Improved Irrigation System Planning and Management

Aids to Maintenance, Incorporating Guidelines for Monitoring System Condition

G. Cornish

TDR Project R6260
Report OD/TN 94
June 1998

HR Wallingford

DFID Department For International Development

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HR Wallingford

Address and Registered Office: HR Wallingford Ltd. **Howbery Park, Wallingford, OXON OX10 8BA**
Tel: +44 (0) 1491 835381 Fax: +44 (0) 1491 832233

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Contract

This report describes work carried out in collaboration with the Irrigation Department of Sri Lanka, for the Engineering Division of the Department for International Development, under the Technology Development and Research programme.

The Research Number and Project details are as follows:

Theme:	Improved availability of water for sustainable food production and rural development
Theme No	W5
Project:	Improved Irrigation System Planning and Management
Project No.	R6260

Prepared by ....[signature].......... *(name)*

..........IRRIGATION SPECIALIST.......... *(Title)*

Approved by ....[signature].......... *(name)*

..........Project Leader.......... *(Title)*

Date..........22/06/98..........

Summary

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The report describes problems of efficiently scheduling maintenance on irrigation schemes in the developing world, and describes a procedure which was developed to help in defining priority needs. The work was undertaken with the Irrigation Department, Government of Sri Lanka under the former TDR research program of DFID's Engineering Division.

Funds for maintenance are invariably in short supply. Irrigation managers are therefore continually faced with the need to weigh the relative importance of necessary work, both within individual schemes and between different schemes.

The procedure, which is intended to be reasonably general in application, was developed at Muruthawela Scheme, Weeraketiya Division, in southern Sri Lanka. One of the outputs from the work was the software MARLIN, which was designed to assist in maintenance planning. Rational maintenance decision-making requires comprehensive information on system condition over time, and identification of those problems which have prime impact on the performance of the scheme. Standardised methods for system inspections, for assigning priorities to different works, and for keeping track of component condition were developed.

When funds for maintenance are very short, as in Sri Lanka, it is not possible to conduct annual system surveys prior to the maintenance closure period, as some other countries do. In these circumstances, records of component condition could be built up over time by requiring field staff to return standard condition and work reports every time tasks are contemplated or completed. The introduction of computerized methods for scheduling maintenance depends on the systematic input of records, preferably by a designated operator, or at least under the immediate control of such a one.

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1. IRRIGATION SYSTEM MAINTENANCE – BACKGROUND TO THE PROJECT

1.1 Introduction

The importance of irrigation to the economies of developing nations is reflected in the large investments made in the irrigated sector by governments, supported by international loans and grants under bilateral and multilateral aid programmes. In the decade to 1993, the average, annual, combined lending for capital works in irrigation and drainage by the International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA) was $980 million, representing some 7% of their total joint lending. In the same period, the Asian Development Bank (ADB) lent some $500 million annually for irrigation projects.

Despite such heavy investment, systems are failing well within their design lifetimes. Approximately two thirds of recent international irrigation lending has been spent on rehabilitating systems which have suffered premature technical failure. Billions of dollars invested in the original infrastructure are being written off unnecessarily because maintenance is inadequate. Jones, in an evaluation of irrigation and drainage lending by the World Bank, (1995) concluded that:
…. " O&M problems can be seen in the Bank's financing of so many rehabilitation projects. Almost all of them, when scrutinised, turn out to be deferred maintenance projects".

Gulati and Svendsen, (1994) describing cost recovery for O&M of irrigation schemes in India illustrate one of the consequences of the inadequate investment in maintenance:

"Under-funding of O&M costs has led to a situation where some $2300/ha (1988-89 prices) is spent on development of irrigation facilities, whereas existing irrigation potential is under-utilised for lack of a small sum of $20/ha for maintenance. It needs to be kept in mind that if this small recurring cost is not made available, the productivity of the entire system, which has been built up at enormous cost, will fall to abysmally low levels."

The inadequacy of funding for the maintenance of irrigation infrastructure is widely reported, (Skutsch, 1997; Carruthers & Morrison, 1994; Gulati and Svendsen, 1994). However, Carruthers & Morrison, 1994 warn that:

"Throwing more money at the maintenance problem as it is presently diagnosed is very unlikely to resolve it."

Svendsen, (1994) stresses that both operational and strategic changes are required if improvements in irrigation maintenance are to be achieved. Operational change occurs at the individual scheme level and is brought about by actions such as, training, physical restoration, introduction of new technology or implementation of new management techniques. Strategic change addresses the policies, priorities and management institutions at agency level and is brought about through actions relating to technological modernisation, pricing and funding, increased user participation, organisational restructuring and the reform of property rights.

Although there is general concern for low levels of funding and low status given to maintenance by irrigation departments, it is not easy to demonstrate a clear linkage between maintenance activity, scheme performance and the consequences of neglect. Research is required to define the linkage, under different operational objectives, to justify greater investment in maintenance and target limited resources to best effect. This report describes work carried out by the Overseas Development Unit (ODU) of HR Wallingford in collaboration with the Irrigation Department in Sri Lanka under DFID's former Technology Development Research programme. The work builds upon a number of earlier studies of irrigation maintenance and performance carried out by the ODU and other agencies which are reviewed in the following paragraphs.

1.2 Previous Work

1.2.1 Sedimentation, Gezira Scheme, Sudan

Lawrence (1991) describes serious siltation problems in the Gezira scheme, Sudan. Sediment concentrations in the Blue Nile have increased five-fold since 1930 in response to changing land use practices in the catchment area. The problem is worsened because managers now start the irrigation season when the flood waters are rising, so that the system is operating at a time when the sediment load is at its highest. The available staff and equipment have proved unable to control the accumulation of sediment in the system under these changing circumstances.

The minor canals were designed to allow overnight storage of water at a time when irrigation was mainly restricted to daylight hours. Under the heavy intake of sediment, the minor canals function as settling basins, the bulk of material settling down at the head, so that their storage capacity has been greatly reduced. Francis (1989) reports that the bed levels at the head of minor canals have risen by as much as 1.4 metres since the establishment of the scheme. In order to overcome the problem, system operators allow the water level in the main canal to rise, substantially infringing upon freeboard. Even so, many minor canals cannot draw an adequate supply.

Present-day farmers in the Gezira tend to irrigate for 24 hours a day, exploiting the high moisture-holding capacity of the black cotton soil by leaving their outlets open overnight. In these circumstances, loss of storage capacity in the minor canals is less important than formerly.

In these circumstances a targeted maintenance regime would aim to keep minors operating with an adequate supply without infringing the freeboard of the major canals. It would not attempt to remove all sediment from minors to restore a storage capacity that is not required. Maintenance for sediment control could be targeted by monitoring the water level at the head of minor and major canals together with the canal discharges with intervention occurring when the stage discharge relationship deviated beyond an acceptable band.

1.2.2 Deterioration of Canal Linings, Indian Punjab.

Goldsmith and Makin (1989) investigated the performance of rendered brick and brick linings in distributary canals and watercourses in the Indian Punjab, measuring seepage rates and the equity of supply between head and tail. Field measurements indicated that seepage losses from watercourses with linings more than four years old were comparable with those of unlined channels. They attribute the rapid deterioration of the linings to poor construction quality and subsequent levels of maintenance, reporting particular problems of direct leakage through cracks, eroded mortar and structural failure of the lining where the channel was in fill. Despite these failures lined distributaries showed greater head to tail equity than unlined channels.

Where the principal justification for lining is seepage reduction both construction *and* maintenance must be of a high standard. To sustain the economic justification for lining, maintenance must be of a sufficient standard to maintain low rates of seepage.

1.2.3 Detecting Maintenance Needs by Monitoring Scheme Performance

The value of routine irrigation performance monitoring as a diagnostic tool to target maintenance was demonstrated in field research at the Kraseio irrigation scheme in Thailand, (Bird *et al*, 1990). Daily monitoring of flow identified canal reaches with inadequate conveyance capacity. Field inspection identified localised accumulation of sediment as the cause.

Brabben & Bolton (1988) describe the use of performance monitoring –measuring discharge and water level – to detect the effect of submerged weed growth on channel capacity in Upper Egypt. A sonar system mounted in a small boat was used to identify reaches in large conveyance canals with extensive subsurface weed development so as to target weed-cutting work in those reaches.

Maintenance request forms which explicitly state the current and required conveyance capacity of a canal reach and reporting forms showing the capacity after maintenance intervention have been evaluated in Nepal, (Thoreson *et al*, 1997). Although the approach focuses on a single function – conveyance – and takes no account of maintenance to maintain control or prevent future deterioration, it does introduce a linkage between maintenance and a measure of system performance. The same authors propose three levels of priority for maintenance within a scheme based on distinctions between corrective and preventive works and whether the asset is part of the acquisition or distribution infrastructure. Cost:benefit analysis is used to justify corrective maintenance intervention based on simplifying assumptions about the productivity of additional water supplied to farmers after maintenance.

The impact of maintenance on the conveyance capacity of canals and drains has also been used by workers in Mexico to develop a procedure for prioritising maintenance expenditure, (Fregoso and Jimenez, 1993). Again, the procedure does not address the benefits of timely preventative maintenance or the need to maintain control as well as conveyance capacity.

Cornish and Skutsch (1997) set out a procedure to identify the causes of under-performance in irrigation schemes affected by declining yields and/or reduced irrigated area. The work was aimed at improving the objectivity and consistency of studies for the rehabilitation of schemes, but the procedures have application in planning periodic maintenance work.

1.2.4 Determining Maintenance Needs by Hydraulic Modelling

Van Waijjen *et al* (1997) describe the targeting of corrective maintenance work using a hydraulic model to simulate the effect of different de-silting strategies and structural modifications to outlets on the equity of water distribution over a single secondary canal. The method provides a powerful tool for evaluating the impact of different maintenance strategies but requires skilled staff to set up and run the model. The authors conclude that detailed modelling is not appropriate for routine use by irrigation managers but could be used for strategic studies to develop regular maintenance strategies for selected canals.

1.2.5 Asset Management Planning – Water Industry Practice

Some have highlighted the need to make more explicit linkages between measures of irrigation performance or service provision and maintenance investment. Burton *et al* (1996) examined the application of asset management planning procedures (AMP), developed in the UK water supply industry, to irrigation and drainage infrastructure in the developing world. AMP is a procedure to formulate medium (5 year) and long-term (20-25 year) investment plans, which relies on engineering inspection of a small sample of the total asset base. Engineering judgements are made to link a defined level of condition to measures of performance or customer service, statistical analysis predicts what fraction of the total asset base will lie in each condition-category and using standard cost models the investment profile required to ensure a specified level of customer service is determined. Used thus the procedure does not identify the specific assets within any system that require maintenance, repair or replacement but it underscores the connection between asset condition and performance. The AMP then requires that an accurate inventory of the network infrastructure is prepared and that standardised condition assessment methods are developed. These are frequently lacking in irrigation maintenance planning procedures but they potentially represent an important step in the development of improved practice.

1.3 Scope and Objectives of the Project

The objective of the project, by the Overseas Development Unit of HR Wallingford and the Irrigation Department of Sri Lanka with funding from DFID, was to strengthen irrigation agencies' capacity to manage their infrastructure by developing methods to target cost-effective maintenance actions. The three year project, based on a medium-sized scheme, involved investigation of infrastructure, formulation of maintenance inspection and targeting procedures, development of software (MARLIN), and training of engineering staff. The field work supporting the development and testing of the procedures and the MARLIN software took place in a selected Irrigation Division in southern Sri Lanka and details of existing maintenance planning procedures, budget allocations and system performance within that Division are presented in this report. However, the outputs of the project are intended to have more general application for the planning of periodic maintenance on large irrigation systems and wherever possible specific observations and field data have been used to formulate more widely applicable procedures and conclusions.

1.3.1 Site Selection and Characteristics

It was initially intended that the project be conducted with the Ministry of Water Resources, PR China, who claimed to have a large database on asset condition, maintenance works, and costs. The Ministry manages large numbers of systems in semi-arid areas, many affected by a range of maintenance problems and including schemes of around 20,000 ha with a reliable water supply, which were considered ideal conditions for the development and introduction of improved maintenance procedures.

However, it was found during detailed discussions with the provincial irrigation authorities in Shandong Province, that improved water management is currently the main focus of government efforts to improve the output of existing schemes which have not been scheduled for rehabilitation. However, the Irrigation Department in Sri Lanka was interested in collaborative work to improve maintenance planning.

Schemes in Sri Lanka are relatively small by world standards. Many are based on centuries-old irrigated developments drawing supply from streams and tanks. Although there are marked differences in annual rainfall across the island, the climate is monsoonal so paddy rice is grown as a monoculture in many parts.

The Department put forward alternative schemes for consideration. After site visits, it was agreed that Muruthawela scheme in Hambantota Range would be suitable. Muruthawela is a medium-sized scheme in Sri Lankan terms with a command area of some 1740 ha. (4300 acres). The scheme represents 30% of the irrigated lands administered by the Weereketiya Division (Figure 1). There are also two adjacent series of minor schemes, served by anicuts on the Kirama Oya and Urubokka Oya rivers, which present substantial O&M problems. Figure 2 is a schematic showing the relationship of Muruthawela and the minor schemes.

The command areas of the systems are as follows:

	Area	
	Acres	Hectares
Muruthawela System (3 tracts)	4300	1740
Urubokka Oya + High Level Canal (8 anicuts, 7 tanks)	5050	2044
Kirama Oya (18 anicuts)	4800	1943

The Muruthawela scheme is served by a tank on the Urubokka Oya having a live storage capacity 47.6 Mcm (38,700 acre feet) from a catchment area of 109km2 (42 square miles). The tank also serves the minor schemes on the Urubokka Oya.

The Muruthawela command is made up of three tracts, as illustrated in Figure 3. The dam, main canal, and Tract 2 were completed in 1968/69. It was intended to serve Tract 1 from the main canal but there were problems in agreeing with local landholders, so Tract 3, at the tail of the system, was subsequently developed instead. In practice, there has been increasing loss of water over the years to Tract 1 farmers via a number of informal offtakes in the first 4½ miles of canal. Under current plans, the main canal is being modified so that Tract 1 becomes formally integrated into the scheme. The effective boundaries of Tract 1 are not well defined, but its inclusion represents an expansion of some 30% in the present scheme area.

