Management of irrigation maintenance

21st WEDC Conference Kampala, Uganda, 1995

SUSTAINABILITY OF WATER AND SANITATION SYSTEMS

Management of irrigation maintenance

Peter Barker, Cath Ferguson, Ian Smout and Max Wade, WEDC

THE PRINCIPLE REASON for maintenance is the avoidance of economic costs caused by failures in delivering and removing water from the system in accord with crop requirements. Failures may affect the quantity of water or the timing of water delivery and removal.

Secondly, failure to maintain to an adequate standard may result in the generation of external diseconomies of production. Diseconomies are the incidental, unwanted and costly by-products of economic activity. These are frequently associated with environmental degradation and in the context of irrigation are manifested by salinity build up and waterlogging.

Thirdly, poor maintenance may introduce conflicts and arbitrary redistributions of income between those dependent on the system. The interdependencies inherent in irrigation systems mean that individual neglect has implications for the welfare of other users. This consideration is important for the organizational design of maintenance programmes and the way in which incentives and sanctions are deployed in the design.

Typically an irrigation system is composed of canals, channels, drainage and civil works. Access roads, offices and subsidiary plants such as ginneries or mills may be part of the wider definition of the irrigation project. In the present study the area of interest is confined to water delivery and drainage and more particularly with management of weed and silt maintenance. The assets vulnerable to weed invasion and reduced performance are embankments, canal and channel beds and drainage channels.

Inadequate maintenance of these assets will eventually produce the inefficiencies and inequities outlined above.

The principle adverse effects of large amounts of weed in irrigation and drainage channels are as follows:

- weeds interfere with water flow in canals and drains, inhibiting water delivery to the crop and drainage from the fields;
- weeds entrap sediment, causing a progressive reduction in the capacity of a channel or reservoir;
- weeds reduce reservoir capacity by occupying useful volume and increasing water loss through evapotranspiration;
- weeds block pump intakes, interfere with the operation of regulator gates and weirs, and threaten structures such as canal linings and bridges;
- weeds assist the spread of diseases such as schistosomiasis and malaria by reducing flow velocities and providing habitats for the intermediate vectors of the parasites causing these diseases;
- weeds in irrigation and drainage channels provide a source of weeds which may spread into irrigated fields;
- weed control operations may require the drainage of canals and reservoirs, thereby interfering with irrigation schedules; and
- weed control operations utilize scarce resources including finance, labour and equipment.

Of these adverse impacts, weed growth-induced flow resistance and siltation may impose the most serious economic costs. The relationship between vegetation and hydraulic resistance (resistance to water flow) is of considerable importance to watercourse designers and managers. The most commonly used indicator of the reduction in discharge capacity caused by weed growth is Manning's roughness co-efficient (n) derived from the Manning equation:

$$Q = A.R^{0.67}.S^{0.5}/n$$

where: Q is the discharge;
A is the cross-sectional area of flow;
R is the hydraulic radius;
S is the slope of the water surface;
and n is the roughness (retardance) coefficient.

The presence of weed in a channel increases the hydraulic resistance and raises the value of Manning's n above the design specification for the channel. The direct effects of reduced discharge capacity are inadequate water supplied at the far ends of irrigation canals and an inability of drainage channels to remove water from waterlogged areas.

Hydraulic performance and conditions

The management of weeds in irrigation and drainage channels can be analyzed by using the concepts of 'hydraulic performance' and 'condition'. The hydraulic performance of a canal or drain, at a particular time, can be expressed by reference to its hydraulic objective, i.e. to pass a target discharge along the channel while ensuring that the freeboard (distance from water level to bank top level) is not less than the design, or target, freeboard. On many irrigation schemes, the target discharge varies throughout the year according to irrigation requirements which, in turn, depend on the crop calendar and climate. By contrast, the target freeboard would normally be the same throughout the year, to provide a safety margin against water over-topping the bank.

Thus, hydraulic performance can be represented quantitatively by the 'delivery performance ratio' (DPR) and the 'freeboard ratio' (FBR), defined as follows:

$$DPR = \frac{\text{Actual Discharge}}{\text{Target Discharge}} \qquad FBR = \frac{\text{Actual Freeboard}}{\text{Target Freeboard}}$$

For optimum hydraulic performance at a particular time, the DPR = 1 and the FBR = >1.

The actual freeboard at any time depends on both the actual discharge and the condition of the channel (Q, A and n in Manning's equation). Thus, at those times of year when irrigation requirements are low, and hence target discharge is low, a poorer channel condition can be tolerated because the optimal values for hydraulic performance parameters may still be attained (i.e. $DPR = 1$, and $FBR = >1$).

The condition of a canal or drain at a particular time depends on the degree of structural and dimensional deterioration, and the degree of weed infestation and siltation. Thus, the condition worsens over time, but it may be improved by maintenance operations.

