Hydrobiologia **340**: 163–172, 1996.
J. M. Caffrey, P. R. F. Barrett, K. J. Murphy & P. M. Wade (eds), Management and Ecology of Freshwater Plants.

The management of weeds in irrigation and drainage channels: integrating ecological, engineering and economic considerations

P. J. Barker, C. M. Ferguson, I. K. Smout & P. M. Wade
Water, Engineering and Development Centre, Loughborough University, Loughborough, Leicestershire LE11 3TU, United Kingdom

Key words: irrigation channel, drainage channel, aquatic weeds, hydraulic performance, cropping calendar, engineering economics

Abstract

The management of aquatic weeds in an irrigation scheme is constrained by the agro-economic system in relation to scheme layout, the nature and ecology of the aquatic weeds, agricultural practice, irrigation and drainage requirements, and the available resources for maintenance. The way in which the ecology, engineering and economics of irrigation and drainage channels interact to produce a pattern of management is investigated for the Mwea Irrigation Settlement Scheme, Central Province, Kenya. This is used to develop a simple model which enables the economic implications of varying the aquatic weed management practice to be identified. The model brings the selection of a weed control programme within the principles of engineering economy.

Introduction

Mwea Irrigation Settlement Scheme is located in the Kirinyaga District of Central Province, near Embu, Kenya. It extends over 12 140 ha and is the largest producer of rice in Kenya (JICA, 1988). The scheme is managed by the National Irrigation Board (NIB) but rice production is carried out by tenant farmers in accordance with a cropping schedule prepared by the NIB (Figure 1a).

The layout of the irrigation and drainage systems at Mwea is typical of irrigation schemes throughout the developing world (Kay, 1986). The scheme is divided into sections, each of which is administered by a NIB Irrigation Officer. Individual sections are sub-divided into units which, in turn, are split into fields. Irrigation water originates from the Thiba and Nyamindi Rivers and is distributed by gravity through a network of predominantly unlined open channels. Link and main canals (primary channels) and branch canals (secondary channels) convey water into the sections. Main or unit feeders (tertiary channels) carry water from the main and branch canals into the individual units, and feeders (quaternary channels) distribute water to the fields. Each feeder serves two lines of fields. The standard field measures 0.4 ha and is rectangular, with one short side abutting on the feeder, the other adjoining the field drain.

Drainage at Mwea is provided by networks of drains which discharge into the Kiruara, Thiba, Murubara or Nyamindi river. Field drains (quaternary channels) running almost parallel to the feeders on the opposite sides of the fields, discharge into collector drains (tertiary channels) which evacuate water from the units. Collector drains may deliver drainage water directly to a river; alternatively, they flow into main drains (primary or secondary channels) and thence into a river.

The growth of aquatic weeds in irrigation and drainage channels of schemes such as Mwea increases resistance to water flow (Chow, 1983; Brabben & Bolton, 1988), reducing the system efficiency. The NIB, in conjunction with the tenant farmers, has developed a channel maintenance programme integrated into the crop production cycle. This paper describes the management cycle for the scheme which takes into account both the crop and the weeds in the channels. Consideration is then given to the way in which the ecology, engineering and economics of the channels interact to produce the current pattern of management. A simple model is developed which enables the economic implications of varying the aquatic weed management practice to be identified.

Management programme

The management of weeds in irrigation and drainage channels at Mwea Irrigation Settlement Scheme is summarised in Table 1. Maintenance is apportioned between the NIB Works Department and the tenant farmers. The Works Department is wholly responsible for the primary and secondary channels and employs both mechanical and manual means of weed control. Mechanical control involves the use of hydraulic excavators to remove silt and weed from the channels (dredging), whilst manual control comprises clearance of weeds and some silt with simple hand-tools such as machetes.

The individual farmers at Mwea are obliged to maintain the irrigation and drainage facilities which directly serve their holdings (feeders and field drains, i.e., the quaternary channels). Channel clearance is carried out by hand, as described above. The management of weeds in main or unit feeders and collector drains is undertaken by the Works Department and the farmers. The Works Department generally shoulders the responsibility when the channels require dredging. Management on the part of farmers involves a communal effort by those individuals served by a particular watercourse.

