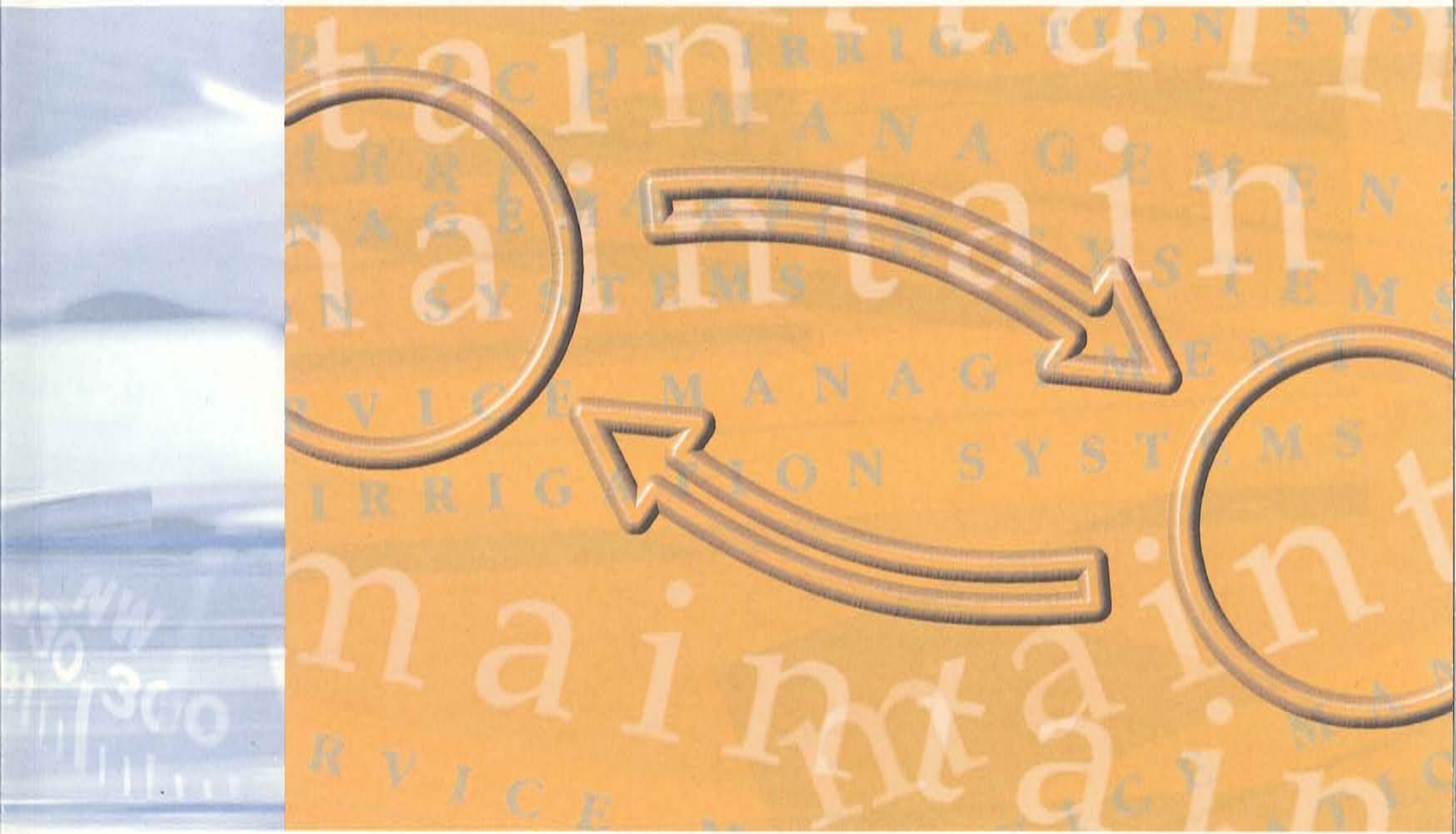
MAINTAIN – Thematic Paper No. 11

Division 45
Rural Development



Mark Svendsen and Walter Huppert;
Gilbert Levine;
Klaus Urban;
David G. Cone

What is Optimal Maintenance in Irrigation?

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Chapter 1

Optimal Maintenance in Irrigation

Mark Svendsen and Walter Huppert

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1. Introduction

Irrigation systems deteriorate. The rate at which they do this may be gradual or rapid, and the impact on the ability of the system to serve its purposes may be affected much or a little. But the deterioration is inevitable, and the human institutions which operate these systems must acknowledge the deterioration and deal with it.

Dealing with deterioration, which is the simplest definition of maintenance, involves many human choices -- choices relating to technology, timing, frequency, level of effort, and resource use among other things. The most basic choice, however, relates not to means but to ends. It is the choice of the strategy to be employed in maintaining, and, embedded within it, the purpose and objectives of the maintenance. These purposes and objectives are not always explicitly selected. In fact, regrettably, they are perhaps more often than not established accidentally and by default rather than being consciously and explicitly set out. Yet *de facto* operating objectives and standards do emerge which guide decision making in performing maintenance activities. These objectives and standards may be "optimal" in some sense, or they may not be, and that opens another important question – that of deciding what "optimal" really means.

This paper explores the questions of how systems deteriorate, and what constitutes optimal maintenance to forestall or manage that deterioration. The often-raised question of why systems deteriorate is also present, but is addressed obliquely through the exploration of optimal maintenance. In approaching it thus, we hope to find fresh insights that will serve as more useful stepping off points than the standard conclusion that maintenance funding has been inadequate, or that the original design was poor. In addressing these questions, we will frame maintenance as a twin service of irrigation water delivery, look at the different roles involved in service provision, and examine the implications for optimal maintenance.

2. Perspectives on irrigation system maintenance

2.1 Overview

Like the irrigation systems themselves, system maintenance can be directed at a variety of ends. These include preserving physical assets, providing a particular level of irrigation service, and providing employment for maintenance personnel. From here, ends can extend on into the darker realm of personal gain for officials in charge of functions such as procurement and contracting. In this paper, the focus will be on providing a specified level of irrigation service, which in turn, is aimed at the private economic objectives of the farmers utilizing the irrigation water provided. These aims, presumably, center around maximizing profit from farming over time. These aims are the ones that lead to overall economic efficiency in the sector and are the grounds on which most irrigation development (and rehabilitation) projects are justified. Although other objectives certainly operate in practice, these are often inconsistent with sound public economic policy or with prevailing legal and moral standards of behavior and are best addressed in other ways[1].

Consistent with the overall MAINTAIN approach to maintenance which employs a three-cornered framework comprising Technology, Economics, and Institutions, we can examine definitions of maintenance, and optimal maintenance, in terms of these three categories, recognizing that the most useful perspectives lie in the space inside the three corners (Figure 1). Below, definitions of optimal maintenance are explored under these headings.

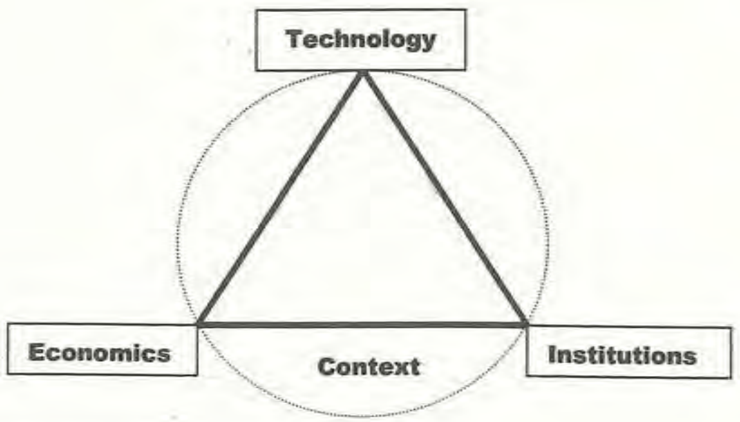


Figure 1.
Problem space for irrigation maintenance

2.2 Technology

In its simplest form, maintenance can be defined *as any activity that slows the deterioration of a facility, whether caused by use or aging* (Ostrom, et al, 1993). Another technically-oriented definition describes maintenance as *planned and auditable procedures to pick up problems before they become critical, and tight financial control to prevent waste* (New Civil Engineer, 1996).

Traditionally, most views of maintenance have the idea of arresting deterioration at their core. One can break out three archetypal technology-based maintenance strategies – *gold-plated*, *pragmatic*, and *minimal* – to provide terms for discussion. These are defined below.

Gold-plated maintenance, as described by Cone (1999) is maintenance to a level which virtually stops all system deterioration. Equipment is repaired or replaced once it shows any signs of wear, canal cross-sections are returned to design values annually, roads are always graveled and graded, and so on.

[1] Ways include increasing transparency of decisionmaking and financial transactions, strengthening traditions of investigative journalism, improving overall maintenance management, raising salaries of maintenance personnel, and giving users a role in oversight.

Pragmatic maintenance attempts to keep a system in "good but not perfect working order" (Skutch, 1998). Under this type of regime, routine maintenance is performed at certain frequencies, but some deterioration, rust, weediness, and road rutting between passes is tolerated.

Minimal maintenance repairs those things that are absolutely necessary for major parts of the system to convey water, but is not concerned with levels of reliability, with some areas going out of service, or with diminished conveyance capacity. Access to system facilities may deteriorate because roads are not maintained.

Input specification

Technology-based definitions can specify either the level of inputs to be provided for maintenance activities, or the results of the maintenance activity. Most maintenance around the world is still managed by specifying particular levels of inputs. Given a fixed level of input, a certain amount of work will be done with the funds made available and other things will be deferred. The underlying logic is that maintenance managers will prioritize expenditures by allocating funds to those problem areas which are the most critical. This may or may not be the case, in practice. Often, for example, staff levels expand to absorb the bulk of available resources, leaving little money to actually operate with (Gulati, Svendsen, and Choudhry, 1994).

Annual maintenance allocations often grow out of an administrative budgeting process based on the previous year's allocation. There may be adjustments up or down for inflation, storm damage, or other factors. Sometimes there is a nominal linkage between maintenance allocations and performance through rules of thumb, suggesting that a certain amount of money is needed to maintain each hectare of irrigated area or meter of canal. Such rules of thumb are usually not empirically derived, however, and are often out of date. Some rules are simply based on a particular percentage of the original capital cost – usually 1 to 3 percent (Skutch, 1998).

Providing particular levels of maintenance inputs will have impacts on both system condition and on system outputs. The exact shape of the relationship between input level and system performance will vary according to factors such as system design and technology employed, soil conditions, slope, rainfall patterns, and the working efficiency of the maintenance-providing organization. However, performance will tend to follow certain characteristic patterns (Levine, 2000; Skutch 1998). Moreover, output levels will not be constant in response to a constant input level over a period of years, but will change with the age of the system.

The three archetypical maintenance strategies described above are depicted conceptually in Figure 2 through Figure 5, which show system output over time in response to different constant values of funding for maintenance. The time scales of these graphs are not quantified, but one can think of each figure as covering a period of 15 to 30 years. These representations ignore many nuances in the actual relationships depicted in the interest of simplicity.

Figure 2 depicts scenario 1 (S1) in which **minimum maintenance** is carried out. This level of maintenance is determined by a fixed[2] low level of funding, F1, being supplied. As seen, after a short period of maximum performance, system output declines, first rapidly and then at a decreasing rate. This functional shape is hypothesized, but is consistent with the generally accepted notion of the deterioration pathway of infrastructure and with Skutch's (1998) observation that "irrigation systems tend to fail gradually, becoming increasingly ineffective." Output finally stabilizes at a relatively low level which can be thought of as the "natural" area which can be irrigated in a steady-state condition, given the level, F1, of funding provided.

Figure 3 and Figure 4 depict **pragmatic maintenance** scenarios (S2 and S3) in which successively higher levels of funds (F2 and F3) are provided for upkeep. As seen, the effect in each case is to lengthen the period during which maximum or near maximum output is produced, while yielding higher steady-state output levels. S2 an S3 raise a complication, however, in that maintenance allocations during the early years of the project are now in excess of needs, which tend to rise with time. The shaded areas in the figures represent this "excess" allocation.

This is so because large "lumpy" elements of system infrastructure such as concrete control structures, canal linings, or pumps, have minimal maintenance needs in their early years, but need more attention as they age and require major overhaul or replacement after a definite "lifetime." Even though a gold-plated maintenance regime may keep a system in like-new condition virtually all the time, the level of effort required to do this will increase as the system ages. Some of this 'lumpiness" can be forestalled by higher levels of routine maintenance but not all. In the hotel industry, for example, while routine maintenance is done on guest rooms from the time of opening, it has been found that at some point it is more cost effective to close entire floors for complete refurbishment rather than to continue to try to maintain the rooms on a piecemeal basis.

With appropriate financial discipline and incentives, these excess allocations could be placed in reserve and used later as the system ages and maintenance needs increase. Alternatively, a well-managed system could request an increasing level of funding, following the dotted lines in the figures. However, managers will often be reluctant to do this for fear of establishing a precedent in the early years which could not be easily changed later. A more realistic variation, in the case of state-run systems, will be for administrators (or patronage-minded politicians) to use the surplus to increase staff levels, which

[2] All financial flows in this discussion are assumed to be in constant value terms.

then become a permanent sponge for maintenance budgets in subsequent years, further exacerbating the pace of system deterioration.

Scenario S4 (Figure 5) represents maximum or gold-plated maintenance. Here a very high level of maintenance funding (F4) keeps the system at peak performance virtually all of the time. Note the large excess allocation existing during the first half of the period, however.

In real life, scenarios S1 and S2 are the more likely ones to prevail, particularly in developing countries[3]. This then raises the need to restore performance to maximum levels periodically and the result is the cycle of rehabilitation and decay shown in Figure 6. The construction and maintenance history of most irrigation systems are thus typically marked by periods of very heavy expenditure – at initial construction or major rehabilitation – and by variable costs of more routine maintenance during the intervening periods.

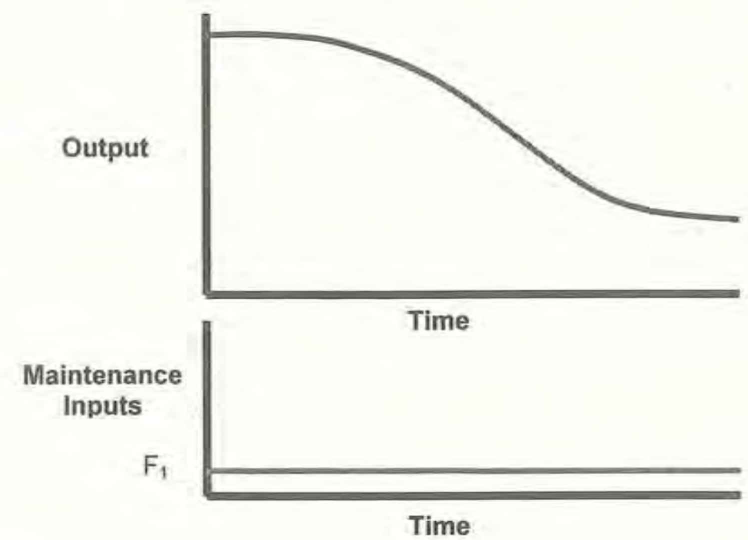


Figure 2.
Scenario1, low constant maintenance input

[3] Community managed schemes may be exceptions to this generalization, as they are often maintained so as to provide a constant or even an increasing level of output with time.

