CHAPTER 8

EXAMPLES AND COST COMPARISON OF MAINTENANCE STRATEGY OPTIONS

8.1 Introduction

Chapter 6 set out procedures for identifying the maintenance strategy options and a balanced programme for each option. Chapter 7 showed how to determine the annual costs and the present value and annualised costs of each option or programme using an example based on the existing practice for main and branch canals at Mwea ISS in Kenya. In this chapter we present further examples of maintenance strategy options, and cost comparisons based on data from Mwea ISS.

In analysing the maintenance strategy options, we have tended to round up the number of units of equipment (i.e. resources) used, but retained precise estimates of unit costs, to clarify the calculation process and the derivation of the figures. In practice, one would round these cost estimates, especially as the final costs are heavily dependent on the utilisation of expensive major equipment and the sharing of its costs between the different uses.

The calculations are indicative, and readers may observe ways in which they could be refined further in practice. This refinement has not been attempted here as it would tend to obscure the principles which we are trying to illustrate in these simple models.

8.2 Maintenance strategy options

Current practice at Mwea ISS (Maintenance Strategy Option A, Table 8.1) is based on desilting the main and branch canals annually by dredging using a hydraulic excavator. As well as removing sediment deposition, these operations have a major impact on weeds. In addition, weeds are cut twice per year by manual methods.

For this analysis, we consider other maintenance strategy options:

- reduce the frequency of dredging and increase the frequency of other methods of weed control
- introduce mechanical cutting of weeds using a mowing bucket on a hydraulic excavator
- introduce chemical control of weeds using herbicide applied by a knapsack sprayer
- spread operations over a number of years, for example, by desilting using hydraulic excavators every two years, operations may be spread over a two-year cycle, with half the length of canals desilted each year to achieve a more balanced use of resources.

Clearly there are other options which could be considered, but these have been chosen to illustrate the analytical methods while giving similar outputs to existing practice.

Three different maintenance strategy options are analysed, as shown in Table 8.1. The method applied is to calculate the present value of costs for each maintenance option.

The option is then subjected to alternative assumptions concerning the size of discount rate and a variety of assumptions relating to economies in input use.

Table 8.1 Maintenance strategy options, showing frequency of operations

Operation	Maintenance Strategy Options			
	A	B	C	
			canals in group I: km 0-45	canals in group II: km 46-90
Desilting				
dredging	Y1, Y2, Y3 etc.	Y1, Y3, Y5 etc.	Y1, Y3, Y5 etc.	Y2, Y4, Y6 etc.
manual desilting				
Weed control				
manual cut	Y1 x2, Y2 x2, Y3 x2 etc.	Y1 x1, Y3 x1 etc.	Y1 x1, Y3 x1 etc.	Y2 x 1, Y4 x 1 etc.
mechanical cut		Y2 x2, Y4 x2 etc.		
herbicide			Y1 x3, Y2 x3, Y4 x2, Y6 x2 etc.	Y1 x 3, Y2 x 3 Y3 x 2 Y5 x 2 etc.

Notes:

- canal groups I and II refer to the spread of operations over two years, with operations on one group of canals in one year and on the other group in the following year
- Y1 means Year 1
- x2 means two operations undertaking during the year

The essential pattern of the calculation is to identify the costs (either capital or recurrent costs) associated with each maintenance strategy option. The method follows the steps:

- identify the output to be achieved
- with respect to a specific maintenance strategy option, assign specific tasks to particular years over the assumed planning period

- using the methods exemplified in Chapter 7, calculate the input quantities and associated costs at current prices of fulfilling the tasks identified above
- assign input costs to specific years using current prices
- apply the appropriate discount factors to bring the stream of annual costs to their present values
- sum the annual discounted costs to yield the present value of costs for each maintenance strategy option
- compare and identify the least cost strategy either on a present value of costs basis or annualised cost per km basis.

8.3 Maintenance Strategy Option A

Maintenance Strategy Option A is based on the current weed management practice on primary and secondary canals at Mwea. Ordinarily the entire length of main and branch canals (approximately 90 km) is mechanically dredged between January and March every year. In addition, the entire length of these canals is manually cut on two occasions later in the year. This existing practice has been analysed in detail in Chapter 7 (Section 7.3) and the calculation of life cycle costs, present values and annualised costs was given in Table 7.7 using a 15-year planning period and a discount factor of 20%.