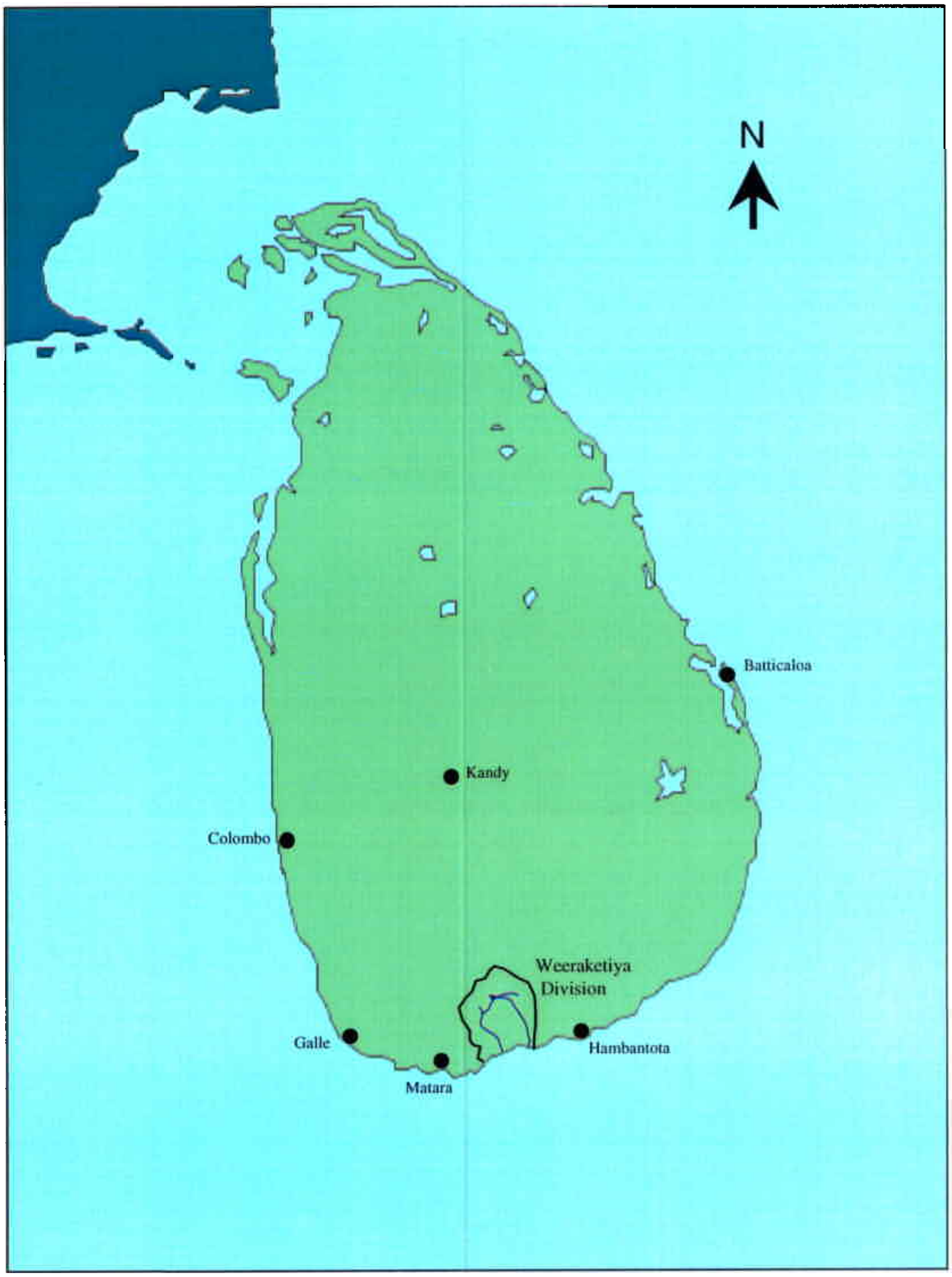

Figure 1 Weeraketiya Irrigation Division, Southern Sri Lanka

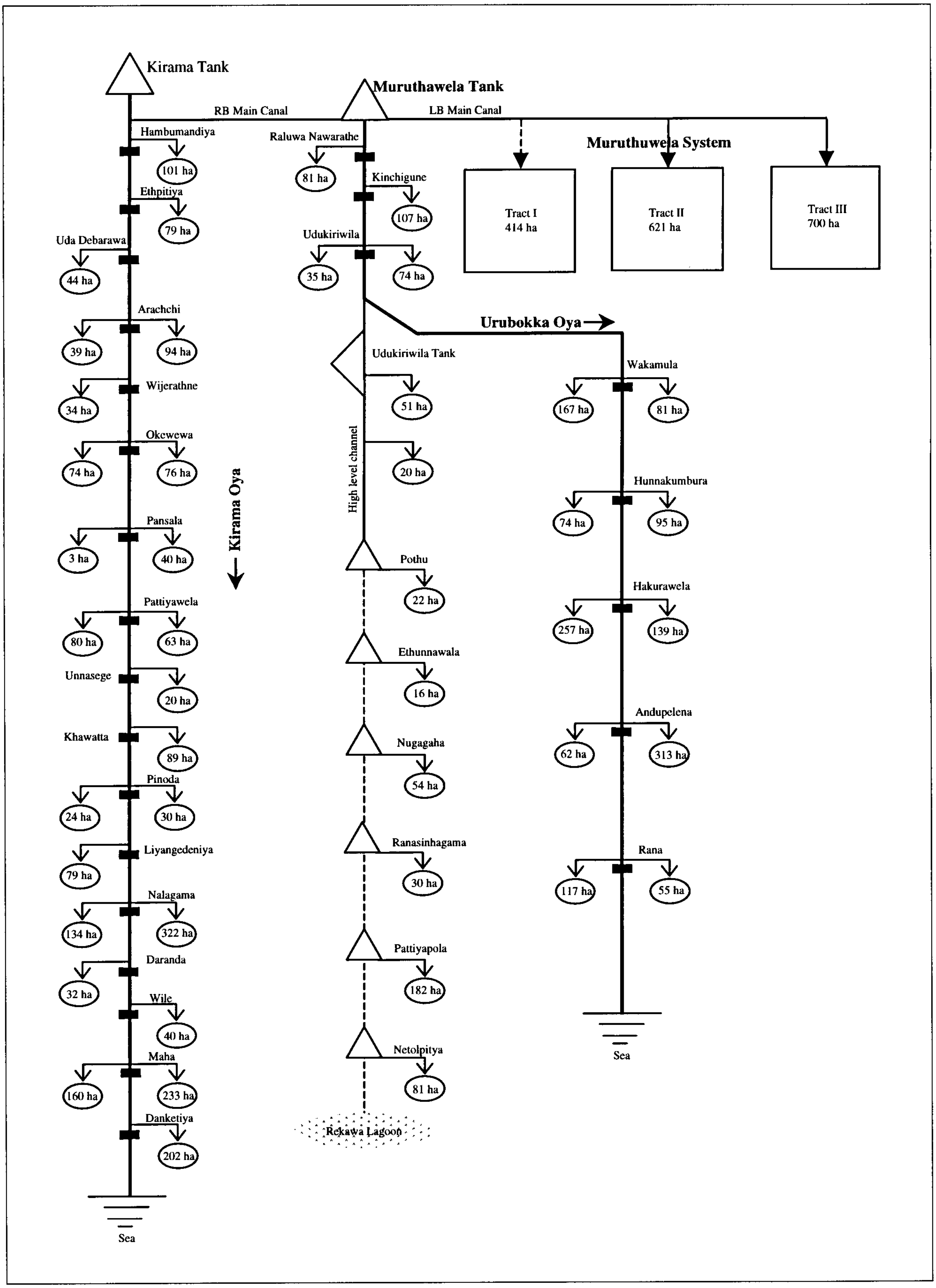

Figure 2 Schematic of Minor Schemes and Muruthawela System, Weeraketiya Division

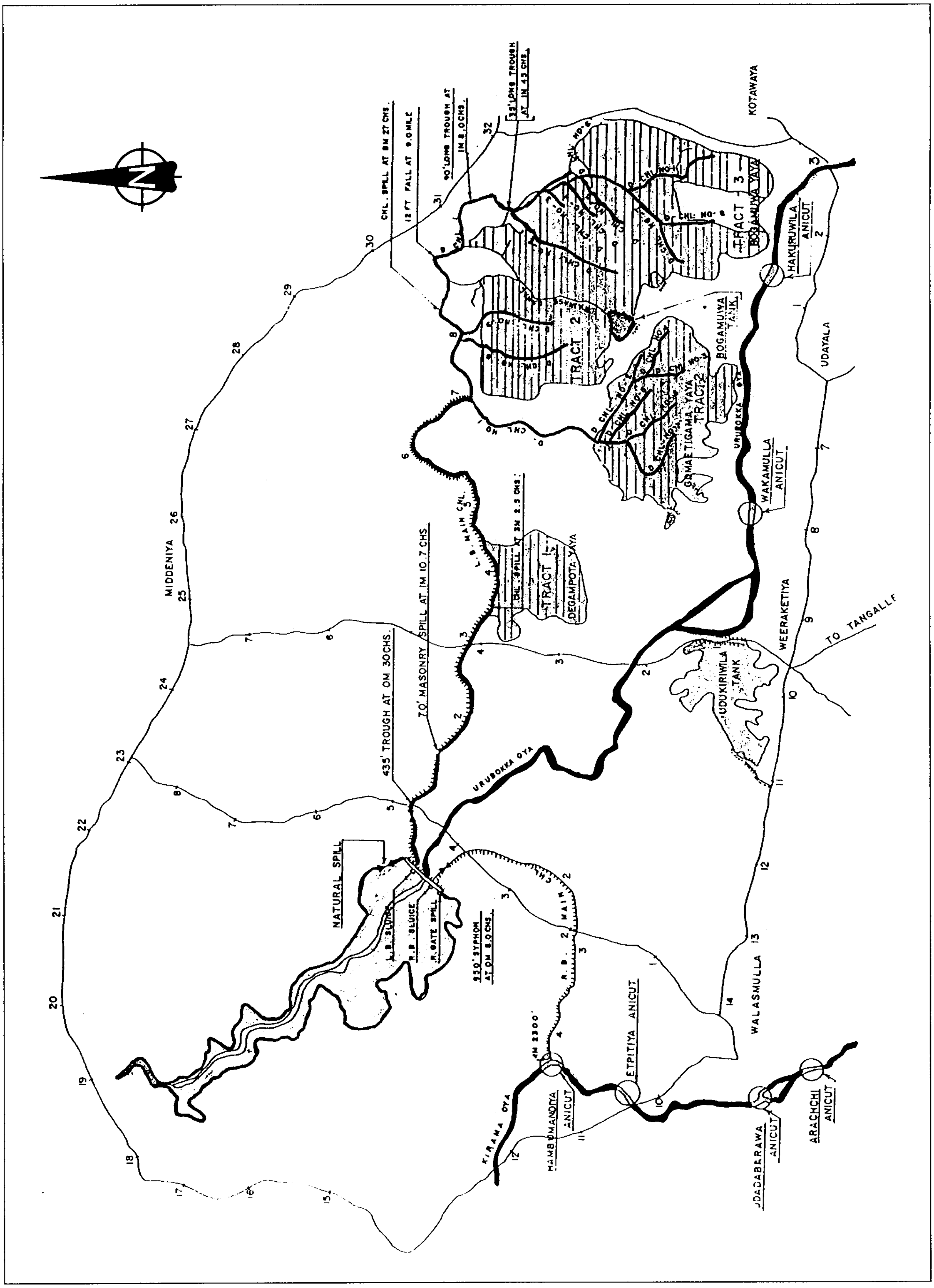

Figure 3 Detailed Layout of Muruthawela System

	Area	
	Acres	Hectares
Tract 1	1025	415
Tract 2	1535	621
Tract 3	1746	707
	4306	707

Seasonal rotation between Tracts 2 and 3 is presently required owing to limitations in the capacity of the main canal. Tract 2 normally receives water for paddy cultivation during the drier, Yala, season whilst rice is irrigated in Tract 3 during Maha.

Appendix 1 includes details of the scheme, design characteristics, its operation and seasonal water allocations.

2. MAINTENANCE PROCEDURES IN THE IRRIGATION SECTOR

2.1 Maintenance Definitions

Irrigation agencies and researchers writing about the maintenance of irrigation infrastructure use a variety of differing terms to describe maintenance activities. Tasks may be classified by their frequency of occurrence, by their intended effect on the item maintained or by the magnitude of the work undertaken.

Sagardoy *et al* (1986) adopt a classification defining:

Term	**Definition**
Routine or Normal maintenance	All work necessary to keep the irrigation system functioning satisfactorily.
Special maintenance	Maintenance required due to damage by unforeseeable events such as floods, typhoons etc.
Deferred maintenance	Work carried out under special programmes to address problems arising from insufficient routine maintenance

The guidelines for the preparation of O&M manuals, prepared under the NIRP project in Sri Lanka, (NIRP, 1995) present a similar but longer list of maintenance categories:

Term	**Definition**
Normal or Routine maintenance	Tasks conducted annually as a matter of course.
Emergency maintenance	Unforeseen and urgent work required to prevent serious structural failure and consequent loss of function.
Deferred maintenance	Tasks not addressed under the “normal maintenance plan” due to lack of resources. This term describes maintenance that is not done.
Essential structural maintenance	A term used by Skogerboe (1986) referring to repair of flow control and measurement structures to improve system operation.
Catch-up maintenance	Another term used by Skogerboe and Merkley(1996). It describes work done to reduce or eliminate the accumulation of deferred maintenance.

Preventive maintenance	Action to address minor deterioration before function is inhibited.
Rehabilitation	Major programme of works to address the accumulated effects of inadequate routine maintenance.

These are both simple classifications or lists, which mix notions of cause, objective, and frequency. As a result they are not helpful in formulating thinking about the purpose or objective of different maintenance tasks.

Thoreson *et al* (1997) present a framework to understand the objectives and priorities of different types and categories of maintenance. They make the important distinction between corrective and preventive maintenance, a distinction also made by Verdier and Millo (1992), describing these as different maintenance *types*.

Term	**Definition**
Corrective maintenance	Any action taken to restore functionality or performance to a required level. It is an action taken after a component has failed or performance has significantly deteriorated.
Preventive maintenance	Any action taken to sustain the performance of an asset and reduce the probability of future failure or deterioration. Maintenance of this type will be prompted by condition assessment or by a systematic maintenance programme that schedules actions at a given frequency. Preventive maintenance is justified when the cost of repair after failure is greater than the cost of the preventative action.

In addition to differentiation between types of maintenance based on purpose and immediate impact on scheme performance, it is also helpful to classify maintenance activities on the basis of the planned frequency of action. In this regard, three categories of maintenance are commonly defined:

Term	**Definition**
Routine maintenance	Work carried out on continuous basis within an irrigation scheme. It is usually very minor in nature and is that which can be done manually with little or no use of materials. Routine maintenance includes both preventative actions, for example lubrication, painting, and corrective actions such as weed cutting and sediment removal. The effects are sometimes more cosmetic than functional if the work is not carefully overseen or directed.
Periodic maintenance	Work carried out intervals with fixed or irregular frequency. For high cost /high-risk plant there may be scheduled maintenance intervals with specification for inspection and replacement. For most of the low-cost, simple assets common to irrigation schemes there is only informal inspection and irregular periodic maintenance. Asset type and long established convention may determine the allocation of money for periodic maintenance work which may not result in targeting issues of greatest need.
Emergency maintenance	By its nature maintenance work in this category is unexpected. Planning and targeting procedures cannot programme when or where such maintenance should occur, but a budget should be set aside for this type of intervention dependant on the likelihood and magnitude of unexpected damage or failure.

Distinctions between corrective and preventive action and the classification of work by the frequency of intervention are helpful in planning maintenance according to its impact on performance. The development of appropriate inspection and planning procedures to prioritise different works should take account of these distinct maintenance types.

For many irrigation agencies periodic (annual) and emergency maintenance consist mainly of corrective maintenance, carried out in response to complaint, unacceptable levels of performance or fears for structural safety. Preventive maintenance is commonly restricted to works carried out with minimal expenditure as part of routine maintenance. Occasionally preventive works may be undertaken within a periodic maintenance programme or as emergency work, normally to prevent serious structural failure. Scheduled, periodic, preventive maintenance tends to be confined to high cost or high-risk components such as pumps, electro-mechanical gate mechanisms and the components of large dams or other major structures.

Economic justification for maintenance is rarely undertaken (Skutsch, 1998). However, in planning corrective maintenance it is possible to apply a number of simplifying assumptions regarding actual and potential water supply, land area and crop production and use cost:benefit analysis to justify and prioritise expenditure. Where preventive maintenance is contemplated further assumptions must be made regarding the timing and magnitude of failure due to inaction. Such failure models are not available and planning decisions must therefore be based on "best engineering judgement". In practice, best engineering judgement is the approach normally applied by irrigation agencies in planning annual maintenance of a corrective or preventive nature. There are many examples of serious deterioration and consequent high repair costs resulting from insufficient preventive maintenance. This, in turn, can lead to other works being deferred and a cycle of increasing deterioration of condition can set in.

2.2 Asset Functions and Types of Failure

Maintenance must ensure that the structures, channels and roads that make up a surface irrigation system can fulfil their individual functions and operate together to deliver an acceptable standard of service to farmers and other stakeholders influenced by the irrigation system. The primary functions of irrigation and drainage assets can be grouped under the following headings:

Water acquisition and storage
Water conveyance – supply or removal
Water control and measurement

Additional functions may include:

Environmental protection – including human health and safety
Provision of transport via canal access roads

In considering how agencies plan the allocation of resources for maintenance it is useful to identify:

a) The possible types of asset failure
b) The effect of failure on asset function
c) The impact of loss of function on "performance"

The last of these pre-supposes that measures of system performance, or standards of service, agreed upon by service users and providers, are defined. This is seldom true and, as a consequence, irrigation maintenance planning is not explicitly linked to performance criteria. This aspect is examined further in Section 2.5.

Table 1 summarises the types of failure that may affect channels, structures and roads and their potential effects on asset function.

The importance of any of these types of failure, and hence the priority assigned to its repair, is influenced, in part, by the physical and financial hazard associated with it and the location of the asset within the scheme. The maintenance of assets influencing a large area will command greater importance than similar assets controlling a small area. Problems of a gradual, cumulative, nature may be seen as less important than those that threaten sudden and substantial structural failure with a consequent loss of supply and high cost of repair. However, it is gradual problems such as the accumulation of sediment or weeds which impinge directly on conveyance capacity and therefore on hydraulic performance. Structural or mechanical deterioration may ultimately threaten costly or dangerous failure, but in the early stages they have limited or no impact on hydraulic performance.

Table 1 Types of Failure and Their Effect on Asset Function

Asset Type	Type of Problem/Failure	Effect on Function
Channels	Accumulation of sediment or weed in channel.	Gradual reduction in conveyance capacity
	Growth of weed above FSL.	Reduced access to the channel
	Bank erosion / loss of design cross section	Reduced freeboard → reduced conveyance capacity → risk of breaching and structural failure
	Seepage	Reduced supply →risk of slope failure
	Break-up of lining	Increased seepage → reduced supply. Possible bank erosion
Structures	Accumulation of sediment / debris → blockage	Reduction in conveyance capacity
	Damaged/missing gate(s)	Loss of flow/level control
	Failure of electro-mechanical components	Loss of flow/level control
	Leakage (via gate seals, joints or cracks)	Reduced supply and/or loss of control
	Movement	Possible structural failure → loss of control or conveyance capacity
	Scour and erosion	Possible structural failure → loss of control or conveyance capacity
	Material ageing / deterioration	Possible structural failure → loss of control or conveyance capacity
	Seepage	Possible structural failure → loss of control or conveyance capacity
	Unstable slopes / retained soils	Possible structural failure → loss of control or conveyance capacity
Roads	Surface deterioration	Increased journey times
	Embankment erosion / failure	Reduced capacity, risk of sudden failure
	Cross drainage impeded	Risk of structural failure

The distinction between gradual, chronic, problems and those that threaten sudden, catastrophic failure, is a simplification. Problems such as scour and erosion and material ageing and deterioration, which may lead to sudden, catastrophic failure, are themselves gradual processes. Equally, the gradual build-up of sediment or weed may result in overtopping and canal breaching where control is poor. It is more helpful to distinguish between failures that influence conveyance and control, and therefore hydraulic performance, and those that primarily influence structural or mechanical integrity. The former are failures requiring corrective maintenance as they impinge on some measure of system performance. The latter require preventive action to avoid catastrophic failure in the future.

Levine (1986) has argued that an irrigation system can accommodate a certain reduction in canal conveyance capacity without effect on crop yields. Accommodation is achieved through infringement of design freeboard, efforts on the part of farmers to better manage a reduced supply and tolerance of crops to limited water stress. It is suggested in the preceding paragraph that some forms of structural deterioration have no impact on control or conveyance capacity though they may ultimately lead to sudden and serious structural failure. There are therefore certain "tolerable levels of deterioration" for several of the failure types listed in Table 1. Such tolerance levels should ideally be determined by reference to their impact on hydraulic performance and threat to structural integrity. In the absence of simple, quantitative indicators by which acceptable tolerance levels can be identified for any channel or structure, asset inspection and maintenance planning have relied upon "intuitive feel" to judge when preventive or corrective action should be taken.

2.3 Maintenance Funding

Maintenance planning in irrigation systems is normally undertaken once a year to support requests for funds. Longer term, strategic planning is not generally done. Agencies find that their budget is determined by the availability of funds, rather than by need, and they experience a growing backlog of deferred work. The asset management planning procedures developed in the UK water supply sector and evaluated by Burton *et al* (1996) for application in the irrigation sector, only came about as the sector was privatised. At that time private investors wanted to know the scale of future maintenance requirements and the impact of future expenditure on profit. Where irrigation continues to be state-funded without focus on standards of service and profitability, longer term planning of maintenance requirements is unlikely to be adopted. It may find greater application where irrigation management has been transferred to water user groups who have full responsibility for funding the operation and maintenance of their schemes.

2.3.1 Sri Lanka

In Sri Lanka, the budget allocation to ranges is determined at national level by the Irrigation Department, working within the constraints placed on them by the national treasury. Funds are managed under a number of different categories controlled by two Departments – the Irrigation Department and the Irrigation Management Division – under the Ministry of Lands, Irrigation and Mahaweli Development. As a consequence, detailed analysis of maintenance allocations is a complex task.

The different "votes" or budget lines contributing to the total O&M budget are:

a) Under the Irrigation Management Division

- i) O & M of major irrigation schemes
- ii) Improvements to major irrigation works
- iii) Improvements to water management

b) Under the Irrigation Department

- i) Salaries for work supervisors and permanent labour
- ii) Strengthening and safety of headworks in major irrigation schemes
- iii) Flood damage repairs
- iv) Departmental roads

Budgets a(i) and b(i) together fund system operation and routine maintenance activities. The other five budget lines are allocated to annual maintenance plans on the basis of annual inspections and the preparation of a prioritised list of tasks.

TEAMS Pvt (1991) carried out a study of the management and costs of routine O&M under the Irrigation Systems Management Project. The study obtained maintenance data from four medium sized schemes and one large scheme for the five years 1985 to 1989. The report describes the procedures in place at that time, the difficulties experienced in analysing data and the discrepancies found to exist between the different schemes studied. The study found, amongst other conclusions, that routine O&M funding is diminishing over time. A high percentage of the budget is spent on salaries, transport and other establishment costs leaving little for actual maintenance works. Scheduling and monitoring of maintenance tasks during the year is poor. Management information on predicted and actual work progress and expenditure is not available and, as a consequence, financial and human resources are poorly utilised.

The report makes a number of recommendations, including the need for:

- Improved procedures to plan, monitor and review specific maintenance tasks at the scheme level with monthly progress and cost records
- Improved identification and costing of required maintenance tasks
- Reduction of divisional staff numbers and establishment costs to meet actual requirements rather than department "norms"
- Greater involvement of water user groups in O&M.

Nothing arising from the present study contradicts the conclusions and recommendations of the TEAMS study nor indicates that practical procedures have been put in place at the Divisional level to address the weaknesses identified in 1991.

Budget allocations for routine O&M and the five budget lines for periodic maintenance for Weeraketiya Division from 1995 to 1997 are set out in Table 2. The budgetary data makes an arbitrary division between monies spent on operation and routine maintenance. This is no more than a bookkeeping rule that divides the total O&M funds 35%, 65% between operation and maintenance respectively and it is not shown in the Table. Operation and maintenance activities are interrelated and are often carried out by the same staff. Once the general charges – covering salaries and allowances for work supervisors, labourers, watchmen and casual office employees, vehicle running costs, office consumables and office maintenance – are removed, the remaining budget for materials and specific maintenance tasks is small and is not easily identified in divisional records.

The data on routine O&M allocation indicate that the percentage allocation of funds between systems is not constant but it is not clear what factors lead to the change in allocation between years.

Table 2 Budget allocation for routine and periodic maintenance – Weeraketiya Division, Sri Lanka ($US / ha)

Budget line	1995	1996	1997
Routine O & M			
Muruthawela (1740 ha)	N/a	4.08	4.03
Kirama Oya (1943 ha)	N/a	6.10	4.97
Urubokka Oya (2044 ha)	N/a	5.09	5.33
Division average for Routine O & M		5.13	4.81
Periodic O & M			
Departmental roads	0.77	0.81	0.92
Flood damage repairs	0.60	0.64	0.92
Safety of H/works	1.11	1.13	1.23
Improvements to major works	0.60	0.73	0.77
Imp. to water management	0.51	0.73	0.77
Division average for Periodic maintenance	3.59	4.04	4.61

The total budget allocated to routine O&M for 1996 and 1997 is greater than the total disbursed through the five budget lines for periodic maintenance. However, there is no information available to indicate the allocation of these routine O&M funds between establishment costs and specific maintenance tasks.

The tasks to which funds were allocated under the five budget lines are shown in Appendix 1.

The annual maintenance plan is prepared in the following way. In early November, the seven technical assistants (TAs) overseeing the 33 minor schemes and Muruthawela submit a list of required work to the divisional Irrigation Engineer (IE). Cost estimates are given, based on minimal field measurements and unit prices issued by the Irrigation Department. The IE visits all proposed sites to assess the nature and urgency of the work, taking account of the views the field staff and farmers, the condition of the asset, the risk of further deterioration and its consequences. Based on this information, the IE submits a list of tasks under each of the budget lines to the divisional Deputy Director (DD) who may also make field visits to assess the need for any proposed work. The DD reconciles the submissions of the Divisions under his control with the budget made available from Colombo.

The nature and scale of the tasks undertaken are illustrated by the figures relating to the annual maintenance plans for 1995 to 1997, set out in Appendix 1, These data indicate that:

i) The total value of work actually carried out in each year is between 2 and 3½ times the original "tentative allocation", suggesting that additional funding is made available in the course of each year.
ii) The value allocated to each budget line by the central office is not reflected in the value of work actually carried out under each budget. The "Safety of Headworks" budget receives the largest share, with between 27 and 31% of the total allocation. Departmental Roads is the second largest budget line, with an allocation of 20% of the total. However, actual expenditure recorded under Safety of Headworks, in the three years of record, is between 17% and 26% of the total and expenditure on roads is between 7 and 12%. Given these significant variations between allocated and actual expenditure patterns the rationale for the different budget headings is called into question.
iii) The total value of work submitted by the Technical assistants (TAs) is consistently greater than the work actually carried out.
iv) In the three years 1995 – 97 the Muruthawela system, the only medium sized scheme in the division, received just less than 1% of the actual annual maintenance budget allocated to the division, for the improvement of the main canal access road. This minimal expenditure may, in part, be explained by the fact that the system was receiving funds from other budgets for the construction of a new aqueduct and reshaping of the main canal section to increase conveyance capacity to overcome original design constrains. However, these works do not substitute for annual maintenance.
v) Almost the entire periodic maintenance budget was spent on the minor headworks structures – replacing gates, repairing flood damage (including the repair of washed-out canal sections) and maintaining access roads. There is a mix of corrective and preventive actions. 22% of expenditure is on the repair or replacement of control gates, a corrective action that may have immediate effect on water supply to the command areas of the headworks. 11% was spent on headworks access roads. Distinction between repair of gradual deterioration (corrective maintenance) and prevention of complete structural loss cannot be made. Irrespective of the type of maintenance, the work will not have an immediate and quantifiable impact on hydraulic or agricultural measures of performance. Nonetheless, it is clearly important to maintain vehicular access to these strategic control structures. 67% of expenditure was on repair and up-grading of minor headworks. This was mainly preventive maintenance to sustain the structures and avoid major, and costly, structural failure. Approximately 40% of this expenditure is a consequence of repairing flood damage.
vi) Almost the entire periodic maintenance budget of the division is used in the maintenance of minor headworks. Work to improve channel conveyance capacity, both on the Muruthawela system and

at Hunnakumbura anicut was proposed in 1996 but was eliminated from the final annual programme.

The Weeraketiya Division benefits from a relatively abundant water supply. 70% of the irrigated area is controlled by minor schemes where the Irrigation Department is only responsible for the headworks and the first mile of distribution canal. On the Muruthawela system the Department is responsible for the dam and 14 km of main canal – all distribution canals are transferred to the responsibility of farmer groups. Under these circumstances, periodic (annual) maintenance is focused on sustaining the minor headworks in an operable condition. The only maintenance of the canal conveyance network occurs under the routine O&M budget and is confined to weed control on canal banks.

2.3.2 Mexico

By way of comparison, information on budget allocation for maintenance in Mexico are presented here. The irrigated agricultural sector in Mexico has undergone significant change in the last 10 years as the government has reduced its role in the supply of agricultural inputs, extension services and marketing and guaranteed prices have been phased out. In parallel with these changes in agricultural policy, the government has transferred responsibility for the operation and maintenance of irrigation infrastructure to newly formed water user associations, or 'modulos'. The area farmed by an individual within a 'modulo varies greatly but will normally lie in the range 2.5 to 12 ha with a modal value of approximately 4 ha.

Under the terms of system transfer, ownership of the irrigation and drainage infrastructure remains with the National Water Commission (CNA), the government agency responsible for all aspects of water policy, but responsibility for maintenance is transferred to the module. The modulos are obliged to prepare an annual maintenance plan, which is submitted to the CNA District office for approval. CNA checks that the modulos' spending on maintenance is in accordance with an agreed percentage of expenditure defined in a "Base Budget" prepared when the module is formed.

Kloezen *et al* (1997), working with IIMI's Mexico field programme presents data on revenue and expenditure for two modulos in the Rio Lerma Irrigation District for the period 1993 – 1995, the first three years after their formation. These are reproduced in Table 3.

