Study on Reservoir Dredging Simulation

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***Abstract*-The increase in annual sediment deposits in the Feitsui Reservoir is a serious problem. Reservoir dredging is 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 five reservoirs that were dredged in Taiwan were used to calculate the input variables for Program Dredge, and a computer program that simulates the effects of dredging. The program was run to calculate the benefit-cost ratio for the five reservoirs. The values of the input variables from the five other watersheds and conservative assumptions were applied to calculate the benefit-cost ratio of dredging for the Feitsui Reservoir.**

Keywords- Reservoir Dredging; Program Dredge; Cost-Benefit Analysis

I. INTRODUCTION

In order to maintain the functions of a reservoir, dredging is used to recover the reservoir's effective capacity and its efficiency. Efficiency is determined by measuring the storage capacity after a dredging program. Although not all reservoirs are used for the same purposes, the most common uses include:

(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 Taiwan's Feitsui Reservoir has becomes a serious problem. Reservoir dredging is an alternative that can extend the reservoir's life and thereby eliminate the need for a new water storage project. A cost-benefit analysis was required to estimate the benefit-cost ratio of dredging for Feitsui Reservoir by using the data and information related to the reservoir dredging of Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoirs in Taiwan.

II. METHODOLOGY FOR PROGRAM DREDGE

The purpose of a model is to save money, time, effort, some other valuable commodity or any combination of the above. A computer program called Program Dredge was developed to assist the cost-benefit analysis of dredging. In this study, Program Dredge was slightly modified to perform the 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.

A. Input Variables of Program Dredge

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

(1) annual interest rate (the rate of interest an investor earns in a year after accounting for the effects of compounding);(2) wholesale water price (NT$/cubic meter);(3) reservoir storage utilization frequency;(4) unit dredging cost (NT$/cubic meter);(5) reservoir storage at the 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 = medium, 3 = coarse);(11) simulation period in years;(12) stages of dredging; and(13) dredge volume.

Furthermore, reservoir storage utilization frequency is equal to annual water supply divided by live storage. The trap of Brune's trap efficiency curve (1 = fine, 2 = medium, 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 into fine, medium, and coarse, the size ranges of which are 0.016 – 0.008 mm (fine), 0.031 – 0.016 mm (medium), and 0.062 – 0.031 mm (coarse).

The trap efficiency is the proportion of sediment in the water flowing into the reservoir that is trapped in the pool of the reservoir. Moreover, the trap efficiency is an important factor of the amount of sediment that accumulates in a reservoir over the design life. McCuen (2005) states that the "Brune trap efficiency relationship is for (1) primary highly flocculated and coarse-grained sediments, (2) medium-grained sediments, and (3) primary colloidal and dispersed fine-grained sediments".

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B. Output Variables of Program Dredge

The program output includes the following:

(1) reservoir storage in the first year; (2) sedimentation volume; (3) reservoir storage in the final 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 in the first year in cubic meters; (3) C/I: reservoir storage / annual runoff volume; (4) TRAP: clastic sediment yield 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 in the final 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.

C. Reservoir Dredging Program

Implementing a reservoir dredging program is an effective method that can approach the economic efficiency of reservoir storage increments. In terms of reservoir storage simulation, whether a reservoir is dredged or not, it will lose some effective storage due to natural sedimentation. A dredging program can recover most of a reservoir’s original capacity, but some sediment will naturally remain. A simulation should also depict a reservoir’s future water capacity when continuously using a dredging program.

In the simulation, annual sedimentation volume can be estimated using data of trapped sediment from annual sediment inflow. The variability for the simulated period can be estimated by repeating this calculation. Sediment yield can be simulated with and without a dredging program situation in order to calculate the change in reservoir storage after implementing reservoir dredging. In terms of Brune’s theory, analyzing the relationship between the value of Brune’s theory [C/I ratio (reservoir storage / annual runoff volume) and clastic sediment yield] can predict average annual reservoir sedimentation between the average of the annual sedimentation rate and the average of the C/I ratio.

D. Computer Simulation of Reservoir Storage

In order to calculate the benefit-cost ratio, the reservoir dredging program needs to be simulated after carrying on the reservoir dredging program. The reservoir capacity in the absence of a dredging program can be simulated. Clastic sediment yield of the first year can be calculated using the C/I ratio (beginning reservoir storage for simulation / annual runoff volume for simulation). The sediment volume of the first year will be calculated using the 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 year will be the sum of the initial reservoir storage and the hypothetical dredging volume during the simulation period of years.

