# Maintaining the Value of Irrigation and Drainage Projects

## TDR Project R 6650

J C Skutsch

Report OD/TN 90
February 1998

HR Wallingford

DFID Department For International Development

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# Contract

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# Summary


Maintaining the Value of Irrigation and Drainage Projects

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Large investments in irrigation and drainage continue to be made by national governments and the international community.

Good maintenance can help prevent unnecessary losses of production, extend the effective lifetime of irrigation systems and delay the need for new capital expenditure on rehabilitation or modernisation. Poor maintenance may also have impacts which are more difficult to quantify, including inequities of supply and farm income, environmental problems, and the risk of sudden failures of infrastructure. This desk study, funded by the Department for International Development (DFID), UK, under its TDR programme, examines how maintenance affects project economic outcome.

After an Introduction, various institutional, economic, social and technical failings, which limit the effectiveness of maintenance in many parts of the developing world, are identified in Section 2. The premature failure of many irrigation systems is often promoted by a shortage of funds. International banks readily provide loans for the construction and rehabilitation of irrigation infrastructure, but have consistently refused to fund maintenance, seeing O&M as the responsibility of the host nation. The annual cost of satisfactory maintenance is low by comparison with the initial capital investment, say 2% for a system reasonably well designed and constructed. Even so, governments throughout the world, particularly in developing economies, tend to assign inadequate resources to maintenance. Schemes producing crops other than rice are particularly affected by poor condition of the infrastructure.

Section 3 reviews issues affecting scheme performance, including policies for financing maintenance and analysis of project economic sustainability. In many cases the charges to farmers for water, which were once intended to cover the costs of system O&M and sometimes also a part of the system construction costs, have been allowed to fall substantially in real terms. The rate of collection of due charges is also often unsatisfactory. Current bank policies encouraging governments to turnover large parts of public irrigation systems to farmers have developed in response to national under-spending on maintenance, and an expectation, as yet generally unconfirmed, that O&M should improve when end-users are responsible for parts of the system.

Section 4 includes outline analyses linking maintenance expenditure with project returns. The examples chosen are considered reasonably representative of conditions in South and South East Asia. Almost no data linking maintenance and scheme performance are available. The study was therefore based on averaged crop outputs and maintenance expenditures on schemes which had been

rehabilitated under international funding, supported by informed assumptions about scheme performance over time derived from background experience.

The study concludes, Section 5, that satisfactory maintenance produces high returns. The estimated equivalent annual net benefit of satisfactory funding over typical levels of under-spending varied between $50/ha and $100 /ha at 1992 prices, depending on crop and location. On a medium-sized project of 20,000 ha, the net benefits would thus have amounted to $1.0-2.0 million per year.

Poor maintenance would have entailed extra government expenditure of up to $200/ha as the schemes would have needed rehabilitation well before the end of their design life. The savings on the 20,000 ha project could otherwise have been used to provide a safe supply of drinking water to over 25,000 people (World Bank estimated cost of $150/head).

The study highlighted the lack of reliable data needed to guide government policies on basic issues including the restructuring of irrigation institutions, the charges to be made for water and the turnover of systems to farmers. Apart from studies in Mexico, which in many respects is not typical of developing economies, there is almost no documentation on the effects of system turnover on the irrigation infrastructure. It is likely that the outcome will depend very much on local socio-economic conditions. Billions of dollars of investment are at risk.

Section 6 recommends field investigations to obtain the information necessary to derive relationships between maintenance, system condition, institutions and performance. Better methods to target available funds to areas of greatest need are also needed to improve maintenance planning. New methodologies for project economic planning are also overdue. System maintenance, in particular low maintenance designs, needs to be given much greater importance in project preparation.

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# 1. INTRODUCTION

## 1.1 Background

Irrigated agriculture presently provides 30% of world food production. In some arid countries, such as Egypt, the entire national food output depends on irrigation. The Food and Agriculture Organisation (1996) has estimated that irrigated agriculture will need to provide 60% of the extra food needed to meet population growth throughout the first half of the next century.

The strategic 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 by grants under bilateral and multilateral aid programmes. For example, in the early ninety eighties, under the Sixth Five Year plan, India was investing some $2.4 billion annually in the irrigation sector (Jurriens, 1993). Throughout the decade to 1993, the World Bank and the Asian Development Bank together lent some $1.5 billion annually for irrigation, comparable to their commitments for roads. Irrigation received more bank funding than any other type of development except the power sector. Worldwide expenditure on irrigation has declined sharply in recent years, though it is still substantial.

Despite such heavy capital investment, systems are failing well within their design lifetimes. Perhaps 66% 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 because maintenance is inadequate. Jones (1995) concluded:

…. " 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".

The lending agencies have traditionally been reluctant to fund recurrent expenditures. Under normal lending agreements, developing governments are required to commit themselves to an agreed level of spending on O&M. International banks readily provide loans for the construction and rehabilitation of irrigation infrastructure, but have consistently refused to fund maintenance, seeing O&M as the responsibility of the host nation. Current bank policies to encourage governments to turnover large parts of public irrigation systems to farmers have developed in response to national under-spending on maintenance, and an expectation, as yet generally unconfirmed, that O&M should improve when end-users are involved.

"… The Bank's classic remedy for O&M problems (apart from making rehabilitation loans) has been to require increased public spending on O&M, the spending to be covered by higher charges for water. Higher water charges have been embedded in the legal covenants of hundreds of loans. In the case of irrigation, the Bank has linked cost recovery to O&M. There is, however, no evidence yet of better cost recovery or of compliance with covenants to increase spending on maintenance " (Jones, 1995).

The prevailing lack of knowledge about the economic and social implications of neglect in irrigation systems contrasts with information from other development sectors, which may provide useful analogies.

Much is known about the effects of road deterioration in the developing world, partly as the result of research work commissioned by the World Bank from 1971 onwards. Relationships between economic lifetime, design and construction standards, maintenance, and operating costs, were developed to guide the Bank's lending policies (WB, 1991). More than $20 million was contributed to the research by national governments, including that of the UK.

The Bank (1994) also reviewed the effectiveness of road maintenance under alternative institutional arrangements in forty-two developing countries. It concluded that backlogs in work were fewer, and the condition of roads was consistently better, where responsibility for maintenance was decentralised to independent local governments. Over thirty percent of unpaved roads were found to be in poor condition under central management but only fifteen percent were poor where maintenance was decentralised. However, decentralisation was also associated with higher unit maintenance costs and greater variation in quality of work between regions, attributed to differences in institutional or human capacity. The Bank concluded that decentralisation was inherently neither good nor bad. Success depended on incentives, capabilities and costs.

In the water supply and sanitation sector, a three-tiered organisation is recommended by the Bank. Under this set-up, the national agency handles long-term planning, sets standards and provides technical assistance; regional utilities are responsible for monitoring compliance with standards, supervision and staff training; local agencies manage systems, collect fees, monitor use and maintenance and prepare budgets. The active participation of end-users in project identification and preparation is also important. A study of 121 completed rural water supply projects in Africa, Asia and Latin America showed that projects involving a high degree of participation were much more likely to maintain good supplies than schemes where decision-making was centralised. (WB, 1994).

A 1985 Bank review, undertaken five to ten years after the completion of twenty five agricultural and rural development projects, found that participation by beneficiaries and grass-roots institutions was a key factor in long-term success. Without participation, projects were generally not well maintained and failed to produce sustained benefits.

In a 1994 review of overall spending on all infrastructure, the World Bank concluded:

- $45 billion of investment in roads in the developing world had been lost through neglect over the preceding 20 years.
- Developing countries could have made savings of 25% in the $200 billion spent on infrastructure each year, without affecting output.
- Over three years, the losses in infrastructure owing to technical deficiencies could have been used, for example, to provide one billion people with a safe supply of drinking water. (WB, 1994).

Gulati and Svendsen, on irrigation in India (1994), say:

"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."

In an assessment in 1994, the World Bank estimated potential rates of return to satisfactory maintenance of irrigation systems in India of up to 40%.

Since conditions vary considerably between schemes, the establishment of an appropriate target level for maintenance spending is not straightforward (Section 2.3). Once funding reaches a certain level, the returns to further expenditure become increasingly marginal. It can also be argued that a high standard of maintenance leads to postponement of the date at which a system should really be modernised, that is physically updated and its management and institutions improved to meet enhanced objectives, rather than rehabilitated to original standards. The design lifetime of a system is usually set at 25 or 30 years, and project returns are predicated on that basis. Important social and technical changes may have taken place by the end of the period, so a radical review of project standards would be justified at the end of that period. However, projects not infrequently require major works within 15 years of construction, rather than at the end of the design life. If major changes to system functioning appear to be needed so early, then the original design brief was inadequate. In a context where maintenance practices are frequently poor, under-funding of recurrent costs so as to allow early modernisation of a project would appear to institutionalise unplanned obsolescence and argue against sustainability. The economic justification for the project also becomes seriously distorted.

## 1.2 Scope and Objectives

The objective of the study is to demonstrate to governments and funding agencies the returns to maintenance of irrigation systems and the economic consequences of neglect. The analyses are broadly based on schemes, which underwent rehabilitation under international funding, so that the outcome has some relevance to the real world.

It is important to emphasise that the study is concerned with maintenance, and not with the combined impact of operations and maintenance (O&M). The role of better operations in improving scheme performance is now widely recognised, whereas the fundamental part played by maintenance in sustaining performance is not. For reasons discussed later (Section 2.1), the response of irrigation authorities to declining system performance is generally to rehabilitate the infrastructure rather than try to improve maintenance.

In a climate where governments are increasingly keen to turnover operation and maintenance tasks to farmers, it is important to be able to predict the expenditure needed for maintenance. If the financial commitments are too heavy in relation to the benefits, farmers will be unwilling or unable to take over new responsibilities. There is a risk that turnover policies may fail and that schemes will disintegrate. At the same time the World Bank is advising governments to levy varying rates of service charge for water, depending upon the circumstances of individual schemes. A much better understanding of the links between maintenance and scheme economic performance is therefore urgently required.

The study aims to highlight the issues involved, without resorting to fully detailed economic analysis. Alternative approaches are valid. Berkoff (1998) comments "It may be true that the need for maintenance is self-evident. But I believe that the best way to demonstrate it is to turn the economic argument upside down. First ask the question: what increases in intensities, or yields or changes in cropping patterns are needed to justify the level of maintenance expenditures proposed. And second: are such increases likely, and under what conditions?"

# 2. NEGLECT OF MAINTENANCE

An ideal maintenance regime would include "planned and auditable procedures to pick up problems before they become critical, and tight financial control to prevent waste" (New Civil Engineer, 1996).

Maintenance practices on public irrigation systems in many parts of the developing world fall short of the ideal in many respects. Evaluations carried out by the World Bank (WB 1985, Jones 1995) showed that operations and maintenance procedures were unsatisfactory in 55% of completed projects. Schemes where crops other than rice are grown, particularly in arid/semi-arid areas, are particularly at risk under poor maintenance.

Apart from adversely affecting irrigation supply and reducing system lifetime, poor maintenance is also an important cause of drainage congestion, flooding and waterlogging problems. The limited sums available for scheme maintenance are invariably spent on irrigation supply, rather than on the drainage system. The consequences for agricultural production of poor drainage condition may be as serious as inadequate irrigation supply. Finney (1997), describing problems with sub-surface drainage in Turkey, comments: " – on some schemes as much as 60% of the existing sub-surface drains was found to need deferred maintenance --- the drainage benefits in scheme areas where deterioration has occurred are certain to be reduced well below their potential level." Of Pakistan he says: -- " given the severe public sector financial constraints --- adequate recovery of drainage O&M costs from farmers is essential if the system is to be operated and maintained effectively. In the few projects where drainage cesses are applied they are, however, set at negligible levels at present."

## 2.1 Causes

Most governments assign low priority to maintenance. For example, in 1996/97 the UK Government further slashed spending on road maintenance, which had already been reduced to a level at which pavements were showing rapidly increasing wear and tear. It was estimated by roads engineers that the costs of necessary reconstruction in future would exceed immediate savings three times over.

Irrigation departments in the developing world face a number of special difficulties to compound problems of overstaffing, poor motivation, skill shortages and corruption, which are endemic to government bureaucracies in many parts of the world.