Table 3. Expenditure and Income of two Mexican Irrigation Modulos 1993 –95. (After Kloezen, *et al*, 1997)

	Salvatierra						*Cortazar*					
	1993		1994		1995		1993		1994		1995	
Expenditure	%[1]	$/ha	%	$/ha	%	$/ha	%	$/ha	%	$/ha	%	$/ha
Maintenance	45	30	46	29	27	9	9	9	18	15	22	7
System operation	20	13	18	11	18	6	6	6	21	18	21	6
Administration	15	10	16	10	13	5	9	8	14	11	14	4
Official wells	12	8	12	7	8	3	7	7	12	10	14	4
Machinery	0	0	1	1	1	0	2	2	3	3	4	1
Fee to CNA	12	8	11	7	9	3	22	22	22	19	20	6
Salaries & others	1	0	1	1	3	1	2	2	2	2	1	0
Total	104	71	106	67	79	27	56	55	93	77	96	29
Income												
User fees	100	68	100	63	72	24	97	96	97	82	87	26
Machine rental	0	0	0	0	22	8	0	0	0	0	0	0
Interest	0	0.1	0	.2	6	2.0	3	2.6	3	2.1	13	3.9
Total	100	68	100	63	100	34	100	98	100	84	100	30
Surplus		-3		-4		7		43		6		1

1. Percent of total income

The Salvatierra module has a command area of 13,340 ha under surface irrigation and public (official) wells with an additional 2,753 ha irrigated from private wells. Cortazar commands 12,898 ha from surface water and official wells with a further 5,796 ha irrigated from private wells. There is significant variation between the two modulos' total levels of expenditure and income and the distribution of expenditure. Both modulos are reliant almost entirely on user fees for their income and both experienced a large drop in income in 1995 due to devaluation of the peso. The dollar value of user fees income fell by 62% and 68% for Salvatierra and Cortazar between 1994 and 1995 although peso income only dropped by 10 and 24% respectively.

Salvatierra spent almost half (45%) its income, US $30/ha, on maintenance in 1993 and 1994 but this figure fell in 1995 to $ 9/ha or 27% of income. Cortazar shows a contrary trend, spending only $ 9/ha (9% of income) on maintenance in 1993 but increasing this to 18% and 22% in 1994 and 1995.

There is a large difference in the level of payments made to CNA by the modulos. Salvatierra's payments reduced from 12% to 9% of income (8 – 3 $ / ha) between 1993 and 1995 while Cortazar's payments varied between 22% and 20% (22 – 6 $ / ha).

The percentage allocation of funds to operation and administration (office staff salaries, office rental and services, etc), remained almost constant in Salvatierra. In Cortazar, operation and administration costs were low in 1993 but rose sharply to remain constant in percentage terms in 1994 and 1995.

As a consequence of low expenditure, Cortazar had a surplus of $554,000 in 1993. Increased expenditure and reduced income resulted in much smaller surpluses in 1994 and 1995.

Table 4 shows the allocation of money between maintenance tasks in 1995 made by the two modulos.

Table 4. Distribution of funds between different maintenance tasks, Salvatierra and Cortazar Modulos, 1995.

	Salvatierra		Cortazar	
Maintenance Task	%	$/ha	%	$/ha
Cleaning/weeding banks	6	0.56	1	0.07
Canal/drain De-silting	24	2.23	49	3.22
Bank repairs	6	0.56	6	0.39
Road repairs	16	1.48	4	0.26
Structure repairs	11	1.02	7	0.46
Machinery maintenance	17	1.58	3	0.20
Salaries/other	20	1.86	30	1.97
Total	100	9.28	100	6.57

The greatest expenditure in both modulos was on de-silting of canals and drains with Cortazar spending almost 50% of its maintenance budget on this one item. The second largest item in both modulos is staff salaries and staff related costs. The high expenditure on machinery repairs by Salvatierra reflects the condition of equipment transferred to the modulos by CNA. The Cortazar module took the decision to replace rather than maintain similar equipment. Salvatierra also made significant expenditure on maintenance of roads and structures, which reflects the poorer condition of infrastructure in this module at the time of transfer.

The figures reflect the dynamic nature of planning and budgeting in the newly formed modulos. The variation in expenditure on maintenance over time reflects high initial expenditure to catch up on maintenance tasks deferred when the systems were under state control. There is considerable variation in the income and expenditure budgets of these two modulos which belies any attempt to identify "average" operation and maintenance costs, even within a single Irrigation District.

2.4 Maintenance Requirements and System Characteristics

2.4.1 The General Case

The rate of deterioration of irrigation schemes, and the impact of deterioration on system performance, are affected by many factors:

- Physical/Environment
    - Topography
    - Natural drainage characteristics
    - Soils, especially swelling/shrinking clays
    - Climate
    - Vegetation
    - Water supply (water-short schemes put special demands on O&M)
    - Water-borne sediment
    - Cropping system (paddy rice schemes tolerate lower levels of maintenance)
    - Scheme design: types of structures/ pumps/ electro-mechanical operation/control equipment
    - Quality of construction and materials
    - Maintenance/rehabilitation history and funding
    - Scheme age
    - Occurrence of severe natural events: earthquakes, typhoons etc.
- Social and institutional
    - Behaviour of farmers
    - Skills of O&M staff

In view of the diversity of factors that can affect maintenance needs, the concept of an 'adequate' level of maintenance expenditure applicable to all schemes is dubious, although it is helpful in setting a rough benchmark for funding. If meaningful comparisons of maintenance expenditure and performance are to be made between schemes, some kind of system classification is needed so as to compare like with like. Since funds for maintenance are invariably limited, it is important that budgets are allocated on the basis of need so as to safeguard initial capital expenditure.

The unit costs of maintenance will also clearly vary between countries and regions, depending on the relative availability of materials, labour, skills and the methods adopted – the extent of mechanization – so that inter-country comparisons of maintenance expenditure are far from straightforward.

2.4.2 Muruthuwela

The dam, main canal and Tract 2 of the scheme have been in operation for 30 years. During that time there have been no programmes of special maintenance, up-grading or rehabilitation. Operation of the scheme has been sustained with a minimal routine maintenance programme and occasional work carried out under the annual maintenance plan. A review of available data and interviews with O&M staff and farmers show no evidence of diminishing cropped area, declining yields or significant water shortage at the tail ends of distributary channels, notwithstanding the impression of deterioration gained by walking through the system. Distributary channel sections are irregular, there are many illegal offtakes, and collapsed structures are commonplace. Most of the gates on the offtakes at distributary and tertiary level are missing, and many of the drop structures are broken up as a consequence of deterioration, scour and settlement.

Farmers complain that without gates on tertiary offtakes it is difficult to control water allocations between users at the time of land preparation, but they use informal methods to overcome the problem. The absence of gates at the head of distributary channels presents some difficulties to the Irrigation

Department because seasonal rotations between tracts must be imposed. In response, the Department has used substantial barriers to flow, including temporary concrete plugs in preference to locked gates. At times of peak demand, O&M staff are assigned to police the rotations.

Work has been carried out in some locations in the past to stem natural and man-made erosion of banks on the main canal. The problem is particularly acute at distributary and tertiary levels where farmers may undercut the outer shoulder of the bank to gain extra land for cropping. Localized lining is then sometimes undertaken for structural reasons, rather than to reduce seepage. There are reaches in the first four miles of the main canal where the freeboard has been reduced, in part because of localized deposition of sediment brought in from drainage level crossings, which give rise to concerns about overtopping since the canal is in high fill for substantial lengths. Improvements will be made under the current upgrading programme. Weed growth in the wetted area of the main canal does not represent a problem, vegetation above the water level is controlled by maintenance labourers within the routine maintenance programme. There is extensive weed growth in distributary and tertiary canals but it is adequately controlled by farmers, with funding from the Irrigation Department, prior to the first irrigation release of the season. The barrels of many of the cross drainage culverts in the first few miles of the main canal have been damaged by farmers in Tract 1 so as to gain illegal supply.

The characteristics of the scheme that have permitted it to continue to deliver an adequate irrigation supply with low levels of maintenance, albeit with seasonal rotation between tracts, may be compared with the factors listed in section 2.4.1 above:

- Water supply is abundant
- No major sources of sediment inflow
- Paddy rice cropping with minimal requirements for accurate water control structures
- Few high risk structures, for example canals on steep hill sides
- Adequate natural drainage

2.4.3 Minor Anicut and Tank Schemes

The anicut structures represent the principal need for maintenance and improvement works in the minor schemes on the Urubokka Oya and Kirama Oya systems.

One or more of the gates tend to be missing, defective, or non-functional on most of the anicuts. The operating mechanism is particularly at risk on the most commonly used gate design. The spindle tends to buckle between lateral restraints and the frame cross heads have often worked free at the anchorage points to the structure. General degradation of the downstream riverbed threatens the apron at some structures, causing undermining and damage to wingwalls and sidewalls.

The Irrigation Department has rightly assigned priority to dealing with these structures, as and when funds permit, because operational failure or progressive structural damage under high river discharges can potentially cause damaging flooding or generate destructive flood waves.

2.5 Linking Maintenance to Standards of Service

Numerous recommendations have been made that hydraulic and agricultural performance data should be collected on a routine basis to improve water control and management and provide data for system diagnosis and maintenance planning, (IIMI, 1989; Bird *et al 1990;* Mott MacDonald 1990; Teams PVT, 1990, NIA, 1993; Welch, 1995; Halcrow, 1996). Although the idea of linking maintenance priorities to measures of system performance is attractive, the following obstacles must be recognised:

1. Structural and mechanical deterioration may not be detected by such analysis.
2. The collection and routine analysis of operational data, at the intensity required to provide scheme-wide early warning of corrective maintenance needs, is not seen as a practical investment by many irrigation agencies.

3. Measures of hydraulic performance must be linked to estimates of economic impact if they are to provide the basis for traditional cost:benefit analysis. The simplifying assumptions applied to establish such linkage may be misleading.

2.5.1 Hydraulic Performance and the Detection of Need

Examples of recognisable linkages between the failure to maintain and hydraulic performance are given in Section 1.2 of this report and are summarized in Table 5.

Table 5. Examples of Research Illustrating Links Between of Maintenance, System Condition and Hydraulic Performance.

Failure type	Performance measure	Based on:
Sediment accumulation (Lawrence, 1991; Bird et al, 1990)	Adequacy of supply	Head/discharge relationship at specified points
Weed Growth (Brabben & Bolton, 1988)	Adequacy of supply	Head/discharge relationship. Detection of submerged weed with sonar.
Sediment accumulation & outlet design (Van Waiijen et al, 1997)	Equity of supply	Numeric modelling of existing channel conditions.
Deterioration of lining (Goldsmith and Makin, 1989)	Seepage rates Equity of supply	Measurement of seepage

With the exception of outlet design, the examples in Table 5 relate to the gradual deterioration of channels, corresponding to plot 1 of Figure 4. These problems can, theoretically, be linked to a decline in hydraulic performance and maintenance to correct the problem can be justified by an improvement in hydraulic performance. In contrast, structural and mechanical decline – plot 2 in Figure 4 – do not result in a gradual decline in hydraulic performance. In these cases maintenance intervention is justified on the basis of the anticipated scale of lost performance and replacement costs if failure occurred. The planning of such maintenance requires predictive indicators that give warning of future failure rather than measures of hydraulic performance. However the need is detected, structures such as drops, cross-regulators, and off-takes may cease to function according to design with only minimal effect on the adequacy of supply, although control will be lost and therefore equity may be seriously reduced. Failure of other structures such as the headworks, siphons, aqueducts, culverts and canal banks will have major impact on conveyance and the adequacy of supply, and these asset types should therefore take priority in the planning of preventive structural maintenance.

2.5.2 Standards of Service

The concept of quantitative standards of service to be maintained in the management of an irrigation system, is not well established. Design duties and full supply levels are well understood and used for design purposes. The same values provide an obvious starting point for the definition of a standard of service against which performance is judged, provided that any significant changes in cropping pattern, command area or system operation are accounted for. This is the basis of routine stage/discharge monitoring advocated by Lawrence, Bird *et al* and others. However, the practical problems and costs associated with quantitative monitoring of performance, and the difficulties that can occur in distinguishing between operational and maintenance constraints, means that this approach is seldom applied. Rather, farmers and irrigation agency staff rely on notional or subjective, “standards” in evaluating the adequacy of irrigation and the requirements for channel maintenance. These “standards” are based on individual or group perception of adequate conveyance or control capacity and there is scope for dispute over both the target and the degree to which it has been met. With few measurements or reference values, the line between tolerable and intolerable deterioration is ill defined. Qualitative evaluation of the present degree of under-performance is combined with assessment of future risk and the cost of repair. No formal estimate of benefit is made but again notional or fuzzy assessments will be held in mind when comparing different maintenance tasks. Linkage of maintenance planning to hydraulic

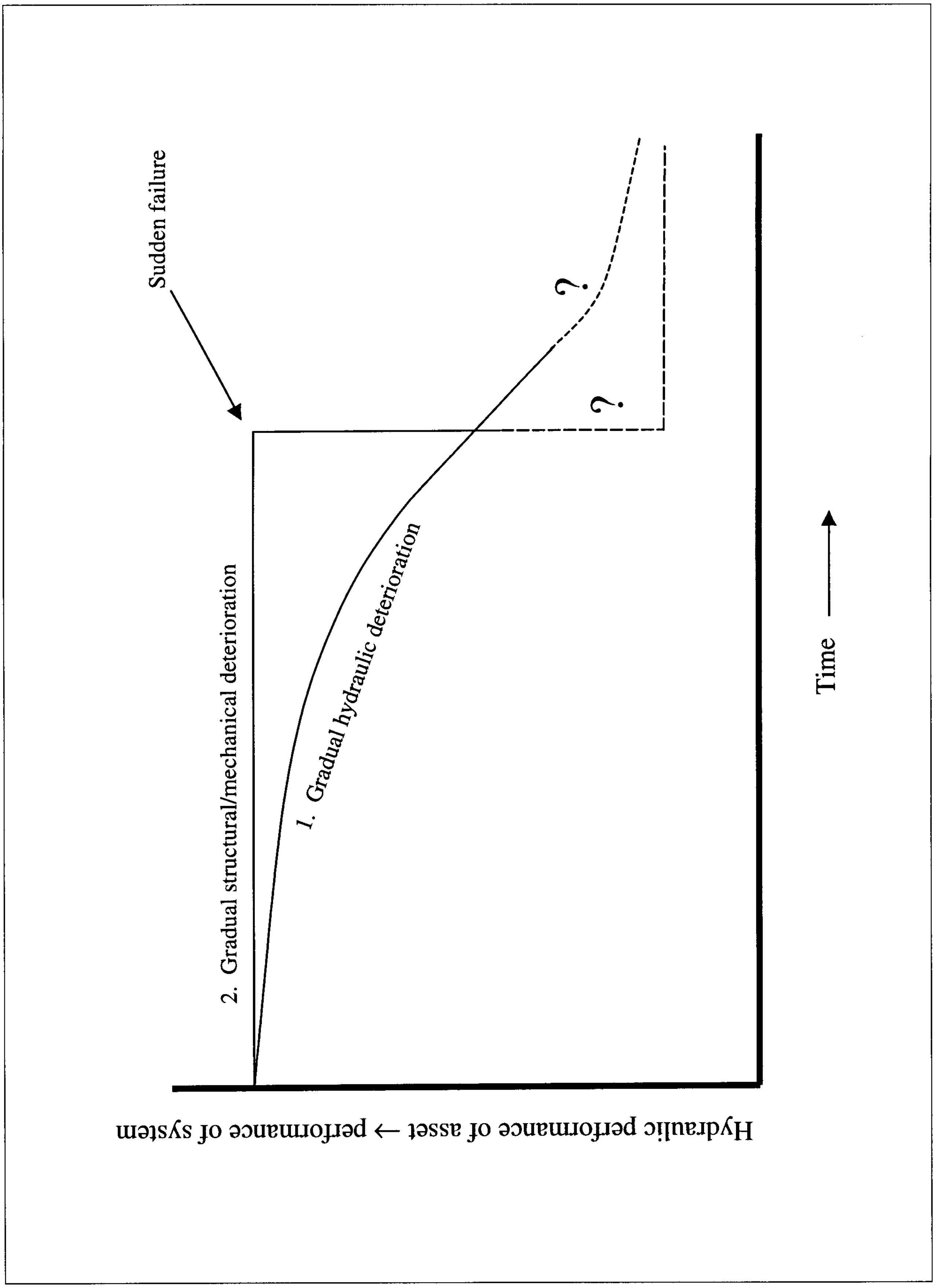

Figure 4 Patterns of Asset Deterioration and Their Impact on Performance

performance and standards of service therefore takes place as part of a wider, qualitative, assessment of risk, benefits and costs.

Where schemes are small, maintenance problems are simple, and operation is well understood by staff an intuitive, "fire-fighting" approach to maintenance planning may be adequate. On larger schemes, where staff are unfamiliar with the entire network or where the cause of observed under-performance is not immediately obvious, a more structured and quantitative procedure for maintenance planning and prioritisation is required. Under this project such a procedure has been developed using field assessment of asset condition to determine hydraulic functionality and structural condition. By allocating a score to specific assessment questions the likely impact of condition on hydraulic performance is quantified. The procedure also incorporates information on the cost of repair, the relative importance of different types of asset and the fraction of the command area influenced by the asset. In this way the elements of existing, intuitive, procedures are standardised and built upon.

The application of the procedure and its potential strengths and weaknesses are described in section 3.

3. AN IMPROVED MAINTENANCE PLANNING PROCEDURE

3.1 The MARLIN Procedure

The project has developed procedures for objective, function and performance based condition assessment of infrastructure. By combining an assessment of condition with knowledge of an asset's key functions and its location within the irrigation system, an indirect measure of the impact of condition on scheme performance is derived. This measure is used to rank the importance of both preventative and corrective maintenance tasks. Prioritising tasks in this way allows for some qualitative judgements and decisions to be made where it is not practical to make an immediate link between maintenance cost and benefit. This frequently applies to routine and periodic preventative maintenance actions such as the repair of structures, re-forming of canal bunds or clearing of blocked side escapes or drainage under-crossings.

The MARLIN procedure moves away from the intuitive assessment of maintenance needs and priorities, which relies heavily on the technical skill of individuals, to provide more objective and standardised procedures. Specific objectives of the procedure are to provide:

- A planning tool for periodic maintenance programmes using objective criteria to prioritise need and target expenditure.
- Simple, standardised condition assessment procedures for assets that link condition to hydraulic function and structural stability.
- Assessment of need for both corrective and preventive maintenance works.
- Guidance on the relative priority of needs with freedom to override this where justification is provided.
- A permanent record of the number of assets, their condition and past maintenance history which is retained when staff are transferred.

Development of the procedure was guided by the following considerations:

- Condition assessment should be based on a rapid and simple field inspection that can be carried out by relatively unskilled staff.
- The assessment of condition should reflect the effect of condition on the asset's fitness for function.

To meet these requirements, proformas for different asset types are used giving the user a series of questions requiring a Yes or No response. The questions relate to the expected modes of failure or deterioration that may affect the main components of each type of asset. A positive response to any question attracts a score in the range 0 – 100, the lower the score the more severe the expected impact of that condition on function. Assets are classified into four categories – Good, Fair, Poor, Very Poor – based on the single lowest (worst) condition score associated with the asset.

A second series of proformas supports more detailed inspection of assets by more highly trained staff. These are used for:

a) Routine inspection of dams and river diversion structures (Tanks and anicuts). These are large, strategically important structures.
b) Detailed inspection of assets either identified by rapid inspection as being in Poor or Very Poor Condition or which, for other reasons, give cause for concern.

The proformas and guidelines for their use in the field are given in part II of this report.

3.2 Applying the Procedure

The procedure supports the preparation of periodic (annual) maintenance plans. It is not appropriate for planning and monitoring routine maintenance tasks. On first applying the procedure the following steps must be completed:

3.2.1 Rationalisation of the System Inventory

The MARLIN procedure is computer based. As a first step the network of canal reaches and structures for which the irrigation agency is responsible, must be defined in a database through the creation of a scheme map. Many irrigation systems retain obsolete structures that are no longer required to meet present operational requirements. Where a structure is redundant and no longer maintained it should be omitted from the database. This may require consultation between operations staff and users to clearly identify redundant structures.

Canals are defined as reaches to permit the assessment of condition, the identification of constraints and the targeting of work. A logical system of nomenclature should be developed if one is not already in place, which will identify both reaches and structures. A standard reach length of 1 to 1.5 km is normally appropriate but the precise location of reach breaks should correspond with the location of structures or points where the canal section changes from lined to unlined or from cut to fill.

Finally, in defining and rationalising the inventory of assets the command area influenced by each asset must be determined as this is one of the inputs used by the procedure to determine the relative priorities of maintenance needs.

3.2.2 Initial inspection of Assets

The second step is to carry out rapid assessment of all assets using the proformas generated by MARLIN and the assessment guidelines set out in part II. This assessment corresponds to the informal inspection of assets which forms part of existing maintenance planning procedures whereby field staff submit budget requests based on their own knowledge of the assets for which they are responsible. The procedure aims to formalise this knowledge base, standardise the assessment criteria used by different staff and pool the knowledge in a central database so that prioritisation of need can be based on more objective criteria.

Inspection may be carried out by field staff in the course of other duties – when a reach or structure is visited a condition assessment proforma is completed. Using this approach, data on condition are collected over an extended period. Alternatively a walk-through survey can be carried out specifically to assess condition. The staff and time requirements for such a survey can be calculated as follows:

Estimated survey speed	2 km /hr
Size of survey team	2 persons (one on each bank)
Effective working time per day	6 hrs

Example:

Scheme area	8600 ha
Length of primary and secondary canals	120 km

A single team of two people could complete the survey in 10 working days.

Ideally a full survey should be carried out annually prior to preparation of an annual maintenance plan. However, with limited resources it is more realistic to carry out a full survey every second or third year. In other years new data are only collected for assets which staff believe require maintenance. In this way the procedure again emulates and formalises existing planning procedures.

More detailed inspection to confirm the findings of rapid inspection and to prepare more detailed estimates of cost to carry out required maintenance is guided by the Engineers inspection proformas and the guidelines given in part II.

3.2.3 Preparation of the Priority List

Once information on asset condition is entered, the MARLIN software calculates a "Priority Index" for each asset based on the asset's condition, the fraction of the command area that it influences and the importance of the asset type. The priority index is used to rank all assets on the database with those at the head of the list expected to show the greatest benefit form maintenance. Detail of how these three factors are quantified and combined is given in Cornish and Skutsch, (1997).

