | 896984. | 1545789. | 0.5278 | 0.9836 | 12226. | 1533563. | 636796. | 636579. | 3408641. | 0. |
| 8 | 896984. | 0.3062 | 0.9657 | 12003. | 884981. | 1533563. | 0.5236 | 0.9835 | 12225. | 1521339. | 636579. | 636358. | 3214594. | 0. |
| 9 | 884981. | 0.3021 | 0.9652 | 11998. | 872983. | 1521339. | 0.5194 | 0.9834 | 12223. | 1509115. | 636358. | 636132. | 3031571. | 0. |
| 10 | 872983. | 0.2980 | 0.9646 | 11990. | 860993. | 1509115. | 0.5152 | 0.9833 | 12222. | 1496893. | 636132. | 635899. | 2858942. | 0. |
| 11 | 860993. | 0.2940 | 0.9637 | 11979. | 849014. | 1496893. | 0.5111 | 0.9832 | 12221. | 1484672. | 635899. | 635657. | 2696108. | 0. |
| 12 | 849014. | 0.2899 | 0.9629 | 11968. | 837046. | 1484672. | 0.5069 | 0.9832 | 12220. | 1472451. | 635657. | 635405. | 2542510. | 0. |
| 13 | 837046. | 0.2858 | 0.9620 | 11957. | 825089. | 1472451. | 0.5027 | 0.9831 | 12219. | 1460232. | 635405. | 635143. | 2397625. | 0. |
| 14 | 825089. | 0.2817 | 0.9611 | 11946. | 813143. | 1460232. | 0.4985 | 0.9829 | 12217. | 1448015. | 635143. | 634873. | 2260963. | 0. |
| 15 | 813143. | 0.2776 | 0.9602 | 11935. | 801208. | 1448015. | 0.4944 | 0.9826 | 12213. | 1435802. | 634873. | 634595. | 2132062. | 0. |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 801208. | 0.2735 | 0.9593 | 11924. | 789284. | 1435802. | 0.4902 | 0.9823 | 12209. | 1423593. | 634595. | 634309. | 2010486. | 0. |
| 17 | 789284. | 0.2695 | 0.9584 | 11912. | 777371. | 1423593. | 0.4860 | 0.9820 | 12206. | 1411387. | 634309. | 634016. | 1895819. | 0. |
| 18 | 777371. | 0.2654 | 0.9574 | 11901. | 765471. | 1411387. | 0.4819 | 0.9817 | 12202. | 1399185. | 634016. | 633714. | 1787671. | 0. |
| 19 | 765471. | 0.2613 | 0.9565 | 11889. | 753582. | 1399185. | 0.4777 | 0.9814 | 12198. | 1386987. | 633714. | 633405. | 1685670. | 0. |
| 20 | 753582. | 0.2573 | 0.9555 | 11877. | 741705. | 1386987. | 0.4735 | 0.9811 | 12194. | 1374793. | 633405. | 633088. | 1589468. | 0. |
| 21 | 741705. | 0.2532 | 0.9545 | 11865. | 729841. | 1374793. | 0.4694 | 0.9807 | 12190. | 1362603. | 633088. | 632763. | 1498738. | 0. |
| 22 | 729841. | 0.2492 | 0.9536 | 11852. | 717988. | 1362603. | 0.4652 | 0.9804 | 12186. | 1350417. | 632763. | 632429. | 1413167. | 0. |
| 23 | 717988. | 0.2451 | 0.9525 | 11840. | 706148. | 1350417. | 0.4611 | 0.9801 | 12182. | 1338235. | 632429. | 632086. | 1332464. | 0. |
| 24 | 706148. | 0.2411 | 0.9515 | 11827. | 694321. | 1338235. | 0.4569 | 0.9798 | 12178. | 1326057. | 632086. | 631735. | 1256352. | 0. |
| 25 | 694321. | 0.2371 | 0.9505 | 11814. | 682507. | 1326057. | 0.4527 | 0.9794 | 12174. | 1313883. | 631735. | 631375. | 1184571. | 0. |
| 26 | 682507. | 0.2330 | 0.9494 | 11801. | 670707. | 1313883. | 0.4486 | 0.9791 | 12170. | 1301713. | 631375. | 631006. | 1116875. | 0. |
| 27 | 670707. | 0.2290 | 0.9483 | 11788. | 658919. | 1301713. | 0.4444 | 0.9788 | 12166. | 1289547. | 631006. | 630628. | 1053032. | 0. |
| 28 | 658919. | 0.2250 | 0.9473 | 11774. | 647145. | 1289547. | 0.4403 | 0.9784 | 12162. | 1277385. | 630628. | 630240. | 992824. | 0. |