The Works Department's weed management programme is largely dictated by climate and the cropping calendar (specifically the irrigation and drainage requirements) and the available resources of labour and hydraulic machinery. From December to mid-March, following harvest, rice fields are dry and free from any crop so any in-field maintenance which requires machinery is carried out at this time since plant can pass freely through the fields. During the same period management of the irrigation system commences with the primary and secondary canals and those tertiary canals serving the fields which are to be rotavated early in the year. Drainage is not an important function at this time; however, major drains are dredged during this period in preparation for the long rains in March/April. With the arrival of the long rains resources are focused on drainage maintenance to prevent water-logging (and bogging of tractors) in the fields, and to prevent water from over-topping drains and flooding in-field roads, restricting vehicular access.

Irrigation system maintenance recommences in May/June, canals being cleared systematically in advance of irrigation and rotavation of the fields they serve. September and October represent a critical period for water management. The demand for water is high since all the fields are under crop and high temperatures cause considerable evapo-transpiration (Figure 1b, c). Coincidentally, river flows are at their lowest during this period. It is imperative that the irrigation system has been maintained by this time.

During the period September–November the focus of the maintenance program reverts to the drainage system in preparation for the short rains in October/November and for the pre-harvesting drying-off period (Figure 1b, c). At this time main drains are maintained and flood protection works are carried out in the river channels.

The Works Department's management of weeds in irrigation and drainage channels is not confined to dredging. The recovery rate of vegetation is very rapid and the Works Department periodically deploys maintenance gangs to clear weeds from the channels by hand (Table 1).

Figures 2a, b illustrate the variability of clearance effort over an agricultural year at Mwea Irrigation Settlement Scheme. The maintenance records for 1992 indicate that the peak period for canal maintenance was May to July, and for drain maintenance, July to October. The records show that the allocation of labour and hydraulic machinery is consistent with the reported priorities of the management programme. The overwhelming requirement here is that rice-harvesting should commence in December and be completed as quickly as possible thereafter. All clearance effort is planned to secure this objective.

Ecology

The primary factor in managing weeds in the channels of irrigation schemes such as Mwea is the succession of the vegetation through seven clearly recognisable stages post-maintenance (Figure 3). The succession from one stage to the next is rapid due to both favourable light and temperature regimes, and the persistence of rhizomes, roots and other propagules in the channel bed beyond the reach of current maintenance techniques. The size of channel is also a significant factor in the successional process. The deeper and wider

Table 1. Weed management in irrigation and drainage channels at Mwea Irrigation Settlement Scheme.

Channel	Dimensions	Flow Regime	Principal Weeds	Maintenance Activity
Main Canal[a]	13330 m total length 2.00–6.50 m base width 0.80–1.50 m canal height 0.56–1.31 m water depth 1.95–6.35 m^3 s^{-1}	Flow year round – water supplied for domestic use as well as irrigation	*Acmella caulorhiza Commelina* sp. *Cyperus dives Polygonum senegalense*	Dredging to remove silt and weeds, once per year, in January/February Manual clearance of weeds, using pangas, hoes or spades, twice per year in June and September
Branch Canal[a]	45580 m total length 0.30–3.50 m base width 0.30–1.40 m canal height 0.12–1.23 m water depth 0.04–2.73 m^3 s^{-1}	Flow dependent on cropping program – February to November	*Acmella caulorhiza Ageratum conyzoides Commelina* sp. *Cyperus latifolia Eclipta alba Leersia hexandra Ludwigia abyssinica Panicum repens Polygonum senegalense Rhynchosia* sp.	Dredging to remove silt and weeds, once per year, before area served by canal is irrigated Manual clearance of weeds, using pangas, hoes or spades, twice per year
Main / Unit Feeder	*c.* 1.50–3.00 m bank top 0.028 m^3 s^{-1} / 20.25 ha (1 cusec / 50 acres)[b]	Flow dependent on cropping program – February to November	*Acmella caulorhiza Ageratum conyzoides Centella asiatica Commelina* sp. *Cynodon dactylon Leersia hexandra*	Dredging to remove silt and weeds, infrequently, as required Manual clearance of weeds, using pangas, hoes or spades, twice per year, during production period
Feeder	*c.* 0.50–2.00 m bank top 0.028 m^3 s^{-1} / 20.25 ha (1 cusec / 50 acres)[b]	Flow dependent on cropping program – February to November; period varies from 6–10 months	*Commelina* sp. *Cynodon dactylon Leersia hexandra*	Manual clearance of silt and weeds, using pangas and hoes, three times per year, before flooding, before transplanting and before top-dressing
Field Drain	*c.* 1.50–3.00 m bank top 0.003 m^3 s^{-1} / 1 ha) (0.05 cusec / acre)[b]	Flow dependent on cropping program – February to December; period varies from 6–10 months	*Commelina* sp. *Cynodon dactylon Echinochloa colona Fimbristylis* sp.*Leersia hexandra Ludwigia stolonifera*	Dredging to remove silt and weeds, infrequently, as required Manual clearance of weeds, using pangas and hoes, three times per year, before flooding, before transplanting and before draining for harvest
Collector Drain	*c.* 1.50–3.50 m bank top 0.003 m^3 s^{-1} / 1 ha) (0.05 cusec / acre)[b]	Flow dependent on cropping program – February to December	*Commelina* sp. *Cynodon dactylon Leersia hexandra Ludwigia stolonifera Panicum repens*	Dredging to remove silt and weeds, infrequently, as required Manual clearance of weeds, using pangas, hoes or spades, twice per year, in April/May and November/December
Main Drain[a]	32800 m total length 1.50–15.00 m base width 0.70–3.20 m canal height 0.42–2.83 m water depth 1.00–40.90 m^3 s^{-1}	Flow dependent on cropping program – February to December	*Commelina* sp. *Cynodon dactylon Echinochloa colona Echinochloa pyramidalis Leersia hexandra Marsilea* sp. *Polygonum senegalense Typha latifolia*	Dredging to remove silt and weeds, once per year Manual clearance of weeds, using pangas, hoes or spades, two or three times per year, before rains