The score used to represent condition takes account of the likely impact of condition on hydraulic performance and structural stability, thereby accounting for both forms of decline shown in Figure 4. The measures of area and asset importance are decision criteria applied in existing, subjective planning methods, (see 2.5.1). Area influenced by the asset serves as a proxy for the potential economic benefit arising from maintaining a given asset. The measure of asset importance reflects the importance of the asset's function; the risk associated with its failure and the cost of repair or replacement relative to other structure types.

3.2.4 The Need for Engineering Judgement

The MARLIN procedure is not intended to replace but support engineering judgement in the preparation of periodic maintenance schedules. It standardises the criteria used by different staff to assess maintenance need and by combining measures of condition, area of influence and asset importance it makes an empirical linkage between maintenance and benefit. However the output from the MARLIN procedure is seen as a guide for decision-making. Engineering judgement is still required to evaluate:

a) The financial benefit of any maintenance task and its cost.
b) The linkages that may exist between a series of assets and their maintenance and therefore the need to group tasks together in a logical sequence.
c) The relative importance of different functions. For example, is it more important to maintain drainage or supply infrastructure or to maintain the headworks (acquisition) supplying a small system or a canal (conveyance) serving a larger command. The benefits of maintaining these different functions can best be compared in terms of their resulting financial value, which is not directly educible from the MARLIN procedure. Thus, further engineering and economic evaluation may be required to achieve a logical allocation of funds where an agency is maintaining assets with notably different functions.

3.2.5 Constraints on the Use of Improved Planning Methods

While engineering staff responsible for the preparation of periodic maintenance plans work under conditions and incentives which place low value on the achievement of improved irrigation performance, procedures such as MARLIN, that underscore the linkage between maintenance and hydraulic performance, may not be widely adopted. The TEAMS report (1991), described in section 2.3.1, recommended the adoption of improved procedures to identify and cost routine maintenance tasks and plan and monitor their implementation. Similar improvements may be urged for the management of periodic maintenance. However, unless such changes are called for and facilitated at a strategic level, they are unlikely to occur. This project has demonstrated that at the operational level improved procedures can be developed, but few individual engineers will adopt and promote novel procedures where the pressures to conform and stay in line far outweigh the rewards for innovation, (Svendsen, 1994).

Data from the Weeraketiya Division shows that where a maintenance budget is spread over many small schemes and one medium, priority goes to the structural maintenance of headworks in preference to maintenance of conveyance and control capacity. This prioritisation is not misplaced but in such a setting a MARLIN type procedure may be seen as unnecessary with too great a focus on conveyance and control functions rather than water acquisition.

The adoption of more objective procedures is more likely when:

a) There is greater demand from those providing funds – central agency or farmers– to see objective justification for the allocation of those funds to maintenance tasks.
b) The allocation of funds is spread over a single large scheme requiring more careful evaluation of the benefits arising from different maintenance interventions.
c) The management environment is accustomed to the routine collection and processing of field data by computer to provide management information.

4. CONCLUSIONS

4.1 General Conclusions

1. Requirements for maintenance vary from scheme to scheme. The rate of deterioration of a scheme's infrastructure and the impact of deterioration on performance, are affected by: physical factors, including design, cropping system (rice or upland), the local climate, and the environment (erosion/sediment, vegetation); and also its history: quality of construction, age of scheme, previous maintenance regime, period since major works or rehabilitation (if any), behaviour of farmers.

So long as all funding for maintenance is provided by Government, it is convenient for irrigation departments to allocate available funds between schemes and between regions proportionate to the area served, rather than according to an assessed priority need (except where emergency works are clearly required). The reasons are not difficult to find:

- objective methods for prioritising between tasks are not available
- funds are in short supply, so the resources and the time needed to provide the basic information on system condition are not assigned

2. The maintenance tasks commonly faced by scheme management may either affect system performance in the short to medium term (sedimentation, weed growth, bank erosion), or at some indefinite time in the future (sudden structural failures, mechanical/electrical problems).
Work programmes should aim to include priority tasks in each category. Variations in the characteristics of schemes will mean that the proportion of the budget to be spent on corrective and preventative tasks will vary. In practice, in many countries including Sri Lanka, the budget allocated by the Finance Ministry is insufficient to cover more than emergency works, routine maintnenace such as greasing gate spindles, and minor corrective works.

3. Improved procedures for targeting activities to tasks having prime effect on performance are essential, to make the best use of available maintenance money. However, to achieve substantive improvements in

maintenance efficiency, other constraints on the performance of government-run schemes also need to be removed. Changes at a strategic level are required to overcome problems including:

- Allocations from government to the irrigation department may bear little relationship to funding requests, which in turn may not represent priority needs.
- Good information and adequate site records on system condition and history are generally lacking.
- Procedures for assigning available funds both between, and within, schemes are inflexible.
- Technical and financial audit procedures are lacking, or defective.

4.2 The MARLIN Procedure

1. The MARLIN procedure provides the following functions to support periodic maintenance planning:

- A planning tool for periodic maintenance programmes using objective criteria to prioritise need and target expenditure.
- Simple, standardised condition assessment procedures for assets that link condition to hydraulic function and structural stability.
- Assessment of need for both corrective and preventive maintenance works.
- Guidance on the relative priority of needs with freedom to override this where justification is provided.
- A permanent record of the number of assets, their condition and past maintenance history which is retained when staff are transferred.

2. The procedure stops short of making a quantitative assessment of improvement in hydraulic performance resulting from a given maintenance activity or any consequent financial benefit for the following reasons:

- To quantify the impact of a corrective maintenance task on hydraulic performance in anything but the simplest channel system requires substantial data collection on existing and required flows and channel conditions. While such an approach may be justified for rehabilitation planning it is normally impractical for planning periodic maintenance.
- Linking preventive maintenance works to hydraulic performance is made additionally complex by the need to simulate the probability and impact of future failure on performance.
- To permit cost:benefit analysis of different tasks, possible improvements in hydraulic performance must be converted to a monetary value. This requires further data and assumptions linking maintenance to improved water supply and improved supply to additional crop production and crop value. The potential for error in such a procedure is great and the outcome may provide no greater accuracy than intuitive reasoning.

3. MARLIN supports operational change through the introduction of new technology – computer software – and new management techniques, at the Divisional office level. The same procedure, applied nationally by the Irrigation Department, would represent strategic change through technological modernisation. However, widespread use of MARLIN, or any other similar procedure, will only occur when:

- Policy makers perceive that existing procedures for maintenance planning, budget allocation and the monitoring of works are failing to make best use of limited funds.

- An alternative procedure is demonstrated to address current weaknesses without incurring large additional workloads or expenditure.

- Management staff are accustomed to the routine collection and processing of field data by computer to provide management information.

4.3 Muruthawela Scheme, Weeraketiya Division

1. The principal constraints to water supply in the main canal on the Muruthawela scheme appear to be structural, reflecting the increased demand since the scheme was implemented. Apart from the doubling of the aqueduct in mile 1, which is needed for the planned increase in discharge capacity, there are losses through cross drainage culverts. Available freeboard on the embankments may begin to represent a serious problem in reaches of high fill. There are many structural faults and some failures at D-channel level, which nonetheless do not materially affect supply.

In general, vegetation develops above the water line on the main canal and the wetted cross section remains reasonably clear. There are some reaches where sediment drawn in from drainage level crossings has settled out, but the surveys show that the accumulated material is generally less than 0.30m deep, increasing to 0.60m over limited stretches. Given that to date the canal section has been over-large for the required discharge, deposited sediment has not represented a maintenance problem. In some places, the banks have needed local reinforcement to prevent erosion.

2. More serious maintenance problems are present in several of the anicut schemes. A general degradation of the downstream bed is threatening the apron in some locations, causing undermining and damage to wingwalls and sidewalls. One or more of the multiple gates are faulty, and sometimes missing, in most structures. The operating mechanism is particularly at risk. The prevailing spindle design is inappropriate, leading to buckling between lateral restraints, and failures where the frame cross heads are anchored into the concrete structure. The Irrigation Department has rightly assigned priority to dealing with these structures, as and when funds permit, because operational failure or progressive structural damage under high river discharges can potentially cause damaging flooding, or flood waves. First priority should be given to structures where there is a danger that gates can jam in the closed position, where there is associated risk to property and life, and where the continued integrity of the structure is at risk.

5. ACKNOWLEDGEMENTS

The Engineering Division of DFID provided funding for this project, under the TDR programme.

The collaboration and support of the Irrigation Department, Sri Lanka throughout the course of this project, is gratefully acknowledged. Particular thanks are due to Eng. K.S.R. De Silva, Project Director of the National Irrigation Rehabilitation Project, who gave valuable time and logistical support on numerous occasions. Eng. A.B.S. Nandalal, Irrigation Engineer in charge of the Weeraketiya, played an important role in the development and testing of the MARLIN software during his assignment at HR Wallingford and provided support during field testing in Sri Lanka. Thanks are also due to the Technical Assistants, Mr Sumathipala and Mr Bandusiri and to the Project Manager. All three gave considerable time in the field assisting in the collection of information and testing of assessment procedures.

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Appendices

Appendix 1

Analysis of performance and maintenance constraints on the Muruthawela System

Contents

Appendix 1 Analysis of performance and maintenance constraints on the Muruthawela System

A1. OPERATIONAL DATA AND SEASONAL WATER ALLOCATIONS

A1.1 Season Characteristics

The Maha season runs approximately from October/November to February/March and Yala from March/April to August/September. Figure A1.1 illustrates the variation that has occurred in season start date and duration from April 1985 to December 1997. Mean seasonal rainfall total during Maha (10 year mean, 1986 –95) was 550 mm and 360 mm during the corresponding Yala seasons.

A1.2 Cropping Intensity

The minor schemes on both the Urubokka Oya and Kirama Oya systems normally achieve an annual cropping intensity of 200%, cropping paddy rice in both the Maha and Yala seasons. Due to the limited conveyance capacity of the main canal of the Muruthawela system cropping intensity in the three tracts of this system is variable:

	Area Acre	(ha)	Area double cropping Acre	CI
Tract 1	1025	(415)	1025	200 %
Tract 2	1535	(621)	740	148 %
Tract 3	1746	(707)	289	117 %
	4306	(1743)	2054	148 %

Because of the limited capacity of the main canal, seasonal rotation is enforced for Tracts 2 and 3. Tract 2 normally receives water during the drier, Yala, season and Tract 3 is irrigated in Maha. This arrangement is advantageous to the farmers in Tract 2 as those in low-lying areas and areas receiving drainage flows from Tract 3 can grow a second paddy crop and others can grow short season rainfed crops in the Maha Season. Few Tract 3 farmers can exploit drainage returns from Tract 2 during the Yala season. The small number that cultivate a second crop obtain water unofficially from the Uda Walawe right bank canal that runs adjacent to their land. Farmers in Tract 1, at the head of the scheme, obtain water from unauthorized offtakes in both seasons and achieve 200 % cropping intensity. The figure of 740 acre cropping in both seasons in Tract 2 is based on the estimate of the Project manager and is an approximate figure. The data for Tract 3 is based on estimates made by the technical assistant responsible for the tract and is more accurate, being based on knowledge of farmers' access to the Uda Walawe water in each distributary in the tract.

A1.3 Seasonal Water Releases and Rainfall

Water releases into the Left bank main canal are measured at the sluice gate of the dam. Measurement is made upstream of a bifurcation structure that diverts water into the Urubboka Oya river channel to supply water to the anicuts and minor tanks on that river. There is no accurate measurement made of the division of flow between the two systems at this bifurcation making it difficult to obtain an accurate picture of water management at even the most basic level.

Release of water into the Urubokka Oya occurs relatively infrequently as the Urubokka system obtains much of its water from drainage flow from the Muruthawela system. To estimate the releases made into the Muruthawela system the following assumption was made. As the maximum conveyance capacity of the main canal is reported to be 90 cusec (2.55 m^3/s), all flows in excess of 90 cusec were trimmed at that value. Where flow was less than 90 cusec all flow was assumed to supply Muruthawela.

Seasonal releases and total rainfall are shown in Table A1.1 and in Figures A1.2 and A1.3.

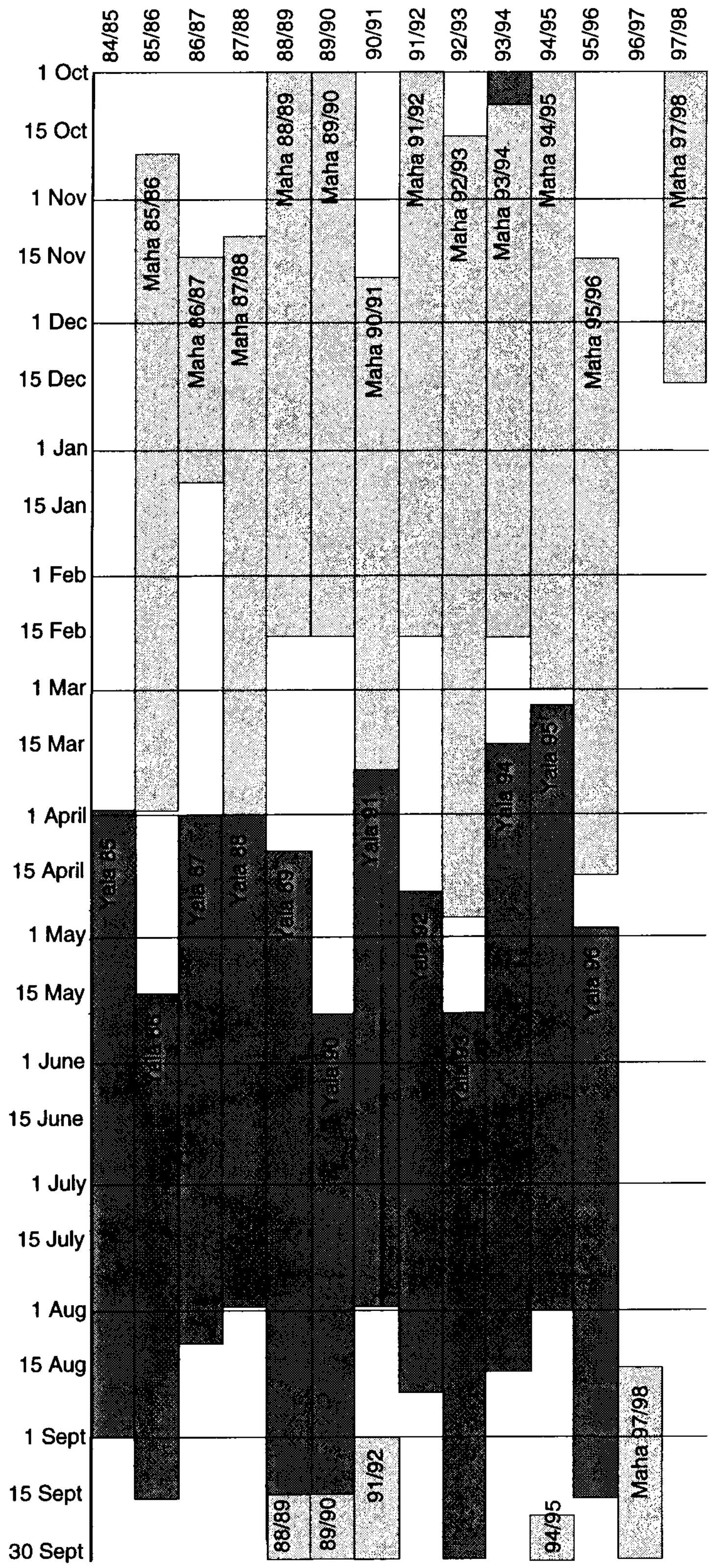


Figure A 1.1 Season Dates and Duration, 1984 to 1998

Table A1.1 Operations data, Yala 1986 to '97, Maha 86/87 to 95/96

Season	Volume released (Acre ft)	Rainfall (mm)	Crop area [1] Estimate (ac)	Total Supply (rain [2] + irrigation) (ft)
Yala 86	9,244	77	2,560	3.8
Yala 87	3,879	396	2,560	2.6
Yala 88	13,443	518	2,560	6.7
Yala 89	17,153	365	2,560	7.7
Yala 90	10,982	0	2,560	4.3
Yala 91	11,698	491	2,560	5.9
Yala 92	11,668	326	2,560	5.5
Yala 93	13,209	679	2,560	7.1
Yala 94	17,358	209	2,560	7.4
Yala 95	18,822	596	2,560	9.0
Yala 96	20,218	243	2,560	8.6
Yala 97	23,178	544	2,560	10.6
Maha 86/87	5,223	313	3,539	2.2
Maha 87/88	14,311	518	3,539	5.2
Maha 88/89	16,188	743	3,539	6.3
Maha 89/90	17,057	78	3,539	5.0
Maha 90/91	7,511	560	3,539	3.4
Maha 91/92	16,800	537	3,539	6.0
Maha 92/93	17,325	762	3,539	6.6
Maha 93/94	14,462	1095	3,539	6.6
Maha 94/95	17,602	491	3,539	6.1
Maha 95/96	22,561	371	3,539	7.2

Notes:

1. The estimates of actual cropped area use the following assumptions:

Yala		Maha	
All of Tract 1	= 1025 ac	All of Tract 1	= 1025 ac
All of Tract 2	= 1535 ac	50 % of Tract 2	= 768 ac
None of Tract 3	= 0 ac	All of Tract 3	= 1746 ac
	2560 ac		3539 ac

2. Rainfall is assumed to be 85% effective in Yala and 75% effective in Maha. Mean monthly rainfall is shown in Figure A1.4.

The data in Table A1.1 and in Figures A1.2 and A1.3 indicate that:

- There is little correlation between the seasonal rainfall and the volume released from Muruthawela tank in either season.
- There has been a trend over the last seven years to release more water in each successive season. This is particularly marked in the Yala season. The Divisional office has no reliable data on the area actually cropped in each season. The records show only the nominal command area of the tract that is officially receiving water in any season but for operational purposes it is acknowledged that water is supplied to meet the requirements of Tract 1. The increase in total release, season by season, may indicate that a larger area is being irrigated in each successive season though this was not indicated in interviews with farmers and operations staff.