The reservoir storage volume after simulating 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 the annual sediment volume from the initial reservoir storage capacity. Repeating this calculation will yield predictions of future reservoir storage with and without a dredging program.

E. 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 and Chingmien Reservoir watersheds are based on a 1994 Water Resource Bureau, Ministry of Economic Affairs report. Variables for the Shihmen Reservoir come from a 2002 report from the Water Resource Bureau, Ministry of Economic Affairs and Nungpang Technical Adviser Limited Corporation. See Table 1 for the complete list of variables used in the simulation.

TABLE 1 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

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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)
Brune’s trap efficiency curve (1=Fine, 2=Medium, 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 refers to each stage for a whole year as the assumption for modeling; dredge volume refers to the total dredge volume as the assumption for modeling. Source: Water Resource Bureau, Ministry of Economic Affairs

The data and information for Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoirs come from reports done by the Water Resource Bureau, Ministry of Economic Affairs (2000). Although the data and information of the five reservoirs come from different reports, they are all available and supported by water resource government authorities.

F. 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 requires the consideration of possible variations in their circumstances, including the use of the best dredging method based on season; for example, mechanical dredging is most appropriate during the dry season, while hydraulic dredging works with normal water levels. Furthermore, costs of items such as labor and transportation may differ by location.

Estimates of the benefit-cost ratio for the five selected reservoirs are shown in Table 1. The Paiho Reservoir has the lowest benefit-cost ratio while the Tapu Reservoir has the highest benefit-cost ratio.

Because the Shihmen Reservoir is near the Taipei metropolitan area, the reservoir has a higher dredging cost due to using both hydraulic and mechanical methods. Finally, Table 2 below also shows that the higher the dredging cost, the lower the benefit-cost ratio.

TABLE 2 DREDGING COST AND B/C RATIO FOR FIVE 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 Economic Affairs & Department of Hydraulic and Ocean Engineering, National Cheng Kung University (1994) & Water Resource Bureau, Ministry of Economic Affairs & Nung pang Technical Adviser Limited Corporation (2002).

This study assumes a simulation period of 50 years for Paiho, Tapu, Mingte, Chingmien, and Shihmen Reservoirs. These five reservoirs dredging benefit-cost ratios are 1.502, 9.906, 4.008, 2.102, and 1.961.

G. 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 Water Resource Bureau, Ministry of EconomicAffairs (2000) and the Taipei Water Department (see Table 2), as well as other variables assumed by calculating simulation input variables; they are 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 the beginning of simulation = 400,028,000.

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

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

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(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=Medium, 3=Coarse) = 2.

(11) Simulation period in years = 50.

(12) Stages of dredging = 1.

(13) Dredge volume = 600,000.

H. 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 B for the complete analysis.

The results of the dredging simulation and cost-benefit analysis were divided into three parts: without dredging, with dredging, and dredging residuals. Appendix B for the Feitsui Reservoir is divided into 14 columns to interpret each result. Only the first and second rows are used as examples to explain the calculations.

1) Without Dredging:

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

The number 400,028,000 in the first row comes from the beginning storage for simulation. The number 399,031,200 in the second row comes from the fifth column [E STOR C.M. (reservoir storage in the final 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 0.4031 in the second row comes from the first column 399031200 [B STOR C.M. (reservoir storage in the initial year in cubic meters)] divided by 990,000,000.

(3) TRAP: clastic sediment yield using Brune’s clastic sediment yield curve

The numbers of the 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)] divided by [QAP (average annual runoff for the record period in cubic meters)]. The formula presents the average trap efficiency under a circumstance without dredging; XSQ equals [STOR1 (storage without dredging at the beginning of a year)] divided by [Q (Q=QA)]. The linear interpolation method is applied to estimate the range in reservoir capacity-inflow ratio (SQ) and trap efficiency for the median curve.

Therefore, the XSQ equals STORP divided by QAP [400,028,000 / 990,141,760 = 0.404]. The number 0.404 ranges between 0.40 and 0.50 in reservoir capacity-inflow ratio. Furthermore, the number 0.404 ranges between 0.975 and 0.983 in trap efficiency for the median curve. Estimating the trap efficiency for the median curve is done by applying 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. The number 0.9754 in the first row is the trap efficiency.