8.4 Maintenance Strategy Option B

The cost profile for Maintenance Strategy Option B relates to an alternative management practice for primary and secondary canals at Mwea ISS as follows:

- the entire length of main and branch canals (approximately 90 km) would be mechanically dredged every second year (i.e. Years 1,3,5, etc.) and manually cut once during each of these years
- the entire length of main and branch canals would be mechanically cut on two occasions during the interim years (i.e. Years 2,4,6, etc.).

The operations are summarised in Table 8.1. The resources required and their costs are estimated below.

8.4.1 Mowing bucket - number required and capital cost

8.4.1.1 Unit cost of mowing bucket

Capital cost of Herder MSZ300 K mowing bucket, bucket carrier and hydraulic pipes for Komatsu PC200-5 hydraulic excavator (Herder BV, Middleburg, The Netherlands, August 1995)	KSh.522,580
Carriage, insurance and freight (Herder BV, August 1995)	KSh.31,490
Capital cost of mowing bucket and attachments including carriage, insurance and freight	KSh.522,580 + KSh.31,490 = KSh.554,070

8.4.1.2 Number of mowing bucket units required

Operation	To mechanically cut 90,000 m of main and branch canals twice a year within a period of three months on each occasion.
Average output for mechanical cutting	150 m length of main or branch canal per hour.
Number of excavator hours required to mechanically cut 90,000m of main and branch canals	$\frac{90,000}{150}$ = 600 hours
Standard number of operating hours for one excavator in a three month period, based on a six hour working day and 26 working days per month (National Irrigation Board, Mwea, 1994)	6 x 26 x 3 = 468 hours
Average rate of excavator utilisation	*c.* 80 %
Average number of operating hours for one hydraulic excavator in a three month period	468 x 80 % = 374 hours
Total number of excavators and mowing buckets required to mechanically cut 90,000m of main and branch canals within a period of three months	$\frac{600}{374} = 1.6 = 2$

8.4.1.3 Input cost of mowing buckets for Maintenance Strategy Option B

Capital cost of 2 MSZ300 K mowing buckets and attachments	KSh.554,070 x 2 = KSh.1,108,140
Number of months mowing buckets employed cutting 90,000m of main and branch canals twice in alternate years	six months out of 24 months
Total number of productive months mowing buckets used in 24 months	six months (Maintenance Strategy Option B) + say six months (elsewhere) = 12
Capital cost attributable to main and branch canals maintenance programme	KSh.1,108,140 x $\frac{6}{12}$ = KSh.554,070

8.4.2 Mowing bucket - annual recurrent costs

8.4.2.1 Input cost per bucket

Recurrent cost of MSZ300 K mowing bucket - 10% of capital costs (Herder BV, 1994)	KSh.522,580 x 10% = KSh.52,258

8.4.2.2 Annual input cost of mowing bucket for Maintenance Strategy Option B

Annual recurrent costs of two mowing buckets in Years 2, 4, 6 etc.	KSh.52,258 x 2 = KSh.104,516
Number of months mowing buckets employed on main and branch canals in Years 2, 4, 6 etc.	six months
Annual recurrent costs attributable to main and branch canals in Years 2, 4, 6 etc.	KSh.104,516 x $\frac{6}{12}$ = KSh.52,258

8.4.3 Hydraulic excavators - number required and capital cost

8.4.3.1 Unit cost of excavator

Capital cost of Komatsu PC200-5 hydraulic excavator including import duties (Panafrican Equipment, Nairobi, October 1994)	KSh.9,000,000

8.4.3.2 Number of excavator units required

Years 1, 3, 5 etc.:

Operation	To mechanically dredge 90,000m of main and branch canals within a period of three months
As for Maintenance Strategy Option A: total number of excavators required to mechanically dredge 90,000m of main and branch canals within a three month period each year	five excavators
Annual utilisation of excavator	5 x 3 = 15 excavator-months

Years 2, 4, 6 etc.

Operation	To mechanically cut 90,000 m of main and branch canals twice a year within a period of three months on each occasion.
As for mowing buckets: total number of excavators and mowing buckets required to mechanically cut 90,000m of main and branch canals within a period of three months	two
Annual utilisation of excavators	2 x 6 = 12 excavator-months

Therefore, the excavators are utilised on the main and branch canals more in Years 1, 3, 5 than in Years 2, 4, 6. The programme should be adjusted to take account of this, for example by dividing the canals into two groups, with dredging and manual cutting undertaken on half the length each year, and mechanical cutting on the other half,

alternating each year. This would also spread the use of the specialist mowing buckets.