| 29 | 647145. | 0.2209 | 0.9461 | 11760. | 635385. | 1277385. | 0.4361 | 0.9781 | 12157. | 1265228. | 630240. | 629843. | 936043. | 0. |
| 30 | 635385. | 0.2169 | 0.9450 | 11746. | 623639. | 1265228. | 0.4320 | 0.9778 | 12153. | 1253075. | 629843. | 629436. | 882496. | 0. |
| 31 | 623639. | 0.2129 | 0.9439 | 11732. | 611907. | 1253075. | 0.4278 | 0.9774 | 12149. | 1240926. | 629436. | 629019. | 831999. | 0. |
| 32 | 611907. | 0.2089 | 0.9427 | 11717. | 600190. | 1240926. | 0.4237 | 0.9771 | 12144. | 1228782. | 629019. | 628592. | 784378. | 0. |
| 33 | 600190. | 0.2049 | 0.9415 | 11702. | 588487. | 1228782. | 0.4195 | 0.9767 | 12140. | 1216642. | 628592. | 628154. | 739470. | 0. |
| 34 | 588487. | 0.2009 | 0.9403 | 11687. | 576800. | 1216642. | 0.4154 | 0.9764 | 12136. | 1204506. | 628154. | 627706. | 697122. | 0. |
| 35 | 576800. | 0.1969 | 0.9388 | 11669. | 565131. | 1204506. | 0.4112 | 0.9760 | 12131. | 1192375. | 627706. | 627244. | 657185. | 0. |
| 36 | 565131. | 0.1929 | 0.9373 | 11650. | 553481. | 1192375. | 0.4071 | 0.9756 | 12127. | 1180248. | 627244. | 626767. | 619522. | 0. |
| 37 | 553481. | 0.1890 | 0.9357 | 11630. | 541851. | 1180248. | 0.4030 | 0.9753 | 12122. | 1168126. | 626767. | 626275. | 584003. | 0. |
| 38 | 541851. | 0.1850 | 0.9340 | 11610. | 530242. | 1168126. | 0.3988 | 0.9749 | 12118. | 1156009. | 626275. | 625767. | 550507. | 0. |
| 39 | 530242. | 0.1810 | 0.9324 | 11589. | 518653. | 1156009. | 0.3947 | 0.9745 | 12113. | 1143896. | 625767. | 625243. | 518918. | 0. |
| 40 | 518653. | 0.1771 | 0.9307 | 11568. | 507085. | 1143896. | 0.3905 | 0.9742 | 12109. | 1131787. | 625243. | 624702. | 489129. | 0. |
| 41 | 507085. | 0.1731 | 0.9290 | 11547. | 495538. | 1131787. | 0.3864 | 0.9738 | 12104. | 1119683. | 624702. | 624145. | 461037. | 0. |
| 42 | 495538. | 0.1692 | 0.9272 | 11525. | 484013. | 1119683. | 0.3823 | 0.9734 | 12099. | 1107584. | 624145. | 623571. | 434547. | 0. |
| 43 | 484013. | 0.1652 | 0.9254 | 11502. | 472511. | 1107584. | 0.3781 | 0.9730 | 12095. | 1095489. | 623571. | 622979. | 409566. | 0. |
| 44 | 472511. | 0.1613 | 0.9236 | 11480. | 461031. | 1095489. | 0.3740 | 0.9727 | 12090. | 1083399. | 622979. | 622368. | 386010. | 0. |
| 45 | 461031. | 0.1574 | 0.9217 | 11456. | 449575. | 1083399. | 0.3699 | 0.9723 | 12085. | 1071314. | 622368. | 621739. | 363798. | 0. |
| 46 | 449575. | 0.1535 | 0.9198 | 11432. | 438143. | 1071314. | 0.3658 | 0.9719 | 12080. | 1059234. | 621739. | 621091. | 342854. | 0. |
| 47 | 438143. | 0.1496 | 0.9177 | 11407. | 426736. | 1059234. | 0.3616 | 0.9715 | 12075. | 1047159. | 621091. | 620423. | 323105. | 0. |
| 48 | 426736. | 0.1457 | 0.9149 | 11372. | 415364. | 1047159. | 0.3575 | 0.9711 | 12070. | 1035089. | 620423. | 619725. | 304480. | 0. |
| 49 | 415364. | 0.1418 | 0.9120 | 11336. | 404028. | 1035089. | 0.3534 | 0.9707 | 12065. | 1023023. | 619725. | 618996. | 286915. | 0. |
| 50 | 404028. | 0.1379 | 0.9091 | 11300. | 392728. | 1023023. | 0.3493 | 0.9703 | 12060. | 1010963. | 618996. | 618235. | 270349. | 0. |

