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DESIGNING EFFECTIVE INTERVENTION FOR IRRIGATION MANAGEMENT: CASES FROM THE INDRAWATI WATERSHED IN NEPAL

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Abstract

Prior research and assistance experiences have suggested that technological fixes alone are not likely to improve irrigation performance. An intervention project stands a chance of success only if it could help develop robust local institutions to support the operation and maintenance of engineering infrastructure, and enhance social capital that has already existed in the local community. While the principle for designing successful intervention project seems to be straightforward, turning the principle into the design of intervention projects is not as simple as some might expect. In particular, how to keep the intervention effect last and sustained in the long run poses a substantial challenge.

In 1985, the Water and Energy Commission Secretariat (WECS) of Nepal and the International Irrigation Management Institute (IIMI) initiated an intervention project to assist 19 farmer-managed irrigation systems located in the Indrawati watershed in Nepal. The project was designed with a view to developing and testing methods for delivering assistance that could enhance farmers' organizing ability for irrigation operation and maintenance at the same time as the irrigation infrastructure was improved. The intervention was evaluated as being very successful soon after completion. In this paper, we will draw on several rounds of measurement for the systems involved in the project so as to assess and understand how the intervention has affected the operation and performance of the systems in a decade and a half after completion. By comparing the systems' experiences of irrigation management, we will identify factors that help explain why there are differences in the long-term effects of this project, and discuss the implications of the WECS/IIMI experience for the design of intervention projects in future.

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The Puzzle: How to Help Farmer Managed Irrigation Systems

Many farmer-managed or co-managed irrigation systems in the rice-growing regions of Asia are robust in the sense that they are able to keep water within target levels within an irrigation system under many uncertain environmental disturbances for long periods of time. The engineering aspect of an irrigation system can be threatened by two disturbances coming from the broader environment. One is the threat of flooding due to excessive rainfall. The other is the result of too little rainfall and the consequent inadequate supply of water for the farmers.

The way engineering works try to protect against flooding is the construction of very strong weirs, gates and other control mechanisms that enable the system to survive even though water is pouring down from the hillsides and stressing the strength of the control mechanisms, walls and other engineering parts of the irrigation system. The way that irrigation systems try to protect against drought is the provision of storage in the system. Many run-of-the-river systems, however, have no facilities for storage. Thus, the core mechanisms for coping with drought have to do with the institutional rules used by a system for allocating water under systems of scarcity (Carruthers, 1981; Burns, 1993).

Institutional rules are also important in regard to the maintenance of the engineering works themselves. All irrigation canals, whether constructed from rock, mud or concrete need regular maintenance. The maintenance must be done either by the farmers sharing the work-load, by officials of an irrigation system for an agency-managed irrigation system, or by both when the system is co-managed (Lam, 1996a, 1998, 2006b). The crucial thing is that there are either cooperative arrangements developed or an effective taxing system that contributes the necessary resources to provide the essential resources for maintaining a system.

As discussed in Lam (2006a), some irrigation systems have evolved rules over a very long period of time at multiple levels that enable their systems to be quite robust. However, even systems that have been robust for multiple decades, or even centuries, may face additional threats beyond flooding and drought. If external authorities do not understand the way a system is organized, they may come in and make changes that threaten the foundation of the institutional arrangements that keep such systems going over the long run (Vermillion, 2005; Lam, 2005; Ostrom, 2005b).

A puzzle that has presented itself to many governments and donor agencies is what to do when farmer constructed and operated irrigation systems are not robust in several senses. One of the most important senses is when the farmers are not able to grow a substantial crop due to the unpredictability of water or its inadequacy at key times in the agricultural cycle. Another sense is the loss of regular support by farmers for contributing time and effort to rebuild key parts of the system or for regular maintenance. Systems may also lose their robustness when economic conditions change so that occupations other than farming become more attractive and lure younger families away from the region (Baker, 2005). Obviously, conflict in the region is also a major disturbance that may disrupt how irrigation systems and other core activities operate.