In the face of pressing demands to provide basic amenities like clean water and sanitation, rural electricity, health, education and welfare for rapidly growing populations, developing governments downgrade the needs of agricultural systems in remote areas. The budgets allocated to O&M departments are generally inadequate to prevent progressive deterioration of their systems. For example, the Government of India allocated $4 - 8 / ha. for O&M in 1992, whereas figures of $10 - 17 / ha. were recommended by its Maintenance Finance Committee (Desai and Jurriens, 1992).

This fundamental constraint leads to a spiral of decline: deterioration of the system; cynicism amongst agency staff; worsening water supply; falling output; anger, despair and reduced investment by farmers; refusal to pay water charges; vandalism; increased conflict.

The problem of inadequate funding is aggravated by a large number of issues, economic, technical and institutional, as summarised below:

- Maintenance suffers by being grouped in the O&M budget with operations. Available money is generally assigned to:

    1) establishment costs
    2) operations (e.g. power, particularly on pumped schemes)
    3) maintenance

  in that order. The budget is mostly swallowed up by large establishment costs covering all staff activities, not just those relating to O&M. It may be used to fund the entire set of overhead duties. Such other activities generally consume an inordinate share of staff time and cost. The proportion of the budget available for expenditure on maintenance works is usually quite small, typically below 20% of the total, though the amount is hard to estimate.

- Available funds are not necessarily targeted to areas of greatest need and returns, because there is no standardised way of prioritising works. The nature and severity of problems may vary widely, both within a project and between projects. For want of better procedures, regional offices commonly allocate funds on the basis of a flat rate per unit of area.

- Over the last four decades the revenue from water service fees in many countries has fallen far behind the costs of O&M, owing to inflation and poor rates of collection. Irrigation is therefore seen as a net drain on national revenues. More profitable sectors of the economy invariably take precedence in a competition for scarce resources.

- Water fee collections are generally sent direct to the Finance Ministry and are not available to the irrigation department for expenditure on O&M. There is thus no link between fee collection and expenditure on maintenance, nor any incentive to improve collection rates.

- Staff are likely to be traditionally educated in design and construction. They are not trained in the special tasks involved in O&M and often lack motivation because postings are generally in remote areas, offering poor rewards and prospects for career development.

- Irrigation systems tend to fail gradually, becoming increasingly ineffective. It is rare that a system fails with major hazard to life or limb, unlike for example a national railway system. The implications of functional failure are not dramatic, not publicised and not understood.

- New projects, attracting soft international loans, have a high profile. There is no political capital to be derived from maintaining existing systems.

- The turnover of services to farmers still leaves the Government responsible for expenditures on the main system, a major component of overall O&M cost. If the farmers refuse to accept increased responsibilities, Government is forced to subsidise tertiary level O&M or see the system disintegrate.

The problems of poor maintenance are thus far from being purely financial in origin, but little improvement can be expected unless more resources can be made available. Alternative arrangements to increase funding or reduce costs are discussed in Section 3. McLoughlin (1988) considers that spending on irrigation O&M is essential to "the maintenance of a very high percentage of the national product, and on a recurrent basis". There are five main aspects to "this self-evident truth":

- define what costs and benefits should be included
- decide on economic or opportunity pricing
- resolve problems of methodology and lack of data
- use total costs and benefits or incremental changes to them
- select O&M activities on basis of economic ranking

(There is) "--- a virtual absence of any sense of economics in O&M enhancement programmes. And no published work on the economic ranking of O&M alternatives under constrained conditions. Planning/investment alternatives do not seem to have been analysed in terms of their relative contributions to agricultural output".

## 2.2 Effects

Declining production, financial, and economic returns, cannot be ascribed solely to poor condition of the irrigation infrastructure. Cornish and Skutsch (1997) identified a large number of economic, social and environmental problems that can affect output. The World Bank (1996) identified the unfavourable prevailing world price for rice as having over-riding influence on the performance of schemes in South East Asia at the time of evaluation.

Nonetheless, there are some types of annual maintenance problems, notably channel blockage by deposited sediment and weed growth and embankment failures, Figure 1, which have major potential to affect water supply to the scheme, and thus affect output and equity. Levine (1986) points out that canal and cropping systems actually possess in-built capacity in excess of that theoretically available, so that the effects of e.g. progressive channel blockage, will not be felt immediately. However, the onset of problems with water distribution will merely be delayed and not eliminated. The issue is further examined in Section 3.1.

Chaudhury (1989) describes frequent breaches and interruptions in water supplies on systems in Pakistan. Maintenance was severely limited by financial constraints. Costs had increased because necessary work had been deferred and the system was steadily ageing. Revenues generated by the system had not kept pace with rising costs.

Carruthers (1993) summarised the effects of poor O&M on project performance as follows:

- Below-capacity working and/or erratic water supplies which lower the area cultivated and depress yields.
- A shift by farmers to lower value crops.
- Reduced use of inputs.
- Reduced on-farm investment.

All the above trends will have an immediate effect on economic output.

There are also longer-term consequences:

- International loans for premature rehabilitation must be repaid in foreign currency earned from exports or saved as a result of import substitution. Although lending agreements normally include extended grace and repayment periods and the interest rates are low[1], scarce foreign exchange is lost from the economy.
- Local funds, which could be productively employed in other sectors of the economy, are spent on unnecessarily rehabilitating deteriorated systems.
- A decline in food production could require scarce foreign exchange to be spent on importing basic foodstuffs.

Clear, but unquantified, adverse socio-economic effects also result from poor maintenance:

- Farmers in the more favoured parts of the system may continue to receive an adequate supply, whilst those at the tail can face ruin. Poor maintenance thus directly contributes to inequities within the community.
- Smallholder farmers operate on a narrow margin between success and failure. Land is sometimes mortgaged against the following harvest to pay for the cost of agricultural inputs. The consequences of a single disastrous crop failure can include the loss of a farmer's land and migration to seek work in already overcrowded cities.

Poor maintenance can also produce negative environmental consequences, for example, waterlogging and salinity caused by impeded drainage and adverse impacts on health from water-related diseases such as schistosomiasis and malaria.

A fully comprehensive economic accounting of the impacts of poor maintenance on performance would be complex and beyond the scope and purpose of the present study. Simplified, but indicative, analyses are summarised in Section 4 and Appendix 2. The economic/social costs of poor maintenance have been taken as the value of lost production and the cost of early rehabilitation triggered by reduced output from the scheme. The analyses therefore understate the returns to satisfactory maintenance.

## 2.3 Expenditures on maintenance

Expenditure on capital items or infrastructure is normally clearly documented and monitored. O&M expenditure is less well managed, whilst the sums involved are sizeable over the lifetime of a project.

Operation and maintenance are invariably grouped under a single budget heading. Irrigation departments may, in addition, be able to draw upon a number of other budget lines covering, for example, emergency works or strategic components of the system, such as headworks. Institutional costs, the money spent on maintaining the irrigation bureaucracy, which commonly accounts for the major part of the total budget,

[1] Under multilateral bank rules, loans to developing countries come with either a 1 % or ¾% service charge, a grace period of 10 years and repayment period of 35 years. There is thus a large element of grant in the agreements.

are also usually included under the general O&M budget. It is therefore not a simple process to determine actual spending on maintenance works.

Tables 1 shows estimated average per hectare spending on maintenance works, excluding operation and establishment expenditures, in a number of developing countries at the dates shown. The variations reflect differences in the costs of living between the various nations, and also the extent to which mechanisation is used in maintenance. For example, excavators and draglines are used for canal maintenance in Mexico, whereas much of the maintenance in South and South East Asia is carried out by hand.

**Table 1 Actual and recommended spending on maintenance, by country ($/ha).**

Budgets generally include sums for operation, maintenance and a large component for establishment costs. The figures below are, unless otherwise stated, for expenditures on maintenance works, excluding operations and establishment costs.

| Country | Budget $/ha | Reqd $/ha | Year | Source |
|---|---|---|---|---|
| India (avge) | 4-8(O&M) | 10-17 | 1992 | Jurriens (1993) |
| Some states: | | | | |
| Bihar | 3.3 | N/A | 1991 | Jurriens (1993) |
| Haryana | 2.6 | N/A | 1991 | Jurriens (1993) |
| Madhya P | 3.0 | N/A | 1990 | Jurriens (1993) |
| Punjab | 1.4 | N/A | 1991 | Jurriens (1993) |
| Uttar P | 4.2 | N/A | 1990 | Jurriens (1993) |
| Pakistan | 2.7 | 5.7 | 1993 | World Bank (1994) |
| Indonesia | 5-13 | 18-28 | 1991 | Gerards et al (1991) |
| Sri Lanka | 8 | 28-38 | 1993 | Geijer et al (1995) |
| Mexico | 18-26 | (18-26) | 1993 | Johnson (1993) |

**Table 2 World Bank recommended expenditure on O&M for Projects in India.**

Variation in recommended O&M expenditures ($/ha)

| Project | State | Year | O&M |
|---|---|---|---|
| Kadana | Gujarat | 1970 | 2.3 |
| Chambal | Rajasthan | 1974 | 3.6 |
| Chambal | M.P. | 1975 | 5.5 |
| Nagarjunasagar A.P. | Tamil Nadu | 1976 | 5.1 |
| Periyar-Vaigai | Tamil Nadu | 1977 | 5.7 |
| Jayakwadi Purna | Maharashtra | 1977 | 8.6 |
| Medium projects | Orissa | 1977 | 5.7 |

Source: Gulati, Svendsen and Choudhury, 1994.
Notes: 1 Expenditures needed to cover all O&M costs.
2 Exchange rate $1US = rp 8.75 (1977).

Target spending figures for a number of countries, produced by different authorities for particular areas, are also shown in Tables 1, 2. They are the amounts which, if correctly used, should safeguard the proper functioning of the scheme over the long term. It is probably true that the system would continue to function reasonably if expenditure were lower for limited periods, particularly in the early part of system life (Levine, 1986), but sustained performance would be put at risk. It is apparent that the sums actually allocated were very generally less than 50% of the estimated target levels. The figures are necessarily approximate but they indicate the scale of the problem. Table 3 shows a relatively high proportion of the O&M budget in Sri Lanka is spent on maintenance.

**Table 3 Proportion of total O&M budget assigned to maintenance (selected schemes in Sri Lanka)**

| Scheme | Maintenance | Operations and general charges |
|---|---|---|
| Giritale | 40% | 60% |
| Ridibendi Ela | 44% | 56% |
| Gal-Oya L.B | 42% | 58% |
| Inginimitiya | 23% | 77% |
| Mahakandarawa | 40% | 60% |
| Source: TEAMS, 1991 | | |

It is not a simple task to arrive at estimates of satisfactory (target) spending, the average sum per hectare needed to maintain the system in good, but not perfect, working condition. The local environment and the behaviour of the irrigating community will affect requirements. There is clearly a trade-off to be made between the incremental costs and benefits of increasing levels of maintenance spending. It is not appropriate merely to factor up inadequate existing expenditure, because in many cases the available resources may not be spent efficiently. The level of spending needs to be set such that 'immediate' problems - loss of canal capacity through deposition of sediment, growth of weeds and bank failures - are held in check, whilst so-called 'incipient' problems, which ultimately may lead to structural failure, are monitored and tackled when appropriate (Table 4). Allowance should be included for minor repairs, unblocking of culverts and road grading. A programme of regular maintenance is obviously highly desirable but for the purposes of the present study, it is assumed that a regime of 'pragmatic' maintenance, as suggested above, is followed and that published target spending levels quoted by irrigation departments and consultants were set on this basis. A typical methodology used to derive target levels of maintenance expenditure is described by e.g. TEAMS Consultants (1991).

Statements by McLoughlin (1988) suggest that the target levels are not excessive:

"With no exceptions to this writer's knowledge, historical efforts to estimate the funding needed for 'adequate' O&M have chronically underestimated such 'full funding' requirements. A review of such efforts in numerous countries suggests that however much financial budgets are moved upwards, both operations and maintenance still cost relatively more; the budget boosts tend to be too little too late, and maintenance suffers more than operations. The boosts are often tied in turn to revenue receipts from water charges and rates of various kinds ----"

He continues "---Some economists would argue that the 'full funding' concept is not relevant, since it is an ideal of engineering physical efficiency, and that O&M should instead be funded up until the marginal benefits equal the marginal costs". However, he points out "the sheer impracticability of even assessing this rather 'textbook' concept in the real world".