TOTAL BENEFIT (PRESENT WORTH IN TERMS OF YEAR 1) = NT$ 80466480.

TOTAL COST (PRESENT WORTH) = NT$ 38280000.

B/C RATIO = 2.102

## Shihmen Reservoir Dredging Cost-benefit Aanlysis (50 years)

Shihmen Reservoir Dredging Cost-benefit Analysis

Bases for Analysis:
Annual interest Rate = 0.060
Wholesale Water Price = 10.0 NT$/C.M.
Reservoir Storage Utilization Frequency = 2.49 per period
Unit Dredging Cost = 200.000000 NT$/C.M. per period
Beginning Storage for Simulation = 309120000. C.M.
Annual Runoff for Simulation = 535567360.C.M.
Average Past Storage for Calibration = 234000000.C.M.
Average Annual Runoff for Calibration = 534273888.C.M.
Average Annual Sedimentation Rate for Calibration = 1860000. C.M.
Trap Efficiency determined from Brune's median curve

Number of Dredging Stages = 1
Stage No. 1 Volume = 300000.C.M.

Results of Dredging Simulation and Cost-benefit Analysis (in the absence of externalities)

| YEAR | WITHOUT DREDGING | | | | | WITH DREDGING | | | | | DREDGING RESIDUAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | BEG. C.M. | END C.M. | BENEFIT NT$ | COST NT$ |
| 1 | 309120000. | 0.5772 | 0.9846 | 1872022. | 307247968. | 309420000. | 0.5777 | 0.9846 | 1872042. | 307547968. | 300000. | 300000. | 7050000. | 60000000. |
| 2 | 307247968. | 0.5737 | 0.9845 | 1871895. | 305376064. | 307547968. | 0.5742 | 0.9845 | 1871916. | 305676064. | 300000. | 300000. | 6650944. | 0. |
| 3 | 305376064. | 0.5702 | 0.9844 | 1871768. | 303504288. | 305676064. | 0.5708 | 0.9845 | 1871788. | 303804288. | 300000. | 300000. | 6274476. | 0. |
| 4 | 303504288. | 0.5667 | 0.9844 | 1871640. | 301632640. | 303804288. | 0.5673 | 0.9844 | 1871660. | 301932640. | 300000. | 300000. | 5919317. | 0. |
| 5 | 301632640. | 0.5632 | 0.9843 | 1871511. | 299761120. | 301932640. | 0.5638 | 0.9843 | 1871531. | 300061120. | 300000. | 300000. | 5584262. | 0. |
| 6 | 299761120. | 0.5597 | 0.9842 | 1871381. | 297889728. | 300061120. | 0.5603 | 0.9842 | 1871402. | 298189728. | 300000. | 300000. | 5268172. | 0. |
| 7 | 297889728. | 0.5562 | 0.9842 | 1871250. | 296018464. | 298189728. | 0.5568 | 0.9842 | 1871271. | 296318464. | 300000. | 300000. | 4969974. | 0. |
| 8 | 296018464. | 0.5527 | 0.9841 | 1871119. | 294147360. | 296318464. | 0.5533 | 0.9841 | 1871140. | 294447328. | 300000. | 299968. | 4688405. | 0. |
| 9 | 294147360. | 0.5492 | 0.9840 | 1870986. | 292276384. | 294447328. | 0.5498 | 0.9840 | 1871008. | 292576320. | 299968. | 299936. | 4422552. | 0. |
| 10 | 292276384. | 0.5457 | 0.9840 | 1870853. | 290405536. | 292576320. | 0.5463 | 0.9840 | 1870875. | 290705440. | 299936. | 299904. | 4171774. | 0. |
| 11 | 290405536. | 0.5422 | 0.9839 | 1870719. | 288534816. | 290705440. | 0.5428 | 0.9839 | 1870741. | 288834688. | 299904. | 299872. | 3935216. | 0. |
| 12 | 288534816. | 0.5387 | 0.9838 | 1870585. | 286664224. | 288834688. | 0.5393 | 0.9838 | 1870606. | 286964096. | 299872. | 299872. | 3712270. | 0. |