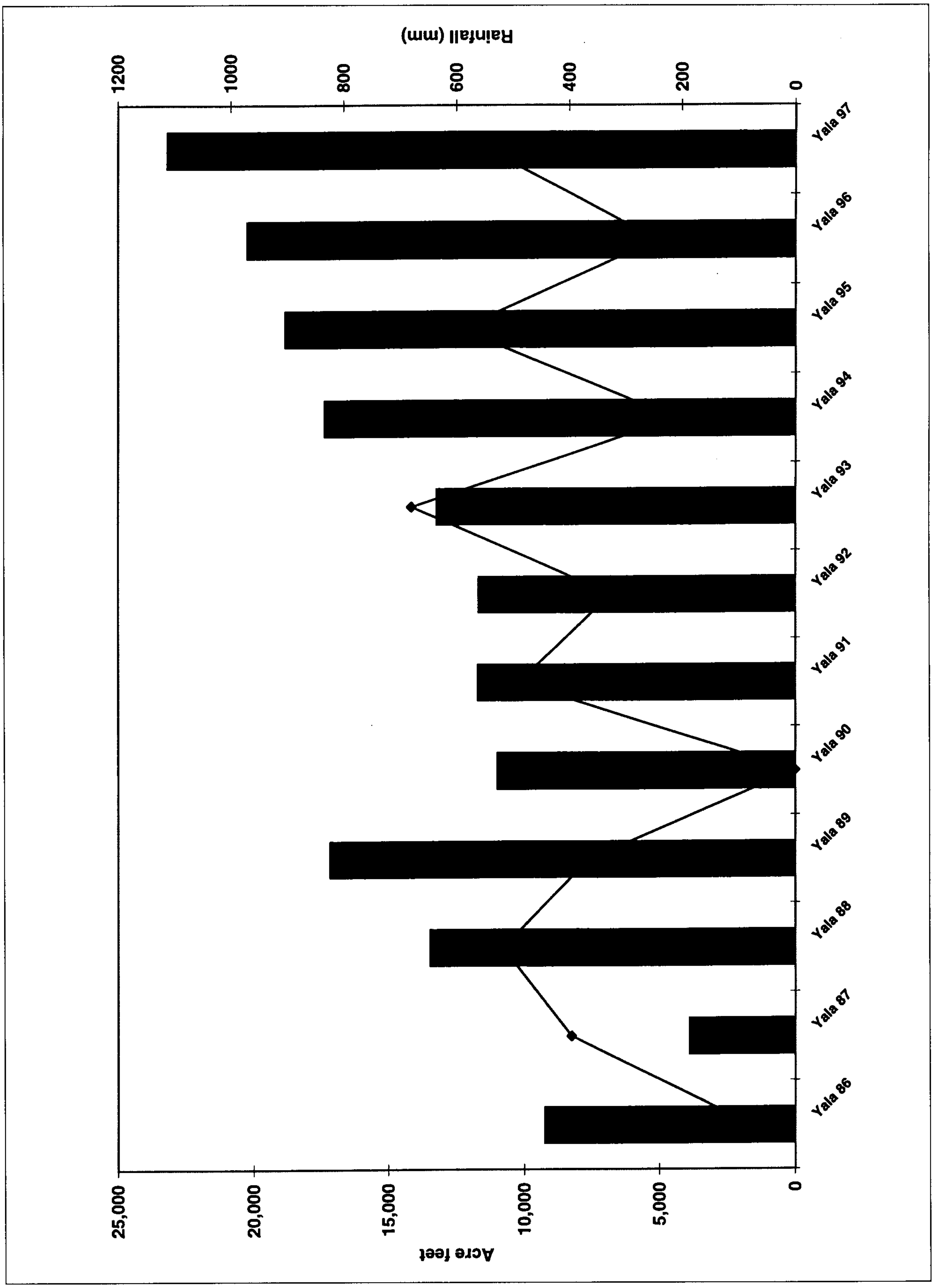


Figure A 1.2 Yala Releases and Rainfall

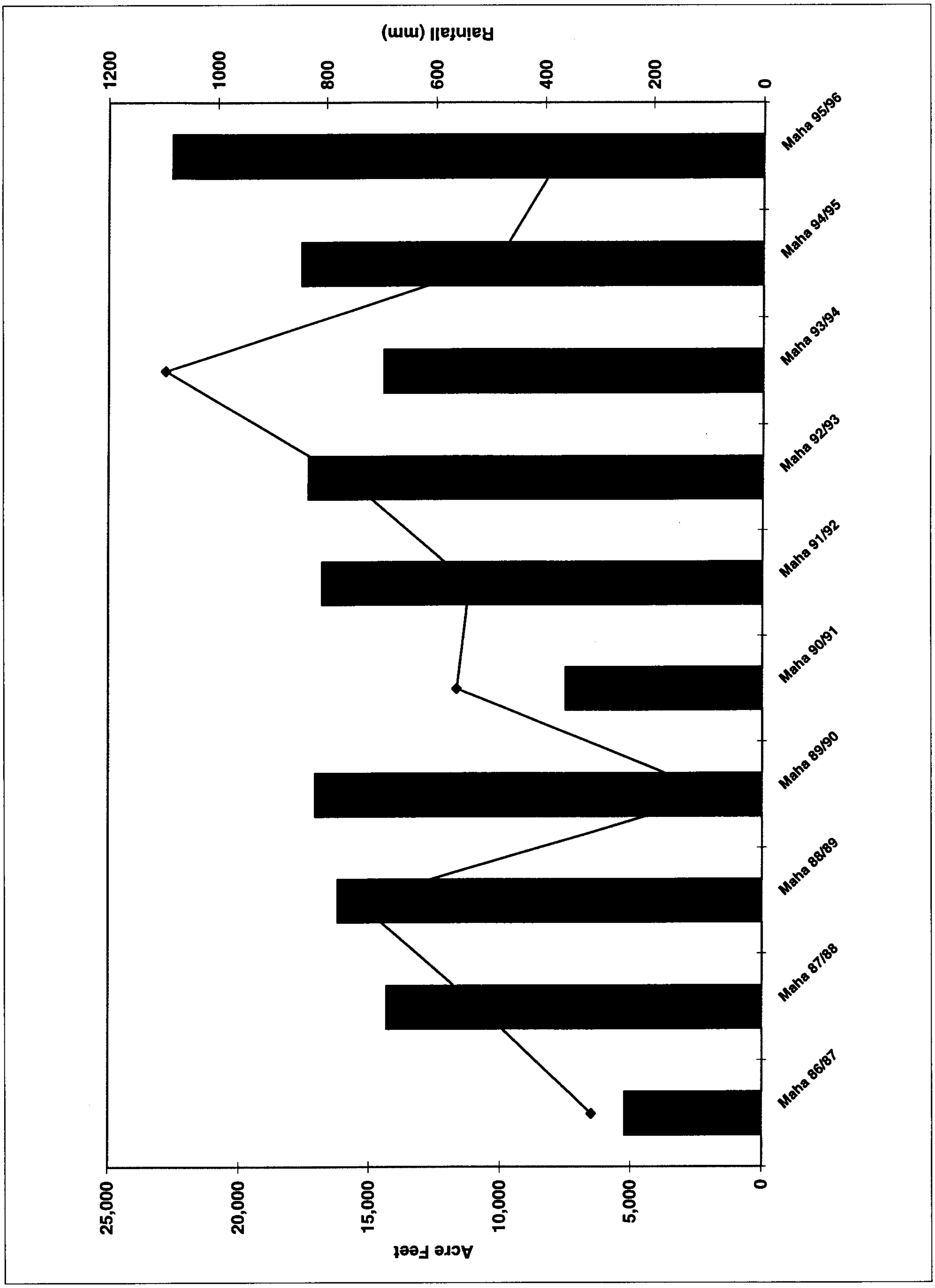


Figure A 1.3 Maha Releases and Rainfall

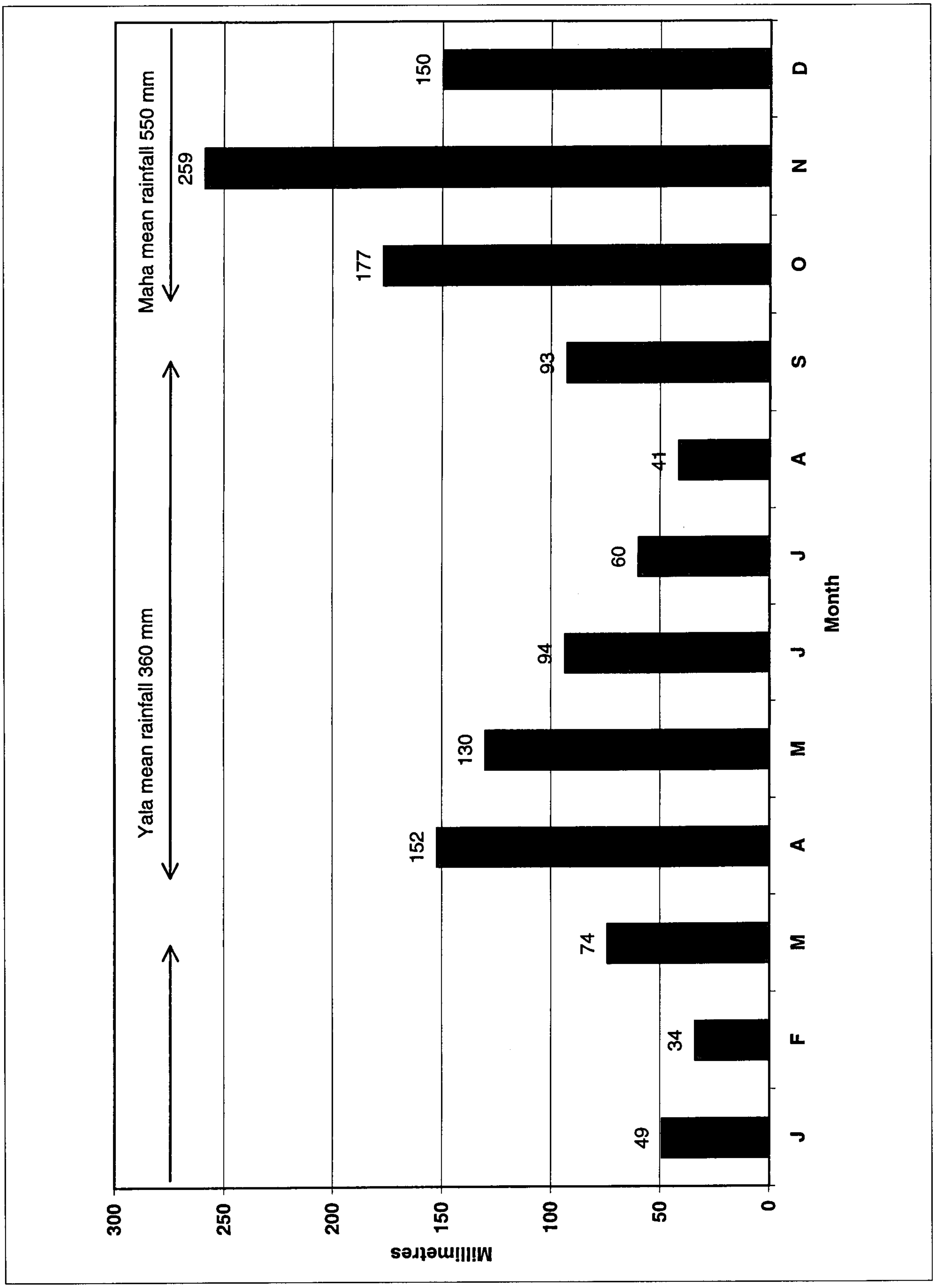


Figure A 1.4 Mean monthly rainfall

- An alternative explanation of these high releases is found by comparing seasonal releases with the tank water levels in Figure A1.5. The following seasons had very low releases:

  Maha 86/87
  Yala 87
  Yala 90
  Maha 90/91

  With the exception of Maha 90/91, these seasons correspond with periods when tank storage was very low. Conversely, the recent seasons, when releases have been very high, correspond with periods when tank levels have been high or very high. This suggests that the dominant factor influencing the volume of water released is the volume held in storage rather than any effort to match releases to crop water requirements.

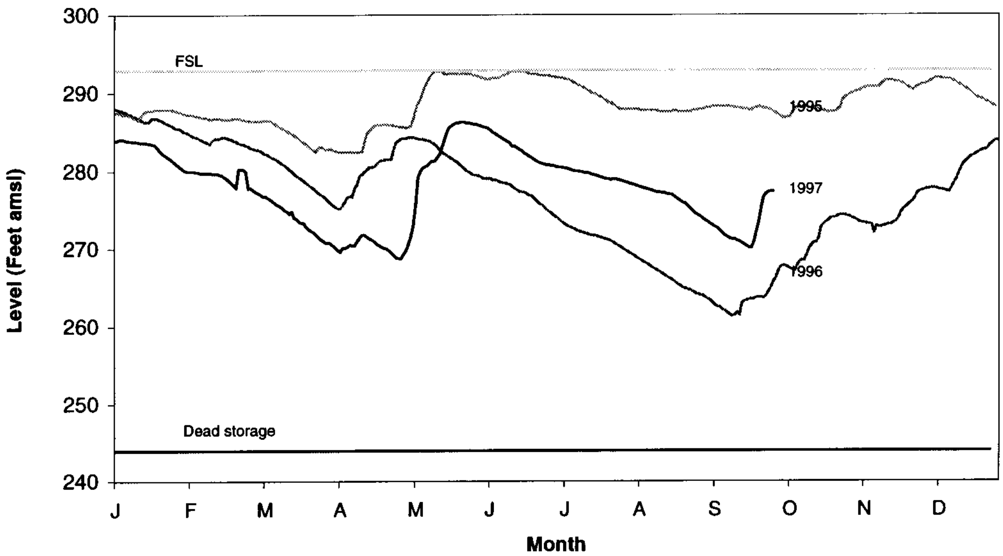
- If the estimates of irrigated area used in Table A1.1 are correct the releases in 1995 – 97, giving duties of 8 to 10 ft in Yala, have been excessive, based on the following calculation of seasonal requirements:

Table A1.2 Calculation of Seasonal Duty for Paddy rice in Maha and Yala Seasons

	Yala	Maha
Seepage & percolation (mm/day)	3	3
Mean ETc (mm/day)	5	6
Season duration (days)	115	115
Land preparation requirement (mm)	200	200
Total in-field requirement (mm[ft])	1120 [3.7]	1235 [4.0]
Effective rainfall (mm)	300 [1.0]	380 [1.2]
In-field irrigation requirement (mm [ft])	820 [2.7]	855 [2.8]
Conveyance efficiency	50 %	50 %
Irrigation duty at headworks (mm [ft])	1640 [5.4]	1710 [5.6]
Total duty (irrigation + rain) (mm [ft])	1940 [6.4]	2090 [6.8]

With data on water releases only available at the head of the system it is not possible to use water management data for detailed analysis of system performance or the diagnosis of possible physical constraints requiring maintenance intervention. However, when water is available in the tank and management staff choose to make large releases, the main canal is capable of conveying flows that result in very ‘generous’ seasonal supplies but operations data give no indication of the uniformly of water distribution across the command area.

Although the main canal conveys more than adequate supply under seasonal rotation between Tracts 2 and 3 this is an unsatisfactory arrangement for the farmers who cannot double crop and for the operations staff who must implement the rotation and prevent water theft. It is therefore necessary to review the design and present capacity of the main canal to understand why seasonal rotation is implemented and whether inadequate maintenance has contributed significantly to reduce the conveyance capacity.



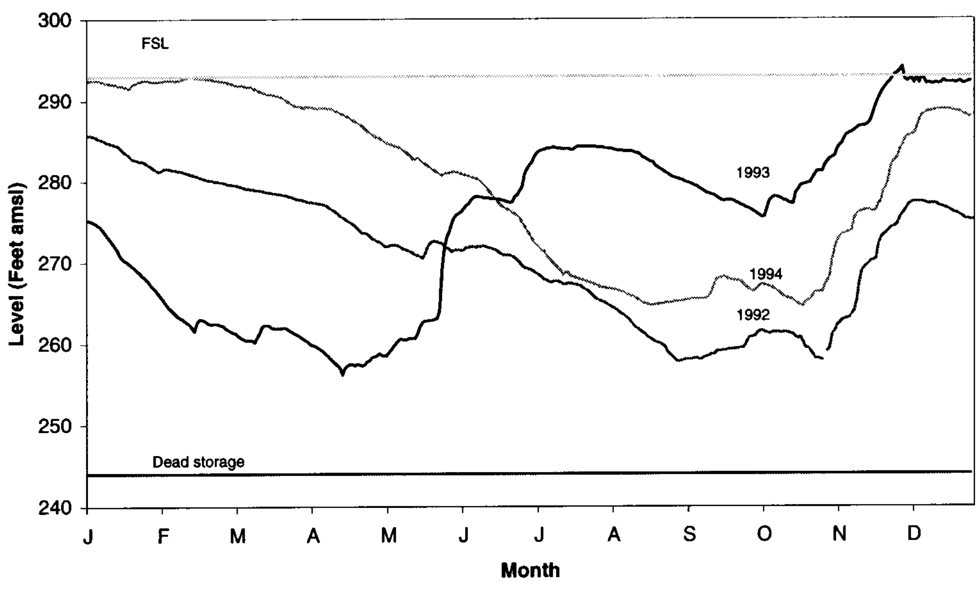
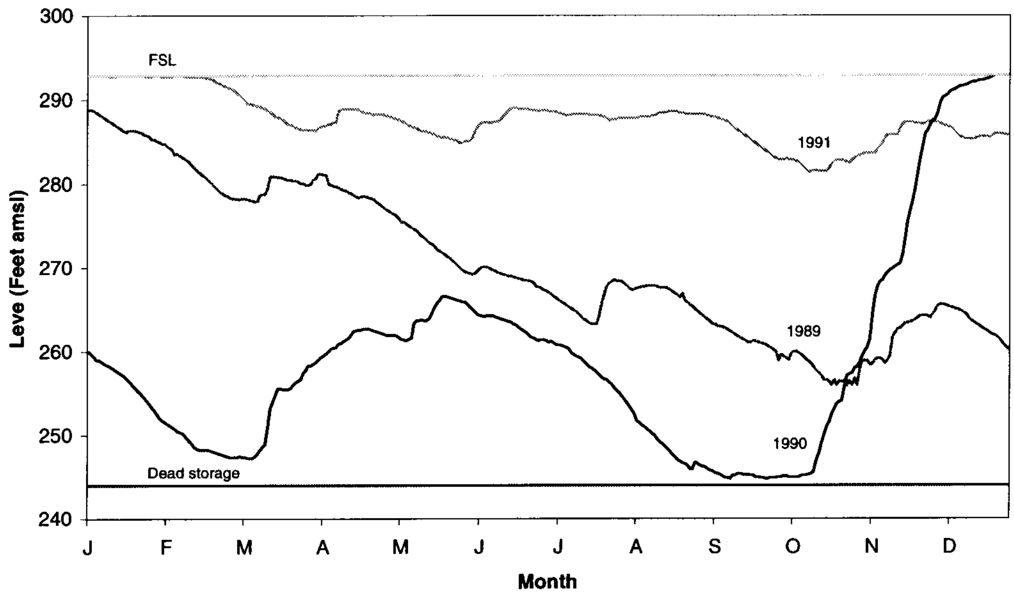


Figure A 1.5a Tank Water Levels, Muruthawela Tank, 1997 - 1992



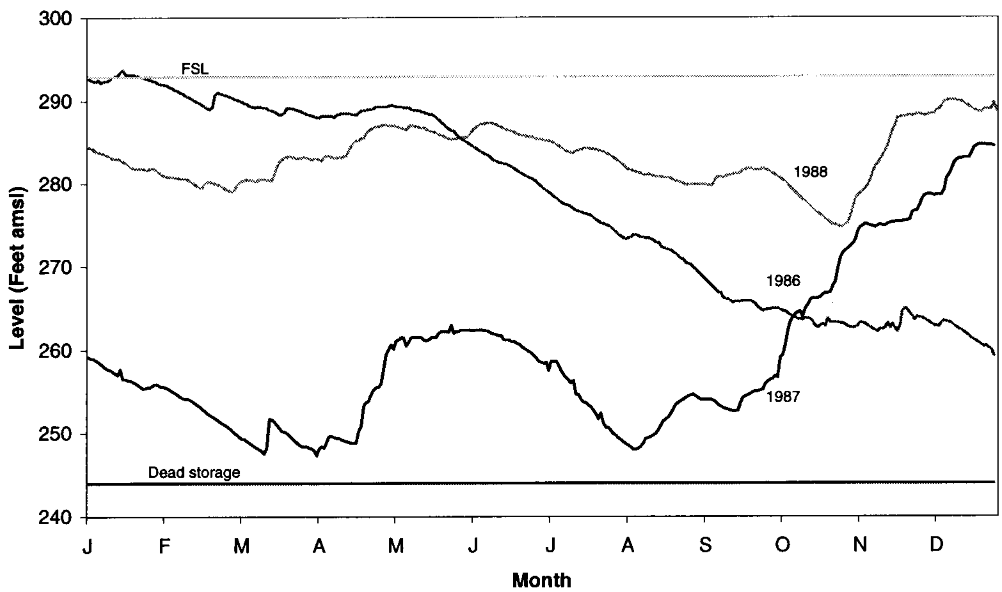


Figure A 1.5b Tank Water Levels, Muruthawela Tank, 1991 - 1987

A2 DESIGN DUTIES AND CHANNEL CAPACITIES

A2.1 The Main Canal

The design dimensions of the main canal from the head to 7 miles 14 chains, are:

Bed width	12 ft	(3.66 m)
Full Supply Depth	2.8 ft	(0.854 m)
Side slope	1:1	
Bed slope	0.0003	
Manning's n	0.025	
Design Q	69.6 cusec	(1.97 m^3/s)

The Irrigation Department uses a design duty of 35 acre/cusec or 2.0 l/s/ha.

Therefore the main canal could serve:

70 x 35 = 2450 acre

The canal was oversized to serve the Tract 2 area of 1535 acre but the completion of Tract 3 in 1977 increased the authorised command area to 3281 acre, requiring a peak discharge of 94 cusec. This requires a flow depth of 3.33 ft (1.015 m) infringing freeboard by 6 inches. Assuming a design freeboard of 3 ft, in accordance with standard Department dimensions, this would reduce freeboard by 16%. However, the canal supplied water not only to the official Tracts 2 and 3 but also to the unauthorized area of Tract 1, assumed to be approximately 1000 acre. A total command area of 4300 acre requires a peak capacity of 123 cusec. This requires a flow depth of 3.88 ft, i.e a 1ft infringement of freeboard.

Operations staff would be reluctant to operate the canal with this level of surcharge but more importantly the rectangular trough section at 0 miles + 30 chains is identified as limiting conveyance capacity. The trough dimensions are:

Width	4.5 ft	(1.372 m)
Height	5.0 ft	(1.525 m)
Slope	0.0024	
Manning's n	0.018	

If the trough runs brim full $Q = 3.46\ m^3/s$ (122 cusec)

If the trough retains 6" freeboard $Q = 3.04\ m^3/s$ (107 cusec)

Due to the marked difference in slope and roughness between the trough and the downstream channel, the exit from the trough will be drowned and will limit discharge. The conveyance capacity of the trough is therefore less than these figures suggest. This constraint arises from the original design assumptions and the subsequent unofficial "development" of Tract I and is not attributable to inadequate routine or periodic maintenance.

A2.1.1 Re-Modelling The Main Canal

It is primarily the limited capacity of the trough that has enforced the regular adoption of seasonal rotation. To overcome this design constraint the Irrigation Department is now building a second, parallel, trough of equal dimensions to provide a total conveyance capacity of approximately 180 cusec. This capacity is well in excess of that required by the command area of 4300 acre, but despite this a phased programme is under way to re-model the main canal as far as mile 7 to provide a flow capacity of 185 cusec. Such over-sizing of the main canal will be costly, particularly in those reaches in high fill, but it should ensure adequate water supply to all three tracts in both seasons, provided the distributary canals have adequate capacity.

However, the plan to expand the total annual cropped area from the present 6100 acre to 8600 implies that much stricter water management will be required in the operation of the Muruthawela and Urubboka Oya systems. The data below show how the annual water requirement will increase:

Table A1.3 Present and Future water demands for Muruthawela System

Present Season	Area (acre)	Duty (ft)	Volume (acre ft)
Maha	3,539	5.6	19,818
Yala	2,560	5.4	13,824
Total	6,099		33,642
Future			
Maha	4,300	5.6	24,080
Yala	4,300	5.4	23,220
Total	8,600		47,300

Figure A1.6 shows that annual water releases from the tank have fluctuated greatly over the 12 years from 1986 – 97 with releases being driven by the antecedent inflows into the tank. Increasing the annual volume require from 34,000 acre ft to 47,000 will place much heavier demands on pre-season planning and in-season scheduling and control as the scheme changes from one of water abundance to one facing regular scarcity.

A2.2 The Distributary Channels

The conveyance capacities of the distributary (D) canals, as evaluated from a series of rapid field measurements, are summarised in Table A1.4.

Table A1.4 Field Observations and Calculated Freeboard on Selected D Channels

			Field measurements				**Calculated**		
D channel name & location	Service area (acre)	FSQ (m^3/s)	Top width (m)	Bed width (m)	Free-board (m)	Flow depth (m)	Side slope (m)	Depth at FSQ (m)	Freeboard at FSQ (m)
DC1 T2 Head	1043	0.843	3.50	2.72	0.6	0.57	0.33	0.79	0.38 (Fair)
DC1 T2 d/s of fc 15	863	0.70	3.95	1.46	0.6	0.55	1.06	.88	0.38 (Fair)
DC2 T2 Head	302	0.24	3.00	1.42	0.5	0.15	1.13	0.46	0.19 (poor)
DC1 T3 d/s of DC2	1456	1.18	4.5	2.0	Dry	Dry	0.92	1.01	0.33 (fair)
DC2 T3 Head	290	0.23	2.90	1.10	Dry	Dry	1.05	0.52	0.43(good)
DC1 T3 u/s of DC3	1438	1.16	4.10	2.80	Dry	Dry	0.61	.89	0.18 (V. Poor)
DC1 T3 d/s of DC4	1208	0.98	4.3	2.36	Dry	Dry	0.79	0.86	0.36 (fair)

Note:

FSQ based on duty of 35 acre/cusec

Calculations assume a bed slope of 0.003 and Manning's n of 0.032

Using conservative assumptions for bed slope and channel roughness all of the distributary canals, with the exception of the head of distributary 2 in Tract 2 appear to have adequate conveyance capacity for their authorised command areas.