The number 0.9753 in the second row comes from XSQ being equal to STOR1 divided by QA [399,031,200 divided by 990,141,760 equals 0.403 (between 0.40 and 0.50) in reservoir capacity-inflow ratio and ranges between 0.975 and 0.983 in trap efficiency for the 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 0.9753. The number 0.9753 in 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 divided by trap efficiency. The QSA (average annual sediment inflow) equals [QSED (average annual reservoir sedimentation rate for the record period)] divided by [TRAP (column 3)]. The XSQ equals STORP divided by QAP [391,473,984 divided by 990,141,760 equals 0.395]. The number 0.395 falls between 0.30 and 0.40 in reservoir capacity-inflow ratio. The number 0.395 ranges between 0.965 and 0.975 in trap efficiency for the median curve.

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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)] divided by 0.975 [= 1,021,538]. Finally, the number 996,784 comes from 1,021,538 divided by 0.9754 equaling 996,409. This value is approximately 996,784 in the first row in the fourth column.

The second row of XSQ equals STORP divided by QAP [00,028,000 divided by 990,141,760 = 0.404]. The number 0.404 ranges between 0.40 and 0.50 in reservoir capacity-inflow ratio. Moreover, the number 0.404 ranges between 0.975 and 0.983 in trap efficiency for the median curve. Linear interpolation as applied to estimate the trap efficiency for the median curve. 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) divided by 0.9754 [= 1,021,120]. Finally, the number 996,693 comes from 1,021,120 divided by 0.9754 equaling 996,000. This value is approximately 996,693 in the second row in the fourth column.

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

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

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

2) With Dredging:

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

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

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

The decisive variables of reservoir storage and annual runoff volume come from the simulations. The number 0.4047 in the first row comes from 400,628,000 being divided by 990,000,000. The number 0.4037 in 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 using the dredge computer software in Appendix B. The average trap efficiency (XSQD) equals [STORD1 (storage with dredging at the beginning of a year)] divided by [Q (annual runoff for simulation)].

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

The trap efficiency for the median curve was estimated using 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 in the first row is the trap efficiency.

The number 0.9753 in the second row comes from XSQD being equal to STORD1 divided by Q [399,631,168 divided by 990,141,760 equals 0.404, between 0.40 to 0.50in reservoir capacity-inflow ratio and ranges between 0.975 and 0.983 in trap efficiency for the 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% plus 0.975 equals 0.975. The number 0.9753 in 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 divided by trap efficiency. The QSA (average annual sediment inflow) equals [QSED (average annual reservoir sedimentation rate for the record period)] divided by [TRAP (column 8)]. The XSQD equals STORD1 divided by Q [400,628,000 (400,028,000 plus 600,000) divided by 990,141,760 equals 0.405]. The number 0.405 ranges between 0.40 and 0.50 in reservoir capacity-inflow ratio. Furthermore, the number 0.405 ranges between 0.975 and 0.983 in trap efficiency for the median curve.

The trap efficiency for the median curve was estimated using 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

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(YTRAP). QSA equals [996,000 (average annual sedimentation rate for calibration)] divided by 0.9655 = 1,031,590]. Finally, the number 996,839 comes from 1,031,590 divided by 0.9754 equaling 1,006,213. This value is approximately 996,839 in the first row in the ninth column.

The second row of XSQD equals STORD1 divided by Q [399,631,168 divided by 990,141,760 equals 0.404]. The number 0.404 ranges between 0.40 and 0.50 in reservoir capacity-inflow ratio. Furthermore, the number 0.404 ranges between 0.975 and 0.983 in trap efficiency for the median curve. The trap efficiency for the median curve was estimated using 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)] divided by 0.9754 [1,021,120]. Finally, the number 996,748 comes from 1,021,120 divided by 0.9754being equal to 996,000. This value is approximately 996,748 for the second row in the ninth column.

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

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

The number 399,631,168 in the first row in the tenth column comes from 400,628,000 minus 996,839 being equal to 399,631,161. This value is approximately 399,631,168 in the first row in the tenth column. Furthermore, the number 398,634,432 in the second row in the tenth column comes from 399,631,168 minus 996,748 equaling 398,634,420. This value is approximately 398,634,432 in the second row in the tenth column.

3) Dredging Residual:

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

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

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

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

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

Recording period

[BEG. C.M. in the eleventh column (dredging residual volume at the beginning of the year) + END C.M. in the 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 the thirteenth column (present value of wholesale water efficiency volume for the record period).

The number 15,538,838 in the first row in the 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 in the first row in the thirteenth column. Furthermore, the number 14,658,500 in the second row in the 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 in the second row in the 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 shows zero in the cost column after the second year (row). This is because reservoir dredging has a one-time 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 is represented with a zero.

III. CONCLUSION

It is very important for dredging to maintain and recover reservoir capacity. The economics of the Feitsui Reservoir can be

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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 to evaluate alternative strategies during decision making in the future.

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