| 13 | 286664224. | 0.5353 | 0.9837 | 1870449. | 284793760. | 286964096. | 0.5358 | 0.9838 | 1870471. | 285093632. | 299872. | 299872. | 3502142. | 0. |
| 14 | 284793760. | 0.5318 | 0.9837 | 1870312. | 282923456. | 285093632. | 0.5323 | 0.9837 | 1870334. | 283223296. | 299872. | 299840. | 3303731. | 0. |
| 15 | 282923456. | 0.5283 | 0.9836 | 1870175. | 281053280. | 283223296. | 0.5288 | 0.9836 | 1870197. | 281353088. | 299840. | 299808. | 3116395. | 0. |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 281053280. | 0.5248 | 0.9835 | 1870037. | 279183232. | 281353088. | 0.5253 | 0.9835 | 1870059. | 279483040. | 299808. | 299808. | 2939839. | 0. |
| 17 | 279183232. | 0.5213 | 0.9835 | 1869898. | 277313344. | 279483040. | 0.5218 | 0.9835 | 1869920. | 277613120. | 299808. | 299776. | 2773285. | 0. |
| 18 | 277313344. | 0.5178 | 0.9834 | 1869757. | 275443584. | 277613120. | 0.5184 | 0.9834 | 1869780. | 275743328. | 299776. | 299744. | 2616027. | 0. |
| 19 | 275443584. | 0.5143 | 0.9833 | 1869616. | 273573952. | 275743328. | 0.5149 | 0.9833 | 1869639. | 273873696. | 299744. | 299744. | 2467819. | 0. |
| 20 | 273573952. | 0.5108 | 0.9832 | 1869474. | 271704480. | 273873696. | 0.5114 | 0.9832 | 1869497. | 272004192. | 299744. | 299712. | 2328007. | 0. |
| 21 | 271704480. | 0.5073 | 0.9832 | 1869331. | 269835136. | 272004192. | 0.5079 | 0.9832 | 1869354. | 270134848. | 299712. | 299712. | 2196116. | 0. |
| 22 | 269835136. | 0.5038 | 0.9831 | 1869187. | 267965952. | 270134848. | 0.5044 | 0.9831 | 1869210. | 268265632. | 299712. | 299680. | 2071697. | 0. |
| 23 | 267965952. | 0.5003 | 0.9830 | 1869042. | 266096912. | 268265632. | 0.5009 | 0.9830 | 1869065. | 266396560. | 299680. | 299648. | 1954222. | 0. |
| 24 | 266096912. | 0.4969 | 0.9828 | 1868597. | 264228320. | 266396560. | 0.4974 | 0.9828 | 1868674. | 264527888. | 299648. | 299568. | 1843262. | 0. |
| 25 | 264228320. | 0.4934 | 0.9825 | 1868117. | 262360208. | 264527888. | 0.4939 | 0.9826 | 1868194. | 262659696. | 299568. | 299488. | 1738462. | 0. |
| 26 | 262360208. | 0.4899 | 0.9823 | 1867633. | 260492576. | 262659696. | 0.4904 | 0.9823 | 1867711. | 260791984. | 299488. | 299408. | 1639620. | 0. |
| 27 | 260492576. | 0.4864 | 0.9820 | 1867146. | 258625424. | 260791984. | 0.4869 | 0.9821 | 1867225. | 258924752. | 299408. | 299328. | 1546398. | 0. |
| 28 | 258625424. | 0.4829 | 0.9818 | 1866656. | 256758768. | 258924752. | 0.4835 | 0.9818 | 1866735. | 257058016. | 299328. | 299248. | 1458477. | 0. |
| 29 | 256758768. | 0.4794 | 0.9815 | 1866162. | 254892608. | 257058016. | 0.4800 | 0.9815 | 1866242. | 255191776. | 299248. | 299168. | 1375554. | 0. |
| 30 | 254892608. | 0.4759 | 0.9812 | 1865665. | 253026944. | 255191776. | 0.4765 | 0.9813 | 1865745. | 253326032. | 299168. | 299088. | 1297345. | 0. |
| 31 | 253026944. | 0.4724 | 0.9810 | 1865164. | 251161776. | 253326032. | 0.4730 | 0.9810 | 1865245. | 251460784. | 299088. | 299008. | 1223583. | 0. |