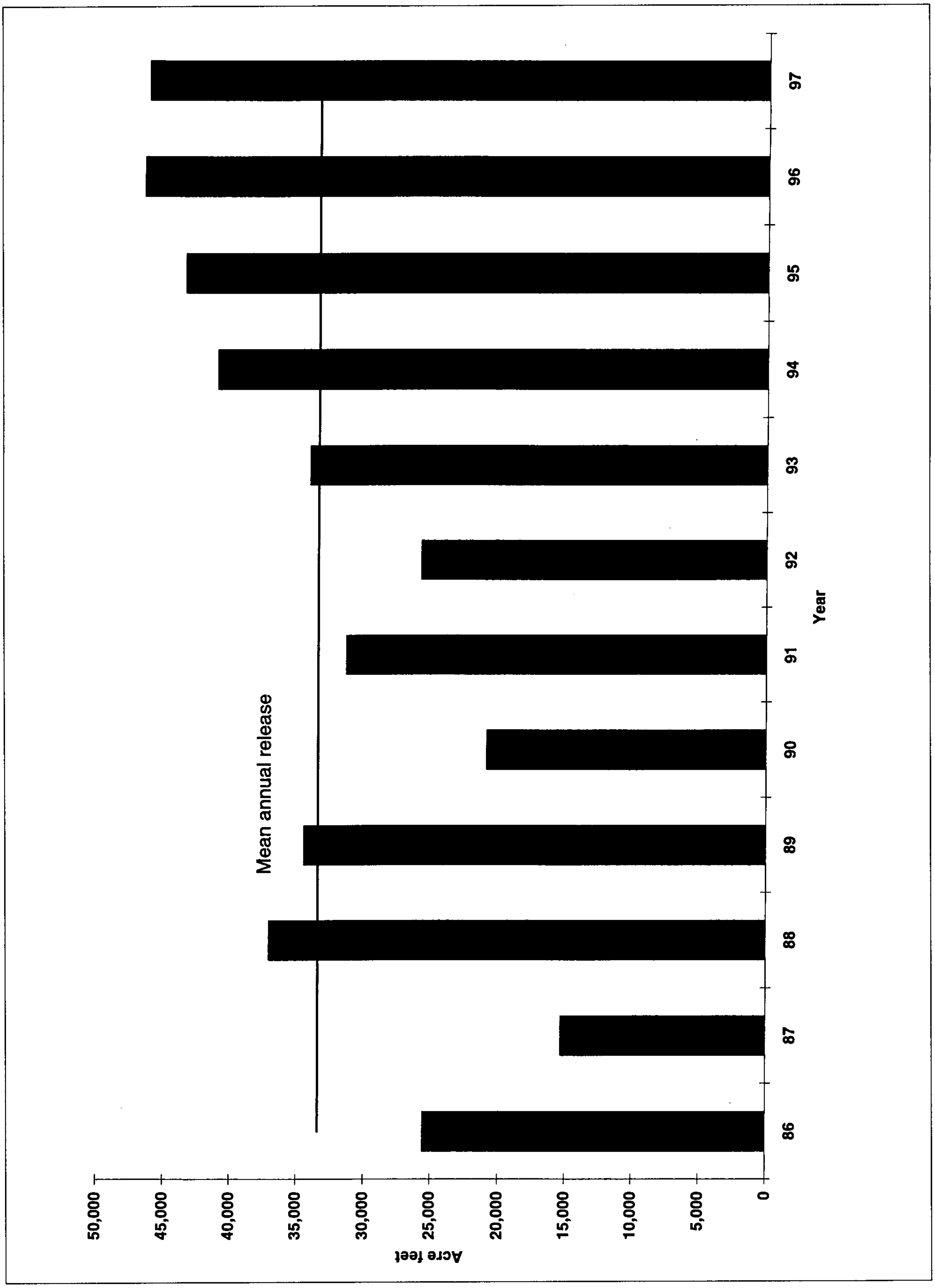


Figure A1.6 Annual Releases, Muruthawela Tank, 1986 - 1997

A3 FARMER QUESTIONNAIRES IN TRACTS 2 AND 3

A questionnaire was used to obtain farmers' views on their crop yields, the adequacy of irrigation supply, flood hazard and the effect of channel and structure condition on water management. The questionnaire was not designed to gather large volumes of data for statistical analysis but to guide discussion with farmers at different locations in order to identify common themes or issues concerning the hydraulic and agricultural performance of the scheme and maintenance requirements. Individuals or groups of farmers were interviewed at eight sites, three in Tract 2 and five in Tract 3.

There was no single outstanding feature common to the majority of farmers. Rather a number of different concerns were expressed, most of which related to the design and operation of the scheme rather than to maintenance constraints.

The present situation of seasonal rotation of supply between Tract 2 and Tract 3 was regarded more favourably by Tract 2 farmers who receive irrigation in the Yala ('dry') season. Some can grow rainfed crops in the Maha (wet) season or exploit drainage flows from Tract 3 to grow a second paddy crop. In contrast, several of the Tract 3 farmers identified the limited conveyance capacity of the main canal as the priority constraint.

All farmers reported that their yields were "average or good" and none saw flooding as a problem in either Maha or Yala season.

Several farmers in both tracts commented on the difficulties of controlling the distribution of water between different field channels due to the absence of gates either in the D channels or at the head of field channels. Farmers said that with the formation of water user organisations there was a greater willingness for co-operation between farmers than was formerly the case. This was put forward to explain why farmers had previously damaged and destroyed gates and to justify their demand that the Irrigation Department should fund their reconstruction. It is not clear to what extent the absence of gates impedes agricultural productivity within the tracts. There was evidence of conventional head to tail differences in supply in Tract 2. Farmers at the top of D channel 1 reported that water supply was normally adequate but those on D channel 6 – at the tail of D channel 1 – said that supply was inadequate.

A4 PLANNED AND ACTUAL BUDGET EXPENDITURES BY BUDGET LINE

The following data for 1995 to 1997 was abstracted from reports made by the Technical Assistants and the Irrigation Engineer in Weeraketiya Division in the preparation of the annual list of priority works.

1995 **Tasks submitted by IE with Estimate**		**1995** **Tentative allocation**	**1995** **Actual Programme**	**% of total** Expenditure
	$ US	**$ US**	**$ US**	
Departmental roads				
Muruthuwela				
Improve LBMC road 0-9 mile	1,951		1,951	
Improve main channel roads T3	1,951		nil	
Kirama Oya				
Access rd to Ethpitiya anicut	1,561		976	
Access rd to Daranda anicut	2,927		976	
Urubokka Oya				
Access road to Hakuruwela anicut	2,927		976	
Access road to Andupulena anicut	1,951		nil	
	13,268	**4,390**	**4,878**	**11.6%**
Flood Damage Repairs				
Kirama Oya				
Repairs to Maha Amura anicut	2,927		2,927	
Repairs to Pinode anicut	6,439		6,439	
Repairs to Hambumandiya anicut	4,878		4,878	
Repairs to Wauwa anicut	5,853		Nil	
Repairs to Kahawatta anicut	3,902		Nil	
Repairs to Danketiya anicut	1,951		Nil	
Urubokka Oya				
Repairs to Wakamula anicut	8,585		Nil	
Repairs to HLC at 1m 0.5 ch	859		Nil	
	35,394	**3,414**	**14,243**	**33.9%**
Safety of Headworks				
Kirama Oya				
Improvements to Udaberawa anicut spill	3,902		nil	
Improvements to Wijerathna anicut spill	2,439		2,439	
Urubokka Oya				
Improvements to d/s cushion of Udukiriwila anicut	4,878		4,878	
	11,219	**6,341**	**7,317**	**17.4%**
Imp. of Major Works				
Muruthuwela				
Repairs to trough LBMC 0m 32ch	1,566		nil	
Construct 2 bay regulator, 8m+12ch	4,819		nil	
Construct 3 bay regulator, 7m+15ch	3,902		nil	
Canal protection work, 3m+28ch	2,439		nil	
Imp. Trough in D1 t 3 at 1m+8ch	995		nil	
Repairs to trough at 1m +50.7ch on D1 T3	595		nil	
Urubokka Oya				
Wakamula transferred from Flood Damage budget			8,585	
	14,317	**3,414**	**8,585**	**20.4%**
Imp. Water Management				
Muruthuwela				
Replace wooden gates at bifurcation	831		nil	
Kirama Oya				
Supply & install gates at Pattiyawela	1,658		1,658	
Supply & install gates at Kongalara	4,390		4,390	
Supply & install gates at Ethpitiya	976		976	
Urubokka Oya				
Construct LB & RB sluice at Ranna	2,927		nil	
Replace gate at Runnakubbura	1,132		nil	
	11,914	**2,923**	**7,024**	**16.7%**
TOTALS	**86,111**	**20,482**	**42,047**	

1996 Tasks listed by TA's with estimate	$ US	1996 Tentative allocation $ US	1996 Tasks submitted by IE with Estimate	$ US	1996 Actual Programme $ US	% of total Expenditure
Departmental roads			**Departmental roads**			
Muruthuwela			*Muruthuwela*			
Access rd in T3	3,693		OUT			
Access rd in T3	3,693		OUT			
Kirama Oya			*Kirama Oya*			
None			Access rd to Daranda	2,770	2,770	
Urubokka Oya			*Urubokka Oya*			
Imp. Access rd Andupelena	1,846		Imp. Access rd Andupelena	1,846	1,846	
	9,232	**4,616**		**4,616**	**4,616**	**7.0%**
Flood Damage Repairs			**Flood Damage Repairs**			
Kirama Oya			*Kirama Oya*			
Repair to RB channel Maha Amuna	7,386		OUT			
Repairs to Pinode Anicut	6,463		Repairs to Pinode Anicut	6,463	6,463	
			Repairs to Hambumandiya Anicut	6,001	6,001	
			Repairs to Kahawatta anicut	3,693	Nil	
Urubokka Oya			*Urubokka Oya*			
Wakamulla Anicut	3,324		Wakamulla Anicut	4,155	4,155	
	17,172	**3,693**		**20,311**	**16,618**	**25.3%**
Safety of Headworks			**Safety of Headworks**			
Kirama Oya			*Kirama Oya*			
Repairs to flank bund Wile Amuna	2,770		Supply/fix gates at Danketiya	2,770	2,770	
Repairs to anicut gates Maha Amuna	2,308		Maha reinstated by DD		2,308	
Repairs to LB d/s side Kahawatta anicut	3,693		OUT			
Urubokka Oya			*Urubokka Oya*			
Construct LB & RB sluice at Ranna	2,770		Construct LB & RB Sluices at Ranna	2,770	2,770	
			Imp. To Udukiriwila anicut	9,232	9,232	
	11,540	**6,463**		**14,772**	**17,080**	**26.1%**
Imp. Major Works			**Imp. Major Works**			
Muruthuwela			*Muruthuwela*			
None			None			
Kirama Oya			*Kirama Oya*			
Construct drainage channel Danketiya	1,846		Imp. To Wauwa amuna	7,386	7,386	
Construct sluice control for Maha Amana	1,846		Maha amuna reinstated		1,846	
Imp. Bifurcation strct. Udukiriwila	2,770		Repairs to flank bund Wile amuna	2,770	2,770	
Urubokka Oya			*Urubokka Oya*			
None			Imp. To bifircation strct. At Udukiriwila	2,770	2,770	
	6,463	**4,154**		**12,925**	**14,772**	**22.5%**
Imp. Water Management			**Imp. Water Management**			
Muruthuwela			*Muruthuwela*			
Imp. LBMC	3,693		none			
Lining DC1 T2 first 7 chains	646					
Imp. to DC 1 T2	2,770					
Imp. To DC 3 T2	1,846					
Imp. To DC 4 T2	1,662					
Imp. LB bund DC1 T3 frm D4 to FC 66	1,846					
Imp. To drop struct. 1m+45ch DC1 T3	2,770					
Imp. To drop struct. LB bund & RB road	6,463					
Kirama Oya			*Kirama Oya*			
Supply/fix anicut gates Kahawatta	2,216		Supply/fix anicut gates Kahawatta	2,216	2,216	
Imp. RB chl & structures Pattiyawela	4,616		Supply/fix anicut gates Ethpitiya	1,846	1,846	
			Supply/fix anicut gates Okewela	3,693	3,693	
Urubokka Oya			*Urubokka Oya*			
Imp. RB channel Hunnakumbura	369		OUT			
Imp. LB channel Hunnakumbura	960		OUT			
Supply/fix 3 anicut gates Andupelena	1,939		Supply/fix 3 anicut gates Andupelena	1,939	1,939	
Tractor crossings LB & RB chnls Ranna	1,846		OUT			
Repairs to chnl structures in Ranna	923		OUT			
Imp. To low LC Udukiriwila	3,693		OUT			
Replace gates Udukiriwila	831		OUT			
			Supply /fix gates Kongalara	2,779	2,779	
	39,089	**4,154**		**12,473**	**12,473**	**19.0%**
TOTALS	**83,496**	**23,080**		**65,097**	**65,558**	

1997 Tasks listed by TA's	$ US	1997 Tentative allocation $ US	1997 Tasks submitted by IE with Estimate	$ US	1997 Actual Programme $ US	% of total Expenditure
Departmental roads			**Departmental roads**			
Muruthuwela			*Muruthuwela*			
Imp. Approach Rd from Weeraketiya to T3	3,511		OUT			
Imp. Approach Rd from Bog wewa toT3	3,511		OUT			
Kirama Oya			*Kirama Oya*			
None			None			
Urubokka Oya			*Urubokka Oya*			
Imp. To Kapugampatha Ela bund rd	1,316		Imp. To Kapugampatha Ela bund rd	1,316	1,316	
Imp. Access rd to Ranna anicut	4,388		Imp. Access rd to Ranna anicut	4,388	4,388	
Imp. Access rd to Hunnakumbura anicut	7,021		Imp. Access rd to Hunnakumbura anicut	6,582	6,582	
	19,747	**5,266**		**12,287**	**12,287**	**12.7%**
Flood Damage Repairs			**Flood Damage Repairs**			
Kirama Oya			*Kirama Oya*			
Rep. Washed out canal sect. Pansala	4,827		Rep. Washed out canal sect. Pansala	4,827	4,827	
Rep. Retain wall d/s of Pinode anicut	5,705		Rep. Retain wall d/s of Pinode anicut	6,144	12,287	
Urubokka Oya			*Urubokka Oya*			
Rep to Wakamula amuna	4,476		Rep to Wakamula amuna	4,476	4,476	
	15,008	**5,266**		**15,447**	**21,590**	**22.2%**
Safety of Headworks			**Safety of Headworks**			
Kirama Oya			*Kirama Oya*			
Imp. To Hambumandiya anicut	4,388		OUT			
Replace radial gates Daranda anicut	7,021		Rep. radial gates & d/s protect Daranda	8,777	8,777	
D/s protection Daranda anicut	1,316					
Imp. To Arachchi anicut	1,755		OUT			
Protection to h.wrks Kahawatta anicut	3,225		Protection to h.wrks Kahawatta anicut	3,511	3,511	
Urubokka Oya			*Urubokka Oya*			
Imp. Of flank bund, Wakamula	878		OUT			
D/s protection at Ranna anicut	1,755		D/s protection at Ranna anicut	1,755	1,755	
Imp. d/s wing wall, Andupelena	2,633		Imp. d/s wing wall, Andupelena	2,633	2,633	
2 x 50' retain. Walls, Andupelena	3,511		OUT			
New RB sluice, Andupelena	1,755		OUT			
75' retain. Wall Andupelena	1,316		OUT			
	29,554	**7,021**		**16,675**	**16,675**	**17.2%**
Imp. Major Works			**Imp. Major Works**			
Muruthuwela			*Muruthuwela*			
None			None			
Kirama Oya			*Kirama Oya*			
Imp. To Kirama wewa feeder chnl	52,659		Imp. To Kirama wewa feeder chnl	26,330	26,330	
Wegalota bund	2,194		OUT			
Urubokka Oya			*Urubokka Oya*			
Const. 2 bay reg. Kattakaduwa Wewa	1,316		Const. 2 bay reg. Kattakaduwa Wewa	1,316	1,316	
Const. LB sluice & d/s protection Hakuruwela	4,388		OUT			
Imp. To Ranna supply chnl	3,511		Imp. To Ranna supply chnl	3,511	3,511	
Const. Of regulator in H? Ela	2,633		OUT			
Const. LB & RB sliuces, Ranna	3,511		Const. LB & RB sliuces, Ranna	3,511	3,511	
	70,212	**4,388**		**34,667**	**34,667**	**35.7%**
Imp. Water Management			**Imp. Water Management**			
Muruthuwela			*Muruthuwela*			
Const. Drop strct. In D3 of T3	1,316		OUT			
Const. Of a regulator at head of D2	878		OUT			
Kirama Oya			*Kirama Oya*			
Imp. To Kuttandoza anicut	5,266		OUT			
Imp. To Katigga anicut	7,899		OUT			
Drainage channel in ?	2,633		OUT			
Imp. Maha Amuna LB channel	8,777		OUT			
Imp. To Ethpitiya anicut	1,755		Imp. To Ethpitiya anicut	1,755	1,755	
Replace gates Maha Amuna anicut	2,194		Replace gates Maha Amuna anicut	2,194	2,633	
Urubokka Oya			*Urubokka Oya*			
Supply/fix gate for RB sluice Hakuruwela	351		OUT			
minor repairs to Hakuruwela anicut	351		OUT			
Imp. Of trough on LB channel Hakuruwela	1,755		OUT			
Repair RB sluice gate, Hunnakumbura	878		OUT			
Minor repairs to Hunnakumbura anicut	176		OUT			
Imp. U/s &d/s of RB sluice, Wakamula	878		OUT			
Minor repair of Wakamula anicut	439		OUT			
Imp. To regulator at 14 ch on HLC	3,511		Imp. To regulator at 14 ch on HLC	3,511	3,511	
Const. Regulator at 12 ch on Marakada Ela	2,194		Const. Regulator at 12 ch on Marakada Ela	2,194	2,194	
Cons. RB sluice Andupelena	1,755		Cons. RB sluice Andupelena	1,755	1,755	
	41,250	**4,388**		**11,410**	**11,848**	**12.2%**
TOTALS	**245,984**	**26,329**		**90,486**	**97,069**	

Analysis of Periodic Maintenance Expenditure 1995 – 97 by Work Type

	$US		Notes
Structural & Channel Improvements at Minor Headworks			
Repairs to Maha Amura Anicut	2,927		Flood damage repair
Repairs to Pinode Anicut	6,439		Flood damage repair
Repairs to Hambumandiya anicut	4,878		Flood damage repair
Improvement to Wijerathna anicut spill	2,439		
Improvement to d/s cushion of Udukiriwila anicut	4,878		
Repairs to Wakamula anicut	8,585		
Repairs to Pinode Anicut	6,463		Flood damage repair
Repairs to Hambumandiya Anicut	6,001		Flood damage repair
Wakamula Anicut	4,155		Flood damage repair
Improvement to Udukiriwila anicut	9,232		
Improvement to Wauwa Amuna	7,386		
Repairs to flank bund Wile Amuna	2,770		
Improvement to bifurcation structure at Udukiriwila	2,770		
Repairs to washed out canal section at Pansala	4,827		Flood damage repair
Repairs to retaining wall d/s of Pinode anicut	12,287		Flood damage repair
Repairs to Wakamula Amuna	4,476		Flood damage repair
Protection of headworks, Kahawatta anicut	3,511		
D/s protection at Ranna anicut	1,755		
Improve d/s wing wall, Andupelena	2,633		
Improvements to Kirama wewa feeder channel	26,330		
Construct 2 bay regulator Kattakaduwa Wewa	1,316		
Improvements to Ranna supply channel	3,511		
Improvement to Ethpitiya anicut	1,755		
Improvement to regulator at 14 ch on HLC	3,511		
Construct regulator at 12 ch on Marakada Ela	2,194		
Sub-Total		137,027	
Percent of total Expenditure		66.9%	
Replacement of Gates at Minor Headworks			
Supply & install gates at Pattiyawela	1,658		
Supply & install gates at Kongalara	4,390		
Supply & install gates at Ethpitiya	976		
Supply/fix gates at Danketiya	2,770		
Maha reinstated by Deputy Director	2,308		
Construct LB & RB Sluices at Ranna	2,770		
Maha Amuna reinstated	1,846		
Supply/fix anicut gates at Kahawatta	2,216		
Supply/fix anicut gates at Ethpitiya	1,846		
Supply/fix anicut gates at Okewela	3,693		
Supply/fix 3 anicut gates at Andupelena	1,939		
Supply /fix gates at Kongalara	2,779		
Repair radial gates & d/s protection at Daranda	8,777		
Construct LB & RB sliuces at Ranna	3,511		
Replace gates at Maha Amuna anicut	2,633		
Construct RB sluice at Andupelena	1,755		
Sub-Total		45,866	
Percent of total Expenditure		22.4%	
Repairs to Access Roads			
Improve LBMC road 0-9 mile	1,951		Muruthawela System
Improve access road to Ethpitiya anicut	976		
Improve access road to Daranda anicut	976		
Improve access road to Hakuruwela anicut	976		
Improve access road to Daranda	2,770		
Improve access road to Andupelena	1,846		
Improvements to Kapugampatha Ela bund road	1,316		
Improve access road to Ranna anicut	4,388		
Improve access road to Hunnakumbura anicut	6,582		
Sub-Total		21,781	
Percent of total Expenditure		10.6%	
Total Expenditure		204,674	

Irrigation Engineer
Weeraketiya Division

- Muruthuwela System: Tract I, Tract II, Tract III
- Kirama Oya System: Kirama - Okewewa, Pansala - Liyangedenia, Nalagama - Danketiya
- Urubboka Oya System: Raluwa - Udukiriwila + HLC, Wakamula - Hakuruwela, Andupelena - Rana

	Tract I 414 ha Headwrks	Tract II 621 ha	Tract III 700 ha	Kirama - Okewewa (7 Headworks 541 ha)	Pansala - Liyangedenia (6 Headworks 428 ha)	Nalagama - Danketiya (5 Headworks 1123 ha)	Raluwa - Udukiriwila + HLC (5 Headworks 753 ha)	Wakamula - Hakuruwela (3 Headworks 813 ha)	Andupelena - Rana (2 Headworks 547 ha)	*Totals/ Average*
Technical Assistant	0.5	0.5	1	0.5	1	1	0.5	1	1	7
ha / TA	1910	2748	700	1910	428	1123	2748	813	547	849
Hdwrks / TA	1+7		0	1+7	6	5	5	3	2	4
Miles canal / TA	n/a	4+5	4	8	9	7	4+5	6	4	6.7
Work Supervisor	1	1	1	2	1	1	1	1	1	10
ha / WS	n/a	621	700	270.5	428	1123	753	813	547	594
Hdwrks / WS	1	n/a	n/a	3.5	6	5	5	3	2	3
Miles canal / WS	n/a	4	4	4	9	7	5	6	4	4.7
Labourer	3	4	4	4	4	6	5	3	4	37
ha / Lab	n/a	155	175	135	107	187	151	271	137	161
Hdwrks / Lab	0.33	n/a	n/a	1.75	1.50	0.83	1	1	0.50	0.8
Miles canal / Lab	n/a	1	1	2	2.3	1.2	1	2	1	1.3

Figure A 1.7 Responsibilities of Field Staff Working in Weeraketiya Division

A5 STAFFING LEVELS

Figure A1.7 shows the distribution of maintenance labourers, work supervisors and technical assistants between the three systems in Weeraketiya Division. Within the Muruthawela system, the Irrigation Department is responsible for the operation and maintenance of the headworks and main canal. Responsibility for operation of structures below the head of the distributaries lies with the farmer organisations, co-ordinated by a technical assistant. The farmers also carry out routine maintenance of the distributaries and field channels, though in some cases the Department pays them for their labour. The technical assistants can request funds from the periodic maintenance budget for works below the main canal level, but Section 4 show that requests are seldom successful as the Department aims to limit its responsibilities to the main canals only in medium and major schemes. The eight labourers and two work supervisors assigned to Tracts 2 and 3 have responsibility for the routine maintenance – weed cutting, de-silting and general oversight – of 8.5 miles of main canal, or approximately 1 mile per labourer.