As funds for maintenance are invariably in short supply, it is important that the available resources are allocated to works which will be most effective in sustaining or restoring system performance and output. At present, maintenance programmes tend to be drawn up on the basis of precedents and generalised criteria, which may not be relevant to individual schemes and may not result in improved output.

**Table 4 Categories of maintenance problems**

Problems commonly addressed in maintenance have been allocated to categories as follows
**Immediate problems**. Considered to have a cumulative effect on the everyday functioning of the system so that designed or target water releases cannot be achieved and the system output is increasingly adversely affected. Problems typically lead to reduced canal/drain conveyance capacity or interruptions in supply.

**Incipient problems/risk.** May not affect the supply and system output over the short - medium term. If unchecked by maintenance, they can lead to serious failures (emergencies) and major loss of output at some stage in the future owing to poor supply, poor drainage, or both.

**Emergencies**
Problems need to be solved immediately. Potential for major loss of output. Regular or periodic maintenance would reduce the risk of occurrence.

Under poor maintenance practice, premature rehabilitation, or special maintenance, may be primarily a response to falling output, as a result of problems of the first type. It would then be expected that problems of the other types would be rectified at the time of rehabilitation.
System operators and farmers generally identify **reduced canal capacity as their principal maintenance problem** because it affects output. Defective structures generally add to management problems but may constrain output in the near term.

| **Category of Problem** | **Effect** | **Impact** |
|---|---|---|
| Immediate | | |
| Build - up of sediment | Reduced channel capacity | Reduced output |
| Growth of weeds | Reduced channel capacity | Reduced output |
| Embankment erosion/slumping | Reduced channel capacity | Reduced output |
| Leakage | Reduced supply | Reduced output |
| Incipient | | |
| Excess earth/groundwater pressures | Potential emergency | Major crop loss |
| Damage under repeated loads (roads) | Poor performance | Early replacement |
| Material ageing/deterioration | Reduced component lifetime | Early replacement |
| Progressive leakage | Potential emergency | Major crop loss |
| Scour and erosion (structures) | Reduced life/emergency | Early replacement |
| Emergency | | |
| Channel/culvert blockage and overtopping | Supply curtailed | Major crop loss |
| Failure of mechanical/electrical components | Supply curtailed | Major crop loss |
| Embankment/slope failure | Supply curtailed | Major crop loss |

**Note.** The categories of problems set out here broadly reflect urgency of need for maintenance. The names are not intended to replace existing terminology used for maintenance scheduling such as “regular”, “periodic” etc.

Resources may not be allocated to areas of principal need because:

- Methods used to allocate funds tend to be inflexible, see Tables 5, 6. The available budget headings may strongly determine how money is to be spent. Managers also often find it simplest to disburse limited funds in proportion to the area served.

- The information on system condition and its probable impact on performance, which would be needed by managers to improve allocations, are rarely available. The size and dispersed nature of irrigation projects make it difficult for managers to hold detailed knowledge of the condition of their system unless regular surveys are undertaken. Records are usually not kept in readily accessible form.

- Actual allocations from government to the irrigation department may bear little relationship to funding requests, which in turn may not represent priority needs.

- Technical and financial auditing procedures are lacking or defective.

**Table 5 Maintenance funding linked to system components**

On a large project in Bangladesh, maintenance funding is linked to the capital cost of system components.

| **Component** | **Percentage of Capital Cost** |
|---|---|
| Main canals | 2% |
| Distributaries | 3% |
| Hydraulic structures | 1% |
| Plant/machinery | 2% |
| Buildings | 1% |

**Table 6 Proportion of maintenance budget allocated to tasks in selected projects**

The tasks involved in maintenance vary widely between systems. But there are common aspects. For example, most run-of-river systems experience sedimentation and weedgrowth.

A percentage of the maintenance budget may be allocated to different tasks:

| **Country** | **Percentage of budget assigned to task/sector** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Silt Clearance** | **Weed/grass Cutting** | **Bank Repairs** | **Roads** | **Structures (incl. hwks)** | **Mech.** | **Misc. (+ tert wks)** |
| **Bangladesh** | **45%** | **--** | **10%** | **--** | **11%** | **22%** | **12%** |
| **Mexico (Kloezen, 1996)** | **37%** | **4%** | **6%** | **10%** | **9%** | **10%** | **24%** |
| **Philippines (Weller, 1992)** | **18-20%** | **66-80%** | **-** | **0-12%** | **0-20%** | **-** | **-** |
| **Indonesia (Iptrid,1994)** | **46%** | **-** | **6% (lining 12%)** | **-** | **34%** | | |
| **Sri Lanka (Cornish, 1998)** | **-** | **5%** | **-** | **20%** | **36%** | **-** | **29%** |

In the absence of better information, rules of thumb such as those cited in Tables 5, 6 provide a starting point for allocating resources.

A maintenance programme should ideally include a mix of works aimed at both immediate and longer-term problems. Unfortunately, funds are commonly so seriously inadequate that such a policy is impossible. Desilting often absorbs the greater part of maintenance funds on run-of-river schemes. The annual budget is commonly insufficient to remove enough sediment to avoid progressive blockage, possibly promoted/aggravated by the growth of weeds

At the present time, practical methods for identifying and prioritising maintenance needs according to the impact of component condition on performance lack refinement (Cornish, 1997). A number of difficulties exist:

- managers naturally enough focus on perceived problem areas ('firefighting' activities). They may be reluctant to allocate resources to regular condition surveys of the system, which are essential for planning maintenance.

- the performance of an irrigation system is potentially influenced by a large number of variables, both technical and non-technical in nature (Section 3). The process of identifying technical constraints and tying them to effects may be complex, requiring considerable experience.

- since the components of an hydraulic system are linked, it may not be possible to attribute benefits uniquely to the improvement of individual components. It is therefore necessary to identify minimum packages of work.

Improved methods of identification and planning are needed. They are the subject of ongoing work at HR Wallingford and elsewhere.

# 3. REVIEW OF ISSUES

## 3.1 Scheme performance

Various studies have shown that the performance and output of irrigation schemes are affected by a large number of factors (Bos, 1982; Mao Zhi, 1989; Jones, 1995; Chancellor and Hide, 1997).

### 3.1.1 Physical performance

- **Immediate problems,** leading to reduced conveyance capacity**.** Co-ordinated maintenance works can restore or safeguard water deliveries, area irrigated and output. Benefits can be measured in terms of the value of output which would otherwise be lost, as well as in delayed capital spending on rehabilitation.
- **Incipient problems.** Ageing and general wear and tear. The returns to better maintenance can be measured in terms of delayed capital spending on rehabilitation. Benefits will be highly site-specific, depending very much on the quality of the original construction and the conditions to which the system is exposed.
- **Emergency problems.** Unpredictable events causing immediate impact on the system.

Levine (1986) argues that the costs of regular maintenance are not immediately balanced by returns in the form of output/income. In the early years of an inadequate maintenance regime, output/income can be maintained in a number of ways:

1) Infringement of canal freeboard. Extra capacity can be gained as the bed fills up with sediment (but sudden failures under peak flows are more likely)
2) Farmers make better use of the available supply**.** Shortage tends to promote better water use efficiency.
3) Crops can tolerate limited water shortage. Reasonable output can be maintained (e.g. for wheat, 85 % of maximum) if the supply falls to 80 % of assessed water need.
4) Farmers maintain net income despite reduced output. Initially farmers may try to compensate for water shortage by increased use of fertiliser. With experience they may reduce inputs and thus cut costs.

"All these factors mean that the impact of poor maintenance may be delayed. When the impact of deferred maintenance is sufficiently strong, irrigators frequently take the initiative to exert pressure through the political system. So, a pattern of deferred maintenance has some advantage for operating bureaucracies – it encourages the efforts of irrigators in the search for additional financial resources".

### 3.1.2 Economic performance

Jones (1995) summarised the results of recent evaluation studies of World Bank-funded schemes. It had been expected by the Bank that economic performance would be primarily influenced by six variables:

1) project irrigated area
2) cropping intensity
3) crop yields
4) output prices
5) unit investment cost
6) implementation time

Jones points out "often factors behind these proximate parameters are what really matter." In particular, the first three variables might be principally determined either by technical factors or non-technical ones. Maintenance was not selected as a variable, although the Bank has frequently expressed its concern about the impact of poor O&M. The reason is likely to be that there appear to be virtually no useable data.

The Bank concluded that cropping intensity and implementation time were not linked with the evaluation estimate of EIRR, whereas the other four factors showed correlations with economic measures of performance. Higher investment costs were inversely correlated with EIRR, whereas the other factors were all directly correlated with it. Maintenance, one of the factors behind Jones' 'proximate' parameters, can affect irrigated area, yield, cropping intensity (and project lifetime).

The Bank (1996) evaluated irrigation projects in Thailand, Myanmar and Vietnam, all rice- growing areas. At the time the world rice price was unfavourable, and it was concluded for those schemes that crop price (Jones' item 4), rather than poor maintenance, was the main determinant of economic performance.

Chaudhry and Ali (1989) developed an econometric model aimed at determining the returns to O&M expenditure on different types of irrigation schemes in Pakistan. The driving force was the need to determine priorities for expenditure in the face of tight budgetary constraints and a very high opportunity cost of capital. Estimated parameters for Punjab were used to simulate the effects of alternative O&M investment options on agricultural output, farm prices, and farmers' gross income.

The model was used to examine the relative merits of investing in three different types of scheme: canal systems; private tubewells; government tubewells. It should be noted that the model included averaged actual expenditure on operations plus maintenance as a primary variable. It was assumed that increased O&M spending would result in increased agricultural production by extending the irrigated area and improving the yield per unit of land. The role of maintenance was not separately examined. In fact, the proportion of the total O&M sum actually spent on maintenance could be expected to vary considerably, in particular between canal systems and tubewells (for which the energy costs of pumping will dominate expenditure). It was also assumed that the major part of O&M funding would come from farmers in the form of water charges, a realistic statement for tubewells, but less so for canal irrigation. The study concluded that the marginal benefits to past and prospective O&M investments in canals and tubewells were substantially better than unity, providing a basis for increased water charges. Table A1.1 shows the estimated marginal benefits over time calculated by Chaudhry and Ali for each of the three types of system. At today's date the procedure, rather than the absolute magnitude of the results, is of more importance. The study is a rational attempt to improve the way in which recurrent investment is made, but the link between expenditure and performance appears somewhat speculative.

### 3.1.3 Lack of information

Underlying factors which could potentially affect the deterioration of schemes, the requirement for maintenance, and Jones' 'proximate' parameters of area, cropping intensity and yield, could be:

- quality of initial construction
- local environment (climate, terrain, land use)
- previous maintenance regime (and expenditure)
- users' behaviour
- age of the scheme, or period since rehabilitation

In order to determine what resources should be devoted to maintenance, better understanding of the influence of underlying factors is needed.

Most of the above factors involve qualitative assessments, though semi-quantitative methods of categorisation could be devised. Inevitably, there will be considerable differences between schemes. However, it might be possible to define broad ranges, to which individual schemes could be assigned once local circumstances had been ascertained. By analogy, Bos and Nugteren (1982), in a benchmark study of irrigation scheme physical performance, were able to correlate overall scheme efficiency with a number of variables, so that designers could select appropriate parameters for given situations.

Field investigation would be needed to provide firm data on maintenance actions, condition, and performance. The information would extend the findings of the present study.

## 3.2 Financing and Organisation of Maintenance

Small (1990) asserts that the financial problem of shortage of funds for maintenance has to be seen in the wider fiscal perspective of irrigation cost recovery. If rates of cost recovery could be increased, irrigation would not be a net drain on public resources.

Jones (1995) concludes of Bank-funded projects, "There is no evidence yet, however, of better cost recovery". He argues that cost recovery is much more than a fiscal issue, as it promotes better use of irrigation facilities.

Gulati and Svendsen (1994) say "The Indian Irrigation Commission of 1972 concluded that irrigation schemes should generate enough annual income to meet the annual costs of O&M, and a part of the capital cost (requirement subsequently waived). Water rates should be revised every five years and should lie within the range 5 –12% of the gross revenue of farmers in the canal command areas, depending on whether the farmers were producing food, grain or cash crops. An Indian Working Group on Major and Medium Irrigation Programmes concluded that the present system of fixing O&M rates as a fixed sum per hectare without considering the nature and type of project, was not rational, as the maintenance need differs between projects—depending on topographical and meteorological factors".