To simplify the illustrative analysis however we have not done this. We assume that five excavators are purchased in Year 1 for this maintenance work, and assigned to main and branch canal maintenance for 15 excavator-months per year, every year, and used productively elsewhere for the remaining 45 excavator-months each year. Therefore 25% of the capital costs of the excavators are charged to Maintenance Strategy Option B. The recurrent costs however are dominated by hourly consumption of fuel and lubricants, so we have charged 25% of the annual recurrent costs to Maintenance Strategy Option B in Years 1, 3, 5 etc. but only 20% in Years 2, 4, 6. These utilisation shares are rounded figures, and depend on how the excavators are used elsewhere. Different assumptions on other uses would give different results.

8.4.3.3 Input cost of excavators for Maintenance Strategy Option B

Capital cost of five PC200-5 hydraulic excavators	KSh.9,000,000 x 5 = KSh.45,000,000
Assignment to main and branch canal maintenance	15 excavator-months = 25%
Capital cost attributable to main and branch canal maintenance	KSh.45,000,000 x 0.25 = KSh.11,250,000

8.4.4 Hydraulic excavator - annual recurrent costs

8.4.4.1 Input costs per excavator

Annual recurrent costs for a PC200-5 hydraulic excavator.

As for Maintenance Strategy Option A: total annual recurrent cost	KSh.701,108.63

8.4.4.2 Annual input cost of excavators for Maintenance Strategy Option B

Annual recurrent costs of five PC200-5 hydraulic excavators	KSh.701,108.63 x 5 = KSh.3,505,543.10
Utilisation dredging main and branch canals in Year 1, 3, 5 etc.	15 excavator-months = 25%
Annual recurrent costs attributable to main and branch canals in Year 1, 3 ,5 etc.	KSh.3,505,543.10 x 0.25 = KSh.876,385.79
Utilisation on mechanical cutting of main and branch canals in Years 2, 4, 6 etc.	12 excavator-months = 20 %
Annual recurrent costs attributable to main and branch canals in Year 2, 4, 6 etc.	KSh.3,505,543.10 x 0.20 = KSh.701,108

8.4.5 Hand tools (panga) - number required and capital cost

8.4.5.1 Capital cost of hand-tool

Capital cost of panga (East African Seed Company, Nairobi, 1994)	KSh.120

8.4.5.2 Number of hand tools required

Operation	To manually cut 90,000 m of main and branch canals within a period of 30 days
Average daily output for manual cutting (National Irrigation Board, Mwea, 1994)	50 m length of main or branch canal per day per labourer.
Number of labour days required to manually cut 90,000 m of main and branch canals once a year	$\frac{90,000}{50}$ = 1,800 days
Number of labourers required to manually cut 90,000m of main and branch canals within a period of 30 days	$\frac{1,800}{30}$ = 60 labourers
Number of hand tools required	60 tools

8.4.5.3 Input cost of hand tools for Maintenance Strategy Option B

Capital cost of hand tools (all of which is attributed to maintenance of main and branch canals)	KSh.120 x 60 = KSh.7,200

8.4.6 Labour for cutting - number required and cost

8.4.6.1 Input cost per unit of labour

Cost of one labour day (National Irrigation Board, Mwea, 1994)	KSh.33.42

8.4.6.2 Number of units of labour required

Number of labour days required to manually cut 90,000m of main and branch canals once a year	1,800 days

8.4.6.3 Annual input cost of labour for Maintenance Strategy Option B

Annual input cost of 1,800 labour days in Years 1, 3, 5 etc.	KSh.33.42 x 1,800 = KSh.60,156 per year

8.4.7 Life cycle costs of Maintenance Strategy Option B

The annual costs of this option are shown in Table 8.2, together with the present value and annualised cost. These are calculated using a 15-year planning period and a discount factor of 20%.

Table 8.2 Life cycle costs, Maintenance Strategy Option B - less dredging, manual/mechanical cutting