In the minor tanks and anicuts of the Kirama Oya and Urubboka Oya systems the Irrigation Department is responsible for the operation and maintenance of the headworks and the first mile of distributary canal on each bank. A better picture of the workload faced by staff is obtained by considering the number of headworks and length of canal managed per head rather than the commanded area.. These approximate indicators of workload are shown on the figure.

The distribution of workload between staff at all three levels varies according to the measure applied. Because of the nature of the asset base – one medium scheme and 33 minor headworks on two river systems each serving one or two diversion channels – it is impossible to achieve a completely uniform distribution between staff. However, the following points merit comment:

- There is a case for merging the two lower sections of the Urubboka Oya system under a single TA and WS to achieve a more uniform allocation of duties.
- Maintenance labourers are normally allocated to the minor schemes on the basis of one labourer per headworks. However, in the two upper sections of the Kirama Oya system five labourers oversee two headworks each because of their physical proximity while the two anicuts at the tail of the Urubboka Oya system each have two labourers assigned. The responsibilities of these labourers appear to be limited to "operation" of the anicut gates and the head gates on the diversion channels, where these are present, and weed clearing over the first mile of the diversion channel. A high percentage of the available budget for routine O & M is allocated to establishment costs. Some cost saving may be achieved by reducing the number of permanent staff and using a smaller number of labourers for maintenance in a team moving between all the minor headworks whilst each labourer retains responsibility for operation – which occurs on an irregular basis – of two headworks. Such an arrangement would require more detailed planning and monitoring of routine maintenance activities as recommended in the Teams Pvt (1991) report. However, such re-organization and shedding of labour would be likely to incur union opposition.

A6 SUMMARY OF CONSTRAINTS

To provide a rapid assessment of the principal constraints influencing the performance of the Muruthawela scheme, a checklist of possible performance constraints, developed by Cornish and Skutsch (1997), was applied. The checklist pre-supposes that under-performance will result in one or more of the following:

Reduced Irrigated Area	– i.e. the total cultivated command area and/or the cropping intensity are lower than regional norms or design targets.
Water shortage	- Consistent reports of significant water shortage in parts or all of the scheme.

Falling crop yields - Yields declining over time or consistently below regional norms.

The checklist groups possible underlying causes of observed under-performance under the following five headings:

- Agricultural and Economic constraints
- Design and/or Operational constraints
- Deterioration of Infrastructure
- Land Degradation
- Water Supply at the Headworks

Under-performance at Muruthawela is manifest in a low annual cropping intensity – calculated to be about 150% – while the surrounding minor schemes achieve 200%. Discussions with operations staff and farmers suggest that neither water shortage nor low or declining yields give cause for concern.

Information gained from first hand observation, discussion with field staff, the Irrigation Engineer, the Project Manager and the farmer questionnaires is summarised in the following sections. Conclusions are drawn in Section 4.3 of the main report

A6.1 Agricultural and Economic Constraints

There is no evidence that scarcity or cost of agricultural inputs, labour nor the incidence of crop pests significantly influence the performance of Muruthawela relative to other schemes in the region.

A6.2 Design and/or Operational Constraints

a) The decision taken during original system construction to exclude the Tract 1 area from the authorised command area is probably the most significant factor influencing the performance of the scheme. Routine theft of water from the main canal by farmers in Tract 1 makes it impossible to irrigate Tracts 2 and 3 simultaneously so cropping intensity is low.

b) Operations staff report that the first two miles of the main canal were under-excavated at the outset and never complied with design dimensions and conveyance capacity. Recent survey data indicate that the bed level is as much as 2.5 – 3.0 ft (0.75 – 0.9 m) higher than the design level over a 1000 ft (300 m) reach in the first mile. In the remainder of the mile the level is approximately 1.5 ft (0.46 m) above design. It is not clear how much is the result of under-excavation and how much is sediment derived from the canal bank where the canal is in a deep cutting. Whatever the cause, the capacity of the trough at 0 miles 28 chains appears to be a greater constraint on conveyance capacity than the channel section, pointing to a problem of design rather than inadequate maintenance.

c) The farmer questionnaires indicate that there are frequent delays in making the first water releases of the season, and operations data (Figure A1.1) show that there is considerable variation in season dates from year to year. Whilst these may be cause for farmer complaint they do not influence the annual cropping intensity.

d) Despite the establishment of farmer user organisations to improve water management at the field channel and D channel levels, interviews with farmers indicate that they fail to adhere to any agreed staggering of land preparation and planting. They consequently compete for water. Any proposal to rehabilitate gates at the heads of field channels might therefore be viewed with caution as new structures might be quickly removed given that farmers have destroyed other control structures. The decision by the Irrigation Department not to spend maintenance money on the up-keep and repair of structures below the turnouts into the D channels appears to be well justified.

e) Seasonal rotation between Tracts 2 and 3 presents difficulties for the operations staff who must try to enforce the rotation and prevent water theft. Rotation is not the cause of under-performance but a consequence of decisions taken at the time of design and construction.

f) A Parshall flume was constructed at the head of the main canal, downstream of the bifurcation to the Urubboka Oya system. However, the flume is totally submerged under normal operating conditions and cannot be used for flow monitoring. It is not clear to what extent submergence would be reduced if the canal were excavated to the design bed level. This is a design or maintenance problem which prevents the accurate, routine monitoring of releases into the Muruthawela scheme but it is a consequence, rather than the cause, of the restricted conveyance capacity of the main canal.

A6.3 Deterioration of Infrastructure

Many of the structures on the scheme, particularly those on the distributary and field channels, are in poor condition. Almost all gates have been removed or the structures by-passed. Many drop structures have serious downstream erosion outflanking the wing walls. Canal banks in both tracts are weak and badly eroded in a number of places. Weed growth is vigorous. Canals and field areas are heavily overgrown during the "off-season"and can appear abandoned. However, "seasonal deterioration" is "repaired" by the farmers just prior to the first water release so a general impression can be misleading.

The main canal is generally in better condition but there are sites with localised bank erosion and reduced freeboard. Numerous unauthorised off-takes serve Tract 1 and several of the drainage-under-crossings are damaged so as to abstract water from the canal.

Despite the general impression of widespread deterioration and neglect, spot measurements of conveyance capacity of the Distributary channels (Table A 1.4) indicate that the canals can still carry their design discharge. The localised areas where banks are weak, particularly in Tract 3, require preventive maintenance to avoid future failure but they are not currently limiting the performance of the scheme. The absence of working control structures in the D channels and field off-takes was noted in 6.2 (d) above. Maintenance/repair of these structures appears unjustified. The unauthorised off-takes serving Tract 1 do have a significant impact on the water supply to Tracts 2 and 3 but this problem cannot be addressed by more intensive maintenance of the drainage under crossings. The problem derives from the original planning decisions and will only be resolved by the re-design of the main canal that is now in-hand to incorporate the Tract 1 area.

A6.4 Water Supply at the Headworks

Data shown in Figure A 1.5 indicate that water supply in Muruthawela tank has not been the factor constraining the area irrigated. However, the work in-hand to re-model the main canal and support 200% cropping intensity on Tracts 1, 2 and 3 will increase the annual demand by 40% (See Table A 1.3). This review of system operations and performance had the objective of identifying links between maintenance and performance. Tank balance calculations and simulation of expected demand against historic inflows has not been carried out but such a study would seem appropriate to indicate the probabilities and severity of seasonal water shortage that may be faced in the Muruthawela and Urubboka Oya systems.

Appendix 2

Marlin Software

Appendix 2 Marlin Software

MARLIN is a maintenance planning tool for gravity irrigation systems. It aims to ensure that the planning of maintenance tasks is based on objective information relating to the condition of system infrastructure and the impact of that condition on the overall hydraulic performance of the system.

It sets out procedures for assessing the condition of system infrastructure and combines that information with data on command area and asset type to rank works according to their impact on the functioning of the scheme. Guided by this priority ranking, the user can prepare annual or seasonal work plans, setting cost estimates against budget totals for any number of different budget lines. Finally, detailed work orders for individual assets can be prepared using standard costing rates held on the database. Should it be required, information from the work orders can be exported into Time Line project planning software where preparation of work schedules, planning of resource allocation and monitoring of actual expenditures and work progress, can be carried out.

MARLIN identifies priority maintenance tasks on the basis of asset type, asset condition and the fraction of the total command area influenced by that asset. However, the extensive reporting capability of the software allows selective reports to be created on the basis of asset type and/or condition and the user can over-ride the internal prioritisation and prepare alternative work schedules. MARLIN also provides the capability to keep track of deferred maintenance, that is, maintenance tasks that have been identified as requiring action but for which funding has not been secured. The deferment history of assets can be incorporated in the priority ranking if the user wishes.

By defining a schematic map of the scheme (or schemes) where the program is to be used, an inventory of system infrastructure is built up. The inventory can hold principal design dimensions of headworks, canal reaches and a wide range of structure types.

Field information on the condition of headworks, canal reaches and structures (assets) is collected using condition assessment questions on proformas generated by MARLIN. Information on past and present condition of assets is held within the database and using a series of scores associated with each question, an overall condition score is calculated and the asset classified as being in Good, Fair, Poor or Very Poor condition. The questions are formulated to assess the condition of asset in terms of hydraulic function and structural stability. The associated condition scores reflect the likely impact of different conditions on the hydraulic function and stability of the asset.

Where it is required, more detailed engineering assessments of assets can be carried out and the results held in MARLIN.

Records of expenditure and quantities of work completed can be recorded and summary reports and graphical output generated within MARLIN.

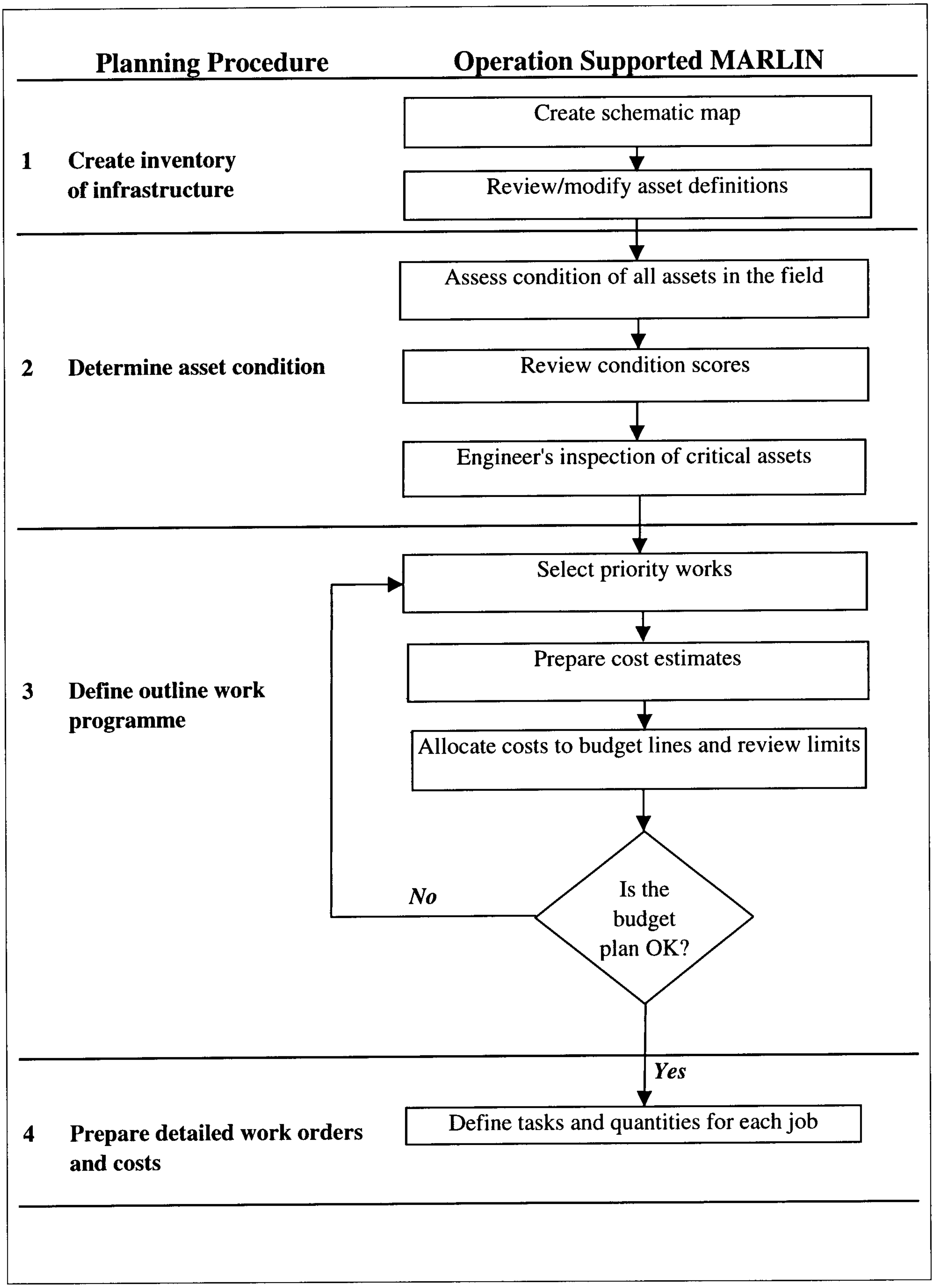


Figure A 2.1 The Planning procedure Supported by Marlin

Part II Guidelines for the Assessment of Asset Condition

ENGINEERING INSPECTION - CANAL REACH page 1

Canal Name: ___________________ Reach ID _____________________

Design Parameters:

Discharge	____________	Flow depth	_____________________
Bed width	____________	Freeboard	_____________________
Bed slope	____________		

A. Hydraulic functions:

	Value	Percentage of design (125- 80%)	(79 - 70%)	(69 - 50%)	(<50%)
Estimated discharge	_____	☐	☐	☐	☐
Average depth	_____	☐	☐	☐	☐
Average clear bed width	_____	☐	☐	☐	☐

Do d/s conditions create backwater problems? Yes* No Don't know*

*Describe d/s condition at section D

B. Channel condition:	Good (None/minimal)	Fair (Minor)	Poor (Serious)	Very Poor (Very serious)
Siltation	☐	☐	☐	☐
Weeds	☐	☐	☐	☐
Freeboard	☐	☐	☐	☐
C. Bank condition:				
Slips	☐	☐	☐	☐
Erosion	☐	☐	☐	☐
Seepage	☐	☐	☐	☐
If lined:				
Primary purpose - structural	☐	☐	☐	☐
Primary purpose - seepage reduction	☐	☐	☐	☐

Condition summary:
Most serious defect ____

Overall classification Good / Fair / Poor / Very poor

D. Notes on Sections A and B:

E. Is any condition expected to become Poor or Very Poor within 12 months, if not already so?

F. **Required action:**

- None ☐
- Repair ☐
- Demolish & rebuild ☐
- Demolish & redesign ☐

Define scope of detailed site survey/investigations, if these are required:

Rough estimate of quantities/materials required:

GUIDANCE NOTES FOR ENGINEERING ASSESSMENT OF CANAL REACHES

1. REACH FUNCTIONS

i. Convey maximum design discharge without infringement of design freeboard, without drowning u/s control or measurement structures and without hazard of structural failure.

ii. Maintain level vs discharge relationship such that all off-takes on the reach can abstract their design proportion of the available flow.

iii. Maintain a stable channel section (neither bed/bank erosion nor deposition) under normal, operating flows.

iv. Convey water without undue seepage loss and without unauthorised abstraction.

2. POTENTIAL MODES OF FAILURE

2.1 Channel degradation:

a) Blockage, caused by:
- Earth slips or other debris
- Sediment accumulation
- Weed growth

b) Bank erosion, caused by:
- Rainfall
- Canal flow
- Human or animal traffic
- Cross drainage flows

c) Reduced freeboard, caused by:
- Bank erosion
- Increased channel roughness
- Reduced cross-sectional area

d) Failure of side drains

2.2 Structural failure:

a) Slippage
- Surface
- Deep seated

b) Lining damage

c) Seepage
- Minor and stable
- Progressive seepage failure

Based on this summary of functions and possible mechanisms of functional or structural failure, guidance for the classification of each factor is presented in the following tables.

GUIDANCE NOTES: Condition of elements

Factor: Discharge capacity

GOOD	No more than 10% reduction in discharge below design capacity when running at FSL. Reduced capacity therefore has little effect on adequacy of d/s supply except at times of peak demand.
FAIR	Discharge capacity reduced by between 10% and 25% when running at FSL. Reduced capacity has a moderate effect on the adequacy of d/s supply.
POOR	Discharge capacity reduced by between 25% and 50% when running at FSL. Reduced capacity has a serious effect on the adequacy of d/s supply.
VERY POOR	Discharge capacity reduced by more than 50% when running at FSL. Reduced capacity results in serious yield loss or failure to crop in some d/s areas.

Factor: Sediment/weeds/other blockages

GOOD	Any sediment, weed or other blockage is insufficient to cause reduction of freeboard here or in u/s reaches when flowing at FSD.
FAIR	Channel cross-section, whether caused by sediment, weeds, or debris in any combination, is reduced by no more than 30% over any sustained length of the reach.
POOR	Channel cross-section, whether caused by sediment, weeds, or debris in any combination, is reduced by between 30% and 50% over a sustained length of the reach.
VERY POOR	Channel cross-section, whether caused by sediment, weeds, or debris in any combination, is reduced by more than 50% over a sustained length of the reach.

Factor: Freeboard

GOOD	Freeboard at normal design Q is equal to or greater than design
FAIR	Freeboard at design discharge is reduced by up to 25% over localized area.
POOR	Freeboard at design Q reduced by between 25% and 50% at any point. **Or** Freeboard reduced by up to 25% over a major part of the reach.
VERY POOR	Freeboard reduced at any point so design discharge cannot pass without risk of overtopping. (Freeboard reduced by >50% at any point.)

Factor: Slippage

GOOD	No slips or signs of surface cracks. No heave at slope toe. No slumping or deep seated movement either in up-slope terrain (cut) or in embankments
FAIR	Minor surface cracks. No heave at slope toe. No slumping or deep seated movement either in up-slope terrain (cut) or in embankments
POOR	Occasional surface slumping of embankments due to over-steep slopes. May contribute to minor sedimentation but no risk of sudden blockage through sliding. Banks not weakened and no immediate risk of structural failure
VERY POOR	Actual or threatened failure of banks, including: □ deep-seated slips, including upslope collapse in cut areas, especially after rainfall, or saturated embankments in fill areas. □ Tension cracks in embankment surface or heave at embankment toe may indicate potential failures.

Factor: Erosion

GOOD	No erosion, either within the channel, on upslope terrain (cut) or on the external face of embankments.
FAIR	Minor surface erosion under rainfall, on upslope terrain (cut) or on the external face of embankments. Minor local scour at hydraulic structures which does not threaten undermining.
POOR	Frequent areas of bank erosion, including major runnelling under rainfall. Cannot be restored to condition by minor maintenance/ turfing. Progressive bed erosion around hydraulic structures may lead to structural undermining. Design bank top width may be reduced locally, but no immediate danger of bank failure.
VERY POOR	Widespread areas of bank erosion, either major runnelling under rainfall or around hydraulic structures. Immediate danger of structural undermining. Bank top width and cross section dangerously reduced.

Factor: Seepage

GOOD	No evidence of seepage from embankment.
FAIR	Minor canals: Limited occasional areas of seepage from embankment. Conveyance canals: No evidence of seepage
POOR	Minor canals: frequent breaches causing visible loss. Conveyance canals: stable, minor seepage/up-welling visible at bank toe.
VERY POOR	Minor canals: frequent breaches seriously diminish channel flow. Conveyance canals: seepage/up-welling at bank toe visibly increasing over time. Seepage may threaten stability of slopes (cut) or embankments.

Factor: Lining damage -
Lining purpose, structural

GOOD	Insitu concrete lining - No significant damage - penetrating cracks, settlement or heave - in any lining panel. Masonry/block lining - Very few isolated instances of damaged or missing blocks may occur. No evidence of washout behind lining at any point. No apparent risk of progressive failure.
FAIR	Insitu concrete lining - An Isolated, few occurrences of penetrating cracks, settlement or heave. Masonry/block lining - minor occurrence of individual damaged/missing blocks or masonry. **and/or** Isolated occurrence of minor washout behind lining. No apparent risk of progressive failure.
POOR	Insitu concrete lining - Frequent, isolated cases of penetrating cracks, settlement or heave, (no more than 20% of panels show damage). No single area of extensive damage. Masonry/block lining - Frequent occurrence of individual damaged/missing blocks or masonry **and/or** Frequent occurrence of washout behind lining. A risk of progressive failure from existing weak points is apparent.
VERY POOR	Insitu concrete lining - Very frequent occurrence of penetrating cracks, settlement or heave, (more than 20% of panels show damage). Or a single extensive area of damage. Masonry/block lining - Very frequent occurrence of individual damaged/missing blocks or masonry. Or a single extensive area of damage. **and/or** Serious erosion and risk of bank failure is evident.