They continue "There is a vast difference between recommended O&M levels and actual ones (because of) the general failure of canal systems to generate sufficient funds at abysmally low water rates. In the middle of the nineteen sixties, the recovery ratio (gross receipts/working expenses) was above 100%. The recovery ratio has been deteriorating over the last two decades. In 1994, receipts stood at less than 50% of expenses throughout the country. The predominant portion of the limited O&M funds available is going towards paying for the establishment costs, as seen by the increasing share of Direction and Administration in all regions. Administrative costs have risen from some 33% to 50% of the overall budget within the last four decades."

Figure 1 (WB, 1997) shows the relative contributions of government and users to system operation and maintenance in a number of countries. Information on the proportion of the O&M budget assigned to maintenance is not directly available from the figure, nor does it show to what degree the total funding is adequate. In countries such as India and Pakistan, the government pays a large proportion of the total expenditure, whilst users contribute between 30-50% of the total costs. The agency manages the main system whilst farmers are responsible for tertiary level operation and maintenance. At the other extreme, the governments of Mexico and Chile contribute a relatively small proportion of the total costs. Water users associations in Mexico contribute to the costs of O&M on the primary canal(s) and manage the works themselves on lower order canals.

It is not the aim of the present study to examine in detail the roles and functioning of institutions. However, increased funding for maintenance, though essential, needs to be accompanied by improvements in the way it is organised and managed. A summary of the alternatives is therefore included here.

Easter (1990) identified four possible ways of increasing resources for maintenance and improving their use:

1) Increase local funding by feeding back the returns from increased fees.
2) Turnover systems to farmers
3) Require government bureaucracies to contract out O&M.
4) Assistance from lending agencies for a limited, transitional period after construction.

### 3.2.1 Funding from increased fees

Fee collection is a financial, social and institutional issue. Easter (1990) states: “The cost of improving water fee collections is no small matter. In the Philippines the cost of collection is about 8% of the total collected. In Maharashtra, India, collection costs range from $1 to $3 per hectare equivalent to 15-20% of O&M costs”.

Easter considers that at least four conditions must be satisfied to achieve a worthwhile improvement in collection.

- an effective information system detailing the use of water
- a reasonably dependable delivery system
- an agency willing and able to collect fees
- feedback of funds collected to improve/maintain the system

Fees should vary according to the project. Collection should begin when the project is new or reconditioned, when farmers are likely to be more willing to pay. Enforceable sanctions for non-payment will be needed.

The World Bank (1997), in a review of water pricing, identified five key issues which must be addressed if water users are to successfully manage and finance irrigation systems:

1) Managing agency to detail all involved costs, services and likely benefits.
2) Users to be involved in determining the level of required services
3) Establish willingness/ability of users to pay
4) Agree charging mechanism – fees, in-kind contributions, property taxes etc.
5) Link fees and level of service

Where the project generates low returns owing to poor local conditions or pricing policies, the Bank concluded that government may still need to cover some of the O&M costs.

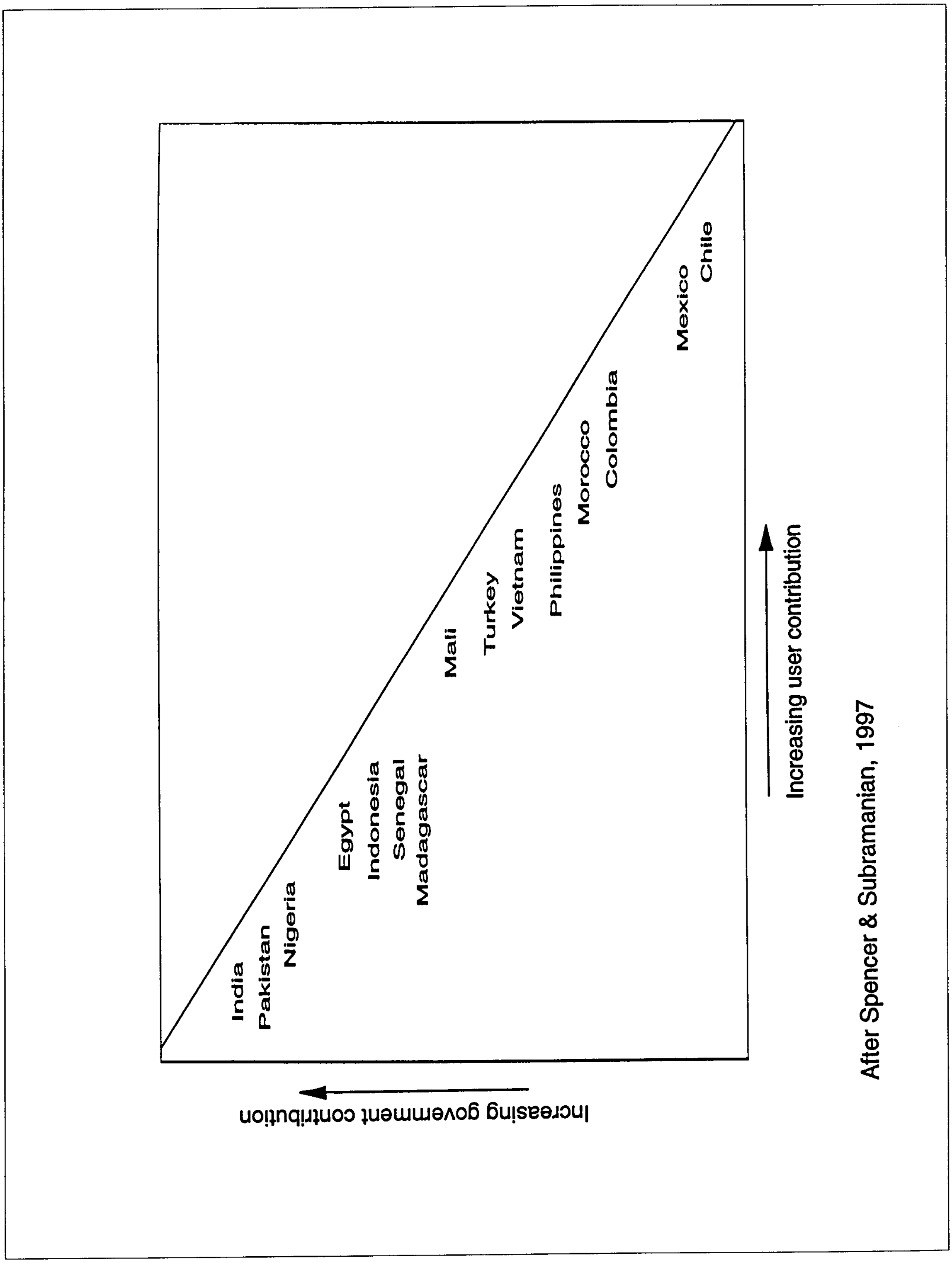


**Figure 1 Indicative mix of government and user contributions to O&M (national averages)**

At present in most countries irrigation fees are remitted to the Finance Ministry. Exceptions are the Philippines and Mexico. The National Irrigation Administration in the Philippines (NIA), is a semi-autonomous entity dependent for its routine operating budget primarily on payments from farmers. Cost recovery or 'viability' is now an important parameter by which irrigation managers' performance is monitored. The changeover in 1974 from a conventional government irrigation agency encouraged NIA staff to provide a satisfactory service to farmers. Each provincial and regional irrigation office is designated a cost centre. Fee collections have improved markedly since the policy was first introduced and the budget department began to remove subsidies. Although it might be thought that managers would have a strong incentive to maximise the area irrigated, there is some anecdotal evidence that they may be motivated to reduce the irrigated area to that which can be fully served by available water, to reduce complaints and ensure that farmers are willing to pay their dues. Collections are deposited in NIA's corporate account and retained by the corporation. Each year, those provinces achieving an excess of income over expenses, in a region where there is an overall operating deficit, receive 10% of their surplus as an incentive. A region, which achieves overall viability, even though some systems may not be viable, receives 20% of its surplus. Units are allowed considerable freedom in the way they use the bonus.

Gerards (1991, 1996) describes the background to the establishment of irrigation service fees in Indonesia. He found that users were more willing to pay if: they were involved in defining needs; the size of fees was tied to the needs of individual systems; fee collections were reused on the system. Water user associations played an important role in setting and collecting fees. Local government was seen as an important intermediary between users and the Provincial Irrigation Service. The involvement of Heads of Districts, Sub-Districts and villages was a key to mobilising and informing farmers and to settling disputes.

### 3.2.2 Turnover

Urged on by the major lending bodies, Governments throughout the irrigating world are trying to reduce expenditure by turning over to farmers the operation and maintenance of the lower levels of public irrigation projects. Much research and investigation has been done by IIMI (Johnson 1993, Geijer 1995, Vermillion 1997) and others (ex. Gerards 1991,1996), but many questions remain about the design and implementation of suitable structures for turnover.

In Mexico, much of the irrigated land has been turned over to farmers' organisations ('modulos') since 1989. 'Modulos' are typically large groups farming around 10,000 ha. It was originally expected that the Mexican Government would only turn over schemes which had recently been rehabilitated. However, in practice, schemes were generally turned over without rehabilitation. Turnover is judged a success (Johnson, 1993). Spending by the 'modulos' on maintenance has increased since turnover, the volume of work has increased, and its quality improved. Farmers contract individuals and companies to carry out maintenance on their behalf, generally at secondary canal level and below. Where the irrigation agency continues to have responsibility for main canal management and maintenance it is more responsive to farmers' needs, owing to the strong link between performance and service payments. At the time of turnover, it was claimed by Government that a principal aim was to return non-irrigated land to production. In practice, the land irrigated has not materially increased since turnover, a fact which is attributed to under-reporting by agency staff in the past. It is believed by IIMI that the main reason farmers were keen to take over new responsibility was to secure control over, and avoid uncertainties in, their water supply.

The situation in Mexico is not typical of turnover in the developing world. Turnover is not generally accompanied by a commitment on behalf of governments to agreed standards of water delivery and maintenance. The effects of turnover on the condition of systems are generally unclear (Vermillion, 1997). In some countries, for example Sri Lanka, governments have tried to give farmers greater responsibility for maintenance and to introduce water charges, without success. Small rice-growing farmers in Sri Lanka saw no incentive to take on extra tasks that had previously been managed by government. Government was forced to pay farmers to carry out maintenance below main canal level in order to avoid the collapse of their systems.

Turnover will clearly only work if farmers identify a sufficient improvement in personal circumstances to outweigh the extra cost and responsibilities associated with turnover. Conventional wisdom says that farmers will be reluctant to undertake new enterprises unless they can see a clear opportunity for increasing income by a factor of at least two. Smallholder farmers growing cereals, particularly rice, have until recently found irrigated farming an increasingly marginal enterprise owing to low crop prices. In these circumstances there appears no incentive for them to take on the added financial burdens of maintenance unless the system is effectively not functioning under Government management. Provided water is generally available, the farmer on a rice-growing scheme under supplementary irrigation is likely to be less concerned with system maintenance than his counterpart on schemes growing upland crops, where their sole source of water is supplied on rotation. In fact, it has been argued by Seckler (1985) that rice schemes are "unique in not requiring management - management only makes them worse".

The circumstances under which farmers will be willing and able to take over responsibility for operation and maintenance in any given set of circumstance remain the subject of hypotheses. In particular, the extent of the support needed to make projects sustainable is commonly underestimated.

### 3.2.3 Contracting out O&M

O&M could be provided by a third party, either a private company or an autonomous government agency. Under financial autonomy, the irrigation agency or company is responsible for obtaining resources and has control over their use, whereas under central financing, the agency must remit proceeds to the centre.

Contracts between the company and the farmers would make the managers responsive to their clients' needs.

In many situations, farmers do not want to be involved in O&M and might accept such an arrangement.

Gulati and Svendsen (1994) conclude, "Given the current set-up, with no incentives either for farmers or functionaries to make the system perform more efficiently, no further improvement can be brought about without bringing in innovative changes in the institutions". To make them more responsive he concludes "This can be done adequately by making the Irrigation Departments financially autonomous. Departments will (have) to cover all expenditure with funds they can generate through irrigation revenue and other secondary sources. This will have the dual effect of providing incentives to increase income as well as to reduce cost and help to establish a relationship of mutual dependency between the user groups and the supplying agency ….efforts can be made to incorporate farmers' organisations in the management and financial activities of the irrigation system in India".