| 32 | 251161776. | 0.4690 | 0.9807 | 1864660. | 249297120. | 251460784. | 0.4695 | 0.9807 | 1864741. | 249596048. | 299008. | 298928. | 1154015. | 0. |
| 33 | 249297120. | 0.4655 | 0.9804 | 1864152. | 247432976. | 249596048. | 0.4660 | 0.9805 | 1864233. | 247731808. | 298928. | 298832. | 1088373. | 0. |
| 34 | 247432976. | 0.4620 | 0.9802 | 1863640. | 245569328. | 247731808. | 0.4626 | 0.9802 | 1863722. | 245868080. | 298832. | 298752. | 1026465. | 0. |
| 35 | 245569328. | 0.4585 | 0.9799 | 1863125. | 243706208. | 245868080. | 0.4591 | 0.9799 | 1863208. | 244004880. | 298752. | 298672. | 968104. | 0. |
| 36 | 243706208. | 0.4550 | 0.9796 | 1862606. | 241843600. | 244004880. | 0.4556 | 0.9797 | 1862689. | 242142192. | 298672. | 298592. | 913061. | 0. |
| 37 | 241843600. | 0.4516 | 0.9793 | 1862083. | 239981520. | 242142192. | 0.4521 | 0.9794 | 1862167. | 240280032. | 298592. | 298512. | 861148. | 0. |
| 38 | 239981520. | 0.4481 | 0.9791 | 1861556. | 238119968. | 240280032. | 0.4486 | 0.9791 | 1861641. | 238418384. | 298512. | 298416. | 812164. | 0. |
| 39 | 238119968. | 0.4446 | 0.9788 | 1861025. | 236258944. | 238418384. | 0.4452 | 0.9788 | 1861110. | 236557280. | 298416. | 298336. | 765967. | 0. |
| 40 | 236258944. | 0.4411 | 0.9785 | 1860490. | 234398448. | 236557280. | 0.4417 | 0.9786 | 1860576. | 234696704. | 298336. | 298256. | 722416. | 0. |
| 41 | 234398448. | 0.4377 | 0.9782 | 1859951. | 232538496. | 234696704. | 0.4382 | 0.9783 | 1860038. | 232836672. | 298256. | 298176. | 681342. | 0. |
| 42 | 232538496. | 0.4342 | 0.9779 | 1859408. | 230679088. | 232836672. | 0.4347 | 0.9780 | 1859495. | 230977184. | 298176. | 298096. | 642603. | 0. |
| 43 | 230679088. | 0.4307 | 0.9777 | 1858861. | 228820224. | 230977184. | 0.4313 | 0.9777 | 1858949. | 229118240. | 298096. | 298016. | 606067. | 0. |
| 44 | 228820224. | 0.4272 | 0.9774 | 1858309. | 226961920. | 229118240. | 0.4278 | 0.9774 | 1858398. | 227259840. | 298016. | 297920. | 571592. | 0. |
| 45 | 226961920. | 0.4238 | 0.9771 | 1857753. | 225104160. | 227259840. | 0.4243 | 0.9771 | 1857843. | 225402000. | 297920. | 297840. | 539079. | 0. |
| 46 | 225104160. | 0.4203 | 0.9768 | 1857193. | 223246960. | 225402000. | 0.4209 | 0.9768 | 1857283. | 223544720. | 297840. | 297760. | 508428. | 0. |
| 47 | 223246960. | 0.4168 | 0.9765 | 1856629. | 221390336. | 223544720. | 0.4174 | 0.9765 | 1856719. | 221688000. | 297760. | 297664. | 479508. | 0. |
| 48 | 221390336. | 0.4134 | 0.9762 | 1856059. | 219534272. | 221688000. | 0.4139 | 0.9762 | 1856151. | 219831856. | 297664. | 297584. | 452232. | 0. |
| 49 | 219534272. | 0.4099 | 0.9759 | 1855485. | 217678784. | 219831856. | 0.4105 | 0.9759 | 1855578. | 217976272. | 297584. | 297488. | 426508. | 0. |
| 50 | 217678784. | 0.4064 | 0.9756 | 1854907. | 215823872. | 217976272. | 0.4070 | 0.9756 | 1855000. | 216121280. | 297488. | 297408. | 402247. | 0. |