When governments or donors observe faltering irrigation systems, they sometimes have simply come in and built entire new systems. While that provides new engineering works, it has frequently led only to temporary improvements in the performance of the irrigation system (Chambers, 1988; Johnson, 1991; Ostrom, Schroeder, and Wynne, 1993; Lam 1996b). Further, systems that have received major external help in reconstruction sometimes then become totally dependant on external help. But, what is to be done? How can an external agency help irrigation systems that are faltering without leading them to become dependant on external aid.

In an earlier paper on the subject of strategies of intervention, Joshi, Ostrom, Shivakoti, and Lam (2000) undertook an analysis of 229 Nepali irrigation systems characterized by varying types and levels of interventions (including no interventions). From our research using the Nepal Irrigation Institutions and Systems data base, we were able to evaluate these systems in regard to their physical condition (Table 1), their economic efficiency (Table 2), the availability of water supply at the tail end of the systems (Table 3), and the cropping intensity of these systems (Table 4). In general we found that the performance levels of agency managed irrigation systems in regard to their physical condition, their economic efficiency, water supply at the tail-end of the system, and their agricultural productivity were lower than farmer managed systems in general — whether they had received external help or not.

We examined three types of interventions that varied in regard to the level of farmer involvement in the assistance project. On all four performance measures, we consistently found better performance on the systems that had received a high level of farmer involvement than for those systems with medium or low levels of involvement. A surprising interesting finding was that in regard to some measures, farmer managed irrigation systems (FMIS) that had received *no* external assistance performed at a higher level than those that had been "helped" by interventions lacking a high level of farmer input. For example, the physical condition of the system was rated as poor for 13% of the FMIS who had *not* received external assistance while over 18% of the FMIS who had received external assistance involving only low or moderate levels of farmer involvement were rated as poor in regard to the physical condition of the system. Consistent with other studies comparing agency managed irrigation systems (AMIS) (Lam, 1996b; 1998), over 45% of the agency managed systems were rated low in regard to the physical condition of the system.

Involving the Farmers in Trying to Help Them

In our earlier comparative paper, the set of irrigation systems that consistently had the highest performance across multiple performance indicators were those located in the Indrawati watershed of Nepal and assisted by the Water and Energy Commission Secretariat and the

International Irrigation Management Institute (WECS/IIMI) of Nepal. WECS/IIMI had developed an ingenious intervention program which had a number of relatively innovative aspects to it. The project was designed by Prachandra Pradhan and Robert Yoder who both had long experience with farmer managed systems (Pradhan, 1989a, 1989b; Yoder, 1986, 1994).

The project was innovative in a variety of ways: (1) the farmers could choose whether to be involved or not, (2) the project provided technical assistance but purposively did not provide full funding for engineering improvements and the farmers were expected to provide core labor and some materials, (3) the farmers had to provide a full rank ordering of the improvements that they desired, (4) the farmers examined the engineering plans and had to OK them before they were implemented, (5) if the farmers were able to reduce the monetary expenditures for the highest ranked projects by their own contributions, the released funds were then allocated to the next ranked project on the farmers' lists, (6) participating farmers were expected to go through "farmer-to-farmer" training offered by some of the more productive irrigation systems in Nepal, and (7) each farmer group was expected to write its own internal set of working rules that covered how future decisions would be made for the system.

How **The** Project Was Selected

The Indrawati River watershed in the central hills of Sindhupalchok District was selected for intervention due to its proximity to Kathmandu.[1] The project staff could travel from Kathmandu to the Indrawati River in about an hour and a half. It then took anywhere from 1 to 3 hours to travel on foot to the irrigation systems located in the hills on either side of the Indrawati River. The hydrological boundaries of the watershed were used to define the 200 square kilometer project area. An inventory of all existing FMIS was prepared to fulfill the objective of determining relative needs among systems and establishing criteria for selecting final candidates for assistance. Out of the 119 irrigation systems identified with canals longer than 0.5 kilometer in the area, 23 FMIS met the following criteria:

- Only those systems were to be selected for assistance where expansion of area was possible, which would have a high impact on food production and be used by additional number of families.