Year	Inputs	Input costs per unit	Number of units	Annual input cost	Annual input cost	Discount rate 20%	Present value of costs
1	Capital cost of excavator	9,000,000.0	5	11,250,000.0			
	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Capital cost of hand tool (panga)	120.00	60	7,200.00			
	Annual cost of labour for cutting	33.42	1,800	60,156.00			
	Overheads			excluded	12,193,741.7	0.833	10,157,386.91
2	Annual recurrent costs of excavator	701,108.63	2	701,108.63			
	Capital cost of mowing bucket	554,070.00	2	554,070.00			
	Annual recurrent costs of mowing	52,258.00	2	52,258.00			
	Overheads			excluded	1,307,436.63	0.694	907,361.02
3	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	1,800	60,156.00			
	Overheads			excluded	936,541.79	0.579	542,257.69
4	Annual recurrent costs of excavator	701,108.63	2	701,108.63			
	Annual recurrent costs of mowing	52,258.00	2	52,258.00			
	Overheads			excluded	753,366.63	0.482	363,122.72
5	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	1,800	60,156.00			
	Overheads			excluded	936,541.79	0.402	376,489.80
6	Annual recurrent costs of excavator	701,108.63	2	701,108.63			
	Annual recurrent costs of mowing	52,258.00	2	52,258.00			
	Overheads			excluded	753,366.63	0.335	252,377.82
7	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	1,800	60,156.00			
	Overheads			excluded	936,541.79	0.279	261,295.16
8	Capital cost of excavator	9,000,000.0	5	11,250,000.0			
	Annual recurrent costs of excavator	701,108.63	2	701,108.63			
	Capital cost of mowing bucket	554,070.00	2	554,070.00			
	Annual recurrent costs of mowing	52,258.00	2	52,258.00			
	Overheads			excluded	12,557,436.6	0.233	2,925,882.73
9	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	1,800	60,156.00			
	Overheads			excluded	936,541.79	0.194	181,689.11
10	Annual recurrent costs of excavator	701,108.63	2	701,108.63			
	Annual recurrent costs of mowing	52,258.00	2	52,258.00			
	Overheads			excluded	753,366.63	0.162	122,045.39
11	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Capital cost of hand-tool (panga)	120.00	60	7,200.00			
	Annual cost of labour for cutting	33.42	1,800	60,156.00			
	Overheads			excluded	943,741.79	0.135	127,405.14
12	Annual recurrent costs of excavator	701,108.63	2	701,108.63			
	Annual recurrent costs of mowing	52,258.00	2	52,258.00			
	Overheads			excluded	753,366.63	0.112	84,377.06
13	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	1,800	60,156.00			
	Overheads			excluded	936,541.79	0.093	87,098.39
14	Annual recurrent costs of excavator	701,108.63	2	701,108.63			
	Capital cost of mowing bucket	554,070.00	2	554,070.00			
	Annual recurrent costs of mowing	52,258.00	2	52,258.00			
	Overheads			excluded	1,307,436.63	0.078	101,980.06
15	Capital cost of excavator	9,000,000.0	5	11,250,000.0			
	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	1,800	60,156.00			
	Overheads			excluded	12,186,541.7	0.065	792,125.22
	Sum of present value of costs						**17,282,894.22**
	Sum of present value of costs per						**192,032.16**
	Annualised cost per km						**41,094.88**

8.5 Maintenance Strategy Option C

The cost profile for Maintenance Strategy Option C relates to a second hypothetical management practice for primary and secondary canals at Mwea ISS:

- the main and branch canals would be mechanically dredged every second year (e.g. Years 1, 3, 5, etc.) and manually cut once during each of these years
- the main and branch canals would be treated with herbicide on three occasions during the first two years, and on two occasions during the interim years, commencing in Year 4 (e.g. Years 4, 6, 8, etc.)
- to spread the use of resources and reduce the peak demand, particularly the number of excavators required, the canals are divided into two groups, with dredging and manual cutting undertaken on half the length (approximately 45 km) each year.

The operations are summarised in Table 8.1. The required resources and their costs are estimated below.

8.5.1 Hydraulic excavators - number required and capital cost

8.5.1.1 Unit cost of excavator

Capital cost of PC200-5 hydraulic excavator	KSh.9,000,000

8.5.1.2 Number of excavator units required

Operation	To mechanically dredge 45,000m of main and branch canals within a period of three months
Average output for mechanical dredging	50m length of main or branch canal per hour.
Number of excavator hours required to mechanically dredge 45,000m of main and branch canals	$\frac{45,000}{50}$ = 900 hours
Standard number of operating hours for one excavator in a three month period, based on a six hour working day and 26 working days per month	6 x 26 x 3 = 468 hours
Average rate of excavator utilisation	*c.* 80 %
Average number of operating hours for one hydraulic excavator in a three month period	468 x 80 % = 374 hours
Total number of excavators required to mechanically dredge 45,000m of main and branch canals within a three month period each year	$\frac{900}{374}$ = 2.4 excavators

Therefore it will be necessary to purchase three hydraulic excavators.