TOTAL BENEFIT (PRESENT WORTH IN TERMS OF YEAR 1) = NT$ 117660648.

TOTAL COST (PRESENT WORTH) = NT$ 60000000.

B/C RATIO = 1.961

**Feitsui Reservoir Dredging Cost-benefit Aanlysis (50 years)**

Feitsui Reservoir Dredging Cost-benefit Analysis

Bases for Analysis:
 Annual interest Rate = 0.060
 Wholesale Water Price = 7.2 NT$/C.M.
 Reservoir Storage Utilization Frequency = 3.81 per period
 Unit Dredging Cost = 300.000000 NT$/C.M. per period
 Beginning Storage for Simulation = 400028000. C.M.
 Annual Runoff for Simulation = 990000000.C.M.
 Average Past Storage for Calibration = 391473984.C.M.
 Average Annual Runoff for Calibration = 990141760.C.M.
 Average Annual Sedimentation Rate for Calibration = 996000. C.M.
 Trap Efficiency determined from Brune's median curve

 Number of Dredging Stages = 1
Stage No. 1 Volume = 600000.C.M.

Results of Dredging Simulation and Cost-benefit Analysis (in the absence of externalities)

| YEAR | WITHOUT DREDGING | | | | | WITH DREDGING | | | | | DREDGING RESIDUAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | B STOR C.M. | C/I | TRAP | SEDIMENT C.M. | E STOR C.M. | BEG. C.M. | END C.M. | BENEFIT NT$ | COST NT$ |
| 1 | 400028000. | 0.4041 | 0.9754 | 996784. | 399031200. | 400628000. | 0.4047 | 0.9754 | 996839. | 399631168. | 600000. | 599968. | 15538838. | 180000000. |
| 2 | 399031200. | 0.4031 | 0.9753 | 996693. | 398034496. | 399631168. | 0.4037 | 0.9753 | 996748. | 398634432. | 599968. | 599936. | 14658500. | 0. |
| 3 | 398034496. | 0.4021 | 0.9752 | 996601. | 397037888. | 398634432. | 0.4027 | 0.9752 | 996656. | 397637760. | 599936. | 599872. | 13827667. | 0. |
| 4 | 397037888. | 0.4010 | 0.9751 | 996509. | 396041376. | 397637760. | 0.4017 | 0.9751 | 996565. | 396641184. | 599872. | 599808. | 13043579. | 0. |
| 5 | 396041376. | 0.4000 | 0.9750 | 996417. | 395044960. | 396641184. | 0.4006 | 0.9751 | 996473. | 395644704. | 599808. | 599744. | 12303950. | 0. |
| 6 | 395044960. | 0.3990 | 0.9749 | 996328. | 394048640. | 395644704. | 0.3996 | 0.9750 | 996382. | 394648320. | 599744. | 599680. | 11606263. | 0. |
| 7 | 394048640. | 0.3980 | 0.9748 | 996238. | 393052416. | 394648320. | 0.3986 | 0.9749 | 996292. | 393652032. | 599680. | 599616. | 10948136. | 0. |
| 8 | 393052416. | 0.3970 | 0.9747 | 996148. | 392056256. | 393652032. | 0.3976 | 0.9748 | 996202. | 392655840. | 599616. | 599584. | 10327604. | 0. |
| 9 | 392056256. | 0.3960 | 0.9747 | 996058. | 391060192. | 392655840. | 0.3966 | 0.9747 | 996112. | 391659712. | 599584. | 599520. | 9742243. | 0. |
| 10 | 391060192. | 0.3950 | 0.9746 | 995967. | 390064224. | 391659712. | 0.3956 | 0.9746 | 996022. | 390663680. | 599520. | 599456. | 9189815. | 0. |
| 11 | 390064224. | 0.3940 | 0.9745 | 995877. | 389068352. | 390663680. | 0.3946 | 0.9745 | 995931. | 389667744. | 599456. | 599392. | 8668711. | 0. |
| 12 | 389068352. | 0.3930 | 0.9744 | 995786. | 388072576. | 389667744. | 0.3936 | 0.9744 | 995841. | 388671904. | 599392. | 599328. | 8177158. | 0. |
| 13 | 388072576. | 0.3920 | 0.9743 | 995695. | 387076896. | 388671904. | 0.3926 | 0.9744 | 995750. | 387676160. | 599328. | 599264. | 7713477. | 0. |
| 14 | 387076896. | 0.3910 | 0.9742 | 995604. | 386081280. | 387676160. | 0.3916 | 0.9743 | 995659. | 386680512. | 599264. | 599232. | 7276282. | 0. |
| 15 | 386081280. | 0.3900 | 0.9741 | 995512. | 385085760. | 386680512. | 0.3906 | 0.9742 | 995567. | 385684960. | 599232. | 599200. | 6864051. | 0. |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 385085760. | 0.3890 | 0.9740 | 995421. | 384090336. | 385684960. | 0.3896 | 0.9741 | 995476. | 384689472. | 599200. | 599136. | 6475001. | 0. |
| 17 | 384090336. | 0.3880 | 0.9739 | 995329. | 383095008. | 384689472. | 0.3886 | 0.9740 | 995384. | 383694080. | 599136. | 599072. | 6107840. | 0. |
| 18 | 383095008. | 0.3870 | 0.9738 | 995236. | 382099776. | 383694080. | 0.3876 | 0.9739 | 995292. | 382698784. | 599072. | 599008. | 5761497. | 0. |
| 19 | 382099776. | 0.3860 | 0.9738 | 995144. | 381104640. | 382698784. | 0.3866 | 0.9738 | 995200. | 381703584. | 599008. | 598944. | 5434795. | 0. |
| 20 | 381104640. | 0.3850 | 0.9737 | 995051. | 380109600. | 381703584. | 0.3856 | 0.9737 | 995107. | 380708480. | 598944. | 598880. | 5126617. | 0. |
| 21 | 380109600. | 0.3839 | 0.9736 | 994959. | 379114656. | 380708480. | 0.3846 | 0.9736 | 995014. | 379713472. | 598880. | 598816. | 4835915. | 0. |