[a] Design specifications JICA (1989)
[b] Design specifications Chambers and Moris (1973)

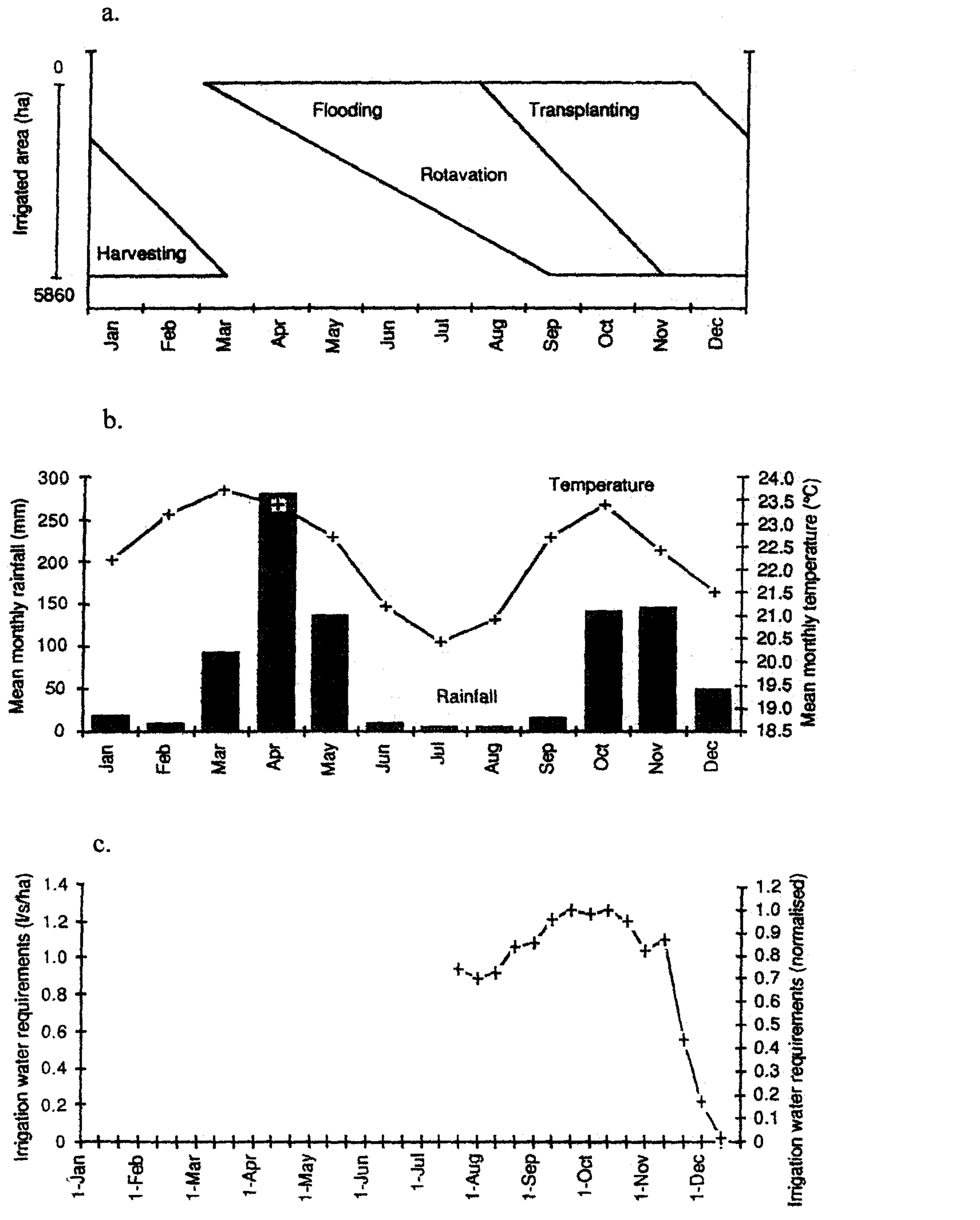

Figure 1. a. Rice cropping schedule at Mwea Irrigation Settlement Scheme. b. Mean monthly rainfall and temperature at Mwea Irrigation Settlement Scheme. c. Irrigation water requirements at Mwea Irrigation Settlement Scheme. (Data not available for January to August.

the channel, the slower the rate of change. Primary and secondary channels at Mwea