8.5.1.3 Input cost of excavators for Maintenance Strategy Option C

Capital cost of three PC200-5 hydraulic excavators	KSh.9,000,000 x 3 = KSh.27,000,000
Number of months excavators employed dredging main and branch canals each year	three months (rounded up from 2.4 months)
Total number of productive months excavators used each year	three months (Maintenance Option C) + say nine months (elsewhere) = 12
Capital cost attributable to main and branch canals maintenance	KSh.27,000,000 x $\frac{3}{12}$ = KSh.6,750,000

8.5.2 Hydraulic excavator - annual recurrent costs

8.5.2.1 Input costs per excavator

Annual recurrent costs for a PC200-5 hydraulic excavator.

as for Maintenance Strategy Option A: total annual recurrent cost	KSh.701,108.63

8.5.2.2 Annual input cost of excavators for Maintenance Strategy Option C

Annual recurrent costs of three hydraulic excavators	KSh.701,108.63 x 3 = KSh.2,103,325.89
Utilisation dredging main and branch canals each year	nine excavator-months = 25%
Annual recurrent costs attributable to main and branch canals each year	KSh.2,103,325.89 x 0.25 = KSh.525,831.47

8.5.3 Hand tools (panga) - number required and capital cost

8.5.3.1 Capital cost of hand-tool

Capital cost of panga (East African Seed Company, Nairobi, 1994)	KSh.120

8.5.3.2 Number of hand tools required

Operation	To manually cut 45,000 m of main and branch canals within a period of 30 days.

Average daily output for manual cutting (National Irrigation Board, Mwea, 1994)	50m length of main or branch canal per day
Number of labour days required to manually cut 45,000 m of main and branch canals	$\frac{45,000}{50}$ = 900 days
Number of labourers required to manually cut 45,000 m of main and branch canals within 30 days	$\frac{900}{30}$ = 30 labourers
Number of hand tools required	30 tools

8.5.3.3 Annual input cost of hand tools for Maintenance Strategy Option C

Capital cost of 30 hand tools (all attributed to maintenance of main and branch canals)	KSh.120 x 30 = KSh.3600

8.5.4 Labour for cutting - number required and cost

8.5.4.1 Input cost per unit of labour

Cost of one labour day (National Irrigation Board, Mwea, 1994)	KSh.33.42

8.5.4.2 Number of units of labour required

Number of labour days required to manually cut 45,000m of main and branch canals once per year	900 days

8.5.4.3 Annual input cost of labour for cutting for Maintenance Strategy Option C

Annual input cost of 900 labour days	KSh.33.42 x 900 = KSh.30,078

8.5.5 Knapsack sprayer - number required and capital cost

8.5.5.1 Unit cost of knapsack sprayer

Capital cost of Cooper-Pegler CP3 knapsack sprayer (Agromed, Nairobi, October 1994)	KSh.6,700

8.5.5.2 Number of knapsack sprayers required

Operation	To spray simultaneously, a 2.5 m swathe along both banks of 45,000 m of main and branch canals, within a period of 30 days.
Total area to be sprayed each treatment	2.5 x 2 x 45,000 = 225,000 m^2 = 22.5 ha

Time taken to discharge herbicide from knapsack sprayer, based on flow rate of 2.5 litre/min and knapsack volume of 20 litre per tank	$\frac{20}{2.5}$ = 8 minutes
Total area sprayed over eight minute period, based on walking speed of 1 m/s and spray width of 1.5 m	1 x 1.5 x 60 x 8 = 720 m^2
Total time required to mix and discharge herbicide, based on a mixing time of five minutes	5 + 8 = 13 minutes
Number of tanks discharged during one working day, based on an eight hour day, a 50 minute working hour, and an allowance of one hour for spray calibration	(8-1) x $\frac{50}{13}$ = 27 tanks
Total area sprayed during one working day	720 x 27 = 19,440 m^2
Number of days required to treat 45,000 m main and branch canals	$\frac{225,000}{19,440}$ = 12 days
Year 1: requirement for 2 tasks undertaken during one month	24 days
Number of knapsack sprayers required (minimum two, to provide capability in case of breakdown)	two sprayers

8.5.5.3 Input cost of knapsack sprayers for Maintenance Strategy Option C

Capital cost of two CP3 knapsack sprayers	KSh.6,700 x 2 = KSh.13,400
Annual number of days knapsack sprayers required for spraying main and branch canals three times per year	24 x 3 = 72 days
Assume sprayers are used 50% on main and branch canals, and 50% on other tasks	
Capital cost attributable to main and branch canals maintenance	KSh.13,400 x 0.50 = KSh.6,700

8.5.6 Herbicide - quantity required and cost

8.5.6.1 Unit cost of herbicide

Capital cost of one litre of Roundup (Twiga Chemical Industries Limited, Nairobi, October 1994)	KSh.750

8.5.6.2 Number of units of herbicide required

Operation	To treat with herbicide a 2.5 m swathe along both banks of 45,000m

	of main and branch canals.
Total area to be sprayed	2.5 x 2 x 45,000 = 225,000 m^2 = 23 ha
Volume of herbicide required to treat 23 ha, based on application rate of 5 litre/ha	5 x 23 = 115 litre

8.5.6.3 Input cost of herbicide for Maintenance Strategy Option C

Operation cost of 115 litre Roundup	KSh.750 x 115 = KSh.86,250

Annual costs will vary with the number of tasks to be undertaken each year.