| 22 | 379114656. | 0.3829 | 0.9735 | 994865. | 378119776. | 379713472. | 0.3835 | 0.9735 | 994922. | 378718560. | 598816. | 598784. | 4561818. | 0. |
| 23 | 378119776. | 0.3819 | 0.9734 | 994772. | 377124992. | 378718560. | 0.3825 | 0.9734 | 994828. | 377723744. | 598784. | 598752. | 4303373. | 0. |
| 24 | 377124992. | 0.3809 | 0.9733 | 994678. | 376130304. | 377723744. | 0.3815 | 0.9734 | 994735. | 376729024. | 598752. | 598720. | 4059569. | 0. |
| 25 | 376130304. | 0.3799 | 0.9732 | 994585. | 375135712. | 376729024. | 0.3805 | 0.9733 | 994641. | 375734368. | 598720. | 598656. | 3829475. | 0. |
| 26 | 375135712. | 0.3789 | 0.9731 | 994491. | 374141216. | 375734368. | 0.3795 | 0.9732 | 994547. | 374739808. | 598656. | 598592. | 3612326. | 0. |
| 27 | 374141216. | 0.3779 | 0.9730 | 994396. | 373146816. | 374739808. | 0.3785 | 0.9731 | 994453. | 373745344. | 598592. | 598528. | 3407491. | 0. |
| 28 | 373146816. | 0.3769 | 0.9729 | 994302. | 372152512. | 373745344. | 0.3775 | 0.9730 | 994359. | 372750976. | 598528. | 598464. | 3214271. | 0. |
| 29 | 372152512. | 0.3759 | 0.9728 | 994207. | 371158304. | 372750976. | 0.3765 | 0.9729 | 994264. | 371756704. | 598464. | 598400. | 3032006. | 0. |
| 30 | 371158304. | 0.3749 | 0.9727 | 994112. | 370164192. | 371756704. | 0.3755 | 0.9728 | 994169. | 370762528. | 598400. | 598336. | 2860078. | 0. |
| 31 | 370164192. | 0.3739 | 0.9727 | 994017. | 369170176. | 370762528. | 0.3745 | 0.9727 | 994074. | 369768448. | 598336. | 598272. | 2697898. | 0. |
| 32 | 369170176. | 0.3729 | 0.9726 | 993921. | 368176256. | 369768448. | 0.3735 | 0.9726 | 993979. | 368774464. | 598272. | 598208. | 2544915. | 0. |
| 33 | 368176256. | 0.3719 | 0.9725 | 993825. | 367182432. | 368774464. | 0.3725 | 0.9725 | 993883. | 367780576. | 598208. | 598144. | 2400606. | 0. |
| 34 | 367182432. | 0.3709 | 0.9724 | 993729. | 366188704. | 367780576. | 0.3715 | 0.9724 | 993787. | 366786784. | 598144. | 598080. | 2264481. | 0. |
| 35 | 366188704. | 0.3699 | 0.9723 | 993633. | 365195072. | 366786784. | 0.3705 | 0.9723 | 993691. | 365793088. | 598080. | 598016. | 2136074. | 0. |
| 36 | 365195072. | 0.3689 | 0.9722 | 993537. | 364201536. | 365793088. | 0.3695 | 0.9722 | 993595. | 364799488. | 598016. | 597952. | 2014949. | 0. |
| 37 | 364201536. | 0.3679 | 0.9721 | 993440. | 363208096. | 364799488. | 0.3685 | 0.9721 | 993498. | 363805984. | 597952. | 597888. | 1900692. | 0. |
| 38 | 363208096. | 0.3669 | 0.9720 | 993343. | 362214752. | 363805984. | 0.3675 | 0.9721 | 993401. | 362812576. | 597888. | 597824. | 1792914. | 0. |
| 39 | 362214752. | 0.3659 | 0.9719 | 993245. | 361221504. | 362812576. | 0.3665 | 0.9720 | 993304. | 361819264. | 597824. | 597760. | 1691247. | 0. |
| 40 | 361221504. | 0.3649 | 0.9718 | 993148. | 360228352. | 361819264. | 0.3655 | 0.9719 | 993207. | 360826048. | 597760. | 597696. | 1595345. | 0. |
| 41 | 360228352. | 0.3639 | 0.9717 | 993050. | 359235296. | 360826048. | 0.3645 | 0.9718 | 993109. | 359832928. | 597696. | 597632. | 1504882. | 0. |
| 42 | 359235296. | 0.3629 | 0.9716 | 992952. | 358242336. | 359832928. | 0.3635 | 0.9717 | 993011. | 358839904. | 597632. | 597568. | 1419548. | 0. |
| 43 | 358242336. | 0.3619 | 0.9715 | 992854. | 357249472. | 358839904. | 0.3625 | 0.9716 | 992913. | 357846976. | 597568. | 597504. | 1339052. | 0. |
| 44 | 357249472. | 0.3609 | 0.9714 | 992755. | 356256704. | 357846976. | 0.3615 | 0.9715 | 992815. | 356854176. | 597504. | 597472. | 1263156. | 0. |
| 45 | 356256704. | 0.3599 | 0.9713 | 992656. | 355264032. | 356854176. | 0.3605 | 0.9714 | 992716. | 355861472. | 597472. | 597440. | 1191593. | 0. |
| 46 | 355264032. | 0.3589 | 0.9712 | 992557. | 354271488. | 355861472. | 0.3595 | 0.9713 | 992617. | 354868864. | 597440. | 597376. | 1124054. | 0. |
| 47 | 354271488. | 0.3578 | 0.9711 | 992458. | 353279040. | 354868864. | 0.3585 | 0.9712 | 992518. | 353876352. | 597376. | 597312. | 1060314. | 0. |
| 48 | 353279040. | 0.3568 | 0.9710 | 992358. | 352286688. | 353876352. | 0.3575 | 0.9711 | 992418. | 352883936. | 597312. | 597248. | 1000189. | 0. |
| 49 | 352286688. | 0.3558 | 0.9709 | 992258. | 351294432. | 352883936. | 0.3564 | 0.9710 | 992318. | 351891616. | 597248. | 597184. | 943474. | 0. |
| 50 | 351294432. | 0.3548 | 0.9708 | 992158. | 350302272. | 351891616. | 0.3554 | 0.9709 | 992218. | 350899392. | 597184. | 597120. | 889974. | 0. |