exhibited all stages of succession, whereas smaller tertiary and quaternary channels characteristically passed from the open water stage directly to one with a high percentage cover of emergent grasses.

Certain species (*Cyperus latifolius* Poir., *Ludwigia abyssinica* A. Rich. and *Polygonum senegalense*

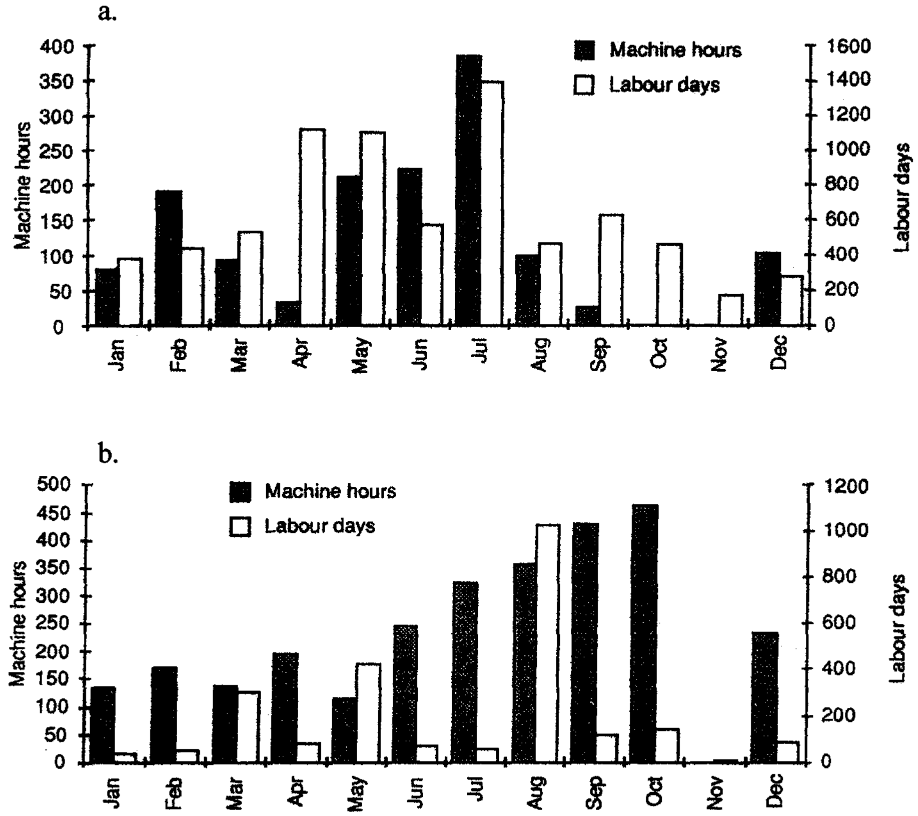

Figure 2. a. Canal maintenance at Mwea Irrigation Settlement Scheme. b. Drain maintenance at Mwea Irrigation Settlement Scheme.