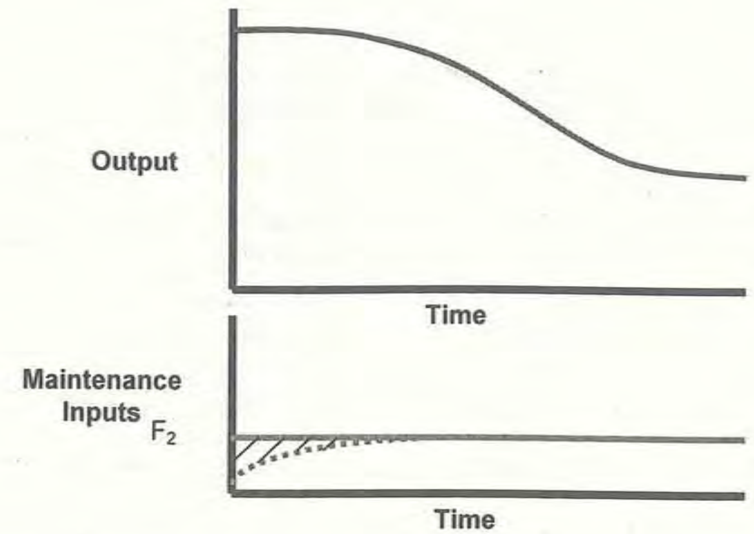


Figure 3.
Scenario 2, moderate constant maintenance input

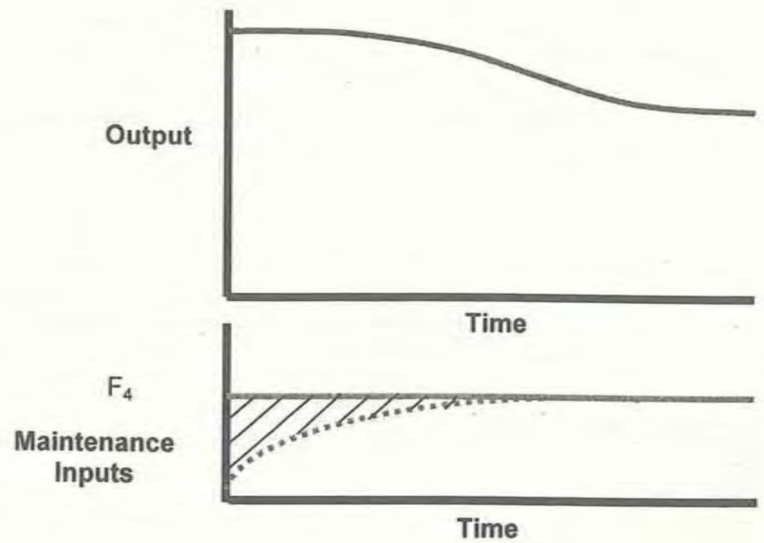


Figure 4.
Scenario 3, high constant maintenance input

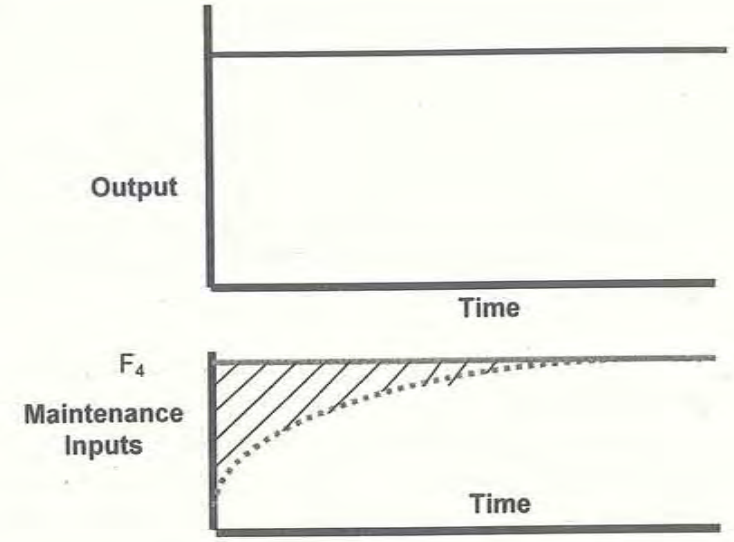


Figure 5.
Scenario 4, very high constant maintenance input

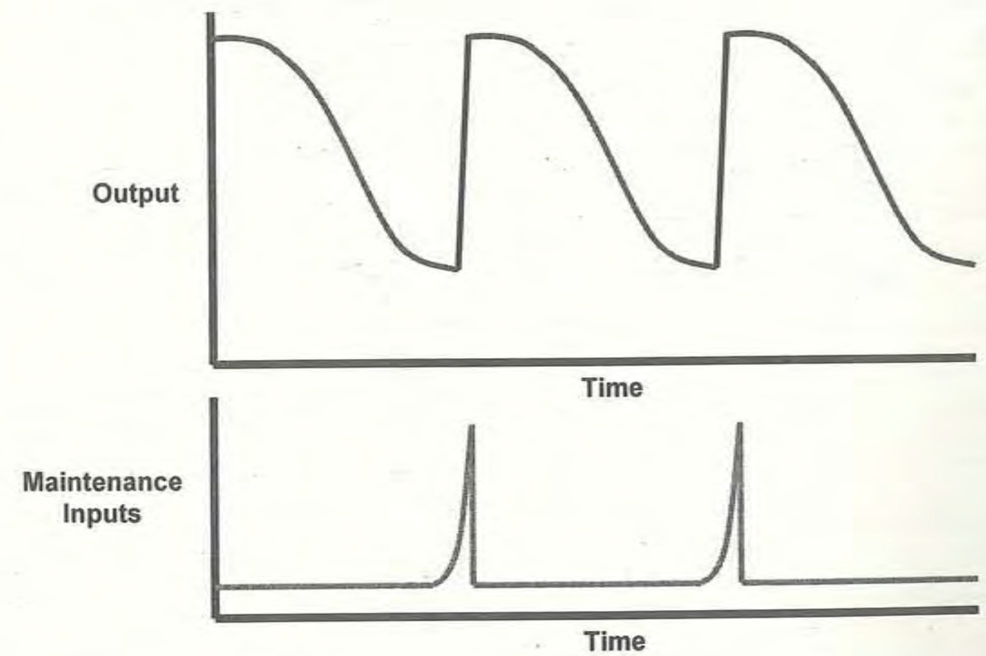


Figure 6.
Cyclic low maintenance, rehabilitation cycle

Cyclic Maintenance

Levine (2000) has developed this last scenario into an interesting and convincing argument which posits the appropriateness of relatively low levels of routine maintenance in developing country irrigation schemes. He argues that because systems are usually designed with excess conveyance capacity, and because more effective system management can compensate for some degree of system deterioration, that loss of system benefits lags deterioration by a significant number of years (). Moreover, because rehabilitation financing is generally available from national budgets or international lenders and donors on concessional terms, a cyclic pattern of minimal maintenance and controlled deterioration, followed by externally-financed[4] rehabilitation, is a logical and effective strategy to follow.

Levine goes on to argue that the macro pattern of decay and renewal also represents an effective longer-term strategy. The primary reason for this is that the real value of water tends to increase over time, leading to needs for basic changes in system infrastructure to increase system technical efficiency and perhaps to mitigate negative environmental impacts. Rehabilitation is a more effective way to provide such basic infrastructural change than is a more incremental approach. This leads to an overall envelope curve of increasing system efficiency over a series of cycles of systems improvement and decay (Figure 8).

The complete Levine argument is contained in another article in this paper (see chapter 2).

[4] External to the irrigation system.

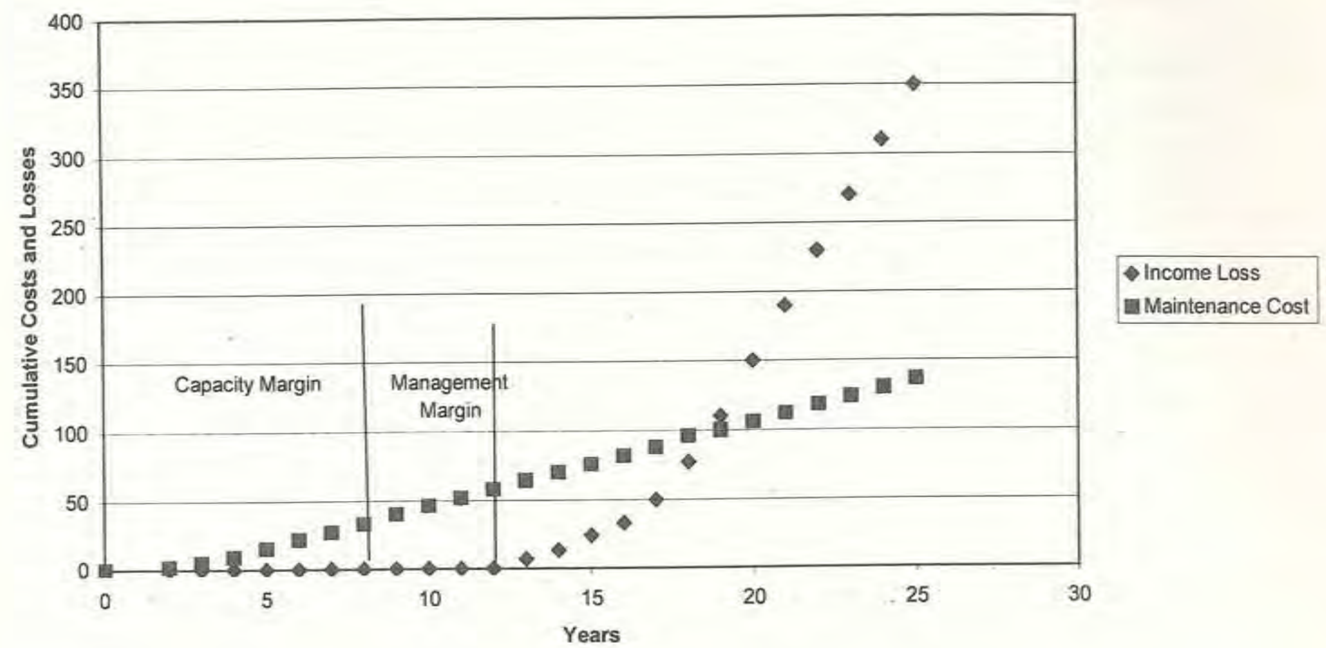
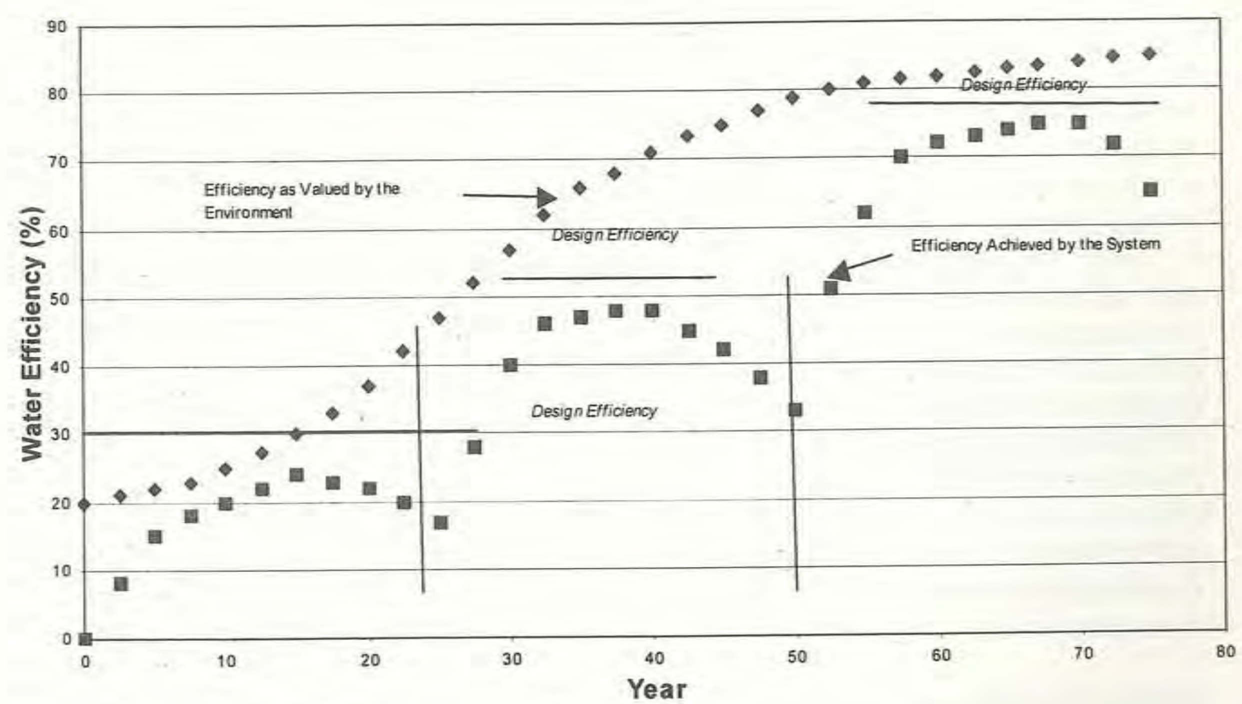


Figure 7. *Income Loss and Maintenance Cost Time Lines*



Source: Levine, 2000.

Figure 8. *Envelope curve of overall system efficiency over time*

Level of Service Specification

Most recent definitions include a reference to system performance and often specify a particular desired level of service as the criterion for successful performance, and successful maintenance. Several such definitions of maintenance are shown in Box 1. These definitions, particularly the first two, place very clearly the emphasis on the system functionality -- its output -- rather than on providing a given input level for the maintenance process.

Box 1. Definitions of Maintenance

A management response to the deterioration of the physical condition of irrigation systems that threatens to make it impossible to achieve operational targets – Karunasena (1993)

Any action required to either return an irrigation system to or keep it at a desired performance level – Thoreson, et al. (1997)

The upkeep of facilities with the goal of efficient operation, minimum breakdowns, good appearance, reasonable costs, extended useful life, and safety – Krause and Temple (1988)

Establishing the connections between a specified level of service and maintenance is difficult, which may explain why it is so seldom done. There are techniques, employed in other infrastructure sectors, for establishing such connections explicitly, but these have rarely been applied in the irrigation sector.

These techniques go under the heading of asset management (Box 2). Burton describes these techniques and suggests ways they could be applied to irrigation system maintenance in another paper in the MAINTAIN series (Burton, 2000).