TOTAL BENEFIT (PRESENT WORTH IN TERMS OF YEAR 1) = NT$ 259283728.
TOTAL COST (PRESENT WORTH) = NT$ 180000000.
B/C RATIO = 1.440

## APPENDIX D
## USEFUL INTERNET SITES

Chia Nan Irrigation Association
http://www.chianan.gov.tw

Central Region Water Resources Office, Water Resources Agency, Ministry of Economic Affairs
http://www.wracb.gov.tw

Environmental Protection Administration, Executive Yuan
http://www.epa.gov.tw

e Taiwan News
http://www.etaiwannews.com

Illinois Environmental Protection Agency
http://www.epa.state.il.us/water/conservation-2000/lake-notes/lake-dredging

Miao Li Irrigation Association
http://www.mlia.gov.tw

Ministry of the Interior, Executive Yuan
http://www.moi.gov.tw/moi/winter.asp

Northern Region Water Resources Office, Water Resources Agency, Ministry of Economic Affairs
http://www.wranb.gov.tw/wranb_spring/index1.asp

South Region Water Resources Office, Water Resources Agency, Ministry of Economic Affairs
http://www.wrasb.gov.tw/index.asp

The 10th River Management Office, Water Resources Agency, Ministry of Economics Affairs
http://www.wra10.gov.tw

The Executive Yuan

http://www.ey.gov.tw/web/index-ey2000.htm

Taiwan Area National Expressway Engineering Bureau, Ministry of Transportation and Communications
http://www.taneeb.gov.tw/home.htm

Taipei City Government
http://www.taipei.gov.tw

Taipei County Government
http://www.tpc.gov.tw

Taipei Feitsui Reservoir Administration Bureau ( TFRAB )
http://www.feitsui.gov.tw

Taipei Water Department
http://www.twd.gov.tw

Taipei Water Management Office of Water Resources Agency, Ministry of Economic Affairs
http://www.wratb.gov.tw

Taiwan Water Supply Corporation
http://www.water.gov.tw/sample1/indexe.htm

U. S. Environmental Protection Agency
http://www.epa.gov

Water Resources Agency, Ministry of Economic Affairs
http://www.wra.gov.tw

http://business.fullerton.edu/mrahmatian/answerkey/Econ%20201%20Mankiw/chap%2010.doc

http://www.green.org.tw/ecology/ecology.htm

http://www.tw.news.yahoo.com