Meisn.) were found to grow only in primary and secondary irrigation channels at Mwea: the depth of water combined with high turbidity preventing the growth of submerged species and the rate of flow inhibiting floating species. Flow and depth combined to slow the rate of encroachment of emergent vegetation. The rate of growth of emergent species in tertiary and quarternary channels was observed to be slower in those channels with a flow, i.e., during irrigation or drainage, than in those with still water conditions.

There are several differences between irrigation and drainage channels such that the ecology of each of these channel types is distinct. For example, flow is typically faster and turbidity usually higher in irrigation channels, particularly in primary and secondary canals. However, irrigation and drainage channels are both temporary aquatic habitats. At Mwea, tertiary and quaternary irrigation channels are without water for two to seven months of the year, and tertiary and quaternary drainage channels are dry for one to six months. Primary and secondary irrigation channels flow almost year-round because, in addition to their irrigation function, they supply water for domestic use. Similarly, primary and secondary drains flow almost year-round since they collect the tail waters from the primary and secondary irrigation channels and in some cases provide land drainage for areas outside the scheme.

Engineering

The management of irrigation and drainage channels can be analysed by using the concepts of condition and performance. The condition of a canal or drain at a particular time depends on the degree of structural and dimensional deterioration, weed infestation, and siltation. The condition worsens over time, but can be improved by maintenance operations.

The weed-related condition of the channel can be represented by its successional stage (Figure 3). Weed clearance changes a channel from a poorer to a better hydraulic condition by returning it to an earlier stage of