8.5.7 Labour for spraying - number required and cost

8.5.7.1 Input cost per unit of labour for spraying

Cost of one labour day	KSh.44.23

8.5.7.2 Number of units of labour required for spraying

Number of labour days required to spray 45,000 m of main and branch canals	12 days

8.5.7.3 Input cost of labour for spraying for Maintenance Strategy Option C

Operation input cost of 12 days labour for spraying	KSh.44.23 x 12 = KSh.530.76

Annual costs will vary with the number of operations to be undertaken each year.

8.5.7.4 Input cost of spraying (i.e. herbicide and labour) for Maintenance Strategy Option C

Operation cost for 45,000 m	KSh.86,250 + 530.76 = KSh.86,780.76

8.5.8 Life cycle costs of Maintenance Strategy Option C

The annual costs of this option are shown in Table 8.3, together with the present value and annualised cost. These are calculated using a 15-year planning period and a discount factor of 20%.

Table 8.3 Life cycle costs, Maintenance Strategy Option C - reduced dredging, manual/chemical control

Year	Inputs	Input costs per unit	Number of units	Annual input cost	Annual total input cost	Discount rate 20%	Present value of costs
1	Capital cost of excavator	9,000,000.00	3	6,750,000.00			
	Capital cost of hand-tool (panga)	120.00	30	3,600.00			
	Capital cost of knapsack sprayer	6,700.00	2	6,700.00			
	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	6	520,684.56			
	Overheads	excluded			7,836,894.03	0.833	6,528,132.73
2	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	6	520,684.56			
	Overheads	excluded			1,076,594.03	0.694	747,156.26
3	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			729,470.99	0.579	422,363.70
4	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			729,470.99	0.482	351,605.02
5	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			729,470.99	0.402	293,247.34
6	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			729,470.99	0.335	244,372.78
7	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			729,470.99	0.279	203,522.41
8	Capital cost of excavator	9,000,000.00	3	6,750,000.00			
	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			7,479,470.99	0.233	1,742,716.74
9	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			729,470.99	0.194	141,517.37
10	Capital cost of knapsack sprayer	6,700.00	2	6,700.00			
	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			736,170.99	0.162	119,259.70
11	Capital cost of hand-tool (panga)	120.00	30	3,600.00			
	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			733,070.99	0.135	98,964.58

12	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			729,470.99	0.112	81,700.75
13	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			729,470.99	0.093	67,840.80
14	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			729,470.99	0.078	56,898.74
15	Capital cost of excavator	9,000,000.00	5	11,250,000.00			
	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour for cutting	33.42	900	30,078.00			
	Spraying (operation)	86,780.76	2	173,561.52			
	Overheads	excluded			11,979,470.99	0.065	778,665.61
	Sum of present value of costs						**11,877,964.54**
	Sum of present value of costs per km						**131,977.38**
	Annualised cost per km						**28,243.16**

8.6 Cost comparisons

Table 8.4 shows the present values for the three maintenance strategy options over the 15 year planning period, and annualised costs per kilometre.

Table 8.4 Comparison of Maintenance Strategy Options

Maintenance strategy option	Present value (KSh.million)	Annualised costs (KSh. per km)
A	17.4	41,353
B	17.3	41,095
C	11.9	28,243

Maintenance Strategy Option A (Table 8.1) represents the current weed management practice at Mwea ISS. It requires the annual dredging over a three month period of 90 km of canals. Additionally, the same length of canal is manually cut on two later occasions each year. This maintenance strategy option requires the use of five excavators and may be viewed as capital intensive. Details of the justifications of inputs and their costs are presented in Chapter 6 - Preparation of maintenance programmes.

Maintenance Strategy Option B (Table 8.1) presents an alternative weed management option in which the 90 km would be mechanically dredged in alternate years with weed control by manual cutting during these same alternate years and mechanical cutting the other years. The similarity of the Present Value of costs results for Maintenance strategy options A and B is attributable to the preponderance of capital costs of excavators in each case.