Asset management (AM) takes an approach which is quite contrary to the cycle of decay and renewal described by Levine. It aims to create a steady state condition of "serviceability" of the set of assets making up the physical infrastructure of the irrigation system. This is not necessarily the "like new" condition implied by the gold-plated maintenance strategy described earlier. Rather, the particular level of serviceability of the scheme is defined by the level of service it is required to deliver to users. The level of asset serviceability may thus be higher or lower than the original design levels. The AM approach thus combines routine maintenance with replacement and even upgrading of the infrastructure. In the Levine model, much of the replacement and virtually all of the upgrading would be accomplished only at relatively long intervals during a rehabilitation.

Box 2. Definition of Asset Management

ASSET MANAGEMENT is a structured and auditable process for planning maintenance of and investment in infrastructure to provide users with a sustainable and defined level of service. *After Burton (2000)*

Asset management establishes connections between maintenance and maintenance expenditure on one hand, and asset condition and system performance on the other. It does this by establishing the following chain of connections (Box 3).

Box 3. Asset management connects maintenance and system performance

Determining the desired level of service

↓

Determining the current extent, condition, value, and performance of individual assets

↓

Relating individual asset extent and performance to system performance

↓

Determining the cost of maintaining or enhancing performance of each type of system asset

↓

Determining the cost of maintaining or enhancing performance of the system as a whole

This is obviously not a simple process and is very data intensive. Most applications are computer-based and generic commercial software for AM is available. Computer-based simulation models of system operation are also useful in specifying some of the relationships involved, that between individual asset performance and system performance in particular. The nearest widespread application of this approach to the irrigation sector is in public water supply systems, where it is used extensively in the UK and elsewhere. It provides an alternative model to that of Levine, which, in many ways, is its diametric opposite. Conditions under which the two models are likely to apply are explored later in the paper.

2.3 Economics

Having looked at optimal maintenance from a technical/financial point of view, we now examine the optimality of maintenance from an economic perspective. Ultimately, devising an optimal maintenance strategy requires examining not only the costs of maintenance, and the resulting level of system output, but also the benefit stream generated by the irrigation service provided and the impact that different levels of maintenance have on this benefit stream. This complicates the picture considerably.

A classic economic analysis of this problem would look at the relationship between incremental expenditures on system maintenance and incremental units of agricultural output. Nominally, expenditure on maintenance would be increased until its cost was just equal to the value of an additional unit of output. However such a relationship involves extremely difficult to measure variables, substantial time lags, and a great many intervening variables. Moreover, the nature of the relationship changes over time, as has been illustrated earlier. All of these factors make such a traditional economic treatment more useful to illustrate concepts than as an operational tool.

Broadening the cost and value concepts slightly leads to a useful framework for placing some of the different maintenance strategies mentioned above in a broader context (Figure 9). We can conceive of a situational matrix in which the perceived opportunity costs of the inputs needed for maintenance, i.e. funds, own labor, own materials, and so on; comprise one axis and the present value of costs or losses incurred due to deficient maintenance are shown on the other. Since it is often not possible to know with certainty what the impacts of particular levels of maintenance might be on system outputs, the latter is represented as a perceived risk of loss. This leads to four quadrants, in which *Minimum Maintenance* and *Maximum Maintenance* correspond to the similarly named categories described earlier, while quadrants B and D represent *Pragmatic Maintenance* from the earlier discussion.

Perceived opportunity cost of maintenance inputs	Perceived risk of deficient maintenance: Low	Perceived risk of deficient maintenance: High
High	**A. Minimum Maintenance**	**B. Essential Maintenance**
Low	**D. Conservation Maintenance**	**C. Maximum Maintenance**

Figure 9.
Alternative maintenance strategies

Quadrant A, in which the perceived opportunity cost of maintenance inputs is high, but the perceived risk of consequences to limited maintenance is low, represents one of the most common circumstances, particularly in low-income developing countries. Farmers are likely growing small grains, e.g. rice, maize, wheat, partly for own consumption and partly for sale. Market value of these crops is relatively low, and at moderate input levels, they are only moderately sensitive to water stress. At the same time, resources for all expenditures are generally scarce, and irrigation system maintenance likely has a relatively low priority in the minds of politicians and civil servants who typically make allocational decisions. Moreover, the incentive structure of maintenance service

providers often do not lead to efficiently provided services. Both routine and preventative maintenance are neglected, while emergency repairs and ad hoc repairs of critical facilities are done. These circumstances combine to yield the type of situation described by Levine, in which a cyclic pattern of decay and rehabilitation may be optimal.

In *Quadrant B*, both the opportunity cost of inputs and the risks of system non-performance are high. This is the situation more likely to be found in middle and higher income countries, where higher value crops are cultivated under high-input cultivation regimes, and production is almost entirely market-oriented. Expectations of system performance are likely higher than in Quadrant A which leads to higher standards of expected maintenance. Here maintenance efforts will generally be targeted on preventative maintenance and on insuring a high standard of reliability for critical system facilities. It is in this quadrant that asset management approaches to maintenance planning and management are most likely to be successfully applied. Some communal irrigation systems in mountainous regions may fall into this quadrant as well. Such schemes may have long main canals over unstable terrain, where maintenance, especially emergency maintenance, may make the difference between having a harvest and having none. Then regardless of the opportunity cost, essential maintenance will be performed.

Quadrant C, where the risk of system non-performance are high while the costs of providing the maintenance are low, is obviously an extremely desirable place to be. At the same time such cases tend to be rare. Model farms, experiment stations, and pilot projects may fall into this quadrant. Here while maintenance may be of high quality and expensive, the high visibility and symbolic importance of the system makes resources for maintenance easy to mobilize. There may also be cases of very high value production in which even gold-plated maintenance strategies require a relatively small share of total variable farm costs and are thus affordable.

Quadrant D, conservation maintenance, is an unpredictable one. Both risks and costs are low, and perceptions of opportunity costs may vary considerably depending on available alternative opportunities. Examples might include systems flood irrigating forage crops or pasture, where economic gains result but short-term failures are not critical, and where facilities are simple and routine upkeep inexpensive.

Complicating this picture is the multiplicity of actors who can take responsibility for the various activities implied in (Figure 9). Tasks involved include mobilizing maintenance resources, allocating maintenance resources, planning and carrying out maintenance activities, and conducting farming operations. Different actors will make very different decisions about resource allocation, for example, depending on who they are and the incentive structure in which they operate.

To shed light on these contingencies, it is necessary to disaggregate the maintenance input/production output equation. The schematic in Figure 10 depicts the chain of connections between changes in maintenance input and changes in net farm income.

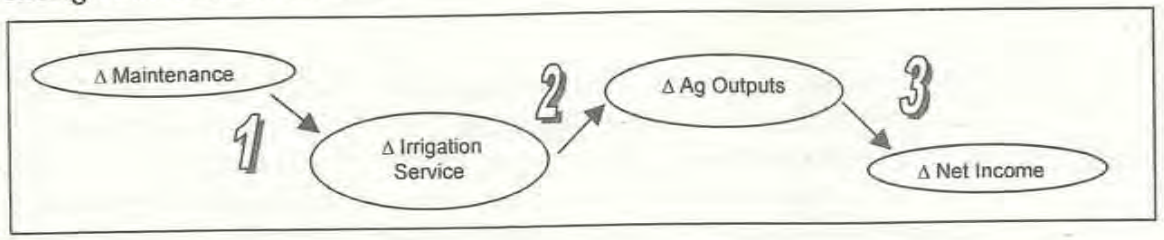


Figure 10. *Maintenance causality chain*

Relationship 1 in the figure comprises the process of transforming maintenance funding into irrigation service. Typically, a single agency organizes and provides maintenance services and produces the irrigation service, though several organizations are sometimes involved. The effectiveness and efficiency with which these services are organized and provided defines the functional relationship between maintenance funding and quality of irrigation service – the bang for the buck that is provided. Asset management techniques can be used to establish this connection.

Relationship 3 takes place within the farming operation. Here the farmer's management skills, along with relative prices, determine the profit he makes.

Relationship 2 is a critical one for the purposes of this paper, for it lies at the heart of what is "optimal" in optimal maintenance. This relationship comprises the "contract" between the irrigation service provider and the clients for the service. We explore this relationship further in a the following section, discussing briefly the concepts involved in treating irrigation and maintenance as "services."

2.4 Institutions

> **Box 4. Sustainability**
> *Sustainability problems are not fundamentally physical resource problems or technology problems, but institutional ones. Over a period of one or a few seasons, no piece of infrastructure, no technology, is stable or sustainable without institutions to operate, repair, adapt, and maintain it* (Svendsen, 1990).

As noted in Box 4, institutions are central to effective irrigation system maintenance. Institutions mobilize financial resources to support maintenance, organize human and technical resources to carry out the maintenance, and determine the amount and type of maintenance to be performed. In doing this, they, implicitly or explicitly, define optimal maintenance. In the following section we outline a service view of maintenance and explore how levels of optimal maintenance can be defined dynamically in a well-performing systems.

A socially constructed definition of optimal maintenance

Irrigation and maintenance as services

Analyzing irrigation system maintenance and operations as services is a powerful way of looking at these functions. In the past, water delivery and maintenance of infrastructure have been treated as technical functions performed in a unified command and control administrative set-up. Attention, in most cases, was focused exclusively on how to carry out the involved tasks. More recently, irrigation water delivery and system maintenance have come to be regarded as services provided by one party to another.

The fundamental difference between task performance and service provision is that the latter implies a relationship among independent parties. It suggests such questions as "who provides what to whom?", "what is provided in return?", and "how is the integrity of the exchange assured?" It also implies substantial interaction between the provider and the client in the provision process.
Basic service relationship

A service transaction can be conceived of as a bundle of four primary functions (Savas, 1987; Svendsen, 1994; Huppert 1994). These functions are arranging the service, providing the service, paying for the service, and using the service (**Figure 11**).

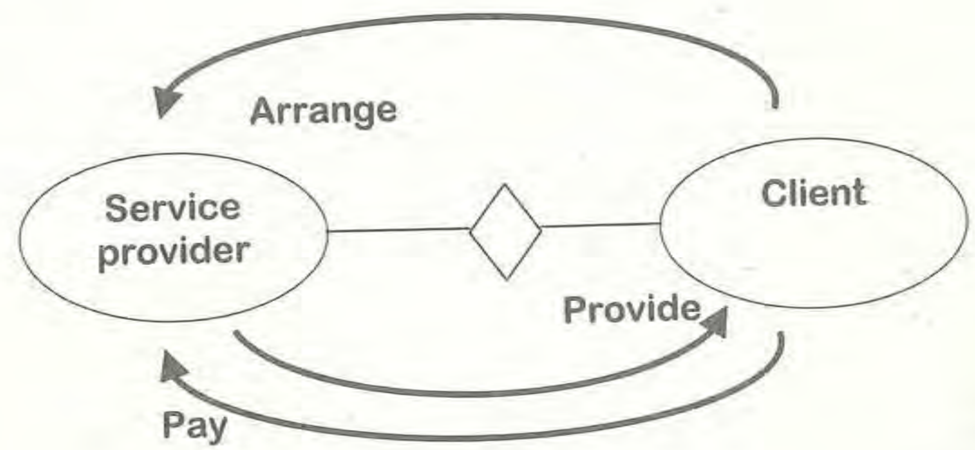


Figure 11. *Basic service transaction*

Arranging the service involves identifying a need, selecting a supplier, and negotiating an agreement with that supplier. The agreement, a form of governance mechanism, is represented by the diamond in the figure. Providing the service involves delivering it in a way that satisfies the terms of the negotiated agreement. Paying for the service requires transferring something of value to the service provider in exchange for the service provided, as specified in the negotiated agreement. Payment is usually made only upon satisfactory delivery, again judged relative to the terms of the agreement, although this is not always the case. Payment is usually made in money, but the transaction can also be arranged on a barter basis, where another good or service is provided in return. Using the service typically takes place simultaneously with its provision, since, by their nature, services generally cannot be stored.

An additional function is making the necessary facilities for delivering the service available for use. This function is performed by the system owner, who is typically concerned with the return on his investment in the facilities and with preserving the assets he has created.

Where services are provided in a multi-actor setting, it is essential to be aware of the mechanisms that govern the exchanges between the different actors (Huppert 1997). *Governance mechanisms* in service relationships comprise:

- formal and informal contracts and agreements between parties
- externally set and enforced laws and regulations
- third-party interventions such as external audits, regulatory actions, adjudication, and operation of joint committees comprising representatives of both sides
- basic norms, values, and common understandings (*cultures*), shared by the exchange partners
- procedures and common practices growing out of rules, regulations, norms and values

Accountability is based on these governance mechanisms, and relies on them for its legitimacy and its practical application. Basic accountability of a service provider to a service user relies on the internal features of the service agreement, such as the terms and conditions of payment. Third party interventions, based on laws and regulations, can also assist in promoting provider-to-user accountability, as can mutual respect for common social norms and values.

Perspectives and roles

Employing the concept of functional roles in a service relationship provides a useful way of understanding the actions of particular actors based on their perspectives. Box 5 summarizes a case study by Urban in which different actors employ very different definitions of "optimal" maintenance based on their perspectives.

Box 5. Optimal Maintenance in Peruvian Irrigation Systems

In the mid 1990s, the German Government supported a program to rehabilitate and improve more than a score of 100 to 200 hectare traditional irrigation systems in the Peruvian Andes. When the program ended in 1997, a mission was sent by the agency funding the work to evaluate the project. The mission found "serious organizational and technical deficits in the operation and maintenance of the irrigation systems on behalf of the water users associations." This disturbing conclusion led to the dispatch of a second mission early the following year. This second mission, including a broader set of perspectives, concluded that deficiencies existed, but that they were not hydraulically significant. They noted farmers had demonstrated the capacity to raise substantial resources to make emergency repairs, and that critical problems were repaired immediately. This experience demonstrates the importance of perspective and the way in which optimal maintenance is defined. After Urban (2000).

In this case, the original evaluation mission can be seen taking the perspective of the system "owner." From this perspective, any condition which causes the appearance and operability of system assets to deviate from their condition at the conclusion of the owner's investment was regarded as a serious failing. The subsequent mission, taking the perspective of the water user and was more concerned with system functionality. Given the easy access to rehabilitation financing enjoyed by the WUAs (see Urban, 2000), the second mission did not see such deviations as serious problems since the system continued to be capable of providing effective irrigation service to its users.

Dynamic tension

Box 6. Optimal Maintenance in a California Irrigation District

The Broadview Water District is a 4,000 hectare irrigation system in California's Central Valley growing a variety of high value crops in a hot dry environment. It is governed by a board comprised of district landowners. Farmers value reliability of supply very highly in this environment, as a delay of several days in a scheduled irrigation can completely eliminate the grower's profit for the season.