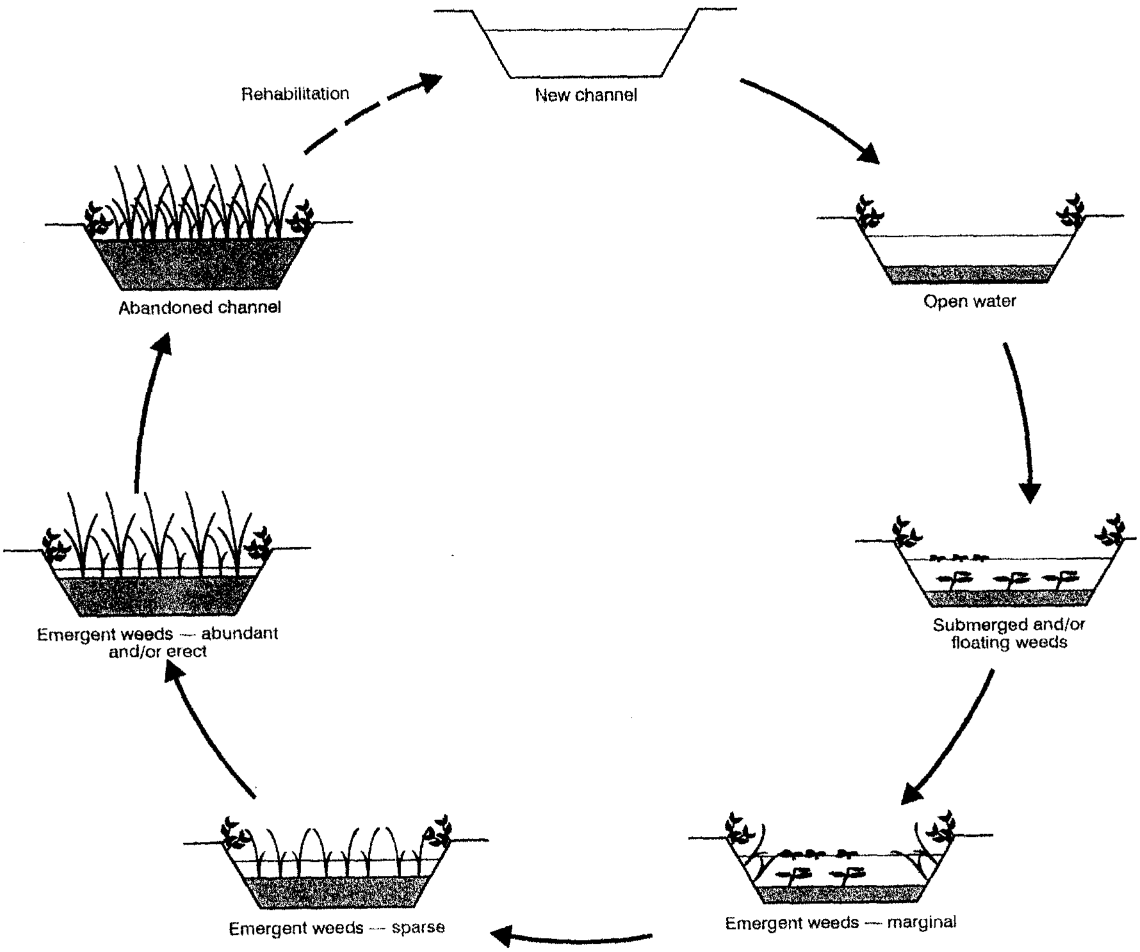

Figure 3. Stages in the succession of vegetation in irrigation and drainage channels.

succession. The silt-related condition can be represented similarly, but siltation normally occurs over a longer timescale, requiring less frequent clearance. Dredging operations remove weed, including root material, at the same time as silt, thereby returning the channel to an earlier stage of succession than do weed clearance operations.

The performance of a canal or drain at a particular time can be expressed by reference to its hydraulic objective: to pass a target discharge along the channel, while ensuring that the freeboard is not less than the target freeboard. The target discharge varies during the year with the irrigation requirements, depending on the crop calendar and climate (Figure 1c). In contrast, the target freeboard would normally be the same throughout the year to provide a safety margin against water over-topping the bank.

Performance can be represented quantitatively by the Delivery Performance Ratio (DPR) and the Freeboard Ratio (FBR), defined as follows:

$$\text{DPR} = \frac{\text{Actual discharge}}{\text{Target discharge}};$$

$$\text{FBR} = \frac{\text{Actual freeboard}}{\text{Target freeboard}}.$$

For optimum performance at a particular time: DPR = 1 and FBR = 1 or >1.

The actual freeboard at any time will depend on both the actual discharge, and the condition of the channel (Q, n and A in the Manning equation (Chow, 1983)). At those times of the year when the discharge is low, a poorer channel condition can be tolerated which will still pass the current target discharge at the target freeboard.

Economics

The central economic principle guiding irrigation and drainage maintenance (including weed management) is marginalist theory: maintenance is worthwhile only when its marginal benefit is greater than its marginal cost. Benefits may be thought of as additional crop values secured by improved yields, better quality produce, or both. They may also take the form of costs avoided, for example, costs attributable to bogged down machinery when drainage is inadequate.

Maintenance effort is governed by the need to convey water to and from the fields. Both of these imperatives require minimum levels of channel performance which vary according to season. At times when performance standards can be relaxed without jeopardising benefits, less effort and cost can be put into maintenance.

The Works Officer at Mwea prioritises the maintenance programme in accordance with the specific tasks required and the specific location of those tasks. Decisions in the formulation of the maintenance programme are largely determined by reference to system performance, but consideration is also given to equity amongst the tenant farmers. The need to disperse machinery to pursue equity occasionally conflicts with the aim of minimising costs.

Although the Works Officer formulates an efficient and fair maintenance programme which meets the requirements of the crop, the current pattern of management at Mwea is restricted to the achievement of short-term goals. It does not take account of the ecology of the succession of different weed communities which comprise the channel life-cycle (Figure 3) in that, in some instances, maintenance at an earlier stage in the cycle could slow down the succession. This could reduce the necessity for maintenance over the medium or even long term.

The current management strategy at Mwea is just one of a series of strategies which are potentially available to fulfil the programme. Other combinations of differing capital (hydraulic machinery) and labour intensity may be constructed to fulfil the maintenance programme. Alternatively, the input mix may be of machinery and herbicides, labour and herbicides, or include biological control. The viability of such a change to the maintenance regime would depend on how it might affect the crop cycle and whether or not there would be an economic gain.