Maintenance Strategy Option C (Table 8.1) is similar to B in the pattern of alternate year dredging and manual cutting. It differs by the replacement of mechanical cutting by herbicide treatment in years in which dredging and manual cutting do not occur, and by the spread of operations over two years by dividing the canals into two groups.

The general cost advantage of Maintenance Strategy Option C over Maintenance strategy Options A and B is attributable to the substantial reduction in hydraulic excavator costs associated with less frequent mechanical operations (i.e. dredging and mechanical cutting).

The calculations are illustrative of feasible alternative means of achieving a common level of maintenance. They are not to be interpreted as incontrovertible evidence that Maintenance Strategy Option C is an 'ideal' programme. Considerations of environmental protection, public health or labour availability may preclude such an option. Rather the calculations are intended to convey the method by which the process of identifying the least cost maintenance strategy option could be undertaken giving due consideration to local conditions and constraints. In this case they also show that the hydraulic excavator inputs have a major impact on the maintenance costs.

8.7 Sensitivity analyses

8.7.1 Effect of variable discount factors on annualised costs

The calculations presented in Tables 8.1 to 8.3 use the 20% discount rate. Such a high figure is justified by the likely high opportunity cost of time to the irrigation agency. The effect of using different discount rates is shown in Table 8.5. In all cases the costs of Maintenance Strategy Options A and B are comparable, while C is considerably cheaper.

Table 8.5 Annualised costs (in KSh. per km) of main and branch canals maintained by different management practices.

Maintenance strategy option	Discount Factor		
	10%	20%	30%
A	37,491.77	41,352.60	46,279.22
B	37,145.44	41,094.88	46,123.83
C	26,403.55	28,243.16	31,179.72

8.7.2 Effect of under utilisation of equipment

All the above calculations assume that the hydraulic excavators are used productively elsewhere for the nine months of the year when they are not required for the canal maintenance programme. If this is not the case, the maintenance programme will have

to bear a larger share of the capital cost of the excavators, causing significant increases in the annualised cost.

For example, consider the effect on Maintenance Strategy Option A if the five excavators are used three months per year on canal maintenance and only six months elsewhere, strategy i.e. standing idle for three months because of the weather or lack of work. The 10,500 hour excavator life would not be reached until Year 10, but the cost share to the maintenance programme would be 33% instead of 25%. This results in a capital expenditure of KSh.15 million in Years 1 and 10. Similarly the lower running hours would reduce the estimated annual recurrent cost to KSh.545,079 per excavator, but again 33% would be borne by the canal maintenance programme. The resulting life cycle costs are given in Table 8.6, which shows that the less efficient utilisation of the hydraulic excavators increases the annualised cost by more than 13%.

Table 8.6 Life cycle costs of Maintenance Strategy Option A with less efficient utilisation of excavators.

Year	Inputs	Input costs per unit	Number of unit	Annual input cost	Annual total input cost	Discount rate 20%	Present value of costs
1	Capital cost of excavator	9,000,000.00	5	15,000,000.00			
	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Capital cost of hand tool (panga)	120.00	60	7,200.00			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	16,035,976.38	0.833	13,357,968.33
2	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.694	713,970.81
3	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.579	595,661.53
4	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.482	495,870.22
5	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.402	413,568.11
6	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.335	344,640.09
7	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.279	287,028.61
8	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.233	239,704.90

9	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.194	199,582.62
10	Capital cost of excavator	9,000,000.00	5	15,000,000.00			
	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	16,028,776.38	0.162	2,596,661.77
11	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Capital cost of hand-tool (panga)	120.00	60	7,200.00			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,035,976.38	0.135	139,856.81
12	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.112	115,222.95
13	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.093	95,676.20
14	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.078	80,244.56
15	Annual recurrent costs of excavator	545,078.63	5	908,464.38			
	Annual cost of labour for cutting	33.42	3,600	120,312.00			
	Overheads			excluded	1,028,776.38	0.065	66,870.46
	Sum of present value of costs						**19,742,527.97**
	Sum of present value of costs per km						**219,361.42**
	Annualised cost per km						**46,943.34**

8.7.3 Effect of increased levels of efficiency on annualised costs

We considered the effects on Maintenance Strategy Option C of increased efficiency in use of herbicide and labour, but these made little difference because the costs are dominated by the hydraulic excavator requirements.

8.8 Labour-based desilting operations

8.8.1 Maintenance strategy

An alternative way to reduce the hydraulic excavator inputs would be to use manual labour for desilting when canals are not in use. This option is illustrated by Maintenance Strategy Option A2 which is a more labour intensive variant of Maintenance Strategy Option A. The number of available excavators is reduced from five to three and this shortfall in capital equipment is compensated for by an increase in labour.