When the current district manager took over several years ago, the system was seriously deteriorated. He convinced owners to impose on themselves a special maintenance fee to be used to bring the system back to the required high standards of reliability. The manager presents the board annually with a proposed budget for the coming year, and the board modifies and approves it, automatically fixing the per hectare fees they will face for the year. After *Cone (2000)*.

A case illustrating the role of governance mechanisms is shown in Box 6. Here the users are also the payers, and through the board, exercise management control over the district manager, hiring (and firing) him and setting his salary. The manager and the staff he hires comprise the service provider. There are thus multiple accountability linkages between the service users and the provider.

In this case, the level of maintenance carried out, determined by the annual budget approved by the landowners, is keyed to achieving a particular level of responsiveness and reliability in irrigation service provision. Through a pattern of interactions with owners, the manager has come to understand what types of maintenance the owners value and what types they are unwilling to support. Owners depend, to some extent, on the manager's representations of what is required to insure system reliability, but through this pattern of interaction, sufficient trust has been established to legitimize this dependency.

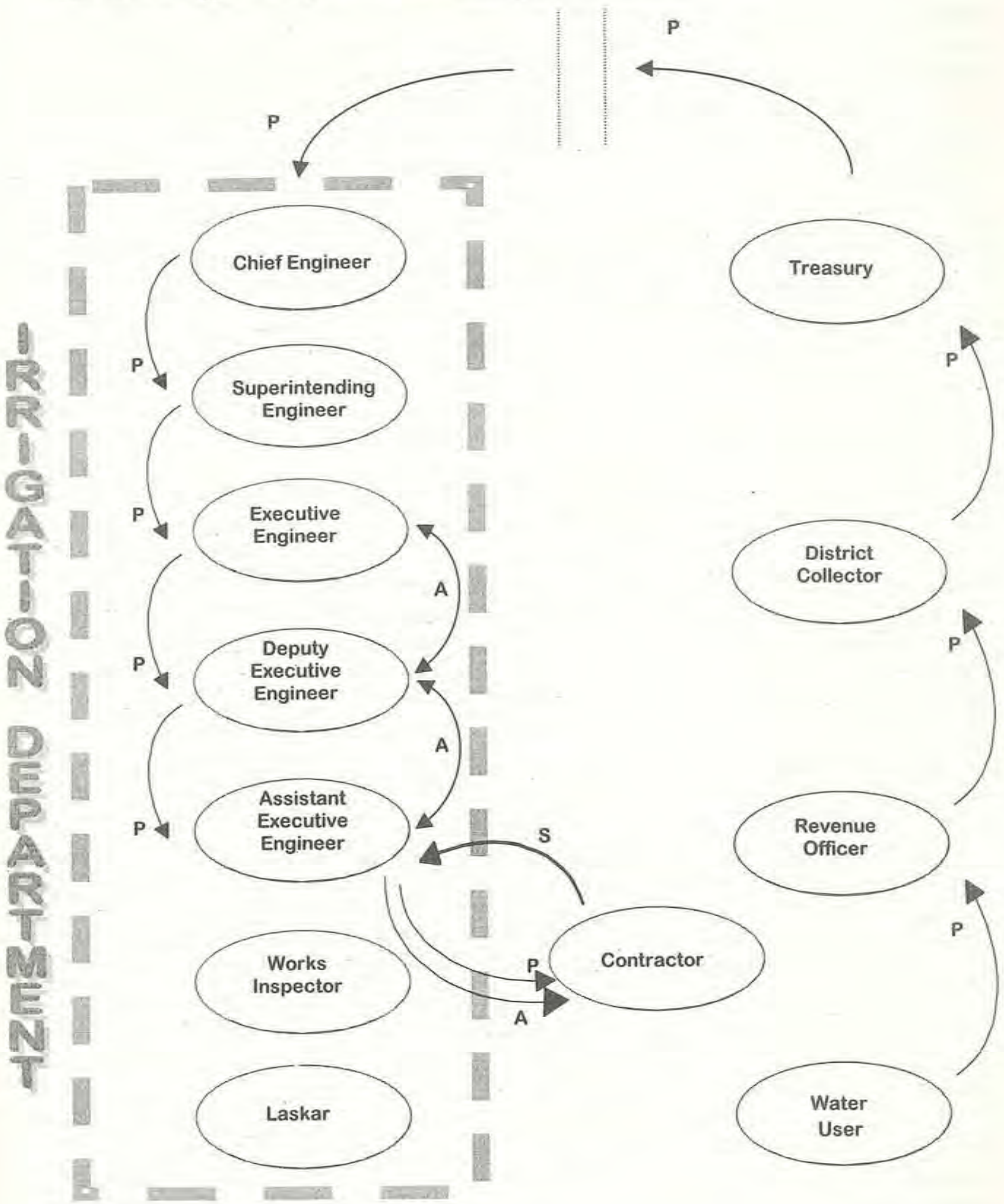
A number of different roles and incentives are at play here. Payers (landowners) desire to minimize their costs, while users (landowners or tenants) desire prompt and reliable service, which costs money. The provider (manager) desires to keep his job, to enjoy salary increases, and to do a high quality professional job. The interplay of these centripetal role-based incentives, countered by administrative and financial governance mechanisms results in a dynamic tension among the elements which *de jure* defines optimal maintenance.

Divided roles in public systems

In both of the examples presented above, there were close accountability linkages between system clients, the water users, and the service (and maintenance) provider. In each case, farmers themselves, through a governing board, made resource allocation and maintenance priority decisions. In many publicly-operated systems, however, these linkages are not closed and accountability to clients is weak or non-existent (see Svendsen and Huppert, 2000). Most commonly, the function of arranging maintenance services is separated from the function of using them, while the payment function is often also divorced from the use function. **Figure 12** shows an archetypical example of such an institutional set-up from India. In the figure P represents a payment for service, A represents an arranging function, and S indicates a service that is provided.

Under such circumstances, the image of "optimal" maintenance will be fragmented, and the pieces of the vision held by the different actors will be incomplete and very likely contradictory. A unified definition of optimal maintenance by stakeholders in a given system is a necessary first step toward achieving it (Urban, 2000). Moreover, the incentives operating on the various actors will be equally diverse. With little or no accountability to users, or to agents who effectively represent their interests, public employees making allocation decisions and providing services are unlikely to act in the best interests of the system clients.

Figure 12: *Primary functional relationships among actors providing maintenance service in a typical large-scale Indian irrigation system*



Source: Svendsen and Huppert, 2000

Governments or irrigation agencies sometimes attempt to close accountability links by shifting *payment* responsibilities to system users. However, because they usually retain the function of *arranging* for maintenance services, a partial measure of this type is almost always ineffective. Fragmented images of optimal maintenance and missing accountability linkages exacerbate other underlying problems such as limited ability to fund maintenance services and often lead to the cyclic degradation maintenance strategy described by Levine (2000).

3. Conclusion

This paper set out to answer the question "what is optimal maintenance?". Having examined the issue from technical/financial, economic, and institutional perspectives, it is clear that there is no clear answer, or at least no single answer. Some of the classic responses, however, are clearly incorrect. Optimal maintenance is not simply keeping a system in "like-new" condition. Nor is it achieved just by equating marginal benefits and marginal maintenance costs, assuming that one actually could do that in practice.

What is optimal in maintenance provision will certainly vary from one situation to the next. We gain some clarity by trying to classify the possible situations, and it is useful to look at the perceived opportunity costs of maintenance and the perceived risk of losses as a result of failure to provide adequate maintenance. In so doing, we see that when resources for maintenance are dear, the magnitude of the potential loss plays a powerful role in determining the maintenance strategy adopted, and the implicit definition of optimal maintenance. The greater the potential loss, the more stringent the requirements for irrigation system performance, and hence the higher the level of maintenance which will be deemed optimal.

This conclusion buttresses the notion of "optimality" built into a number of contemporary definitions of maintenance, which focus on the continuing ability of a system to provide a specified level of service. Such an approach to optimality, however, presupposes a service provider focused on service provision, alert to client and stakeholder needs, and effective and reasonably efficient in responding to those needs. Unfortunately, these traits do not characterize many irrigation management agencies, particularly public sector agencies, around the world. Hence in addition to the physical needs of the infrastructure and the economic calculus of perceived benefits and costs, institutions matter a great deal in defining optimal maintenance.

By this logic, creating a responsive service provider is a necessary precondition for approaching optimality in maintenance provision. Without this fundamental trait, personal and bureaucratic motives will always overbalance the needs generated by the clients of the irrigation service. Creating a responsive provider involves establishing strong accountability linkages and creating the appropriate incentive climate in which the provider operates. It is tempting here to suggest

that if we get the linkages and incentives right, then optimal maintenance will follow. And although there is considerable truth in this assertion, it too, is too simple.

We need to back up a bit at this point, and consider just what might be considered optimal maintenance under some of the earlier scenarios we have developed. First, take the case of a scheme where fixed budgetary allocations define the resources available for maintenance. In this case, with resources fixed, optimal maintenance might be defined in terms of getting the greatest maintenance impact for this fixed level of input. This requires a lean and efficient service provider, but also the ability to target limited resources effectively to get the greatest possible impact on system performance. This could mean, among other things, maximizing the area served, maximizing yields on a specified area, or maximizing the reliability of irrigation service to a specified area. "Optimal" is thus defined beneath a constraint regarded as fixed.

Likewise, if an asset management approach to maintenance is being followed, optimal maintenance might be defined as providing the specified level of service at the least possible cost. This is the classic *value engineering* approach. Here again, a parameter, level of service, is fixed which then allows a workable definition of optimality to be specified.

As these two examples illustrate, optimality is to some degree determined by the amount of freedom we are allowed in which to achieve it. The "working space" in which we define optimal maintenance is thus also very important. Are resource inputs taken as fixed? Can the market environment of agriculture be strengthened or must it be accepted as is? Can international lender policies that provide cheap and frequent credit for system rehabilitation be changed, or are a they a feature of the environment? Is maintenance service provision by a line government agency a given, or can the institutional set-up be modified? Questions like these bear importantly on what level and type of maintenance is "optimal."

Where we come out then, is that optimality of irrigation system maintenance appears to be something which cannot be defined on technical grounds, or economic ones alone, or even on institutional ones alone. Rather it must be defined as a process operating within a set of framework conditions and technical, economic and institutional constraints. Given a responsive service provider, one must define the working space in terms of those conditions which are immutable (at least over the short run) and then create the accountability links, incentives, and constraints which will allow system clients to shape the level and type of maintenance services provided while respecting the interests of other stakeholders. Once this process is working effectively, the resulting level of maintenance can be termed optimal.

Consider an analogy. Desiring to prepare a solution of one part per million of a particular substance in water, rather than taking a liter of water and trying to measure out one millionth of a liter of the substance, it is far easier and more effective to take a thousand liters of water and add to it one cubic centimeter of the substance. After mixing, one liter withdrawn from the solution will contain exactly one part per million of the substance. Although not assessed directly, the process has precisely defined the desired concentration.

So it is with optimal maintenance. Ultimately we must define the objective not in terms of a particular level of inputs, or a particular technology, or a specific quality of service, but in terms of a process and a set of conditions and incentives which will lead system clients to select appropriate maintenance for the system. There is no one optimum and what is optimal for a given group of clients will likely vary over time.

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Chapter 2

MAINTENANCE, REHABILITATION and BETTERMENT – HOW MUCH and WHEN?

Gilbert Levine

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1. Introduction

In the past 50 years, massive investments have been made for irrigation development throughout the world. For the World Bank, alone, this was more than 30 billion U.S. dollars; with country investments added, it represents the largest sector of agricultural investment. This development took place as a result of the combination of concern for meeting the food needs of rapidly growing populations, the recognition that irrigated lands produce more food with lower risks, and the availability of substantial amounts of grant and loan funds for irrigation development from major international sources. Investment peaked during the mid to late1970s when these forces were given added strength by the advent of new agricultural technologies with greatly increased production potentials. These potentials usually can be obtained only with significantly greater use of purchased inputs, with resulting increased financial and economic vulnerability. Irrigation, with its ability to minimize the major risk associated with agriculture -- drought -- was perceived as a prerequisite development for the increased utilization of these new, productive technologies, hence the emphasis on irrigation investment.

In many countries these earlier investments were reasonably successful (World Bank, Sector Study 14908). The expansion in irrigated area was accompanied by major increases in food production -- to the point where surpluses present a problem in many areas. India is a significant example, where food production during the past 30 years more than tripled[5] and where the famines that characterized drought years no longer plague the country. While the current world situation may be as much a result of a surplus of poverty as increased production, there is no question that massive increases in food production have occurred. As a result, world grain prices have been very low for a number of years, and there has been a reevaluation of the role of irrigation in many countries. This has resulted in a marked decline in Investment in irrigation expansion from the peak in the late 1970s and early 80s.

As the investment in new systems declined, concern for improving maintenance of the systems increased. This concern derived in part from the sense that the massive investments in irrigation development were not as productive as the potential would suggest or as assumed in planning, and in part from the feeling that the systems were deteriorating relatively rapidly. Mexico is an example of a country that is placing a major emphasis on maintenance to prevent irrigation system deterioration.

While responsibilities for maintenance in most of the Mexican national irrigation systems have been transferred to Water User Associations (WUA), the annual maintenance plans developed by the WUAs are reviewed and must be approved by the Comisión Nacional del Agua (CNA). CNA regulations require that 60% of

[5] Planning Commission, 1985. Seventh Five Year Plan (2 Volumes), Government of India, New Delhi, India.

the WUA budget must be spent on maintenance, and in situations where it has transferred maintenance equipment, specifies the extent to which that equipment must be used. The basis for this oversight is the fact that the national government, through the CNA, retains title to the physical infrastructure of the systems, and the maintenance requirement is presumed to protect the government assets. In this paper, I will question the underlying rationale for the current emphasis on maintenance.

2. System Deterioration and Maintenance Investment

It is an article of faith in the engineering profession that maintenance is good; generally, the perception is the more maintenance the better. As an ideal, maintenance should keep the system in its original condition. Yet, the failure to maintain irrigation systems is endemic throughout the world. Many reasons for this failure are cited, including inadequate budgetary allocations and a failure to appreciate the needs. However, I argue that there may be (and frequently is) a combination of physical, economic and political rationales which not only explain **why** there is a lack of maintenance, but which suggests that the pattern of deterioration and rehabilitation that characterizes so many irrigation systems is a **reasonable** one[6]. If the arguments I present are valid, then there are serious implications for the level and type of maintenance investments that should be made.

The arguments are presented using a series of schematic paradigms -- in part because there is little formal research devoted to the topic of maintenance and the causes of deterioration, and in part because the main ideas should come through more clearly -- if oversimplified. However, I will buttress the arguments with some case examples.

The general argument that I will develop is that the immediate costs -- financial, organizational and political -- associated with a high level of regular routine maintenance[7] may not be balanced by the benefits from such maintenance, if one discounts the benefits for the time lag between incurring the maintenance costs and obtaining the benefits.