### 3.2.4 Assistance from donor agencies

The reluctance of donor agencies to fund recurrent costs stems from concerns about accountability and the fact that support for O&M will merely defer the time when nations must assume responsibility.

Carruthers (1993) suggests that progressively decreasing support might be supplied during a transition period whilst schemes are transferred from construction to O&M. "A transfer of funds as a grant or loan to a locally-held reserve at the time of main disbursement might overcome donors' objections to continuing O&M obligations".

It is not clear why governments would be more inclined to provide a satisfactory level of funding at the end of a transition period. The experience of lending agencies in this respect has not been positive.

Easter (1990) suggests donors might tie new funding to the performance on existing projects, with more funding for project monitoring and ex-post analysis. The proposal appears logical but may not find favour, as it may conflict with agencies' lending targets.

At the present time, the Banks are supporting policies of turnover because other initiatives to stimulate greater local investment have been unsuccessful. It is likely to be suited to certain situations only. Further attention might be directed to the idea of autonomous maintenance agencies. Some success has been achieved in the maintenance of roads by similar policies.

The above review is intended to indicate the extent of uncertainties involved with the financing and organisation of maintenance. There is, at present, little in the way of guidance for governments contemplating change.

## 3.3 Sustainability and discounting

The World Bank (1985) has frequently expressed concern that projects may not be sustained, and that governments must face increased recurrent costs. Project evaluations now include an assessment of the project's sustainability, based on somewhat subjective criteria.

Conventional methods of economic analysis which emphasise capital as the scarce resource, with a high discount rate for future costs and benefits, tend to favour projects with lower initial capital investment. The assumption is that the project will be sustained over its projected lifetime by a good level of maintenance. Losses arising from inadequate maintenance occur in the future and are heavily discounted. Projects with higher initial cost and lower maintenance costs appear less favourable. In practice, in the recent past, capital for construction has been readily available from international sources, though donors are now increasingly reluctant to replenish development assistance funds. On the other hand, recurrent funds derived from local sources have been consistently scarce.

Such analyses fail to bring out the importance of maintenance in sustaining the life of a system and the livelihoods of farmers. Various methods have been suggested to modify or supplement existing methods so as to overcome the economic bias against sustainable development (Finney, 1984; Carruthers, 1996; Tiffen, 1987; Price, 1993), but in the absence of consensus, project economic justification continues to follow existing methodologies.

Finney (1984) suggests that expenditures like maintenance, which make demands on limited government revenue, should have a higher shadow price attached to them, costs being adjusted in exactly the same way as for the different shadow prices of, say, foreign exchange and unskilled labour. Items for which the opportunity cost were different from the overall opportunity cost of capital in the economy would be adjusted by a factor, and the adjusted cost added to other costs in a particular year and discounted at the main discount rate.

If opportunity costs, as reflected in interest rates, were for example:

| Item | Interest Rate |
|---|---|
| Overall opportunity cost of capital in the economy | 10% |
| Capital costs: | |
| Foreign aid component | 2.5% |
| Locally- funded | 10% |
| O&M costs | 20% |
| then the adjustment factors would be: | |
| Foreign capital aid0.25 | 0.25 |
| Locally-funded capital costs | 1.00 |
| O&M costs | 2.00 |

Appendix 1 includes a comparison of two projects A and B according to traditional analysis and the modified method. According to conventional methods, the low capital cost – high recurrent cost project is preferred whereas shadow pricing makes the high capital cost-low recurrent alternative distinctly preferable.

Finney concludes that the procedure could be used in cases where there is clearly a severe shortage of O&M funds, but that it would probably meet with opposition from lending agencies because it could result in an increase in funding requirements.

Tiffen (1987) points out that since costs and benefits occurring in the more distant future are highly discounted, little benefit is apparently to be derived from extending the life of a new project beyond 10-15 years. "The EIRR of a project which disappears after 15 years and one which is maintained beyond thirty years may appear little different. Yet for a farmer, and also for a nation, it is important that a scheme endures".

She considers the procedure advocated by Finney to be insufficiently radical and suggests would be difficulties in setting an appropriate price. She concludes that overall economic criteria should be supplemented by calculations of the costs and benefits to farmers, and to project administration, to ensure that the costs of O&M can be covered.

Price (1993) comments "There is great institutional convenience in uniform adoption of a standard form of appraisal: it seems to offer consistency, even if only in the form of consistent error. However, the error introduced by inappropriate discounting is not consistent, if the compared investments have different time profile of output, or if quasi discount rates differ". He reviews various proposals to modify discounting to safeguard the interests of the future.

He terms them respectively:

<u>Discounting that gently fades away</u>
Foresters committed to production periods spanning decades object to high discount rates for long-term decisions. Forestry projects tend to use a special rate below that set by the Treasury.

"A number of alternative approaches all use a high discount rate for short-term decisions and a lower one for the distant future. In environmental terms, all encounter the same problems in allocating investment as a non-discounting method. None discriminates between products which are becoming more abundant and those which are growing scarcer".

<u>Discounting plus price adjustment</u>
"Discounting, if it is done at all, should be undertaken at rates specific to products, income groups and time periods, according to predicted scarcity relative to present scarcity. Scarcity should be denoted by changes in real price. But this view is generally depreciated by economists. For example, Fuchs and Zeckhauser assert that: ---"self-respecting economists should not adjust discount rates for externalities stretching to the future or use different rates--- we should adjust our valuations of future benefits upwards, not our discount rate downward".

<u>Discounting plus sustainability</u>
Discounting methods can indicate that forests are not a sound investment, and that the appropriate treatment of a site is to rapidly deplete its fertility. Fisheries economists have tended to strike a balance between maximum sustainable yield and maximum short-term gain.

There are currently two views:

1. The idea of sustainability, by giving absolute importance to future generations, is the ideological opposite of discounting.

2. The idea of sustainability is complementary to discounting. Discounting assures efficient allocation of investment funds; sustainability assures inter-generational equity.

Sustainability, according to Pearce (1989), requires "—the economic efficiency objective (to) be modified to mean that all projects yielding net benefit should be undertaken subject to the requirement that environmental damage should be zero or negative".

Price concludes: "Discounting the value of future goods, services --- and resources, by means of a uniform negative exponential function, cannot be justified". It is clear from the above brief survey that there is considerable divergence of opinion concerning the way in which projects which are required to endure should be analysed.

No conclusion is drawn in the present work as to the best methodology to use. The purpose has been to highlight the conflicts existing between main-stream economics and sustainable development, to which good maintenance makes a substantial contribution.

# 4. THE RETURNS TO MAINTENANCE

## 4.1 Form of analysis

Irrigation schemes suffer generic problems owing to neglect of maintenance, but the nature and scale of problems vary from scheme to scheme. No quantitative data linking scheme performance with maintenance of surface irrigation schemes are known to exist. In the circumstances, it was decided to conduct indicative analyses based on information on maintenance spending and output on systems rehabilitated under international funding, supplemented by informed assumptions about the way systems deteriorate. Sensitivity analyses were undertaken to test the effect on the outcome of changes in the basic parameters.

The analyses are intended to demonstrate the costs and returns to two levels of maintenance termed `poor' and 'satisfactory'. 'Poor' maintenance under constrained budgets was taken, on the evidence of two projects, to lead to premature system rehabilitation. 'Satisfactory' maintenance was assumed to sustain system operations for the design life (30 years). The available information was considered insufficiently precise to allow meaningful analyses to be conducted for intermediate levels of maintenance funding. If, and when, better information becomes available, it would be a valuable exercise to compare the incremental returns to different levels of funding. Actual and target maintenance expenditure, crop/input prices, farm budgets, are based on published information on internationally-funded rehabilitation projects in India and Indonesia. The values are considered reasonably typical of irrigation schemes in South and South East Asia in 1992. The outputs over time under the two maintenance regimes were assumed to follow a non-dimensional production profile (Figure 1). In the absence of detailed information about the deterioration of the selected schemes, the profile was based on experience of irrigation systems elsewhere.

The characteristics of irrigated agriculture are somewhat different in arid/semi-arid zones and the humid tropics. Irrigation is the main, or only, source of water for upland crops in arid areas. In humid areas, irrigation water supplements rainfall through much of the year and rice is very widely grown. Output is generally less sensitive to poor management and system condition than on schemes in dry areas because: rainfall can compensate for irrigation deficiencies; there is a reservoir of water in the fields; water is often passed from field to field; canal leakage tends to be reusable. Because of the relative resilience of rice-growing schemes suffering from defective infrastructure, it was decided to base the analyses on schemes which had been rehabilitated following inadequate performance. One scheme was located in an arid/semi-arid area and the other in the humid tropics.

As pointed out in Section 3.1, a reduction in scheme output is not necessarily caused by poor condition of the system. There are many other possible reasons. Nonetheless, there are examples from many parts of the world where poor condition of the system caused by poor maintenance has caused a serious reduction in scheme output. The fact that rehabilitation was needed on the selected projects was taken to mean that major physical constraints to output had been identified.

The relative magnitudes of costs and benefits will clearly vary between schemes and countries, depending on the value of output, on the costs of labour, local maintenance techniques, the characteristics of the scheme, and the environment.  Data from different parts of the world (Tables 1,2) were compared to ensure that reasonable assumptions were made about the relative magnitudes of spending under 'poor' and 'satisfactory' maintenance regimes.

It was pointed out in Section 2.2 that the returns to satisfactory maintenance include:

- the value of saved output
- postponement of the need for new investment to rehabilitate infrastructure, thus freeing capital for alternative uses
- better equity of supply, thus safeguarding the income of tailend farmers

as well as intangible social and environmental benefits.

In the analyses, the benefits to satisfactory maintenance were taken to consist of the first two items only. The assumption is conservative but consistent with the aim of determining whether satisfactory maintenance is economically well justified.

The benefits and costs of the 'poor' and 'satisfactory' maintenance regimes were deduced on each of two schemes.  Typical high value and low value cropping patterns were used under each maintenance regime on each scheme.  A total of eight cases was thus analysed.

The 'Production Profile', Figure 2, was used to provide a standardised basis for comparing benefit streams in the eight cases.  The figure is intended to show the relative levels of output over 30 years of a project life.  A measure of relative output termed the 'Production Index' is shown plotted on the y-axis.  This parameter is a dimensionless number, representing the annual per hectare output at any time as a percentage of target output.  The latter may be considered to be the value adopted in project formulation, assuming medium farm inputs.  The absolute value of the output is not significant here since the index is used to compare the outputs over time under the two alternative maintenance regimes, (P) and (S).  For the purposes of the analysis, farmers' practice and potential output are assumed constant over the period.

The shape of the profiles is based on judgements about the general way in which projects behave.  It is assumed that a regime of poor maintenance results in an increasing decline in production after year 10 and early rehabilitation after 15 years.  It is not unknown for schemes to undergo rehabilitation even earlier. The selected period to rehabilitation was chosen as a reasonable illustration of the effects of decline well within the design lifetime of 30 years, at which latter date rehabilitation or modernisation would be expected.  Year 1 of the analysis was taken as the first year after construction.
Characteristics of profiles (P) and (S) are discussed below.

Profile (P) - Poor Maintenance

Production is assumed to build up from Year 1 to the target output after 5 years, as farmers become familiar with the system.

Output between years 5 - 10 is taken as 100% of the target value.  In practice, output will fluctuate in response to seasonal conditions, pests and diseases, market prices etc.  Maintenance is inadequate to stem long-term decline, but the effects are not yet apparent owing to reserve capacity within the system (Section 3.1).