- The existing users of these systems were willing to allow their systems to expand and to accept additional farmers as members of the WUO (Yoder, 1991a: 56).

A rapid appraisal study was carried out to collect information about the physical and agricultural aspects of the irrigation systems and about the organizations' management practices. Based on the information from rapid appraisal and discussions with the farmers, the final selection of the systems for assistance was reduced to a total of 19 irrigation systems.

During the same period, a dialogue was initiated between the field supervisors and the water users of each system. As part of a design process, the farmers were asked to help rank all of the desired physical improvements into three groups according to priority:

1. The highest priority was placed on improvements necessary for expansion of the system but difficult for farmers without assistance;

2. The second priority was assigned to work that would improve system operation and maintenance; and

3. The third priority improvements included work that farmers could accomplish using their own skills, labor, and materials (Yoder, 1991a: 57).

The project agreed to allocate funds to cover the cost of only those components that were given first priority. The farmers were told, however, the full amount of money allocated to be spent on their system and that all of these funds would actually be spent on their system. If they could save money on first-priority work, they would be able to use it for second- and even third-priority work. The intention was to create a positive incentive for the farmers to use the project funds with great care.

The terms and conditions discussed in the second dialogue included a requirement that users form a water user organization, unless one already existed. The user organization was responsible for the following tasks:

- identification of existing and future water users (from the expanded area) and the land area each irrigated;
- preparation and acceptance by all water users of a plan for water allocation to the new area;
- preparation of a plan, including rules, for supervising the improvements to be made and for future management of operation and maintenance; and
- setting requirements and rates for free and paid-labor mobilization (WECS/IIMI, 1990: 20).

During the process of the first and second dialogues, and also during the physical and management improvement period, field supervision was carried out by teams that consisted of engineers, overseers, agriculturists, social scientists, and persons with construction skills. The construction activities were to be a "training exercise for the user organizations in making decisions, establishing rules, managing conflicts, mobilizing labor, and keeping records" (WECS/IIMI, 1990: 20).

Farmer to Farmer Training

A major problem identified early was that "the water users of the systems selected for assistance did not function as organized bodies to manage the operation and maintenance activities of their canals" (WECS/IIMI, 1990: 18). Thus, farmer training for irrigation management in each system was identified as a priority for the implementation of the project. Members of the project decided to try a series of farmer-to-farmer training tours as a method of extending ideas about effective governance and management of irrigation systems.

The purpose of the farmer-to-farmer training program, according to Naresh Pradhan, was "to stimulate the transfer of experience from farmers in well-managed systems to those in poorly-managed systems through site visits, informal exchanges, and guided discussions" (1987: 1). The project organized farmer-to-farmer training for five groups of farmers from these 19 irrigation systems with each group consisting of 15 farmers. Each group was accompanied by two facilitators, one of whom was a member of a host system and the other a research assistant who was hired by WECS/IIMI for the project period. The host farmers from the well-managed system also worked as consultants. These consultant-farmers also inspected the canals and structures of the systems and discussed the similarities and differences in their own systems and made suggestions for improvements.

During the tour, the trainee farmers were taken to the intake and canal of the system guided by a group of host farmers. The timing of the tour had been arranged to coincide with the annual meeting of the canal's organization, but the trainee farmers were taken first to meet the host system's committee members. These host farmers described the ways they had devised to deal with issues such as labor mobilization for emergency maintenance, water allocation and distribution, conflict management, and the structure of the organization. The facilitator usually raised questions that covered important issues. In the general meetings, the visiting farmers were observers only and watched the procedures of a general meeting without themselves asking questions at that time.