The array of potential strategies could be filtered down to a small number of two or three by consideration of local economic and technical conditions. In developing countries some of the more important conditions might be:

- availability of labour, bearing in mind other labour-intensive demands (e.g., planting and harvesting crops);
- availability of hydraulic equipment and the need for maintenance facilities, and the need to optimise machine utilisation by spreading channel maintenance activities over time;
- availability of fuel, spares and skilled operatives for hydraulic equipment;
- availability of herbicides;
- public health and safety concerns (e.g., in the use of herbicides);
- weed type and growth characteristics which determine frequency of maintenance operations;
- severity of silting;
- variation in target discharge and hence permissible channel condition during the year.

Consideration of these factors will rule out some potential strategies. For example, at Mwea the use of irrigation water for drinking and bathing rules out certain types of herbicide application in irrigation channels and periodic labour shortages necessitate the use of machinery.

The identification of two or three feasible control strategies leads on to a more detailed specification of each maintenance programme and quantification of inputs (e.g., labour and machinery) required to accomplish it. Knowledge of input requirements and input costs allows unit costs to be calculated. Specification of a programme facilitates the breakdown of costs into capital (fixed) and operation and maintenance (variable) cost categories and, importantly, identification of their incidence through time (Table 2). A maintenance programme should be viewed over a planning period (e.g., 15 years) which allows for the inclusion of episodic components such as silt removal.

With costs classified and the years over which expenditure will occur identified, the selection of a single maintenance programme from the contenders can be accomplished by viewing each programme as an investment project with expenditures flowing through time. The flow of expenditures is likely to be uneven over the planning period because of the differing nature of maintenance tasks and their varied input requirements. No single year will be representative of resource expenditures and the whole programme should be viewed as an interdependent and sequential

Table 2. Maintenance expenditure on 90 km of primary and secondary canals at Mwea Irrigation Settlement Scheme.

Year	Inputs	Input Costs Per Unit	Number of Units	Annual Input Cost	Annual Total Input Cost	Discount Factor 20%	Present Value of Costs
1	Capital cost of excavator	9,000,000.00	5	11,250,000.00			
	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Capital cost of hand tool (panga)	120.00	60	1,183.56			
	Annual cost of labour for cutting	33.42	3600	120,312.00	12,247,881.35	0.833	
2	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.694	
3	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.579	
4	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.482	
5	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.402	
6	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.335	
7	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.279	
8	Capital cost of excavator	9,000,000.00	5	11,250,000.00			
	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	12,246,697.79	0.233	
9	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.194	
10	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.162	
11	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Capital cost of hand-tool (panga)	120.00	60	1,183.56			
	Annual cost of labour for cutting	33.42	3600	120,312.00	997,881.35	0.135	
12	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.112	
13	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.093	
14	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	996,697.79	0.078	
15	Capital cost of excavator	9,000,000.00	5	11,250,000.00			
	Annual recurrent costs of excavator	701,108.63	5	876,385.79			
	Annual cost of labour for cutting	33.42	3600	120,312.00	12,246,697.79	0.065	
	Sum of present value of costs						**17,385,454.54**
	Sum of present value of costs per kilometre		17,385,454.54 / 90				**193,171.72**
	Annualised cost per kilometre		193,171.72 × 0.214 (capital recovery factor)				**41,338.75**

The cost estimates above are in Kenyan shillings and based on operating conditions at Mwea Irrigation Settlement Scheme and, in this instance reflect operation of a Komatsu PC200–5 hydraulic excavator. All costs are measured in constant 1994 prices. No allowance for future inflation is included in the investment appraisals. The annual recurrent costs include insurance, road tax, operator wages and operation and maintenance costs.

series of activities through time. Some expenditure will be employed early in the planning period and some will be employed later. The former involves a larger sacrifice to the agency due to the loss of interest-earning potential.

To reflect the declining burden of later costs, decreasing weights (discount factors) are applied to annual costs in order to bring the series of costs through time to their present value. (Table 2 illustrates a calculation of the annualised costs in Kenyan shillings of dredging 90 km of primary and secondary canals once per year over a 15-year period). The discount rate is typically taken to be the interest rate that the agency has to pay on borrowed funds, or the interest rate that it might have earned on invested funds. Application of the discount rate through time allows the present values of the costs of alternative control programmes to be calculated and the selection becomes a matter of choosing the least cost programme.