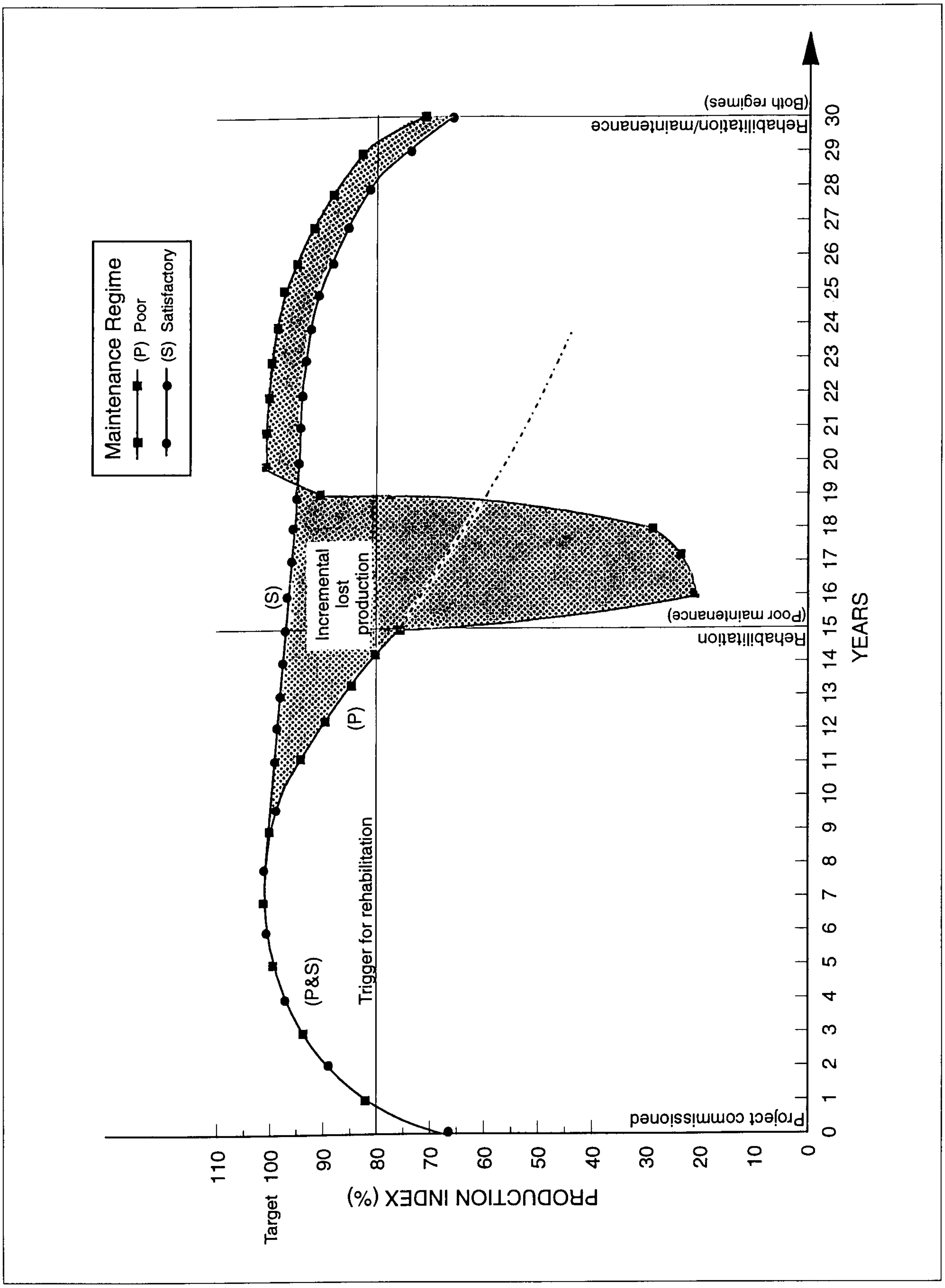


**Figure 2 Relative output over project life – two maintenance regimes**

From year 11 onwards there is a trend of declining output, in response to declining water deliveries, which might not be immediately apparent to the authority owing to normal seasonal variation. It is assumed that reduced outputs are accepted until the loss reaches 20% of the target output, at which point a need for rehabilitation is identified. For the sake of the example, rehabilitation is assumed to start 2 years later. In reality, this is optimistic, and the loss of output would be greater.

A small output is maintained during three years of rehabilitation, after which production rises to the target level, before declining again at Year 25.

Profile (S) - Satisfactory Maintenance

The build up to target output and the production profile to year 10 is similar to profile (a), thus the output is the same for the two maintenance regimes over the first ten years of the project.

During years 11- 19 production is assumed to continue at the target level (in practice it will fluctuate).

Production during years 20 -25 is assumed consistently 5% lower than on the newly rehabilitated scheme. From years 25 onward the pattern of declining production is assumed similar to profile (a).

The analyses compare costs and benefits per hectare. As indicated above, one of the effects of poor maintenance is to increase spatial variation in output. Disadvantaged areas, typically but not always located at the tail of canals, either suffer reduced yields or go out of production. For present purposes, the effects of maintenance on overall scheme output are of immediate importance. Average per hectare yields, representing total scheme output divided by total scheme area, were therefore used in the analyses.

The initial capital cost of the works obviously has a major effect on the economics of a new project (Section 3.4). In the first few years of the project there will be negative cash flows, regardless of the expenditure on maintenance. There will also be negative cash flows, in the case of poor maintenance, at the time of rehabilitation (Years 16-18). Annual maintenance costs under either regime will be relatively small relative to the output. Over a substantial part of the project life, the difference in outputs between 'poor' and 'satisfactory' maintenance will be small, and possibly insignificant. The superior benefits of good maintenance are taken to occur principally where the two profiles diverge markedly, in the years prior to, and during, rehabilitation.

To avoid the dominating effect on the cost streams of the high first cost, the differential cost and benefits streams were calculated for each pair of poor and satisfactory maintenance cases, the initial cost being taken as common. The incremental net present value (NPV) attributable to good maintenance - the difference between the (Benefit – Cost) streams for the two maintenance cases – was derived from the production profiles, the unit costs and benefits. Sensitivity analyses were undertaken to test the effect on the outcome of variations in the basic assumptions.

Section 4.2 describes the results of the analyses.

## 4.2 Discussion of results

Table 7 summarises the outcome of the analyses. More detail is included in Appendix 2.

In all cases, on both schemes under two cropping patterns, satisfactory maintenance showed a positive incremental NPV over poor maintenance. The range was between $ 470 /ha (low value crop) and $950 /ha (high value crop). The equivalent annual incremental net benefits varied from $50 to $100/ha. To set the figures in context, the annual costs of satisfactory maintenance were in the range $13.5-$23/ha.

By avoiding the need for an intermediate rehabilitation, the savings in expenditure on a medium-sized scheme of 20,000 ha under satisfactory maintenance would have been in the range $ 1.0 - $ 4.0 million, based on discounted per hectare cost advantages of nearly $50/ha (Scheme 2) and $200/ha (Scheme 1). The capital thus saved on the scheme might have been used, for example, to provide a supply of safe drinking water to some 7,000 individuals (Scheme 2) and more than 25,000 persons (Scheme 1).

Sensitivity analysis was conducted for four situations, to determine the effect of variation in the assumed conditions.

1) Discount rate increased to 12%.
2) Crop output value reduced by 20%.
3) Target maintenance cost increased by 20%.
4) Decline in output and rehabilitation delayed by 2 years.

Test 1
When the interest rate was raised from 10% to 12%, so decreasing the value of future benefits, the incremental NPV was reduced by some 25% on both schemes.

Satisfactory maintenance still showed an advantage of between $36 and $74/ha per year.

Test 2
Reduction of 20% in the value of crop output resulted in similar reductions in NPV. The equivalent incremental net benefit was still between $40 and $83 per hectare per year.

| Scheme | Net annual crop value ($/ha) | Maintenance regime | Benefits ($/ha) | | Costs ($/ha) | | Incremental NPV (2)-(4) | Equivalent Annual Net Benefit ($/ha) |
|---|---|---|---|---|---|---|---|---|
| | | | (1) Discounted Output | (2) Incremental Output (S)-(P) | (3) Discounted Cost | (4) Incremental Cost (S)-(P) | | |
| | | | | (Incremental benefit of satisfactory maintenance) | | (Incremental cost of satisfactory maintenance) | (Incremental NPV resulting from satisfactory maintenance) | (Incremental annual benefit of satisfactory maintenance) |
| **Low value cropping patterns** | | | | | | | | |
| 1 | 774 | (P) Poor | 6303 | - | 325 | - | | |
| | | (S) Satisfactory | 6740 | 437 | 127 | -198 | 635 | 67 |
| 2 | 754 | (P) Poor | 6143 | - | 268 | - | | |
| | | (S) Satisfactory | 6566 | 423 | 216 | -52 | 475 | 50 |
| **High value cropping patterns** | | | | | | | | |
| 1 | 1334 | (P) Poor | 10,868 | - | 325 | - | | |
| | | (S) Satisfactory | 11,617 | 749 | 127 | -198 | 947 | 100 |
| 2 | 1558 | (P) Poor | 12,693 | - | 268 | - | | |
| | | (S) Satisfactory | 13,568 | 875 | 216 | -52 | 927 | 98 |

**Notes**
(a) Figures in (1) and (3) from Appendix 2
(b) Initial capital costs not included as common to both cases (P) and (S)
(c) Discount rate = 10%

**Table 7 Summary of base case analyses**

Test 3
An increase of 20% in the cost of satisfactory maintenance reduced NPVs and equivalent benefits by negligible amounts since the overall costs were still small relative to the value of saved output.

Test 4
It was assumed that deterioration did not start to become ‘serious’ (20% reduction in output) until year 16. The effect of delaying rehabilitation by two years was to reduce the incremental benefits to good maintenance by 30-40%. Substantial benefits of $30-$65 per hectare per year were still achieved.

The tests showed that satisfactory maintenance was a good policy even when conditions varied considerably from those assumed. In fact, even if all variations were applied simultaneously, i.e. with 12% interest rate, crop value reduced, maintenance cost increased, and deterioration delayed, a small but positive incremental NPV would have been achieved on both schemes for both high and low value cropping patterns.

**Table 8 Effect on NPV and equivalent annual net benefit ($/ha) of varying input parameters (values in $/ha)**

| Test Number | Crop output value | Scheme 1 | | | Scheme 2 | | |
|---|---|---|---|---|---|---|---|
| | | Incremental NPV | Annual Net Benefit | % change on base case | Incremental NPV | Annual Net Benefit | % change on base case |
| BASE CASE Interest rate = 10% | HIGH | 947 | 100 | - | 924 | 98 | - |
| | LOW | 635 | 67 | - | 472 | 50 | - |
| TEST 1 Interest rate = 12% | HIGH | 699 | 74 | -26% | 685 | 72 | -26% |
| | LOW | 455 | 48 | -28% | 338 | 36 | -28% |
| TEST 2 Crop price -20% | HIGH | 783 | 83 | -16% | 762 | 81 | -17% |
| | LOW | 526 | 56 | -14% | 379 | 40 | -18% |
| TEST 3 Maintenance Cost +20% | HIGH | 910 | 96 | -3% | 881 | 93 | -5% |
| | LOW | 589 | 62 | -4% | 438 | 46 | -6% |
| TEST 4 Rehab delay 2 years | HIGH | 618 | 65 | -33% | 581 | 62 | -37% |
| | LOW | 410 | 43 | -33% | 284 | 30 | -39% |

## 5. CONCLUSIONS

Maintenance of irrigation systems in many parts of the developing world is seriously under-funded and often poorly carried out. Governments are reluctant or unable to assign funds for maintenance. In South Asia in 1992 the equivalent of $ 6 - $12 /ha were typically allocated, whereas some $ 13 - $40 /ha were required to prevent progressive deterioration of the system. Maintenance is normally a net drain on the national budget. Water charges are set too low, the rate of collection is poor, and the proceeds are not retained for reuse by the irrigation department. Turnover of systems to farmers does not necessarily solve budgetary problems since the main system, which is rarely turned over, accounts for a major part of maintenance costs.

To demonstrate the value of, and returns to, maintenance, indicative analyses comparing the economic outcome of two alternative maintenance regimes on two schemes were made. ‘Poor’ maintenance corresponded to funding at a level known to have resulted in rehabilitation. ‘Satisfactory’ maintenance was taken as that level of targeted expenditure needed to solve problems directly affecting water distribution, and thus scheme economic performance. Rehabilitation, in the case of poor maintenance, was assumed necessary after 15 years, triggered by a reduction of 20% in overall project output due to technical failings, and not to pricing, social or other factors.