The trainee-farmers were also exposed to the constitution, minutes, and attendance records of the labor contributed by the farmers of the host system. By the end of the second day, the farmers had a clear idea about the management problems in their own systems. The farmers were taken to more than one system. During the visit to the second successful system, the farmers started comparing their own systems with these successful ones and discussed their problems with the host farmers.

The Initial Evaluation

Table 5 provides information about the area of irrigated land added to these 19 systems and the cost of each intervention while Table 6 arrays the head end and the tail end cropping intensity in winter season immediately before and after intervention.[2] A comparison of these two Tables shows that the intervention process was initially quite successful. Substantial improvements in the indicators occurred. While increases in values of productivity indicators are obvious, some interesting questions remain unanswered.

First, even though there was an increase in productivity, can we draw the conclusion that such an increase was caused by the intervention effort? Is it possible that the increase is only a result of chance? Second, what is the magnitude of different factors that affect productivity? Specifically, how substantial is the effect of the intervention process on productivity? Third, how does the effect of intervention operate to affect productivity? Did the intervention process bring about a one-shot effect and cause an abrupt increase in productivity? Or did the intervention effort manifest its impact on productivity by mediating the effects of other input factors, such as the number of labor days spent on the maintenance of the canals?

To address these puzzles, we turned to our NIIS data base for answers. In our NIIS data base, information on various physical and institutional features as well as irrigation performance of the 19 systems prior to the intervention is available. Such information captures the action situation in which farmers found themselves; which can be conceptualized as a time slice—a period of no determinate length during which the rules governing the system, the configuration of irrigators, the technologies employed, the physical characteristics of the system, and the patterns of interaction of irrigators are all relatively consistent. The time slice 1 data can serve as the benchmark against which the impacts of the intervention effort are assessed.

In 1991, members of the NIIS research team visited the 19 systems to conduct the second round of data collection using the coding instruments developed for the NIIS data base. The collected information describes the action situations of the systems a few years after the intervention; which constitutes the time slice 2 data. The availability of data of two time slices allowed for a before-and-after comparison of irrigation performance of the systems.

In an earlier paper by Lam and Shivakoti (2002), statistical analysis was undertaken to study whether and how the WECS/IIMI intervention affected performance. Two statistical models were specified to capture two approaches to understanding what government intervention is understood. The first approach looks at intervention as a one-shot process of transferring resources to farmers. As long as the "shot" is strong enough and farmers are given adequate resources, irrigation will be improved. The second approach emphasizes the facilitative role of intervention; intervention affects performance through enabling farmers to better utilize the physical, human, and social resources that are available to them. Both the direct and mediating effects of an intervention process are important.

The findings of the statistical analysis clearly indicated that intervention is not a one-shot additive process. Specifying the effect as both direct and mediating is better able to capture how intervention impinges upon performance. Intervention has an essential role to play in determining the relationships between input variables, such as maintenance effort, and agricultural productivity as measured by cropping intensity at the tail end. The analysis corroborates the argument that intervention should "enhance" rather than "replace" the efforts of local farmers in irrigation management (Shivakoti, 1992; Shrestha, 1988).

The Sustainability of the Effect of the Intervention

While the intervention brought about significant improvements in terms of technical efficiency and agricultural productivity in the first few years after the completion of intervention, interesting questions remain as to whether the improvements are only temporary, and whether the enhancing effect of the intervention has been sustained. If there is variation in the sustainability of intervention effect among the systems, what are the factors that might have contributed to it? These questions are of major interest to researchers and international donors, who have seen ample examples of intervention improvements beginning to dissipate soon after the completion of intervention.