The first part of the argument is based upon conventional design practice, particularly channel design. It is customary to design channels with a depth approximately 10 per cent greater than the design flow depth that would provide the necessary volume rate of flow and delivery stage. The reason for this 'freeboard' is to protect the channel from overtopping as a result of wave action, to protect against occasional excess flows (perhaps resulting from rainfall) and to provide for some sedimentation of the channel, especially in the first years after

6 Much of this section is based upon Levine,G. 1986.

7 It is appropriate to indicate that the routine maintenance considered here is the regular periodic maintenance usually intended to keep the system at, or near its original operating condition. Breakdowns which have an immediate serious adverse effect obviously must be repaired as rapidly as possible.

construction. While the freeboard is not intended to provide flow depth on a routine basis, it is there, and it **can** be used for that purpose. A 10 per cent increase in depth, for typical channel cross-sections, provides about 15 per cent increase in flow area, and at least that much in discharge capacity.

Figure 1 poses a relationship between the ability of a channel to deliver water and years of channel life under conditions of minimum maintenance. "Years", the x-axis, is used as a proxy for the deterioration that occurs under the minimum maintenance program.

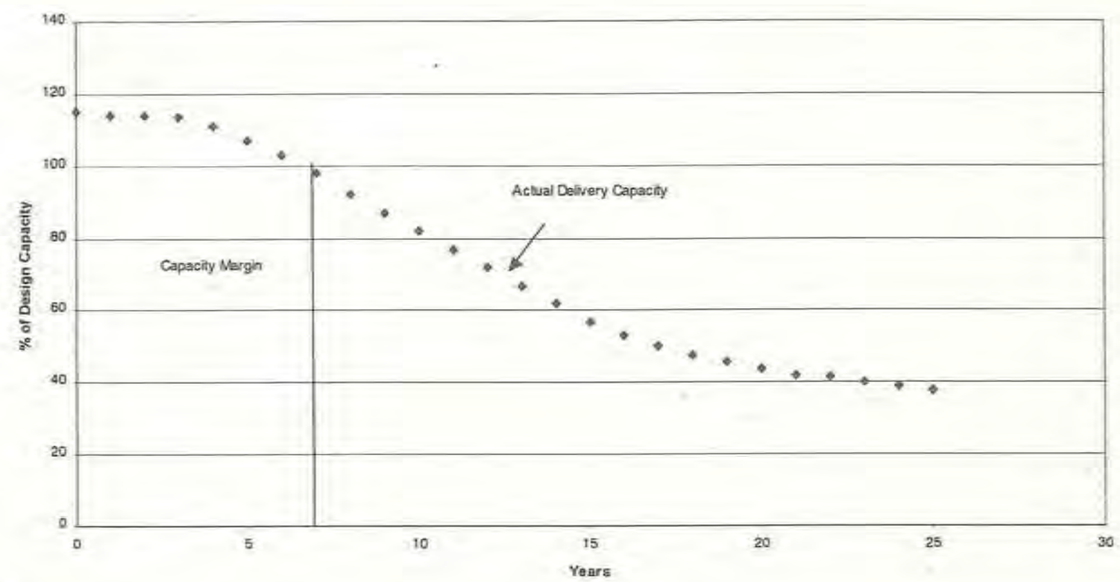

Figure 1. *Channel delivery capacity in relation to years of minimum maintenance*

The figure indicates that the channel initially is capable of delivering more than the design discharge, and that this capability is utilized, as the channel becomes sedimented, overgrown with weeds, and in other ways deteriorated. Thus, there may be a number of years of minimum maintenance before the channel can no longer deliver the design flow.

Even when the channel can no longer deliver the design flow crop yields may not decrease at the same time, nor in proportion to the reduction in flow capacity, as suggested by figure 2.

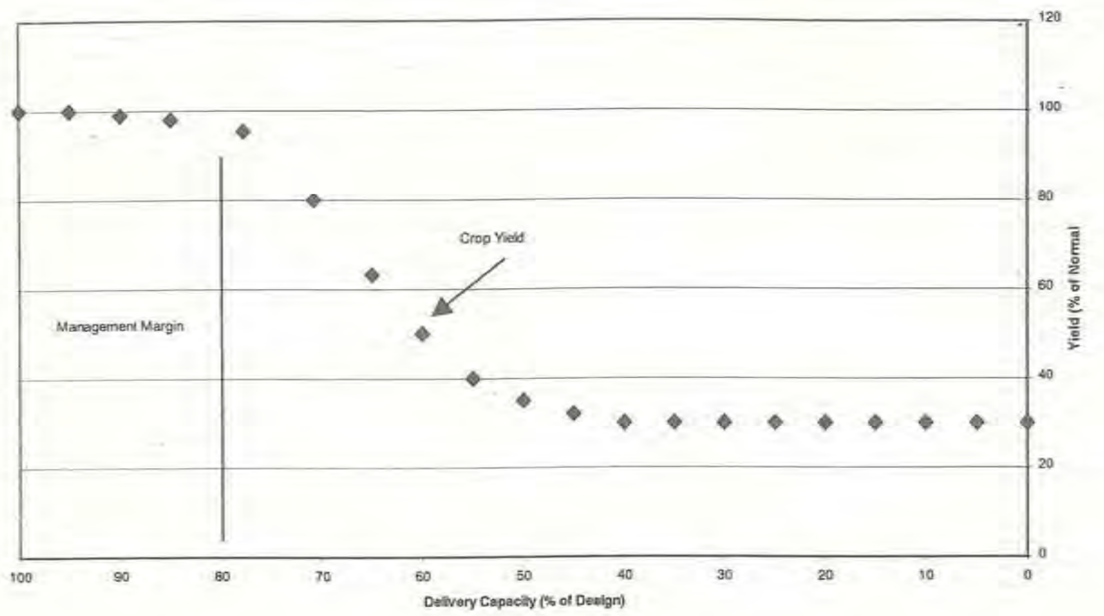

Figure 2. *Yield of crops in relation to water delivery*

The lag in crop response reflects the ability of farmers to `manage` irrigation more carefully when there is a water shortage. Many systems are operated with a Relative Water Supply[8](RWS) of 2 or greater, indicating that there is significant potential for using less water, though with an increased management effort. Frequently, relatively modest increases in management effort can result in significant reductions in water use without adversely affecting yields. Examples can be found in Mexican systems where farmers often manage with RWS values as low as 1.5 (Levine, et al, 1998) with normal yields. It is even possible to maintain yields at RWS values closer to one, but this increased level of management usually can be sustained for only a limited period of time after which the farmers are likely to take other actions. For example, a severe drought in Taiwan was successfully weathered by some of the Irrigation Associations through a series of actions that permitted a water supply about one-half of normal (a relative water supply of approximately one) to produce a crop about 95 percent of normal. The actions of the Yun-Lin Irrigation Association included: more frequent discussions among the farmers about their individual and group needs; paddy dikes near drains were plastered to minimize water losses; common irrigators were hired to take over the irrigation activity from the farmers (minimizing disputes); drainage water was reused[9]; irrigation system staff maintained 24 hour vigil at control gates; the Chairman and Chief Engineer worked long hours to serve as examples for the professional staff.

[8] For a discussion of the Relative Water Supply, see, Levine, G. 1999.

[9] A more complete description of farmer and system response to severe water stress in the Yun Lin system can be found in Levine, G. 1983.

When more intensive management is insufficient to compensate for the diminished water supply, often there are attempts to obtain more water, especially if there are possibilities for increased allocations from the source. There may be formal requests directly to authority at a higher level in the system, or there may be indirect efforts through the political system. Examples of these are cited for systems in Indonesia (Oad, 1971) and the Philippines (Svendsen, 1975).

The non-linear response in figure 2 also reflects the fact that crop production functions have both linear and non-linear portions, with much of the relationship linear between the economic optimum and the lower yield levels.

For purposes of this discussion, I have suggested that intensified management response can delay the impact of reduced delivery capacity for approximately four years (to a RWS of approximately 1.6.)

While it is probable that when yields start to reduce incomes will decline at the same time, It is difficult to suggest the shape of the curve. Some costs are related to yield magnitude, there frequently are cropping pattern adjustments that can be made to buffer the income stream, at least to some extent, and it yield reductions occur over a wide area, crop prices often increase.

My basic argument can be summarized by combining the foregoing relationships, as in figure 3.

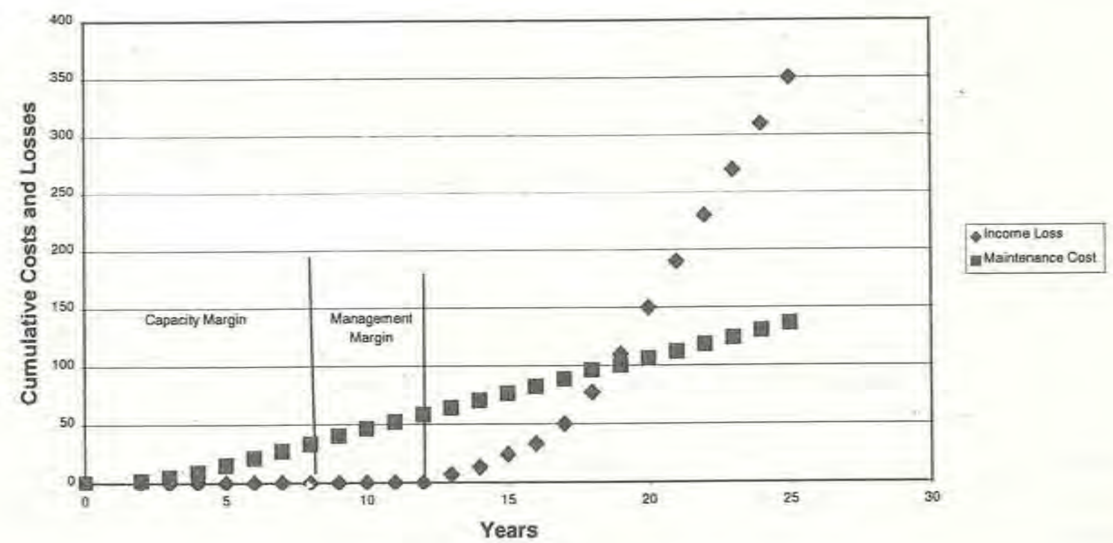

Figure 3. *Maintenance costs and income losses over time*

The excess water delivery capacity and opportunities for management intensification often combine to result in a significant delay in the impact of deferred maintenance on net income to the farmers. Figure 3 also shows a cost stream for a regular maintenance program designed to avoid detrimental impacts. The cost of maintenance (shaded area) must be compensated for by the income protected (cross-hatched area). If one discounts future benefits, and if one accepts the reality of relatively high interest rates in many countries, we can see that the discounted benefits will be relatively small until the situation deteriorates significantly.

For example, if there were a 20% interest rate for the foreseeable future, a $100 return 12 years from now, from maintenance, would justify a maintenance investment of only $11 at the present time. If the interest rate were 30% (not unusual in many developing countries) the $100 return 10 years from now would justify an investment of only $4.29 at the present time. If the period for obtaining the benefits from the maintenance investment was15 years, the corresponding justified investment would be $1.95. Even in Mexico, with an interest rate of approximately 15%, $100 return in 12 years would only justify an investment of $19. Thus, if there is a significant delay in obtaining the benefits from maintenance, a program of maintenance designed to keep a system in its original operating state can be questioned seriously. That such delays are not unusual is evident in the experience of Mexico (Kloezen et al, 1997) and Colombia (Vermillion and Garcés-Restrepo, 1998) where, notwithstanding significantly increased investment in maintenance on the part of the water user associations following transfer, there was no discernible change in gross value of productive output some years after transfer.

This physical/economic argument is reinforced with the realities of the financial situation for many irrigation sectors. Inadequacy of budgetary allocations for maintenance is characteristic of almost all irrigation systems, in developed as well as developing countries. In government systems, efforts to obtain increased allocations usually are the responsibility of the irrigation bureaucracy, which must function within the budgetary structures and strictures of the government. Notwithstanding much `lip service' to maintenance rarely are sufficient funds appropriated in reality. When responsibility for maintenance is assigned to the users, funds for increased investment in maintenance must come from increases in the water fee. However, when the income derived from irrigation is relatively small, the maintenance costs often become unbearable. For example, in Taiwan, at the present time, the agricultural share of farm family income is only 30% (Levine, Ko and Barker 2000). As a result, the Taiwan government now pays for all the costs of system operation and maintenance. In Mexico, while the annual gross return on investment in irrigation systems approximates 20% (in four irrigation districts studied by IWMI), suggesting that it is a good public investment, the net return from irrigation to the irrigators is almost zero. At the present time the users in Mexico are responsible for maintenance expenditures;

whether the current level of maintenance expenditure can or should be maintained is questionable.

To this physical, economic and financial picture we can add the political dimension. When the physical and income impacts of `deferred maintenance' are sufficiently strong, the irrigators frequently take the initiative to exert pressure through the political system to have the situation corrected. The burden of developing budgetary support shifts away from the water users and the operating bureaucracy to the politicians. This shift in the source of pressure often is accompanied by a shift in the source of potential financial support. While maintenance funds for government systems usually are obtained from the general budget or, in the case of transferred systems, from the users, 'rehabilitation' funds frequently are associated with special appropriation funds, including those from external donors and lenders. In India, for example, major development efforts, including major irrigation rehabilitation are supported from the `Plan Budget' of the Centre -- the Government of India (with equivalent participation from the government of the states), while recurrent costs such as maintenance usually are not. In Mexico, rehabilitation funds are available from central government programs, frequently reflecting World Bank or Inter-American Development Bank loans.

A pattern of deferred maintenance, therefore, has some significant advantageous elements for both the operating bureaucracies and the water users. It supports the efforts of the irrigators in the search for additional financial resources; it changes the field of competition from that of the general budget to the more limited set associated with the development; it mobilizes political support for increased funding for the irrigation agency and for the users.

The foregoing is not intended to ignore, or underestimate the problems -- for the farmers, for the government and for the politicians -- which arise during the interim between the time the operating situation becomes seriously deficient and the time the system is ultimately rehabilitated.

For the farmers, the increase in managerial cost associated with operation at lower levels of RWS may be significant. In addition, depending upon the extent and pattern of the maintenance carried out, some farmers will experience the impacts of deferred maintenance earlier and with more severity than others. This places the burden on the system operators, to minimize this inequity, and to optimize the use of the more limited maintenance funds. For the government, there must be a recognition that periodic major rehabilitation/improvement is a requirement to keep the irrigation sector productive and efficient. For the politicians, there is a need to recognize that acceptance of this pattern of periodic rehabilitation/improvement does not mean that no maintenance investment is necessary, and is not an excuse for cutting regular investments, as appropriate.

In summary, given the economic rationale and the reality of the politics of budgetary decision-making, the pattern of periodic deterioration and subsequent rehabilitation may be not only a rationale response to these forces, but also a reasonably efficient (if not necessarily optimum) pattern. I will argue that this is strengthened further by the rationale for the need for `improvement'.