Labour productivity in hand-digging depends on a number of factors both physical and behavioural. Physical conditions such as type of soil, weight, wetness and

disposal distance and height will effect productivity. Likewise, behavioural factors such as motivation, incentives, sanctions, payment mechanism and strength of labourers will all have a bearing on productivity. For management, this reinforces the requirement for sound training, supervision and monitoring of labour performance. Productivity may be enhanced by the effective deployment of incentives and sanctions. Targets and bonus payments may be central in this deployment.

Empirical evidence (De Veen 1980) suggests that productivities within the range

1.5 m^3 to 3 m^3 per labour-day are realistic given the physical and behavioural conditions encountered in developing countries. Canal desilting conditions will generally be relatively difficult. The linear output per labour-day will depend on the size of the canal and the depth of silt, as well as the factors mentioned above. In Maintenance Strategy Option A2, we assume a desilting rate of 3 m length of canal per labour-day, which is probably a fairly low estimate.

8.8.2 Calculations of input requirements

Hydraulic excavator dredges 50 m length of channel per hour, working six hours per day.

Therefore hydraulic excavator achieves 300 m per day.

Hydraulic excavator works 26 days per month for three months

= 300 m x 26 days x 3 months = 23,400m

Assume hydraulic excavator has an 80% utilisation rate

output = 23,400 x 0.8 = 18,720 (say 18,700 m) in three months.

Therefore three excavators would achieve 18,700 x 3 = 56,100m.

Task is 90,000 m to be excavated in total.

Therefore 90,000 - 56,100 = 33,840 m to be excavated by men.

Assuming one man does 3m per day

$\frac{33,840}{3}$ = 11,280 man days needed.

11,280 man days x KSh.33.42 = KSh.375,975

These figures are the extra labour costs incurred due to the substitution of extra labour for the two machines reduction.

The original labour costs for cutting weeds will still be incurred and must be added to the extra labour costs to arrive at the annual cost of labour:

11,280	+	3,600	=	14,880
extra man days		original man days		total labour input

14,880	x	KSh.33.42	=	KSh.497,289
labour input		daily wage rate		Annual labour input cost

8.8.3 Life-cycle costs

Table 8.7 shows the annual costs, and the corresponding present value and annualised cost of this maintenance programme. At the 20% discount rate Maintenance Option A2 records a Present Value of costs slightly in excess of KSh.12.4 million. For each kilometre cleared in each year of the investment cycle the sponsoring institution needs to recover KSh.29,562.64. This may be recovered from charges levied, grants etc. from government or profits from other activities.

Maintenance Strategy Option A2 is therefore an attractive alternative, if a labour-based desilting programme is feasible (as on the Chisumbanje case study described in Chapter 2 and in particular if the requirements can be met for labour availability and for access to the canals. The costs are comparable to those of Maintenance Strategy Option C.

Table 8.7 Life cycle costs, Maintenance Strategy Option A2 -reduced dredging, manual desilting/cutting

Year	Inputs	Input costs per unit	Number of units	Annual input cost	Annual total input cost	Discount rate 20%	Present value of costs
1	Capital cost of excavator	9,000,000.00	3	6,750,000.00			
	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Capital cost of hand tool	120.00	125	15,000.00			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	7,788,121.07	0.833	6,487,504.85
2	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.694	710,046.02
3	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.579	592,387.10
4	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.482	493,144.36
5	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.402	411,294.67
6	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.335	342,745.56
7	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.279	285,450.78
8	Capital cost of excavator	9,000,000.00	3	6,750,000.00			
	Annual recurrent costs of	701,108.63	3	525,831.47			

	excavator						
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	7,773,121.07	0.233	1,811,137.21
9	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.194	198,485.49
10	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.162	165,745.61
11	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Capital cost of hand-tool	120.00	125	15,000.00			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,038,121.07	0.135	140,146.34
12	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.112	114,589.56
13	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.093	95,150.26
14	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	1,023,121.07	0.078	79,803.44
15	Capital cost of excavator	9,000,000.00	3	6,750,000.00			
	Annual recurrent costs of excavator	701,108.63	3	525,831.47			
	Annual cost of labour	33.42	14,880	497,289.60			
	Overheads			excluded	7,773,121.07	0.065	505,252.87
	Sum of present value of costs						**12,432,884.14**
	Sum of present value of costs per km						**138,143.16**
	Annualised cost per km						**29,562.64**

References

De Veen, J. J. (1980) The rural access roads programme. ILO, Geneva