1) The annual costs of satisfactory maintenance were taken to be in the range $13.5 - $23 /ha; poor maintenance costs were $ 6 - $9 /ha. In all the cases examined, satisfactory maintenance, whilst safeguarding output and infrastructure, cost less over the lifetime of the project (30 years) than the combined expenditures involved in poor maintenance and early rehabilitation. On a medium-sized scheme of 20,000ha, the discounted value of savings in expenditure resulting from good maintenance would have been in the range $1.0 - $4.0 million (1992 prices), depending on location. As an example of the possible alternative use of capital, the savings could have been used to provide safe drinking water to between 7,000 and 25,000 people.

The incremental net present values (NPV) resulting from satisfactory maintenance, from production which would otherwise have been lost, were always positive, in the range $470 and $1000/ha depending on the cropping pattern and scheme. The equivalent incremental annual benefits were $50/ha - $100/ha.

Satisfactory maintenance remained an economically sound policy when input parameters were varied under a series of sensitivity tests applied both separately and simultaneously. Even when all the tests were applied simultaneously (interest rate increased from 10%-12%, crop values reduced by 20%, satisfactory maintenance costs increased by 20%, and the need for rehabilitation delayed), a small but positive incremental NPV was achieved.

2) For the purposes of the analysis, only the value of lost production and the cost of rehabilitation were attributed to poor maintenance. The true costs of failing to achieve the predicted returns to the original investment are greater than calculated. They include:

- additional loan repayments by governments; although the terms of repayment will usually be relatively soft, scarce foreign currency will be lost.
- loss of local funds, as well as international money originally invested in the infrastructure, thus capital is written off (sunk costs) within the project design lifetime.
- lost opportunity to use capital spent on rehabilitation in other priority sectors of the economy, such as water supply and sanitation, health and welfare, education etc.

The progressive deterioration of a system also has other effects which are difficult to quantify. The water supply and/or the drainage networks become progressively more unreliable, and the distribution of available water increasingly inequitable, as channels fill with sediment and/or weeds. Farmers in the more favoured parts at the head of the system may continue to receive an adequate supply, whilst those at the tail of the system, or elsewhere, may face ruin. Smallholder farmers operate on a narrow margin between success and failure. Land is sometimes mortgaged against the following harvest to pay for the cost of agricultural inputs. The consequences of a single disastrous crop failure can cause a farmer to lose his land and to migrate to overcrowded cities. Alternatively, when the water supply is unreliable, farmers reduce investment in crop inputs or change to drought-tolerant crops. In either case, both individuals and the nation are the losers.

3) It would seem economically efficient to fund only that maintenance necessary to ensure that the system design lifetime were achieved. If the level of spending is set too high, the output may not improve significantly. In the present state of knowledge, it is only possible to predict that a given low level of maintenance is broadly inadequate, or satisfactory. It seems unrealistic to attempt to select a level of spending which will permit ‘managed’ decline. Better knowledge linking maintenance and performance is needed, particularly since available funds are often spent on activities which do not show corresponding returns. Practical procedures to set maintenance priorities according to returns need to be developed and applied.

4) Better cost recovery is one of a number of alternative policies which have been suggested to increase funding for O&M. Cost recovery is a financial, social and institutional issue rather than an economic one. In the Philippines, cost recovery or ‘viability’ is now an important parameter by which the performance of NIA’s irrigation managers’ is monitored. Each provincial and regional irrigation office should receive most of its income from fees. Collections have improved markedly since the policy was first introduced in 1974 when the budget department began to remove subsidies. As an incentive, centres achieving a surplus of income over costs are allowed to retain a percentage of the collection. The policy was introduced over time with considerable support from government. It is unlikely to work without considerable institutional change and some tradition of self-reliance in farming communities.

5) Another way to reduce government costs, which might be adopted in conjunction with improved cost recovery policies, is to turnover to farmers the operation and maintenance of parts or the whole of public irrigation systems. The cost to farmers of maintaining systems in good condition is significantly less than to government, not least because overheads are lower.

In Mexico, improvement in the condition of the system infrastructure after turnover to groups farming up to 10,000 ha each is attributed to increased spending on maintenance and probably also to better standards of workmanship. Mexico is often cited as an example of the success of turnover, but conditions are not comparable with irrigation in most Asian or African countries. It seems likely that there will be situations where farmers will not necessarily see personal advantage – ultimately judged in terms of financial benefit or better control over a primary input - in taking over tasks traditionally the responsibility of government. In such circumstances, the effect of turnover on the infrastructure is far from clear. To date, insufficient information is available in different circumstances to determine the relative merits of maintenance as managed by farmers or government. Turnover should not be viewed as an easy option for governments. For success, detailed planning, execution and support will be needed.

6) Alternative ways of demonstrating the utility of maintenance are possible. For example, Berkoff (1998) has suggested…“First ask the question: what increases in intensities, or yields, or changes in cropping pattern are needed to justify the level of maintenance expenditures proposed? And second: are such increases likely, and under what conditions?” At the present time, firm information to answer the second question is lacking.

7) To summarise, good maintenance is technically and economically justified. Adequate budgetary allocation and better cost recovery mechanisms, improved procedures, institutional change and better-trained staff are widely needed in the developing world to sustain heavy capital investments in irrigation and drainage infrastructure. Better information is also needed to support maintenance policies. The benefits of good construction and sustained maintenance are illustrated by the fact that there are also many systems throughout the world which still provide an assured output many times greater than originally planned, long after the lapse of the design lifetime. The returns on the original investment are probably incalculable.

## 6. RECOMMENDATIONS

1. Firm information on maintenance spending and its impact on economic performance and project sustainability is needed to guide government policies on water charges, maintenance spending, system turnover and target setting. At present, standardised policies, which take little account of local circumstances, are being applied across the board at the instigation of lending agencies. Field studies in a number of countries/regions are needed to provide data on system deterioration and maintenance performance, identifying the principal determinants of maintenance needs, so as to provide a firm basis for policies.

2. Policies of turnover are being pursued by governments without proper understanding of the implications for the infrastructure of management and maintenance by farmers. Unless farmers are willing and able to maintain relatively complex structures, the system could suffer accelerated deterioration and require urgent intervention to prevent loss of the infrastructure. Studies of institutional and socio-economic aspects of turnover are being conducted throughout the world, but Vermillion (1997) points out "---relatively few studies (covering) brief periods report on maintenance. This shortcoming makes it difficult to answer questions about the long-term physical sustainability of irrigation systems after transfer". Detailed studies are required to identify the circumstances under which turnover is likely to have positive, neutral and negative impact on the infrastructure, and to define the support services which farmers will require. Guidelines to sustaining the infrastructure after turnover are badly needed.

3. There is no guidance available to governments on the best way to restructure inefficient institutions so as to improve maintenance. The appropriateness of possible alternative structures in given situations needs to be investigated and documented.

4. Better methods of identifying maintenance works and putting priorities on those with principal impact on performance are needed, so as to make best use of available resources. Realistically, funds will always be limited. To improve performance and justify funding requests, scheme managers should have access to up-to-date records of asset condition and a rational method for deciding where expenditure is most needed. Methods presently being developed need to be extended and refined (Cornish and Skutsch, 1997).

5. The consequences for national economies of the present 'Build - Neglect – Rebuild' policies need to be more widely recognised and publicised. Standard economic analyses favour projects with low initial expenditure and higher maintenance requirements over those which cost more initially but involve less maintenance. The issues involved in maintenance and sustainability warrant exposure in international publications, and could be brought forward in an international workshop on issues in maintenance. New methodologies for project economic analysis to emphasise sustainability are needed.

6. Low maintenance designs associated with easier and less costly management, decreased maintenance, lower service fees and greater effective life, need to be given greater importance at the feasibility and design stages of project preparation.

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# *Appendices*

# Appendix 1

Choosing Investments

# Appendix 1 Choosing Investments

## (1) Marginal benefits to investments in Pakistan

**Table A.1.1 Historical estimates of marginal benefits to O&M investments in different components of the irrigation system in Punjab province, 1966-86**

Figures in 1971 rupees

| Year | Marginal benefits per Rupee of O&M investment to: | | |
|---|---|---|---|
| | Canals | Public tubewells | Private tubewells |
| 1966 | 11.58 | 0.59 | 15.15 |
| 1967 | 14.90 | 0.76 | 13.60 |
| 1968 | 15.19 | 1.15 | 13.10 |
| 1969 | 16.42 | 0.84 | 14.42 |
| 1970 | 20.39 | 0.69 | 11.92 |
| 1971 | 17.93 | 0.40 | 9.71 |
| 1972 | 18.70 | 0.57 | 9.53 |
| 1973 | 19.08 | 0.43 | 8.76 |
| 1974 | 22.60 | 0.40 | 8.00 |
| 1975 | 18.81 | 0.44 | 6.60 |
| 1976 | 20.24 | 0.36 | 6.84 |
| 1977 | 20.99 | 0.41 | 6.43 |
| 1978 | 21.02 | 0.47 | 6.51 |
| 1979 | 23.54 | 0.35 | 6.63 |
| 1980 | 24.36 | 0.29 | 7.03 |
| 1981 | 26.94 | 0.27 | 7.01 |
| 1982 | 20.06 | 0.27 | 6.87 |
| 1983 | 21.38 | 0.28 | 7.20 |
| 1984 | 15.72 | 0.19 | 5.06 |
| 1985 | 19.29 | 0.26 | 6.37 |
| 1986 | 20.66 | 0.29 | 6.81 |

Source: Chaudry and Ali (1989)

**(2) Choosing alternative investments under (a) Conventional method (b) Adjusted method due to Finney**

| | Cost (£/ha) | |
|---|---|---|
| Alternative 1 (capital cost – intensive) | **Year 1** | **Year 2-20** |
| Capital cost – foreign aid | 700 | - |
| Capital cost – local component | 300 | - |
| O&M costs per annum | - | 50 |
| Alternative 2 (recurrent cost-intensive) | | |
| Capital cost – foreign aid | 350 | - |
| - local component | 150 | - |
| O&M cost per annum | - | 100 |

**a) Conventional analysis (10% discount rate)**

| | | **Alternative 1** | **Alternative 2** |
|---|---|---|---|
| Capital cost | - foreign aid | 636 | 318 |
| | - local component | 273 | 136 |
| | Sub-total | 909 | 454 |
| O&M costs | | 380 | 760 |
| Total PV @ 10% | | 1289 | 1214 |

**Outcome: Alternative 2 preferred**

**b) Adjusted method (Finney)**

| | | **Alternative 1** | | **Alternative 2** | |
|---|---|---|---|---|---|
| | | Yr 1 | Yrs 2-20 | Yr1 | Yrs 2-20 |
| Capital cost | - foreign aid | 175 | - | 88 | - |
| | - local component | 300 | - | 150 | - |
| O&M costs per annum | | - | 100 | - | 200 |
| Totals | | 475 | 100 | 238 | 200 |
| Total PV @10% | | | 1,192 | | 1,734 |

**Outcome: Alternative 1 more attractive**

# *Appendix 2*

Analyses of Costs and Benefits

# Appendix 2 Analyses of costs and benefits

## Costs and Benefits (1992 prices)

**1) Scheme 1 – Semi Arid Area, India**

| Basic data – Costs | | **$/ha** |
|---|---|---|
| a) Annual expenditure, poor maintenance regime | = | 6.0 |
| b) Annual expenditure, satisfactory maintenance | = | 13.5 |
| Rehabilitation costs | = | 1,250 |

Basic data – Benefits

High value Cropping Pattern

| CROP | YIELD (T/ha) | ECONOMIC MARGIN ($/ha) |
|---|---|---|
| Wheat | 2.5 | 664 |
| Cotton | 1.6 | 670 |
| TOTAL | | 1334 |

Low value Cropping Patterns

| CROP | YIELD (T/ha) | ECONOMIC MARGIN ($/ha) |
|---|---|---|
| Rice | 3.5 | 641 |
| Gram | 1.0 | 133 |
| TOTAL | | 774 |