3. Rehabilitation and/or improvement?

There is increasing recognition that **rehabilitation**, the repair and reconstruction of the system to its original condition, is an inadequate response to extended deferred maintenance. This is due to a growing understanding that irrigation systems are part of a dynamic environment and successful systems are those that adapt to the changes in their external environment (Levine, 1982). This adaptation permits the system to remain reasonably efficient with respect to the relative scarcities of the available water, land and managerial resources associated with the system. Systems that have opportunities to change at reasonably frequent intervals are likely to be more successful than those in which system rigidities inhibit change.

3.1 Life cycles of irrigation systems

Figure 4 illustrates an idealized life cycle of an irrigation system, using water efficiency as a parameter of its performance.

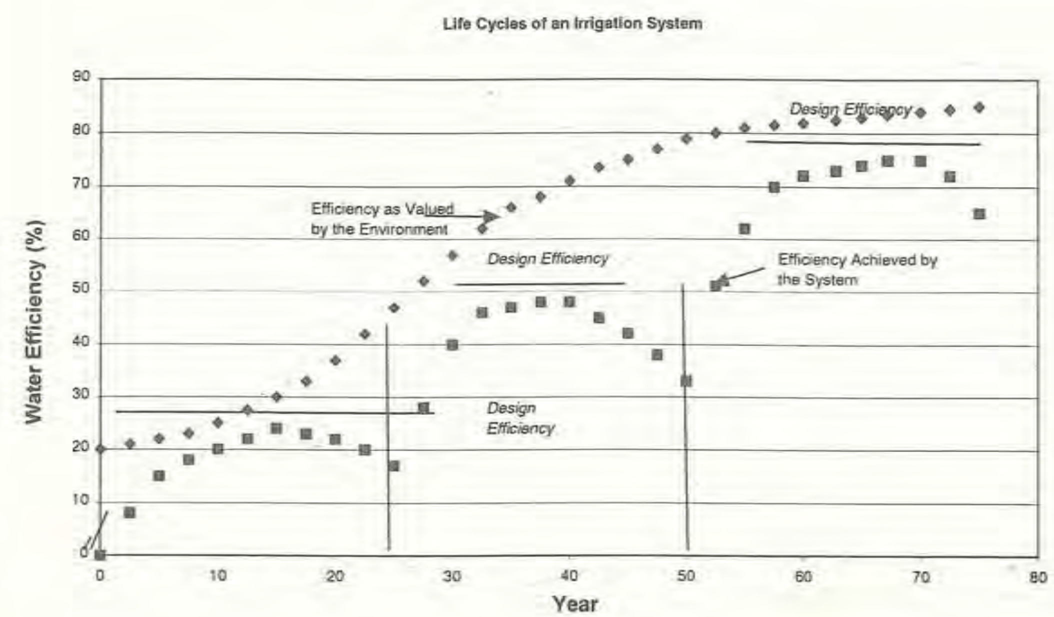

Figure 4. *Idealized water efficiency performance of an irrigation system over its life cycles*

Three basic ideas are suggested here:

-- within each cycle, the system has a pattern of learning, maturation and decline. This argues that there is a period of time required for the system operators and the farmers to adjust to the new, or remodeled facilities, that the system then operates reasonably in accordance with the learning that has taken place, and that system deterioration ultimately adversely affects system performance significantly.

-- the value of water in the external environment is increasing over time. This probably is the most typical situation in most irrigated areas, where there either is pressure to expand irrigated area or to utilize the available water for other, higher value purposes, such as industrial, power or municipal/domestic water. However, there may be situations of plentiful water or very rigid water rights where the implied value of the water does not increase over time.

-- the deviation of system performance from that implied by the resource value is composed of two components -- that derived from the deterioration of the system, and that resulting from the change in the value of the water in the specific environmental context.

I argue that the inadequacies in system performance reflected by the deviation from the `environmentally determined' performance optimum are important, and sometimes the dominant forces, and that the pressures for rehabilitation are not solely the result of the decline from the original (actual) performance levels. To the extent this is a valid argument, the need for `betterment' becomes apparent. Betterment implies a change (improvement) in the system, and I suggest that these changes must be in the direction of optimizing the use of those resources of increasing value in the surrounding social, economic and physical environment.

At this time it is appropriate to offer a strong caveat. The arguments and sketches presented here obviously are oversimplified -- oversimplified in suggesting that they apply to the range of systems to be found in the very different environments around the world. The relation to the external environment, in the foregoing discussion is oversimplified in that it utilizes only one of the many performance parameters that might be considered. I use water efficiency, not because it is the most important performance indicator, but because it is a parameter that can be used for illustration with a minimum confusion of terminology. Frequently, it is not an important indicator, either because there is abundant water, or because recharge to an underlying aquifer or reuse downstream result in high efficiencies on a watershed or river basin scale. Given these oversimplifications, there will be situations where the arguments presented will not be valid. However, I believe they are valid over a wide range of conditions sufficient to justify a serious look at their implications.

3.2 Implications

The foregoing analysis suggests that rehabilitation will be necessary at reasonably regular intervals. Experience suggests this should be on the order of 25 to 30 years, which also represents the effective time for recovery of the initial financial investment. This then becomes a valuable opportunity to reposition the system with respect to its optimization of resources relating to the external environment, as well as to those of its internal environment.

It also suggests that the rehabilitation/improvement process is not solely, nor perhaps even primarily related to the physical system. There is an implication of a need for significant change in the 'rules of the game'; patterns of water deliveries may change – including the amounts and timing received by different individuals and groups; responsibilities of the governmental employees and of the farmers are likely to change; interaction among farmers and between the farmers and the operating department are likely to increase – or, at least will be expected to increase. The program of irrigation transfer in Mexico is a clear example of the "non-structural" nature of much of the rehabilitation/improvement effort.

In those situations where the original patterns of water delivery have taken on the character of **rights**, de facto if not de jure, the rehabilitation/improvement process will have to address the 'taking away' of these rights, and will have to provide an appropriate quid pro quo for the loss.

There is likely to be ambivalence associated with any change in responsibilities. For the irrigation department, there will be a desire to shed certain types of responsibilities – primarily those of maintenance, fee collection and conflict resolution – while retaining those related to control of the water. This is evident in the Mexico transfer program. For the farmers, there will be little incentive to add to their responsibilities, unless they see relatively direct benefits – system improvements, reduced fees or at least fees used for their direct benefit (rather than to a general governmental fund, or to support the salaries of the bureaucracy). In the Mexico transfer program, many water users perceive these benefits (Palacios,1994). In some situations the users accept more responsibility for conflict management, but they frequently perceive benefits from having a higher authority with ultimate responsibility.

Increased interaction, almost a prerequisite for system changes that anticipate increased efficiency, raises implications for changes in social relationships, especially in the relationships between the water users and the bureaucracy. Usually, this will require changes in the attitudes of the irrigation department as an institution, of the irrigation staff, especially the professionals, and of the water users. Where the water users have been in a position of dependency for many years (a not infrequent case), they will not automatically fit into new patterns of

interaction. This appears to be the case of many of the *ejido* water users in Mexico.

There are two situations where the cycle of deterioration, rehabilitation/ improvement may be of such short duration and depth that it does not represent a problem. Where the external environment is changing very slowly, and there is sufficient flexibility in the institutional structure of the system, adjustment to the changes in the environment can take place within the normal process of maintenance. Examples can be found in a number of customary, farmer-managed systems. There may also be cases where the effects of a changing environment are inhibited by legal rigidities. For example, notwithstanding increasing value for water in many irrigated areas, pressure to make major modifications in water distribution and utilization many not result because water rights are defined in ways that tend to insulate the users from the need to change. However, in this latter situation the cycle may only be extended in time.

While I argue that in most cases the cycle of deterioration, rehabilitation/ improvement is essentially inevitable, and reasonable, as we have stated earlier, ***it does not mean that there should be no maintenance***.

4. Maintenance

4.1 Needs

Maintenance needs can be considered both from the standpoint of physical needs and psychological impact. The physical needs fall into two basic categories: emergency and routine.

4.1.1 Physical

-- emergency needs are those that are necessary to keep the system functioning. Failures of major structures, intake gates, etc. that prevent the system from functioning must be repaired rapidly. Thus, financial, equipment and human resources must be available for this purpose.

-- routine needs are those that are typically identified with maintenance programs. Programs of routine maintenance frequently address problems associated with conveyance, distribution, and drainage channels, access roads, and system buildings. Programs usually include painting and minor repairs to gates and other control structures, weed control, desilting, etc.

While it is possible to define a theoretical maintenance program, identifying desirable activities on the basis of the types and extent of the physical infrastructure, rarely are resources sufficient to carry out this type of program. More typically, there is a budgetary allocation that defines the extent of the program, and the components of the program are determined by local criteria. The International Water Management Institute, with Mexican collaborators, compared its local criteria with those built-in to the MARLIN maintenance priority program developed by Hydraulic Research, Wallingford, England (Wester, et al. 2000). In general, there was good agreement between the criteria, but there were some notable exceptions, e.g. where a channel served a local community.

4.1.2. Psychological

In addition to the tangible physical benefits that may result from a program of maintenance, there are psychological benefits that can be expected. When resources are provided to irrigation operators, by either the government or the users, there is an expectation that those resources will have demonstrable impact. It is difficult to demonstrate impact on production, because any production impact is dispersed, and, as suggested earlier, because any production impact is likely to be significantly removed in time from the maintenance input. Therefore, there is value in more obvious evidence of the maintenance effort. Clearing vegetative growth from channels, particularly those that are readily visible from traveled roadways, presents a demonstrable impact. Maintaining roadways with a minimum of ruts has a similar effect, even if it is not likely to have a significant impact on functioning of the system.

While this is a beneficial psychological effect during the early period of a system's life cycle, it is a potentially negative effect during the latter stages. As suggested below, the development of support for rehabilitation/improvement is likely to be dependent upon there being sufficient evidence of system deterioration to establish the justification for the special investment.

4.2 Timing

The earlier discussion on maintenance, rehabilitation and improvement suggested that significant investment in routine maintenance had limited economic rationale, and that system deterioration was a logical consequence. If this is valid, the major timing question relates to the timing of the development of political support for the rehabilitation/improvement effort. Ideally, it should start before there is substantial adverse impact on production. However, it is likely that there must be enough deterioration to be obvious to those with authority over the necessary resources.

5. Conclusions

There are four conclusions that can be drawn from the foregoing:

1. The pattern of system deterioration, rehabilitation/modernization, deterioration that characterizes many irrigation systems is basically rational;

2. There should be a scheduled program of major rehabilitation and betterment on a 25 to 30 year basis;

3. Routine maintenance programs should have as an essential objective, minimizing disparities in the effects of increasing deterioration on users;

4. Sufficient maintenance resources should be available to cope with emergency situations

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Chapter 3

What is ‚Optimal Maintenance' of an Irrigation System? How Different Perceptions of Optimal Maintenance can Complicate Development Cooperation Work: Experiences from a Peruvian Irrigation Project

Klaus Urban

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1. Background and Rationale

In the first decades of international development cooperation investments in irrigation belonged to the priorities worldwide. However, in spite of a number of success stories (especially in the course of the „green revolution" in Asia) the overall evaluation of these efforts shows rather disenchanting results. Very often serious problems (e.g. negative environmental effects, operational problems) have led to the underutilization of irrigation systems and many systems have fallen into disrepair. Consequently, large amounts of money have to be spent on the rehabilitation of existing irrigation systems – in many cases long before the end of their expected "life cycle".

In the middle of the 80s efforts were made to analyse the reasons for these problems. Various international organisations commissioned reports and organised international seminars and expert consultations on the matter. There was a common agreement that organisational and managerial deficits were at the heart of the problem. "Physical reconstruction of older schemes will be of only temporary benefit if changes are not instituted in how the systems are operated" the 1985 USAID 'African Irrigation Overview' stated. It was argued that operation and maintenance investments were far too low and that this favored the deterioration of many schemes. Consequently, low maintenance levels were viewed as indicators of bad system performance entailing the danger of deterioration and need for rehabilitation.

However, the reasons for the low maintenance levels and maybe equally important the question: "What is actually the optimal level of maintenance?" were hardly ever addressed. Both these issues are strongly interlinked and the effort to answer the latter question already implies a close look at the underlying concepts and expectations regarding the respective irrigation systems. What makes things more complicated – especially in the context of international development cooperation – is that different perspectives in the perception of irrigation maintenance necessities within a network of participating actors (financing agency, local authorities, users etc.), above all in intercultural settings, are frequent.

In practice, the institutions, groups or individuals responsible for 'maintenance' usually have to prioritise maintenance investments in the light of resource constraints. But where should the priorities be set? What are adequate levels of maintenance in the respective system? Field experience shows us that the answer to these questions is by no means easy and that very often the priorities differ according to the perspective of the actor involved. Whereas the users might prioritise measures that secure the water delivery on the short run (and neglect investments in the long-term sustainability of the irrigation system), an executing agency or construction company might have to keep in mind liabilities (e.g. towards insurances) – on the other hand donor organisations and local/regional governments might want to prioritize measures in the context of (social) development aims of their respective governments. Consequently, diverging interests might easily be at the root of severe conflicts, if, for example, investment priorities that favor the efficiency of the overall system performance collide with the priorities of the individual farmers that take into account existing opportunity costs (e.g. for undertaking maintenance works instead of important other agricultural and non-agricultural activities).

If maintenance is viewed as crucial for the success of an irrigation system, then a common agreement on what is „optimal maintenance“ among the major, usually numerous, participating actors is a major precondition for this success. Without such a common understanding a realisation of effective maintenance will be very difficult. However, finding such an agreement is not an easy task in light of the striking differences in the perceptions usually to be found – as the following example from Peru will illustrate.

2. Diverging Perceptions of 'Optimal Maintenance': the Case of "Plan Meriss" in Peru

2.1 Background of Plan Meriss

„Plan Mejoramiento de Riego en la Sierra Sur“ (Plan Meriss) was originally the name of an irrigation project in the Vilcanota valley in the Southern Andes supported by the German government. The aim of Plan Meriss was to support local communities in the Andean mountains in the improvement and rehabilitation of their traditional irrigation schemes. These schemes were relatively small in scale, very seldom exceeding a total irrigation area of one or two hundred hectares. Likewise, the organisation, operation and maintenance of these schemes did not follow „modern“ patterns, but was based on traditional rules and regulations, which nevertheless were quite functional. In practically all of the traditional villages – most of the schemes were operated within the boundaries of village communities - one could find functioning *water user associations* (WUAs) with *boards* responsible for the 'organisation of the major tasks of the association' and the *general assembly* of the so-called *socios* (members) responsible for the major decisions with respect to the organisation, operation and maintenance of the system.