To assess the long term sustainability of the intervention effect of the WECS/IIMI project, the NIIS team visited the 19 systems in 1999. Using the coding forms designed for the NIIS data base, the team collected information on various physical and social aspects of the systems, as well as performance measures. The information collected constitutes the core of the time slice 3 data. To supplement the NIIS data and to capture the processes of evolution and change of the systems, the NIIS team visited the systems again in 2001 to conduct a series of intensive case studies. In-depth interviews were conducted, focusing on the processes of change in performance and institutional arrangements. In particular, farmers were asked to identify major events and disturbances since the intervention, and to discuss how the disturbances impinged upon the evolution of rules and collective action. We sought to capture the temporal dimension of farmers' adaptation to change, and to understand whether and how the intervention effect has affected the adaptation process.

Patterns of Change of Irrigation Performance

The availability of the information about the 19 systems in three time slices allows us to study and compare how irrigation performance has changed over the 15 years after the completion of the intervention. Particularly, the data provides useful information on both the short term and longer term effects of the intervention; which allows for an analysis of temporal patterns of performance. The short-term effect is indicated by the change in performance from time slice 1 to time slice 2, and the longer-term effect the change from time slice 2 to time slice 3. The summation of the two effects gives the net effect of intervention. In this section, we will examine five key measures of irrigation performance, namely the size of irrigated areas, the technical efficiency of irrigation infrastructure, water adequacy, the tail end cropping intensity, and the levels of deprivation in a system. The patterns of change of these performance measures can shed light to the way the intervention effect has unfolded.

System areas

Table 7 provides information on the size of irrigated area of the 19 systems in the three time slices; the average sizes in the three time slices are 38.28 hectares, 52.58 hectares, and 58.84 hectares respectively. A comparison of these figures shows that the WECS/IIMI intervention initially brought about substantial increases in the size of irrigated area of the systems; the expansion, however, has leveled off in the longer-run. A note of caution, however, is warranted. While in general the intervention has succeeded to expand the systems, the magnitude of the expansion varied among the systems significantly. In Chhahare Khola Ko Kulo, for example, the intervention expanded the size of the irrigated area from 15 hectares to more than 160 hectares; in Tallo Jhankri Ko Kulo, however, the irrigated area increased by only one hectare. Both the short term and longer term effects are statistically insignificant.

In fact, an expansion did not occur in every system. The pattern of change of the size of irrigated area of the systems over time shows much diversity. During the period between time slices 1 and 2, only 12 of the 18 systems for which information of irrigated area is available showed an expansion of irrigated area; five systems had a shrinking irrigated area in the same period of time. In the period between time slices 2 and 3, while ten of the systems had an increase in the irrigated area, five systems showed a decrease, and four remained unchanged.

More interestingly, Seven of the 19 systems experienced a reversal of intervention effect. Three of these systems started with a positive short term effect, followed by a negative longer term effect; the remaining four had a negative short term effect, then a positive longer term effect. Ten systems showed a positive effect all the way (the magnitude of the effect in two of the systems is small though). Only one system (Magar Kulo) showed a consistent negative effect in the whole period. Overall speaking, the intervention has succeeded to increase the size of irrigated area in a majority of systems, and the drive for expansion of irrigated areas has persisted, although the magnitude of expansion has leveled off in the longer run.

Technical effectiveness of** water **delivery

Other than the expansion of irrigated area, improving technical efficiency of irrigation infrastructure was another major objective of the WECS/IIMI project. Technical efficiency concerns whether the physical infrastructure is able to deliver water so that farmers are enabled to obtain as high crop yields as is feasible, given the other constraints they face. In the NIIS data base, technical efficiency is measured by a four-point scale. Table 8 provides information about the levels of technical efficiency of the systems in the three time slices. The "mode" technical efficiency in the three time slices are "moderately effective", "highly effective" and "moderately ineffective" respectively. Both the differences between time slices 1 and 2, and between time slices 2 and 3 are statistically significant.

The short term effect of the intervention is obvious. Of the 19 systems, 14 of them showed an improvement in technical efficiency, while the remaining 5 showed no impact. Given that engineering improvement works were a major element of the intervention, such an outcome should not be surprising. Although the improvement works involved only primitive technologies, such as putting in gabion boxes to strengthen the water diversion devises and providing simple canal lining, they helped make water flow more predictable and also minimize seepage. With better control of the temporal and spatial availability of water, a higher level of technical efficiency can be attained.