1) **Scheme 1 – Semi Arid Area, India (continued)**

**Table A2.1 Poor maintenance – High value output ($1334/ha)**

| Year | Annual Costs / ha | | Annual benefits / ha | | |
|---|---|---|---|---|---|
| | Capital | Maintenance | % Target output | Benefit | |
| | (2500) | | | | |
| 1 | - | 6 | 65 | 867 | |
| 2 | - | 6 | 82 | 1094 | |
| 3 | - | 6 | 90 | 1200 | |
| 4 | - | 6 | 95 | 1267 | |
| 5 | - | 6 | 100 | 1334 | |
| 6-10 | - | 6 | 100 | 1334 | |
| 11 | - | 6 | 95 | 1267 | |
| 12 | - | 6 | 93 | 1241 | |
| 13 | - | 6 | 85 | 1134 | |
| 14 | - | 6 | 80 | 1067 | |
| 15 | - | 6 | 75 | 1000 | |
| 16 | 450 | - | 20 | 267 | |
| 17 | 450 | - | 25 | 333 | |
| 18 | 450 | - | 30 | 400 | |
| 19 | - | 6 | 90 | 1200 | |
| 20-25 | - | 6 | 100 | 1334 | |
| 26 | - | 6 | 98 | 1307 | |
| 27 | - | 6 | 95 | 1267 | |
| 28 | - | 6 | 89 | 1187 | |
| 29 | - | 6 | 81 | 1080 | |
| 30 | - | 6 | 70 | 934 | |
| **Discounted costs** | $268 | $57 | **Discounted benefits** | $10,868 | **NPV=$10,544** |

Note: Discount rate =10%

## 1) Scheme 1 – Semi Arid Area, India (continued)

**Table A2.2 Satisfactory maintenance – High value output ($1334/ha)**

| Year | Annual Costs / ha | | Annual benefits / ha | | |
|---|---|---|---|---|---|
| | Capital | Maintenance | % Target output | Benefit | |
| | (2500) | | | | |
| 1-10 | - | 60 | 65 | 12,432 | |
| 11 | - | 13.5 | 100 | 1334 | |
| 12 | - | 13.5 | 100 | 1334 | |
| 13 | - | 13.5 | 100 | 1334 | |
| 14 | - | 13.5 | 100 | 1334 | |
| 15 | - | 13.5 | 100 | 1334 | |
| 16-19 | - | 13.5 | 97 | 1294 | |
| 20-25 | - | 13.5 | 95 | 1267 | |
| 26 | - | 13.5 | 93 | 1241 | |
| 27 | - | 13.5 | 90 | 1201 | |
| 28 | - | 13.5 | 84 | 1121 | |
| 29 | - | 13.5 | 76 | 1015 | |
| 30 | - | 13.5 | 65 | 868 | |
| **Discounted costs** | $0 | $127 | **Discounted benefits** | $11,617 | **NPV=$11,490** |

Note: Discount rate =10%

**<u>Discounted costs</u>**

| | | **$/ha** |
|---|---|---|
| <u>Poor</u> | | |
| Capital | = | 268 |
| Maintenance | = | 57 |
| <u>Satisfactory</u> | | |
| Capital | = | 127 |

**<u>Case 1PH Poor maintenance – High value output ($1334/ha)</u>**

| | | |
|---|---|---|
| Discounted benefits | = | 10,868 |
| NPV | = | 10,544 |
| Equivalent annual benefit | = | 1,119 |

**<u>Case 1SH Satisfactory maintenance – High value output ($1334/ha)</u>**

| | | |
|---|---|---|
| Discounted benefits | = | 11,617 |
| NPV | = | 11,490 |
| Equivalent annual benefit | = | 1,219 |

**<u>Case 1PL Poor maintenance – Low value output ($774/ha)</u>**

Discounted benefit $= \frac{\$774}{\$1334}$ x Case 1PH = 6,303

NPV =$6303 - $325 = 5,978

Equivalent annual benefit = 634

## 1) Scheme 1 – Semi Arid Area, India (continued)

**Case 1SL Satisfactory maintenance – Low value output ($774/ha)**

| | | | $/ha |
|---|---|---|---|
| Discounted benefit | $= \dfrac{\$774}{\$1334}$ x Case 1SH | = | 6,740 |
| NPV | =$6740 - $127 | = | 6,613 |
| Equivalent annual benefit | | = | 701 |

## Costs and Benefits (1992 prices)

### 2) Scheme 2 – Humid area - Indonesia

Basic data – Costs

| | | | $/ha |
|---|---|---|---|
| a) | Annual expenditure, poor maintenance regime | = | 9 |
| b) | Annual expenditure, satisfactory maintenance | = | 23 |

Rehabilitation costs = 850

Basic data – Benefits

High value Cropping Pattern

| CROP | YIELD (T/ha) | ECONOMIC MARGIN ($/ha) |
|---|---|---|
| Rice | 5.0 (dry) | 408 |
| Chilli | 5.0 | 742 |
| TOTAL | | 1558 |

Low value Cropping Patterns

| CROP | YIELD (T/ha) | ECONOMIC MARGIN ($/ha) |
|---|---|---|
| Rice | 3.5 (dry) | 310 |
| Chilli | 1.6 | 134 |
| TOTAL | | 754 |

**Discounted costs**

$/ha

Poor

Capital $= \frac{\$850}{\$1250} \times \$268/\text{ha (Case 1)}$ = 182

Maintenance $= \frac{\$9.0}{\$6.0} \times \$57/\text{ha (Case 1)}$ = 86

Satisfactory

Maintenance $= \frac{\$23}{\$13.5} \times \$127/\text{ha (Case 1)}$ = 216

**Case 2PH Poor maintenance – High value output ($1558/ha)**

Discounted benefits $= \frac{\$1558}{\$1334} \times \text{Case 1PH}$ = 12,693

NPV = $12,693 - $268 = 12,425

Equivalent annual benefit = 1,318

**2) Scheme 2 – Humid area – Indonesia (continued)**

**Case 2SH Satisfactory maintenance – High value output ($1558/ha)**

| | | | **$/ha** |
|---|---|---|---|
| Discounted benefits | $= \frac{\$1558}{\$1334}$ x Case 1SH | = | 13,568 |
| NPV | =$13,568 - $216 | = | 13,352 |
| Equivalent annual benefit | | = | 1,416 |

**Case 2PL Poor maintenance – Low value output ($754/ha)**

| | | | |
|---|---|---|---|
| Discounted benefit | $= \frac{\$754}{\$1334}$ x Case 1PH | = | 6,143 |
| NPV | =$6143 - $268 | = | 5,875 |
| Equivalent annual benefit | | = | 623 |

**Case 2SL Satisfactory maintenance – Low value output ($754/ha)**

| | | | |
|---|---|---|---|
| Discounted benefit | $= \frac{\$754}{\$1334}$ x Case 1SH | = | 6,566 |
| NPV | = $6566 - $216 | = | 6,350 |
| Equivalent annual benefit | | = | 673 |

### 3) Sensitivity Tests

1 Interest rate increased to 12%

2 Crop output value decreased by 20%

3 Target (satisfactory) maintenance cost increased by 20%

4 Decline in output delayed 2 years to Yr. 12.
Scheme rehabilitated between Yrs 17-21

## Summary of Test Results

### Table A.2.3 Effect on NPV and Annual Net Benefit ($/ha) of varying input parameters

Values in $/ha

| Test Number | Crop output value | Scheme 1 | | | Scheme 2 | | |
|---|---|---|---|---|---|---|---|
| | | Incremental NPV | Annual Net Benefit | % change on base case | Incremental NPV | Annual Net Benefit | % change on base case |
| BASE CASE Interest rate = 10% | HIGH | 947 | 100 | - | 924 | 98 | - |
| | LOW | 635 | 67 | - | 472 | 50 | - |
| TEST 1 Interest rate = 12% | HIGH | 699 | 74 | -26% | 685 | 72 | -26% |
| | LOW | 455 | 48 | -28% | 338 | 36 | -28% |
| TEST 2 Crop price -20% | HIGH | 783 | 83 | -16% | 762 | 81 | -17% |
| | LOW | 526 | 56 | -14% | 379 | 40 | -18% |
| TEST 3 Maintenance Cost +20% | HIGH | 910 | 96 | -3% | 881 | 93 | -5% |
| | LOW | 589 | 62 | -4% | 438 | 46 | -6% |
| TEST 4 Rehab. delay 2 years | HIGH | 618 | 65 | -33% | 581 | 62 | -37% |
| | LOW | 410 | 43 | -33% | 284 | 30 | -39% |

### Test 1. Discount Rate increased to 12%

### Scheme 1

Poor Maintenance

| High Value Crop | | **$/ha** |
|---|---|---|
| Discounted total costs | = | 230 |
| Discounted total benefits | = | 9,041 |

| Low Value Crop | | |
|---|---|---|
| Discounted total costs | = | 230 |
| Discounted total benefits | = | 5,218 |

**Sensitivity Tests (continued)**

Satisfactory Maintenance

| | | |
|---|---|---|
| High Value Crop | | **$/ha** |
| Discounted total costs | = | 109 |
| Discounted total benefits | = | 9,619 |
| Low Value Crop | | |
| Discounted total costs | = | 109 |
| Discounted total benefits | = | 5,552 |

Summary-Scheme 1

| Cropping | ($/ha) | | | |
|---|---|---|---|---|
| | **Incremental Benefit** | **Incremental Cost** | **Incremental NPV** | **Equiv. Annual Benefit** |
| High value | 578 | -121 | 699 | 74 |
| Low value | 334 | -121 | 455 | 48 |

**Sensitivity Tests (continued)**

**Scheme 2**

Poor Maintenance

| | | |
|---|---|---|
| High Value Crop | | **$/ha** |
| Discounted total costs | = | 196 |
| Discounted total benefits | = | 10,560 |
| Low Value Crop | | |
| Discounted total costs | = | 196 |
| Discounted total benefits | = | 5,110 |

Satisfactory Maintenance

| | | |
|---|---|---|
| High Value Crop | | **$/ha** |
| Discounted total costs | = | 185 |
| Discounted total benefits | = | 11,234 |
| Low Value Crop | | |
| Discounted total costs | = | 185 |
| Discounted total benefits | = | 5,437 |

Summary- Scheme 2

| **Cropping** | ($/ha) | | | |
|---|---|---|---|---|
| | **Incremental Benefit** | **Incremental Cost** | **Incremental NPV** | **Equiv. Annual Benefit** |
| High value | 674 | -11 | 685 | 72 |
| Low value | 327 | -11 | 338 | 36 |

**Sensitivity Tests (continued)**

**Test 2. Crop output value decreased by 20%**

Summary -Scheme 1

| Cropping | ($/ha) | | | |
|---|---|---|---|---|
| | **Incremental Benefit** | **Incremental Cost** | **Incremental NPV** | **Equiv. Annual Benefit** |
| High value | 608 | -175 | 783 | 83 |
| Low value | 351 | -175 | 526 | 56 |

Summary-Scheme 2

| Cropping | ($/ha) | | | |
|---|---|---|---|---|
| | **Incremental Benefit** | **Incremental Cost** | **Incremental NPV** | **Equiv. Annual Benefit** |
| High value | 727 | -35 | 762 | 81 |
| Low value | 344 | -35 | 379 | 40 |

**Test 3. Satisfactory maintenance costs increased 20%**

Summary - Scheme 1

| Cropping | ($/ha) | | | |
|---|---|---|---|---|
| | **Incremental Benefit** | **Incremental Cost** | **Incremental NPV** | **Equiv. Annual Benefit** |
| High value | 760 | -150 | 910 | 96 |
| Low value | 439 | -150 | 589 | 62 |

Summary - Scheme 2

| Cropping | ($/ha) | | | |
|---|---|---|---|---|
| | **Incremental Benefit** | **Incremental Cost** | **Incremental NPV** | **Equiv. Annual Benefit** |
| High value | 899 | 8 | 881 | 93 |
| Low value | 430 | 8 | 438 | 46 |

**Test 4. Rehabilitation delayed to Year 17**

Summary - Scheme 1

| Cropping | ($/ha) | | | |
|---|---|---|---|---|
| | **Incremental Benefit** | **Incremental Cost** | **Incremental NPV** | **Equiv. Annual Benefit** |
| High value | 493 | -125 | 618 | 65 |
| Low value | 285 | -125 | 410 | 43 |

Summary - Scheme 2

| Cropping | ($/ha) | | | |
|---|---|---|---|---|
| | **Incremental Benefit** | **Incremental Cost** | **Incremental NPV** | **Equiv. Annual Benefit** |
| High value | 575 | -6 | 581 | 62 |
| Low value | 278 | -6 | 284 | 30 |

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