At the end of the 90s Plan Meriss had assisted more than 20 traditional villages in the Vilcanota valley in the extension and modernisation of their irrigation systems. The improvements usually consisted of the lining of larger parts of the canals and in the construction of a number of minor infrastructures such as gates, siphons, distribution weirs etc. The vast majority of the systems were simple gravity irrigation systems. In spite of some difficulties in the first years, where Plan Meriss had tended to enforce "technical solutions" that were not functional in the traditional setting of the Vilcanota valley, the project staff gradually learnt to incorporate the traditional working principles of the existing systems in the "new project designs" and thus – in close cooperation with the village authorities – managed to set up a number of quite successful irrigation systems, that were accepted by the users and operated by themselves.

2.2 Evaluation Missions in 1997 and 1998

In 1997 in view of the final closure of the activities in the Vilcanota the German government sent a mission to evaluate the progress made in the Vilcanota valley. In spite of a generally positive view of the goals achieved by Plan Meriss (which was by now the name of the regionally well renowned Peruvian project organisation) the mission returned rather worried after having observed 'serious organisational and technical deficits in the operation and maintenance of the irrigation systems on behalf of the water user associations'. In order to shed further light on this point an additional mission, which was to investigate and analyse the state-of-the-art of the operation and maintenance of the improved and rehabilitated systems in the Vilcanota valley, was organised. This second mission took place in February of 1998[10].

At the end of their field visits the members of the evaluation team presented their findings to the management of Plan Meriss in the form of a preliminary report which was then discussed intensively throughout two days. These discussions – though in a very positive and constructive atmosphere - shed light on the difficulties that can arise in the solution of O&M-problems when diverging expectations and prespectives impede a common understanding of "what is an optimal level of maintenance?" under local circumstances.

2.3 Overall Evaluation of the State-of-the-Art of „Maintenance" in the Vilcanota Irrigation Systems

Originally the mission was set up because of the supposed serious organisational and technical deficits in the operation and maintenance of the irrigation systems detected by the 1997-mission. The second mission that evaluated the systems in 1998 also found a series of technical problems (such as broken valves, deteriorating canals etc.) and also a number of organisational and operational deficits, but did not coincide with the former mission in the overall rating of these problems. Thus their report concluded: "In principle, the actual state of the infrastructure and the maintenance carried out in the 16 projects of phase II/IIa visited do not affect the hydraulic functioning of the irrigation systems in a significant negative manner. All of the irrigation systems are functioning, in

[10] The two members of the mission, one from Germany and the other from Peru, were experts in irrigation economics and irrigation engineering.

spite of the fact that the conduction and distribution of the water could be better or more efficient in some of the projects. ... The users know very well the physical state of their infrastructure and if problems occur that affect the functioning of the conduction/distribution canals, these are repaired immediately due to the proper interest of the farmers" ('Acta de Acuerdos', Plan Meriss/KfW, 27.2.98, pp.3 and 4).

This interpretation coincided with the opinion of the farmers and also of Plan Meriss. For the users in the Andean valleys, generally, maintenance is sufficient as long the operation of the system is not significantly hampered. If deficiencies, such as e.g. a deteriorated canal or a broken valve, do not inhibit the water flow in a significant way they will very often not bother to repair it (or at least not before the beginning of the following season). If however, the damages endanger the basic operation of the system (e.g. if a weir is about to collapse), they will generally repair it immediately, even if this requires substantial financial contributions on the part of the users. This happened, for example, in one of the systems called Vilcabamba (with a total area of 150 ha). In September 1997, after a part of the main canal had collapsed, the WUA collected a significant financial contribution, about 800 US-$, from its 100 members and additionally sold communal land worth 10.000 US-$ to pay for an immediate repair of the canal.

The abovementioned incident shows that different perceptions of what is optimal maintenance can occasionally lead to confusion. It was obvious that the initial judgement on behalf of the first German mission was based on the perception that the visible technical defects were indicators of „suboptimal" maintenance. For the users and for Plan Meriss, however, the „lower" levels of routine maintenance were acceptable and did not indicate serious problems in the overall maintenance of the systems.

2.4 Organisation and Financing of Maintenance

Another critical issue was the 'organisation and financing of maintenance'. The maintenance of the irrigation systems in the Vilcanota is based on ancient customs and traditions. As long as the villager can look back, the irrigation canals have been cleaned and, if necessary, repaired in the weeks before the beginning of the „main season" (winter season) that starts more or less in October. Usually the WUA determines one or more days (depending on the size of the infrastructure) when they will all together clean and/or repair the jointly used infrastructure. Every socio has to participate or send a peón (paid laborer) on his behalf. This process is embedded in a number of rituals connected to this special type of communal work (ayni). The WUA distributes a number of roles – some members have to care for the food, others for music (play in the band) etc. In most of the communities the end of the maintenance activities is marked by the traditional fiesta del agua, where the god of rain is worshipped.

Normally this maintenance work does not imply large costs. If money is required it is collected directly for the purpose it is needed for. The individual shares are determined in a general assembly and collected by the members of the junta directiva (board). Similarly, if additional maintenance requirements are detected, they are solved on an ad-hoc basis by the WUA. Again, if for some of the repairs, a monetary contribution should be necessary, these are decided upon by the assembly and collected by the board. It can be said, that, in general, this "rustic" organisation of the maintenance works quite well in the majority of the systems (also after their improvement).

In this case, again, diverging perceptions of what is the optimal form of "organisation and financing of maintenance" impeded a smooth solution of this issue. It was hardly possible to come to a conclusion between Plan Meriss and the mission because there was no common agreement on the kind of organisation and financing feasible under local circumstances. The mission had initially proposed the establishment of a *‚cuota'* which was to cover the costs for the O&M (preventive and regular maintenance), the administration of the system (costs of the WUAs themselves), the costs for extraordinary (unforeseen) maintenance as well as the costs for the amortisation of the construction costs of the infrastructure. Here, however, it was practically impossible to merge the position of the two sides – above all, because the Plan Meriss team saw little chances in establishing such a sophisticated financing system, especially one that required collecting significant amounts of money in advance (e.g. for extraordinary maintenance), under the given circumstances. For them the users would simply not accept such a system for the following reasons: First, the Andean villagers in the Vilcanota valley do not confy larger amounts of money to

formal bodies (even if they are elected by themselves), mainly because their fear misuse and corruption. Second, there are numerous donor agencies and other public bodies in the area that are willing to finance the repair of „extraordinary damages" in the irrigation systems. So only if time is pressing, as in the example mentioned above, the users will finance this kind of repair by themselves. Under these circumstances of an "overaided region" it would be completely illogical of the farmers to agree to set up a financing system as described above.

After thorough and complicated discussions both parties agreed to distinguish between a i) *cuota ordinaria* (for operation, regular maintenance and administration) and a ii) *cuota extraordinaria* (for repairs after unforeseen maintenance problems). However, it became obvious that the managers of Plan Meriss did not see any chances of implementing even the *cuota extraordinaria* and that the opinions about whether this would make sense at all (in light of the capacity of the WUAs to solve such problems on an ad-hoc basis) continued to be diverging. The plans of collecting a contribution for the amortisation of the investment costs were dropped altogether because of the obvious impossibility of their realisation.

Again the example demonstrates, that the underlying perspectives and expectations have a strong influence on the solution of major issues. On the one hand we have the concept of Plan Meriss basically influenced by what they felt was „technically possible" and „socially" or „politically" achievable under the local circumstances of the Vilcanota valley and on the other hand the position of the evaluation mission based on the rules of the lending agency which emphasizes issues related to economic feasibility and cost recovery. In the mission's point of view, users who were receiving such an enormous support in the physical improvements of their systems should not only participate in the O&M of the system but also in the amortisation of the initial investment. The crucial issue was that there had never been an agreement of what kind of maintenance was actually necessary; what exactly was supposed to be financed by the WUA. Without such a common agreement as a basis, the discussions at this later stage resulted in a confrontation with little relevance for the solution of the conflicts at stake. In spite of the formal decisions taken at the end of the mission, the diverging underlying perspectives of the two sides were not harmonised – implying the risk that underlying conflicts will resurge in the future.

3. Conclusions: How to Address the Issue of 'Optimal Maintenance' in an Interorganisational Context?

The issue to be discussed here is not which of the abovementioned models should have been established – but how to deal with the diverging maintenance perspectives in international development cooperation. In the course of the mission it became apparent, that the perception of ‚optimal or adequate maintenance' depended largely on the standpoint and role of the respective „stakeholder" and his or her expectation.

At the same time one could see in „our case" that a common agreement on what is an optimal level of maintenance and also maintenance organisation had not been reached. This led to a number of problems. Above all, both sides argued on the basis of their own approaches – however without explicitly making this clear. The questions that should have been at stake should have been: 1. What level of maintenance do we regard as necessary in the Plan Meriss irrigation systems? 2. How can this level of maintenance be achieved? The first question, however, was not addressed. The second question was discussed without explicitly referring to the different underlying concepts. Thus a number of „dependent" issues such as the calculation and collection of a higher and differently structured quotas were discussed, without an agreement on the basic underlying concepts to be used. Not surprisingly, without such an agreement, the fine-tuning of the necessary steps in the improvement of the actual irrigation organisation was practically impossible.

3.1 What Do We Learn?

A collaboration between various partners in an irrigation system becomes very difficult if they part from different perspectives and expectations. This is particularly true for the assessment of the 'optimal level of maintenance' required, as well as for the different approaches of its organisation and financing. Even if not all of the conceptual differences can be overcome, at least a common agreement on what a sufficient level of maintenance will be in the future and what will be the organisational setup for the organisation of O&M should be discussed and finally agreed upon by all parties. This should be done as early as possible in the life cycle of a (development) project. If this doesn't happen, this

can entail the risk of ongoing conflicts triggered off by the different underlying concepts. Only by agreeing on shared standards for the future O&M of the irrigation systems to be supported, can these problems be limited to an acceptable level.

Chapter 4

Optimal Maintenance of Irrigation and Drainage Systems from a Field Perspective

David Cone

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Abstract

The optimal level of maintenance for irrigation and drainage systems is a function of the desires of the pertinent agency or Board of Directors and the budget made available for maintenance activities. Directors of irrigation and drainage districts often require their systems to provide reliable and flexible service in support of their farming operations. However, the budgets provided for maintenance are not always sufficient to perform all of the tasks that might be included in a conceptually ideal maintenance program. Rather, district managers usually must design a maintenance program that reflects a Board's desires or requirements, while remaining within a limited maintenance budget. This paper describes many of the issues that district managers must consider when designing an optimal maintenance program, subject to budget constraints and in light of district goals regarding system reliability and cost effectiveness.

1. Introduction

Public water agencies and international donors have given increased attention to operation and maintenance programs during the last 10 to 15 years. Irrigation systems must be maintained to sustain the many benefits they provide to the farming community. Interest in the past was focused more on the building of new projects than on operating and maintaining existing projects. It may be easier for agencies to finance new projects than for improving or even sustaining the current level of operation and maintenance (Bucks, et al., 1990). Now that more emphasis is being placed on maintenance, irrigation system managers must determine the level of maintenance that is necessary and appropriate.

This paper provides some insights into optimal maintenance from a field management perspective. Optimal maintenance implies striking a balance between effectiveness on the one hand and resource constraints on the other. Pertinent questions include: 1) How does an irrigation system manager determine where the balance point is? and 2) Does optimal maintenance vary from one system to another?

Before optimal maintenance is examined, maintenance must be defined. Maintenance has been described by Krause and Temple (1988) as "the upkeep of facilities with the goal of efficient operation, minimum breakdowns, good appearance, reasonable costs, extended useful life, and safety." The U. S. Bureau of Reclamation's Bulletin No. 60 (1967) states that maintenance is necessary to: (1) provide required service to water users, (2) reduce emergency repairs, and (3) lower maintenance costs. Thoreson, et al. (1997) report that maintenance includes repairs, replacements, and betterments. Repairs are further defined "as generally work done on canals and structures to maintain their usefullness." Irrigation system maintenance is summarized as "any action required to either return an irrigation system to (corrective) or keep it at (preventive) a desired performance level."

A manager's perspective regarding maintenance can range from "If its not broken, don't fix it" all the way to achieving and maintaining a gold plated system. In the past, most managers have inherited irrigation systems suffering from some degree of lack of maintenance and most of those systems are in need of modernization.

When I became manager of the Broadview Water District in 1987, I inherited an irrigation system that was suffering from the lack of an adequate maintenance program and was in need of modernization. The district operated a "patch and repair" program apparently to keep water costs low. This approach to maintenance was taking its toll on the pumps, motors, electrical and mechanized equipment, and other components. Operational reliability of the irrigation system was at risk. Farmers do not like to have the irrigation system out of operation

when the temperature reaches 105 degrees (F) and their crops are in need of irrigation.

During the 12 years I have been with Broadview (which includes 4 years of significantly reduced water allocations), we have been performing "catch-up" maintenance. Catch-up maintenance can be described as upgrades to an irrigation system necessary to bring the system up to current technological and operational requirements. The need for catch-up maintenance is the result of the shortage of funds, lack of personnel, poor management, and/or lack of time. As an example, the pumps on our Main Canal were turned on and off with electrical relays attached to electrodes. This old technology has been replaced with programmable electronic controllers connected to pressure transducers. Better reliability and service can be provided with this new technology. We will be able to begin a normal maintenance program in about 2 years. A preventive maintenance program can be fully applied at that time. Catch-up, normal (routine), preventive, essential structural, emergency, and deferred maintenance are described by Skogerboe and Merkely (1996).

2. Background

Irrigation system managers work for some form of an oversight body, such as a Board of Directors. Generally the Directors are farmers actively involved in a farming operation. While costs appear to be the controlling factor in the operation and maintenance of an irrigation system, I have learned that reliability may be of more importance to farmers. After all, the irrigation system was constructed to provide water for irrigation purposes. If it does not function as intended, it has little value.

The type of irrigation system will also determine the level of maintenance needed. Gravity canal systems require a lower level of maintenance to remain operational, whereas an irrigation system requiring pumps and electrical equipment requires a much higher level.

It appears as if some irrigation systems have been designed without sufficiently accounting for the practical aspects of operation and maintenance activities. While the irrigation system will operate, the skill levels of the operation and maintenance personnel may not have been adequately considered. Either the system needs to be designed to meet the available personnel skill levels or training of the personnel must occur providing they have the basic education necessary to understand the system.

While a formal written maintenance program is important, an annual inspection is indispensable to irrigation system managers who must monitor maintenance needs and must modify priorities as required. Inspection guidelines and procedures are described in U. S. Bureau of Reclamation Bulletin Nos. 138 (1986) and 155 (1991) as well as in Skogerboe and Merkely (1996).

3. Operational Criteria to Determine Optimal Maintenance

3.1 Service

The primary function of irrigation system employees is to provide a service to the water users. As I tell my employees, we are here to provide service to our water users. We have not been hired to deliver water at our convenience. If we do not provide this service, the Board of Directors should fire us and replace us with employees that will provide the service.