The weed-related condition of a channel can be described in terms of the stages of hydroseral succession. The weed communities in irrigation and drainage channels pass through clearly recognizable stages of succession.

Weed clearance improves the hydraulic performance of a channel, recovering the weed-related condition from a 'poorer' to a 'better' state by returning it from a later to an earlier successional stage. The extent of the recovery is dependent on the degree of weed clearance. Dredging (or de-silting) operations, for instance, remove weeds and their root material as well as silt, thereby returning the channel to an earlier stage of succession than other weed clearance operations.

Following weed clearance, the successional process recommences. The rate at which it proceeds depends on the persistence of the remaining vegetation and the potential for invasion and colonization by new weeds as well as the frequency of weed clearance operations.

Economics

The central economic principle guiding weed and silt clearance effort is based on marginalist theory. The optimum amount of clearance effort is reached when the marginal benefit of clearance is greater than the marginal cost of clearance. Whilst marginal cost is less than marginal benefit, additional clearance is worthwhile. This condition is important because it underlines the fact that clearance is not an end in itself and that it is a costly business. Clearance can only be justified when additional benefits outweigh costs. 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.

The required amount of clearance is governed by the need to convey irrigation water to the fields and equally by the need to drain water away. 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 clearance effort. The maintenance records at Mwea 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.

The works office at Mwea Irrigation Scheme prioritizes the maintenance programme in accordance with specific tasks required and the specific location of those tasks. Although decisions in the formulation of the maintenance programme are largely determined by system efficiency considerations, due consideration is also given to equity because of the interdependencies inherent in large irrigation systems. Fairness and farmer co-operation partly determine the timing and location of maintenance effort at Mwea.

Irrigation managers such as the works officer at Mwea Irrigation Scheme must formulate an efficient and fair maintenance programme which meets the requirements of the crop and geography. The current pattern of management at Mwea Irrigation Scheme 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 comprize the channel life-cycle 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 management programme in Mwea Irrigation Settlement Scheme is just one of a series of broad control strategies which are potentially available to execute the programme. They may include alternative mixes of capital (e.g. hydraulic machinery) and labour (e.g. manual cutting). Combinations of differing capital and labour intensity can be constructed to fulfil a given 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 broad strategies should 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. planning and harvesting crops);
- availability of hydraulic equipment and the need for maintenance facilities, and the need to optimize machine utilization 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 the frequency of maintenance operations;
- severity of silting;
- variation in target discharge and hence permissible channel condition during the year.

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

The identification of two or three feasible contender control programmes leads on to the more detailed specification of each maintenance programme and specifically the amount of each input e.g. labour and machinery, required to accomplish it. Knowledge of input requirement and input costs allows unit cost 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 1). A maintenance programme should be viewed as a planning period (e.g. 15 years). Such a period allows for the inclusion of episodic components of a maintenance programme such as silt removal which may, in some cases, be necessary only at three-or four-year intervals.

With costs classified, laid out systematically 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. Some expenditures involve a bigger sacrifice to the agency than the same nominal amount of expenditures incurred later in the period. This is because early expenditures involve the loss of interest-earning potential whilst on delayed expenditures interest may be earned. Thus, a dollar's worth of expenditure in year one is a bigger burden than a dollar's worth of expenditure in year eight or 12.

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 1 illustrates a calculation of the costs of dredging 90 km of primary and secondary canals once per year over a 15-year period of Mwea Irrigation Settlement Scheme). 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 value of costs of alternative control programmes to be calculated and the selection becomes a matter of choosing the cheapest 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 'annualized cost'. (Table 1 illustrates the calculation of the annualized cost of dredging 90 km of primary and secondary canals once per year over a 15-year period at Mwea Irrigation Settlement Scheme). For a specified number of years and at a specified interest rate, the capital recovery 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 annual sum of money has to be generated either through grants, loans or farmer payments to finance the selected programme. It makes a valuable contribution to the agency in that it indicates the affordability of a programme over the entire period.

Application of the model outlined above brings weed and silt control programme selection within the principles of engineering economy.

Conclusions

Economic efficiency requires that a specified standard of system performance is achieved with minimum use of resources.

To meet the objective of minimizing expenditure, 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 process.

Given the multiplicity of inputs and the size of irrigations systems, several overall 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. Realized 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 may be deployed to enhance system performance.

References

Bakry, M.F., Gates, T.K. and Khattab, A.F., 1992. 'Field measured hydraulic resistance characteristics in vegetation-infested canals.' *Journal of Irrigation and Drainage Engineering*, 118(2): 256-274.

Brabben, T.E. and Bolton, P., 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, UK.

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

Table 1.

Calculation of annualized cost

Present value of costs (KSh)	× Capital Recovery Factor (20 per cent over 15 years)	Annualized Cost (KSh)
46 158 016	× .214	9 877 815