Factor: Lining damage -
Lining purpose, seepage reduction

GOOD	Insitu concrete lining - Panels to line and level. No evidence of sub-grade erosion. Rare occurrence of hairline cracking only. Joints appear sound, material firmly held in place. No vegetative growth. Masonry block lining - Panels to line and level - no evidence of sub-grade erosion. Very occasional isolated blocks missing but no danger of progressive loss.
FAIR	Insitu concrete lining - Panels to line and level. Occasional points where erosion or settlement of sub-grade may be occurring. Minor cracking, up to 1mm wide, may affect one panel in 20. Joint material generally sound, some joints may require re-sealing. no vegetative growth in joints. Masonry block lining - Panels to line and level. Occasional points where erosion or settlement of sub-grade may be occurring. Small areas of bricks/blocks missing - not more than $0.5m^2$ on main system. Joint generally sound but some minor shear cracking. No cracks greater than 1mm wide.
POOR	Insitu concrete lining - Occasional panels deviate from line and level. approximately one panel in 20 clearly damaged, back erosion and/or bank settlement occurring at such points. Cracks up to 5mm wide randomly distributed over the lining. Frequent joint failures. Clear danger of progressive failure. Masonry block lining - Lining clearly deviates from line and level. Areas of bricks/blocks missing - up to $1.0m^2$ on main system. Frequent joint failures. Clear danger of progressive failure.
VERY POOR	Insitu concrete lining - Line and level lost over groups of panels. Panels collapsed, sub-grade erosion and/or settlement at these points. Other panels cracked, progressive failure occurring. Masonry block lining - line and level lost over tens of metres. Major holes in the lining occur frequently. Bonding lost over virtually full cross section in many places. progressive failure occurring.

ENGINEERING INSPECTION - STRUCTURE page 1

For hydraulic structures complete Sections A and B.
For non-hydraulic structures, e.g. bridges, roads etc. omit Section A

Structure type ___________________ Structure ID ______________________

A. Hydraulic functions:

	Good	Fair	Poor	Very Poor
Conveyance capacity				
Where relevant: Control of discharge/level				
Discharge measurement				
Water tightness				

B. Structural condition:

	Good (None/minimal)	Fair (Minor)	Poor (Serious)	Very Poor (V. serious)
Movement - (settlement displacement/heave/rotation)				
Scour damage to structure				
Scour damage to channel				
Joint condition				
Condition of structural elements (Cracking, etc.)				
Surface condition (Spalling, rust, damaged coatings)				
Stability of slopes/retained soil				

Condition summary:
Most serious defect ______________________________

Overall classification Good / Fair / Poor / Very poor

ENGINEERING INSPECTION - STRUCTURE page 2

C. Notes on sections A & B:
D.

D. Is any condition expected to become Poor or Very Poor within 12 months if not already so?

E. **Required action:**

- None ☐
- Repair ☐
- Demolish & rebuild ☐
- Demolish & redesign ☐

Define scope of detailed site survey/investigations, if these are required:

Rough estimate of quantities/materials required:

Factor: Conveyance capacity

GOOD	No more than 5% reduction in conveyance capacity at FSL. Flow can be distributed evenly across full width of structure.
FAIR	Conveyance capacity reduced by between 5 and 15% at FSL. Flow can be distributed evenly across full width of structure.
POOR	Conveyance capacity reduced by between 15 and 30% at FSL. Part of the open area may not function correctly.
VERY POOR	Conveyance capacity reduced by more than 30% at FSL. Part of the open area may not function correctly.

Factor: Control of discharge/level

GOOD	All gates fully operational. No damage to any fixed control surface. No blockage of any part of the structure
FAIR	All gates fully operational. No damage to any fixed control surface. Accumulation of sediment or debris may affect the control of discharge or level.
POOR	All gates in place. Sub-standard condition of one or more gates limits control of discharge or level. **Or** Fixed control surfaces damaged. Performance of system is affected.
VERY POOR	One or more gates missing or not working. **Or** Fixed control surfaces badly damaged. Structure cannot provide control of level or discharge. Structure is effectively non-functional.

Factor: Discharge measurement

GOOD	Level gauge/s present and correctly sited, clear of drawdown and turbulence. Structure approach, control section and exit in good repair and free from obstruction. Structure is not drowned under any operating conditions.
FAIR	Level gauge/s present and correctly sited, clear of drawdown and turbulence. Structure approach, control section and exit in good repair. Channel obstruction u/s of structure distorts flow profile through the control section. Structure is not drowned under any operating conditions.
POOR	Gauge/s missing/illegible or sited in zone of drawdown or turbulence. **and/or** Minor structural damage to control surface - crest, throat etc. Structure partially drowned.
VERY POOR	Control surface seriously damaged. Structure drowned under normal operating conditions.

Factor: Water tightness/Leakage

Error! Bookmark not defined.GOOD	No meaningful leakage.
FAIR	Minor leakage estimated at < 1% of design discharge of structure.
POOR	Leakage estimated at up to 5% of design discharge. This water may be re-used elsewhere.
VERY POOR	Serious leakage - > 5% of design discharge of structure. Affects water available in system and/or threatens erosion.

Factor: Movement

GOOD	No settlement or heave/rotation or displacement under load, including temperature stress. All joints appear sound. No structural cracking.
FAIR	Minor movement apparent from small structural cracks or minor joint displacement. structure remains basically sound, remedial work may be needed to avoid progressive movement and damage.
POOR	Movement in any plan is clearly apparent. Proper functioning of the structure already impaired. Early action needed to avoid progressive failure.
VERY POOR	Movement in any plane has seriously disrupted proper functioning of the structure. Full depth structural cracks of 5mm width or more. (Hydraulic structure) Rotation and displacement of joints mean that structure cannot retain water.

Factor: Scour at structure

Error! Bookmark not defined.GOOD	No meaningful damage to bed or banks adjacent to structure apparent on de-watering.
FAIR	Progressive erosion to bed or banks adjacent to structure. No structural damage has yet occurred but it may occur if remedial action is not taken.
POOR	Erosion to bed or banks has begun to seriously undermine the structure. Progressive failure is threatened.
VERY POOR	Structure actually or virtually ceased to function as intended. Extensive damage to structural elements.

Factor: Scour in channel

GOOD	no meaningful damage to bed or banks apparent on de-watering.
FAIR	Erosion to bed or banks does not affect conveyance. Bank stability not impaired to date but undercutting is threatened.
POOR	Erosion to bed or banks causing instability to side slopes.
VERY POOR	Progressive erosion to bed or banks causing extensive slips, threatening sudden blockage in sections of cut or bank failure in sections of fill. Excess sediment being deposited in reaches downstream.

Factor: Joint condition

Error! Bookmark not defined.GOOD	Joints appear sound throughout their length. Sealant or filler securely in place. No leakage, observed or expected.
FAIR	Minor defects. Joints generally sound but localised areas where sealant or filler is eroded or damaged. No obvious leakage path.
POOR	Sealant or filler lost or substantially damaged in several places. Joint will allow leakage (hydraulic structures), entry of water, dirt and debris (bridge decks etc).
VERY POOR	Sealant or filler lost over most of the joint length. Joint will be completely ineffective in preventing leakage (hydraulic structures), or entry of water, dirt and debris (bridge decks etc)

Factor: Structural elements

Error! Bookmark not defined.GOOD	Element(s) are sound. No signs of structural cracking, damage or distress.
FAIR	Element(s) are generally sound. Minor damage may have been sustained. Element(s) still fit to perform function within the immediate future.
POOR	Element(s) appear distressed. Structural cracks and/or damage. Performance is, or will shortly be, adversely affected.
VERY POOR	Elements no longer fit for function.

Note: Identify affected elements on the proforma.

Factor: Surface condition

GOOD	Surface sound. No evidence of deterioration under external or internal erosive/corrosive agents.
FAIR	Surface substantially sound. A few areas showing localised defects. Slow deterioration likely.
POOR	Surface noticeably defective:- spalling, cracking or rusting. Structural integrity of the structure at risk.
VERY POOR	Severe surface deterioration. Progressive or sudden failure of the element under external or internal agents is imminent.

Factor: Stability of slopes/retained soils

Error! Bookmark not defined.GOOD	Soil mass stable. No cracking, deformation or movement.
FAIR	Soil mass stable. Minor surface cracking and/or deformation, not extending into body of soil.
POOR	Soil mass marginally stable. Cracking and/or deterioration affecting body of soil. Evidence of minor movement and/or seepage.
VERY POOR	Soil mass unstable, cracking and/or deterioration affecting body of soil. Clear evidence of significant movement with/without seepage. Slip planes may be visible.

Engineer's Tank Inspection Record (Large Tanks)

DIVISION: ______________________ ENGINEER'S REPORT FOR: ______________________ TANK

Inspected by: ______________________ Date: ______________________

Max storage level: ______________________ Ws level: ______________________

Spillway crest level: ______________________ Sluice (LB) open? Y/N __________
Sluice (RB) open? Y/N __________

Bund:

	None	Minor (stable)	Serious	Very Serious (progressive)	NOTES (Location/cause/qty)
Upstream face:					
Settlement	☐	■	☐	☐	....
Surface erosion	☐	☐	☐	☐	....
Cracking, slips	☐	■	☐	☐	....
Rip-rap dislodged	☐	☐	☐	☐	....
Gauged board damaged	☐	☐	☐	☐	....
Downstream face:					
Settlement	☐	■	☐	☐	....
Surface erosion	☐	☐	☐	☐	....
Cracking, slips	☐	■	☐	☐	....
Heave at base	☐	☐	☐	☐	....
Seepage/wet areas	☐	☐	☐	☐	....
Toe drain discharge	☐	☐	☐	☐	....
Vegetation	☐	☐	☐	☐	....

HR Wallingford

Engineer's Tank Inspection Record (Large Tanks)

	None	Minor (stable)	Serious	Very Serious (progressive)	NOTES (Location/cause/qty)
Crest:					
Settlement	☐	■	☐	☐	....
Erosion	☐	☐	☐	☐	....
Cracking	☐	■	☐	☐	....
Road damage	☐	☐	☐	☐	....
Vegetation	☐	☐	☐	☐	....

Overall condition:

Good		Fair		Poor		Very Poor	

Most serious defect:

Spillway gated/ungated:

	None	Minor (stable)	Serious	Very Serious (progressive)	NOTES (Location/cause/qty)
Hydraulic performance:					
Conveyance capacity	☐	☐	☐	☐	....
Control of discharge/level	☐	☐	☐	☐	....
Structural condition:					
Gate, guides damaged/corroded	☐	☐	☐	☐	....
Gate mechanism operating difficulty	☐	☐	☐	☐	....
Gate leakage	☐	☐	☐	☐	....
Scour/bank erosion	☐	☐	☐	☐	....
Cracking-structural	☐	☐	☐	☐	....
Structural movement	☐	☐	☐	☐	....
Surface condition	☐	☐	☐	☐	....

Overall condition:

Good		Fair		Poor		Very Poor	

Most serious defect:

Engineer's Tank Inspection Record (Large Tanks)

	None	Minor (stable)	Serious	Very Serious (progressive)	NOTES (Location/cause/qty)
Sluice (LB):					
Upstream hydraulic performance:					
Conveyance capacity	☐	☐	☐	☐	....
Control discharge/level	☐	☐	☐	☐	....
Gate leakage	☐	☐	☐	☐	....
Structural condition:					
Gate, guides damaged/corroded	☐	☐	☐	☐	....
Gate mechanism - operation difficult	☐	☐	☐	☐	....
Stop log closure problems	☐	☐	☐	☐	....
Trashrack damaged/blocked/corroded	☐	☐	☐	☐	....
Gate housing/access bridge damage	☐	☐	☐	☐	....
Downstream hydraulic performance					
Pipe damage, leaking	☐	☐	☐	☐	State if inspection possible Y/N
Overtopping, structure	☐	☐	☐	☐	....
Structural condition:					
Cracking - structural	☐	☐	☐	☐	....
Structural movement	☐	☐	☐	☐	....
Surface condition	☐	☐	☐	☐	....
Scour/back erosion	☐	☐	☐	☐	....

Overall condition:

Good		Fair		Poor		Very Poor	

Most serious defect:

Engineer's Tank Inspection Report (Large Tanks)

	None	Minor (stable)	Serious	Very Serious (progressive)	NOTES (Location/cause/qty)
Sluice (RB):					
Upstream hydraulic performance:					
Conveyance capacity	☐	☐	☐	☐	....
Control discharge/level	☐	☐	☐	☐	....
Gate leakage	☐	☐	☐	☐	....
Structural condition:					
Gate, guides damaged/corroded	☐	☐	☐	☐	....
Gate mechanism - operation difficult	☐	☐	☐	☐	....
Stop log closure problems	☐	☐	☐	☐	....
Trashrack damaged/blocked/corroded	☐	☐	☐	☐	....
Gate housing/access bridge damage	☐	☐	☐	☐	....
Downstream hydraulic performance					
Pipe damage, leaking	☐	☐	☐	☐	State if inspection possible Y/N
Overtopping, structure	☐	☐	☐	☐	....
Structural condition:					
Cracking - structural	☐	☐	☐	☐	....
Structural movement	☐	☐	☐	☐	....
Surface condition	☐	☐	☐	☐	....
Scour/back erosion	☐	☐	☐	☐	....

Overall condition: Most serious defect:

Good		Fair		Poor		Very Poor	

Engineer's Tank Inspection Record (Minor Tanks)

DIVISION: ______________________ ENGINEER'S REPORT FOR: ______________________ TANK

Inspected by: ______________________ Date: ______________________

Max storage level: ______________________ Ws level: ______________________

Spillway crest level: ______________________ Sluice (LB) open? Y/N __________
Sluice (RB) open? Y/N __________

Bund:

	None (stable)	Minor	Serious	Very Serious (progressive)	NOTES (Location/cause/qty)
Settlement	☐	■	☐	☐	....
Surface erosion	☐	☐	☐	☐	....
Cracking, slips	☐	■	☐	☐	....
Rip-rap dislodged	☐	☐	☐	☐	....
Gauged board damaged	☐	☐	☐	☐	....
Heave at base of d/s face	☐	☐	☐	☐	....
Seepage/wet areas	☐	☐	☐	☐	....
Toe drain discharge	☐	☐	☐	☐	....
Vegetation	☐	☐	☐	☐	....
Road damage	☐	☐	☐	☐	....

Overall condition:

Good		Fair		Poor		Very Poor	

Most serious defect:

Engineer's Tank Inspection Record (Minor Tanks)

	Good (None)	Fair (Minor)	Poor (Serious)	Very Poor (Very Serious)	NOTES (Location/cause/qty)
Spillway gated/ungated:					
Hydraulic performance:					
Discharge adequacy	☐	☐	☐	☐	....
Control of discharge/level	☐	☐	☐	☐	....

	None	Minor (stable)	Serious (progressive)	Very Serious	NOTES (Location/cause/qty)
Structural condition:					
Gate, guides damaged/corroded	☐	☐	☐	☐	....
Gate mechanism operating difficulty	☐	☐	☐	☐	....
Gate leakage	☐	☐	☐	☐	....
Scour/bank erosion	☐	☐	☐	☐	....
Cracking-structural	☐	☐	☐	☐	....
Structural movement	☐	☐	☐	☐	....
Surface condition	☐	☐	☐	☐	....

Overall condition:

Good		Fair		Poor		Very Poor	

Most serious condition:

Engineer's Tank Inspection Record (Minor Tanks)

Sluice (LB):

Upstream hydraulic performance:	Good (None)	Fair (Minor)	Poor (Serious)	Very Poor (Very Serious)	NOTES (Location/cause/qty)
Discharge adequacy	☐	☐	☐	☐	....
Control discharge/level	☐	☐	☐	☐	....
Gate leakage	☐	☐	☐	☐	....

Structural condition:	None	Minor (stable)	Serious	Very Serious (progressive)	NOTES (Location/cause/qty)
Gate, guides damaged/corroded	☐	☐	☐	☐	....
Gate mechanism - operation difficult	☐	☐	☐	☐	....
Stop log closure problems	☐	☐	☐	☐	....
Trashrack damaged/blocked/corroded	☐	☐	☐	☐	....
Gate housing/access bridge damage	☐	☐	☐	☐	....
Pipe damage, leaking	☐	☐	☐	☐	State if inspection possible Y/N
Cracking - structural	☐	☐	☐	☐	....
Structural movement	☐	☐	☐	☐	....
Surface condition	☐	☐	☐	☐	....
Scour/back erosion	☐	☐	☐	☐	....

Overall condition:

Good		Fair		Poor		Very Poor	

Most serious defect:

Engineer's Tank Inspection Report (Minor Tanks)

Sluice (RB):

Upstream hydraulic performance:	Good (None)	Fair (Minor)	Poor (Serious)	Very Poor (Very Serious)	NOTES (Location/cause/qty)
Discharge adequacy	☐	☐	☐	☐	....
Control discharge/level	☐	☐	☐	☐	....
Gate leakage	☐	☐	☐	☐	....

Structural condition:	None	Minor (stable)	Serious (progressive)	Very Serious	NOTES (Location/cause/qty)
Gate, guides damaged/corroded	☐	☐	☐	☐	....
Gate mechanism - operation difficult	☐	☐	☐	☐	....
Stop log closure problems	☐	☐	☐	☐	....
Trashrack damaged/blocked/corroded	☐	☐	☐	☐	....
Gate housing/access bridge damage	☐	☐	☐	☐	....
Pipe damage, leaking	☐	☐	☐	☐	State if inspection possible Y/N
Cracking - structural	☐	☐	☐	☐	....
Structural movement	☐	☐	☐	☐	....
Surface condition	☐	☐	☐	☐	....
Scour/back erosion	☐	☐	☐	☐	....

Overall condition:

Most serious defect:

Good		Fair		Poor		Very Poor	

Engineer's Anicut Inspection Report

DIVISION: ______________________________

ENGINEER'S REPORT FOR: ___________________________ Anicut

Inspected by: _____________________________________ Date: _____________________

Overflow weir? Y/N ____________

Design head on weir: ____________ Head on weir: _____________

Design flood (m^3/s): ____________ Weir discharge: _____________

Discharge equation: ____________ Avg gate opening: ___________

Flood gate type: Vertical ☐ Radial ☐ None ☐

No and size of flood gates (B * H): _______ Nos: ______________
or, (B * H * R): _______ Nos: ______________

Flood gates and/or weir: Hydraulic Performance:	Good (None)	Fair (Minor)	Poor (Serious)	Very Poor (Very Serious)	NOTES
Discharge adequacy	☐	☐	☐	☐	....
Control of discharge/level	☐	☐	☐	☐	....
Water tightness (structure)	☐	☐	☐	☐	State if can be detected: Y/N

Engineer's Anicut Inspection Record

	Good (None)	Fair (Minor)	Poor (Serious)	Very Poor (Very Serious)	NOTES
Flood gates:					
Gate, guides damaged/corroded	☐	☐	☐	☐	....
Gate mechanism - operation difficult	☐	☐	☐	☐	....
Gate leackage	☐	☐	☐	☐	State if can be detected: Y/N

Overall conditions: | Most serious defect:

Good		Fair		Poor		Very Poor	

	Good (None)	Fair (Minor)	Poor (Serious)	Very Poor (Very Serious)	NOTES
Structural condition:					
Scour damage - structure	☐	☐	☐	☐	....
Scour damage - channel	☐	☐	☐	☐	....
Movement - settlement/displacement/ heave/rotation	☐	☐	☐	☐	....
Joint condition	☐	☐	☐	☐	....
Cracking - structural	☐	☐	☐	☐	....
Surface condition	☐	☐	☐	☐	....
Slope stability (entrance/exit)	☐	☐	☐	☐	....

Overall condition: | Most serious defect:

Good		Fair		Poor		Very Poor	

Engineer's Anicut Inspection Record

Right sluice:

No & size of sluice gates: (B * H): __________ Nos: ____________
or (B * H * R): __________ Nos: ____________

	Good (None)	Fair (Minor)	Poor (Serious)	Very Poor (Very Serious)	NOTES
Hydraulic performance:					
Discharge adequacy	☐	☐	☐	☐	....
Control of discharge/level	☐	☐	☐	☐	....
Gate leakage	☐	☐	☐	☐	State if can be detected: Y/N
Structural condition:					
Gate, guide damaged/corroded	☐	☐	☐	☐	....
Movement - settlement/displacement/ heave/rotation	☐	☐	☐	☐	....
Scour damage - structure	☐	☐	☐	☐	....
Scour damage - channel	☐	☐	☐	☐	....
Joint condition	☐	☐	☐	☐	....
Cracking - structural	☐	☐	☐	☐	....
Surface condition	☐	☐	☐	☐	....
Slope stability (entrance/exit)	☐	☐	☐	☐	....

Overall condition: Most serious defect:

Good		Fair		Poor		Very Poor	

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Engineer's Anicut Inspection Record

Left sluice:

No & size of sluice gates: (B * H): __________ Nos: __________
or (B * H * R): __________ Nos: __________

	Good (None)	Fair (Minor)	Poor (Serious)	Very Poor (Very Serious)	NOTES
Hydraulic performance:					
Discharge adequacy	☐	☐	☐	☐	....
Control of discharge/level	☐	☐	☐	☐	....
Gate leakage	☐	☐	☐	☐	State if can be detected: Y/N
Structural condition:					
Gate, guide damaged/corroded	☐	☐	☐	☐	....
Movement - settlement/displacement/ heave/rotation	☐	☐	☐	☐	....
Scour damage - structure	☐	☐	☐	☐	....
Scour damage - channel	☐	☐	☐	☐	....
Joint condition	☐	☐	☐	☐	....
Cracking - structural	☐	☐	☐	☐	....
Surface condition	☐	☐	☐	☐	....
Slope stability (entrance/exit)	☐	☐	☐	☐	....

Overall condition:

Good		Fair		Poor		Very Poor	

Most serious defect:

HR Wallingford is an independent company that carries out research and consultancy in civil engineering hydraulics and the water environment. Predictive physical and computational model studies, desk studies and field data collection are backed by large scale laboratory facilities and long term programmes of advanced research. Established in 1947 as a Government research centre, the Company now employs more than 200 engineers, scientists, mathematicians and support staff, many of whom are recognised international experts. Based on a 36 hectare site near Oxford, HR Wallingford has extensive national and international experience, with offices and agents around the world.

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Address and Registered Office: **HR Wallingford Ltd,** Howbery Park, Wallingford, Oxon OX10 8BA, UK
Tel:+44 (0) 1491 835381 Fax:+44 (0) 1491 832233 Internet Server: http://www.hrwallingford.co.uk

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