Our goal is to meet the needs of the water users within operational guidelines and the constraints of our irrigation system. My staff does an excellent job in meeting their needs.

3.2 Reliability

I have found that reliability is of major importance to farmers. They will commit to increased spending for maintenance and system upgrades in order to enhance reliability. Any maintenance program must focus on system reliability because an irrigation system must be in reliable operating condition. If budget funds are reduced, an irrigation system manager must concentrate the use of limited funds on those items that are needed to maintain basic reliability.

Renault and Vehmeyer (1999) define reliability of irrigation service "as the degree to which the irrigation system, and its water deliveries, conform to the prior expectations of its users." They consider reliability as the probability of non-failure and make a distinction between the physical reliability of the water delivery system and the service to the users. In the context of this paper, I am concerned with the reliability of the water delivery system.

Reliability may be somewhat subjective in its application. I have found that our farmers do not like delays or interruptions in water service for more than a couple of hours or on a reoccurring basis. While they must accept electrical power outages, any reoccurring interruptions resulting from district equipment failure or operational problems are not acceptable. The Board of Directors would expect me to fix the problem before the next farming season. Equipment and operational problems cause scheduling changes to farming activities; such as, labor management, irrigation scheduling, field work, etc. If these delays and interruptions can be reduced or eliminated, farmers have fewer on-farm operations out of their control.

As example, when we have an equipment failure at one of our pump stations, irrigation deliveries may be terminated for a period of time. If the problem lasts

for a few hours, the farm irrigators don't have anything to do. This is a waste of time and money for the farmer. If the equipment failure involves a pump or motor, it may take 3 weeks to replace the pump and 3 days to rewind a motor. This may result in the proration of irrigation flows to affected farm turnouts. The flow rate may be less than the amount necessary to make effective use of irrigator time. Also, when sprinklers are used for irrigation, water is applied by irrigation sets that are time related. Irrigation sets are determined by the amount of water to be applied (6-hour sets = 1.5 inches of water, 12-hour sets = 3 inches, 24-hour sets = 6 inches). Delays and interruptions affect the moving of the sprinkler pipe to the next set location causing scheduling problems for sprinkler line movers.

3.3 Flexibility

In order to provide service to water users for efficient and effective use of water, irrigation systems must be operated to provide flexibility regarding turn on and off times, flow increases and cut backs, etc. Hence, when an irrigation system is designed, operational flexibility should be considered. Farmers are willing to pay for this flexibility because it enhances their ability to generate profitable yields (Merriam 1987).

4. Factors Considered in Determining Optimal Maintenance

I have found the following factors to be the most important for me in determining what may be optimal maintenance of our irrigation system. While there may be other factors, I believe that these are the most important.

4.1 Record Keeping

A successful maintenance program begins with record keeping. Without good records, it is impossible to determine if proper maintenance is actually occurring. The U. S. Bureau of Reclamation has a very complex computerized Maintenance Management System (USBR 1986). At the other end of the spectrum, records may be kept as hand-written notes on sheets of paper. Obviously, somewhere between these extremes is likely most appropriate.

Broadview's irrigation and drainage system has 45 pumps and motors. Each pump and motor has a folder in which invoices describing purchases, repairs, and replacements are kept along with a log of work performed and the results of pump tests. These records have been extremely helpful in maintaining our pumps and motors.

4.2 Scheduling

Maintenance activities must be scheduled in order to avoid conflicts. As an example, it is difficult to schedule pump and motor repairs and maintenance during irrigation periods. Most major maintenance and repairs must occur during shutdown periods or during scheduled outages. During irrigation periods, maintenance items must be limited to those items that do not disrupt irrigation system operations.

4.3 Cost/Budget Constraints

Irrigation system managers prepare budgets annually for maintenance programs. These budgets are presented to the Board of Directors for review and approval. Budgets can reflect the manager's desire, the Board's desire or some combination of the two. Over time, the manager understands the desires of the Board and the budget reflects some combination.

4.4 Type of Irrigation System

Different types of irrigation systems require different levels of maintenance to keep them operational. Pump lift canal and pump pressurized pipe systems usually require a higher level of maintenance because of the mechanical and electrical equipment involved. Gravity canal and pipe systems usually require a lower level of maintenance to keep them operational.

4.5 Labor Availability

The number of personnel necessary to maintain an irrigation system is always an issue for a system manager because employee costs are a significant portion of the budget. Pertinent questions include: 1) How large should the size of the maintenance crew be? 2) Are permanent employees needed or are temporary employees available during the maintenance period? 3) Are employees with the proper skills or training available?

4.6 Equipment and Supply Availability

The availability of equipment and supplies must also be considered. Is the maintenance equipment owned or is it available to rent? Are supplies available during the maintenance period or should they be ordered in advance.

4.7 Timing and Time Constraints

Timing of maintenance and time constraints can affect the level of maintenance that a system manager is able to perform. Are the down times sufficiently long enough to perform the necessary maintenance? Some maintenance can be performed only when the system, or a portion of it, is out of service.

Some maintenance items are best scheduled for when the system is out of service. Minor maintenance and repairs can take place during the season; such as, painting, minor electrical replacements, weed control, minor earthwork, etc. Major electrical and pump maintenance and replacement as well as major earth

and concrete work can take place only when the system is out of service and water has been removed.

During the irrigation season, most field activities are related to water deliveries and minor maintenance items needed to keep the system operational. When the irrigation season is over, the district field crew is able to focus on major maintenance items.

4.8 Pride and Peer Pressure

Farmers often express a sense of pride in the irrigation system. Sanford (1968) refers to this as the "pride factor" and states that it is the most important element in labor management. He further states that the appearance of an irrigation system reflects the efficiency of the maintenance program.

While farmers may not admit it, they are very competitive with one another. Not only are they concerned with crop yield, they are also concerned with how their irrigation system looks. I believe that this sense of pride in the irrigation system is based on the fact that they are owners of the system and it reflects on them personally. A little paint and weed control can make a significant difference in the attitudes of farmers when it comes to budget approval time.

4.9 Political Constraints

Local, state and national politics can also affect maintenance programs. Farmers usually desire supplies to be purchased locally and local contractors to be used even though the costs may be higher. Obviously costs alone are not the controlling factor.

State and federal assistance programs are more receptive to cost-share projects than to grants that provide entire project costs. Program officers often like to see local involvement in projects they support.

4.10 Safety

Safety is an issue in every operation and maintenance program. Not only should there be a concern for the safety of the employees, but the safety of the public must also be considered. An irrigation system must be maintained appropriately to protect employees and the public.

4.11 Age of Irrigation System

The age of the irrigation system must be taken into account when designing an optimal maintenance program. Older systems may need more attention when scheduling maintenance items and when considering system upgrades and replacement of system components. Newer systems may not require an intensive maintenance schedule.

Management Interactions in Determining Optimum Maintenance

As mentioned under Cost/ Budget Constraints, over time, the irrigation system manger understands the desires of the oversight body and the budget reflects that understanding. This understanding is built on the relationship developed between the oversight body and the manager. The manager looks out for the interest of the landowners and farmers and attempts to keep costs as low as reasonably possible.

When an oversight body selects a person to manage and operate their irrigation system, they seek someone who is technically competent. In addition, they are concerned that the replacement manager will be able to work with them and other associated groups; such as, associations, neighboring water agencies, project participants, etc.

A new manager will usually review previous budgets to determine what has been the practice. For the first year or two, budgets will look very similar to budgets of the past. As the manager determines current maintenance needs not reflected in past budgets, he will prepare a revised budget. If the proposed budget increases the cost of water and service, he will determine the limit of the increase the oversight body will approve.

If the oversight body reduces the proposed budget amount, the proposed activities will be modified to allow for the best level of maintenance possible within the budget. If the level of maintenance is insufficient to maintain reliability, the manager must focus activities on those items that will make the irrigation system as reliable as possible. In addition, the manager needs to be sure the oversight body understands the current condition of the system and possible result of budget restrictions.

Farmers are always concerned with costs. During discussions with the oversight body, the manager is able to determine their attitudes and beliefs concerning the balance between service and costs. Sometimes attitudes and beliefs are verbalized but often the manager determines them from observing the farming operations of the oversight body members. When the cost of water is a significant part of farming costs, the oversight body, as well as the manager, are under pressure to keep delivery costs as low as possible. Since most of the water delivery costs are out of the district's control (such as, electrical costs, water storage costs, capital repayment, etc.), the oversight body can only adjust the costs related to the district's operation and maintenance program. As result, the impacts of budget constraints may occur primarily at the local level. If insufficient maintenance funding or poor management continues for a significant time, an irrigation system will become unreliable.

Sometimes the manager must adjust the budget and maintenance levels to respond to the needs of farmers without specific direction of the oversight body. If the manager observes that crop prices and/or crop yields are significantly reduced, or water supply allocations are reduced causing economic hardship to the farmers, the manager may respond by reducing proposed budgets and maintenance activities without being instructed.

During the drought period in the early 1990s, a large portion of the land in our district was idled because of reduced water allocations. I initiated budget reductions during this period. I focused all maintenance on items that needed to be performed in order to achieve the highest level of reliability that could be expected under those budget constraints.

After the drought period ended, I prepared a complete inventory of the items that needed repairs, rehabilitation, or replacement as well as modernization in order to bring the system and equipment to operationally reliability. Along with the list, I prepared a proposed budget to accomplish those items over a reasonable period of time. The proposed budget was divided into two categories.

The first category was for general maintenance; such as, pump repairs and replacement, electrical equipment repairs, motor rewinding, etc. Previous budgets were based on a service charge of $3.50 per acre per month ($42/acre/year). My proposed budget was based on $4.00 per acre per month ($48/acre/year).

The second category was for irrigation system rehabilitation and operating equipment replacement. This category included replacement of pump discharge pipes which had deteriorated to the point of failure at three pump stations (a total of 9 discharge pipes), electrical equipment upgrades and modernization, and the replacement of operating equipment; such as, motor grader, dump truck, spray truck, etc. The equipment was old, unreliable, and in need of major repairs. My proposal included a fee of $0.50 per acre per month ($6.00/acre/year). I anticipated these funds to be collected for only a few years.

I explained to the Board members that if we did not perform this "catch-up" maintenance, they could expect major outage periods and/or periods of reduced delivery flows. The Board and I went over my proposal in detail so they fully understood what I was proposing as well the need for these items. During the discussion, one of the Board members made the suggestion that the monthly fee for general maintenance be increased to $4.50 per acre per month ($54/acre/year). This would allow the District to establish reliability in a shorter period. After further discussion, the Board approved the budget with the general maintenance fee increased to $4.50 per acre per month and the rehabilitation and equipment fee at $0.50 per acre per month. The approved budget was greater than my proposed budget. This illustrates my point that reliability is a significant concern to our farmers.

During the discussion concerning my proposed budget, there was no dissention or haggling among the Board members. They understood the condition of the irrigation system and the need for the work. I had taken photographs of some of the items needing repairs or replacement; such as, photographs from inside the discharge pipes showing the pipe collapsing from deterioration of the steel, etc. In addition, I prepared a spreadsheet showing a detailed list of the equipment needing replacement and a list of the items needing major maintenance.

The budget approved by the Board made our water delivery costs some of the highest in our area. Since our "catch-up" maintenance and irrigation system improvements are almost completed, we will be in the position to reduce our charges and continue to provide water service reliability.

5. Discussion

Obviously, it is an irrigation system manager's responsibility to maintain the irrigation system. The level of maintenance required to properly maintain an irrigation system is difficult to determine.

As an example, some irrigation system managers recondition their pump motors on a 5-year rotating schedule, in which the motors are removed every 5 years and sent to an electric motor repair shop to check the bearings for replacement. The motor stator windings are inspected and then dipped and baked. While such a program may assure that the motors are operational and not likely to fail during the irrigation season, it may not be cost effective.

At this time, Broadview does not recondition its motors on a rotational program. Last year, we removed a pump in order to have it replaced. Because the motor had been removed, we look at the records to determine if it should be reconditioned. According to the records, the motor had been placed into service 30 years before and had never been reconditioned. Obviously, we decided to send it to the shop.

Over the 12 years I have been at Broadview, I have purchased only one motor to replace one that had failed as a result of operator error. The pump propeller was damaged which caused the pump to vibrate. We continued to operate the pump and eventually the pump shaft vibration destroyed the bearings in the motor. The pump shaft then caused the motor rotor to go into the stator windings, resulting in destruction of the motor. It took 6 months to replace the motor at a cost of about $6,500. These old design slow-speed motors can not be purchased off the shelf. Because they are only built when they are ordered, the time required to replace the motors must be considered when evaluating system reliability.

The Broadview irrigation and drainage system has a total of 45 vertical propeller pumps with motors ranging from 5 to 250 horsepower. During the past 12 years,

we have had several pump motors burn up (stator windings shorting out) due to electrical single phasing which resulted from electrical service problems from the power company. In the past, we had believed that our motors had single phasing and overload protection in the electrical panel boxes. However, we later discovered that one of our former maintenance staff, for several years, had problems with the protection equipment during the operating period and had wired around them to keep the pumps running. He never told anyone; nor did he go back and fix the problem. We have since replaced all of the protection equipment while upgrading our electrical equipment. In addition, the power company has improved service and now we rarely have relays trip out from single phasing or overloads.

This discussion demonstrates the extremes in determining optimal maintenance. With regard to motors, manufacturer's operating manuals and warranty requirements should be used as a guide. One of the reasons our motors should have a different reconditioning schedule is their slow operational speed. Our motors, which operate at between 880 and 900 revolutions per minute, are classified as slow-speed motors. The slow speed produces less heat and wear. If the motors were high-speed motors, they would require a higher level of maintenance.

6. Summary and Conclusions

While Skogerboe and Merkely (1996) categorize maintenance as catch-up, normal (routine), preventive, essential structural, emergency, and deferred, Thoreson, etal., (1997) categorize maintenance as corrective, routine, periodic, and emergency. From my perspective, there is only one category, reliability maintenance. Long-term reliability of an irrigation system should be the goal of a maintenance program.

As an irrigation system manager, I have learned that my Board of Directors has a budget level reflected in the cost of water that they will accept. Therefore, my maintenance schedule is prepared under the umbrella of the budget. The budget determines the maintenance program, rather than the maintenance program determining the budget. Over the long-term, the budget must be sufficient to provide for a maintenance program that will assure irrigation system reliability.

The concept of reliability allows for a wide range in maintenance scheduling. Using pump motors as an example, their reliability will not be affected if a 6-year rotation is used for reconditioning instead of a 5-year rotation. This approach allows for adjustments in maintenance schedules to match budgets.

In conclusion, optimal maintenance is the same as reliability maintenance. This concept allows a manager to adjust for budget variations, emergency situations, equipment failures, etc. As long as budgets over the long-term are sufficient to allow for the level of maintenance required to assure reliability, optimal maintenance can be achieved. Since optimal maintenance implies striking a balance between effectiveness and resource constraints, maintaining an irrigation system for reliability will achieve that balance.

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