The investing agency may find it useful to know the constant sum of money required on an annual basis to fund the selected programme. This may be readily achieved by multiplying the present value of costs by the appropriate capital recovery factor to determine the annualised cost (Table 2). For a specified number of years and at a specified interest rate, the capital recovery factor determines the constant annual sum that must be recovered in order to finance capital borrowed plus interest charges incurred to implement a control programme. This level sum of money has to be generated either through grants, loans or farmer payments to finance the selected least cost programme. It makes a valuable contribution to the agency in that it indicates the affordability of a programme over the entire planning period. Application of the model outlined above brings weed and silt control programme selection within the principles of engineering economy.

Potential for increase in efficiency

Economic efficiency requires that either output (maintenance contribution to system performance) is maximised for a given endowment of inputs, or a specified standard of system performance is achieved at the least cost of resources. As the proposed management objective for irrigation and drainage is the attainment of a standard of system performance, it is the second interpretation which is relevant in this context. To meet this objective, maintenance programmes should be formulated to fulfil performance targets as required to meet the water needs of the agricultural cycle. Feasible programmes should then be subjected to least cost analysis over a lengthy planning period.

Input availability should be inventoried and suitable measures of the productivity of maintenance inputs should be constructed. Measures such as distance or area cleared per worker or machine should be recorded. Field observations of the performance of different machines, classes of labour and chemicals should be made in order to measure the productivity of inputs under a variety of working conditions. At the same time, output indicators must be formulated and to this end channels should be classified according to their function and size.

The condition of channels should be assessed in terms of the extent of weeds and their significance for system performance. Because different channels have varying significance for system operation different standards of performance can be tolerated. Permissible minimum standards for each channel or network of channels need to be set allowing for variability over time. This exercise is set against the need to meet crop water requirements through irrigation and drainage at the appropriate times. The prerequisite to successfully accomplish these aims is the clear identification of the crop requirements over time. The agricultural cycle determines the permissible variation in channel performance over the year and consequently the intensity of clearance effort.

To achieve the specified performance objective at channel level, a feasible programme of maintenance needs to be designed taking account of the local constraints on input use. The necessary inputs to accomplish this programme are then identified and quantified. Recognition of the constraints is important because they mould the design of the feasible programme. This procedure is employed for each primary and secondary channel and at tertiary and quaternary level for networks of channels. In this way a series of programmes is designed and their input requirements recorded. The disaggregated system input requirements are then compared with the stock of available resources and, where necessary, adjustments in terms of amount or type of inputs made. The skill of the manager is in iteratively reallocating inputs to render compatible total requirements with the resource base whilst accomplishing the objectives of the system. Given the multiplicity of inputs and the size of irrigation systems, several overall feasible programmes capable of fulfilling system objectives may emerge. Each of these overall programmes can then be subjected to the least cost analysis as outlined above.

Irrigation managers report the importance of experience in the formulation and practice of maintenance programmes. Subjective evaluations of programmes can be greatly enhanced by systematic monitoring of individual programme performance. Realised input productivities can be recorded and compared with historical and expected performances. Targets can be set and in the wider context of system management, incentives and, where necessary, sanctions deployed to enhance system performance.

Acknowledgments

This paper was produced as part of a research project on Management of Weeds in Irrigation and Drainage Channels (R5500) funded by the Overseas Development Administration, UK. Thanks are also expressed to Dr S. K. Mutiso, University of Nairobi, Grace Thendi, John Honor, Welland and Deepings Internal Drainage Board and to the management and staff of the National Irrigation Board, Mwea Irrigation Settlement Scheme for their assistance.

References

Brabben, T. E. & P. Bolton, 1988. Hydraulic impacts of aquatic weeds in irrigation systems. Paper prepared for Joint TAA/ICID (British Section) Meeting on Weeds in Irrigated Agriculture, 14 November 1988. Overseas Development Unit, Hydraulics Research, Wallingford.

Chambers, R. & J. Moris, 1973. Mwea: An Irrigated Rice Settlement in Kenya. Welforum Verlag, Munich.

Chow, V. T., 1983. Open-channel Hydraulics. Twelfth Edition. McGraw-Hill, New York.

JICA, 1988. Feasibility Study on the Mwea Irrigation Development Project. Japan International Co-operation Agency.

JICA, 1989. Basic Design Study Report on the Project for Mwea Irrigation Settlement Scheme Development in the Republic of Kenya. Japan International Co-operation.

Kay, M., 1986. Surface Irrigation: Systems and Practice. Cranfield Press, Cranfield.