The longer term effect, however, shows an interesting pattern. Of the 19 systems, all, except for two that showed no impact, experienced a deterioration of technical efficiency in the period between time slices 2 and 3. As a result, thirteen of the 19 systems have gone through a reversal of the intervention effect—they all experienced an improvement in technical efficiency in the initial years after the intervention, which was then followed by a deterioration of efficiency in the longer term. In terms of the net effect, only two of the thirteen reversing systems have gained net improvement in technical efficiency; three systems in fact wound up having a level of technical efficiency even lower than before the intervention.

All the six systems that did not experience a reversal had a neutral initial response to intervention in the short run, and then experienced deterioration in the longer run. One system, Magar Kulo, showed a neutral response all along. Tallo Chapleti Ko Kulo, is the only system that had a positive initial effect and was able to keep the improvement.

Water adequacy

While engineers might be content with achieving a high level of technical efficiency, farmers are more concerned about whether those of them who want water could actually get it. That a system has a high level of technical efficiency is no guarantee that farmers on the system can actually receive water the way they want it. It is not uncommon that water is efficiendy delivered to the wrong place at the wrong time. On the other hand, a system that has a relatively low level of technical efficiency could provide adequate water to its farmers if the water delivery process is managed properly (Chambers, 1988; Lam, 1998). Water adequacy is determined not only by the physical setting and engineering infrastructure, but also the effectiveness of water management order as well as the level and timing of demand for water (Gill, 1991; Burns, 1993).

The levels of water adequacy at the head end and the tail end in different seasons are shown in Table 9a. The short term effect of the intervention on water adequacy is obvious. Improvement can be found in all three seasons in both the head end and the tail end, and all the positive changes are statistically significant. In time slice 2, an average system has a level of water adequacy higher than 2 in a four-point scale, with 1 being the highest[3], at both the head end and the tail end in all seasons. The data also suggests that the positive effect of the intervention on water adequacy has persisted in most systems. Only a slight deterioration is found among systems at the tail end in spring; yet the difference is not statistically significant.

If one examines the pattern of change of water adequacy with reference to that of technical efficiency, one can see the interesting relationships between intervention, technical efficiency and water adequacy. Intervention brought about an improvement in technical efficiency through enhancing infrastructure works, which in turn fostered an improvement in water adequacy. As time passed, the infrastructure improvement works worn out; the technical efficiency in almost all systems started to deteriorate. The decrease in technical efficiency, however, was not necessarily accompanied by deterioration of water adequacy. Of the 16 systems for which information on water adequacy at the tail end in winter is available, for instance, only four of them experienced deterioration in water adequacy in the periods between time slices 2 and 3 (see Table 9b). It suggests that improved infrastructure might be instrumental to launching farmers' collective action for irrigation management; after the launch, however, as long as a good management order can be maintained, it is possible that farmers be able to attain a high level of water adequacy even with less well-constructed infrastructure.

Tail end intensity

A common measure of the agricultural productivity of an irrigation system is the cropping intensity at the tail end of the system. One crop per year on a plot of land equals 100%; two crops mean 200%. If only part of the land is covered with two crops during the year, the cropping intensity will be less than 200%. Table 10 shows the tail end cropping intensity of the systems in the three time slices. The data suggests that the short term effect of the intervention on tail end intensity was mixed. Only six of the 19 systems had an increase in agricultural productivity between time slices 1 and 2, six other systems had a decrease and six showed no effect. In terms of the average tail end intensity, there was a slight increase from 244.22% to 246.16% during the period, yet the difference is statistically insignificant.

The average cropping intensity dropped from 246.16% in time slice 2 to 241.76% in time slice 3; the drop is statistically significant. It suggests that, generally speaking, the intervention effect on agricultural productivity could not sustain. However, if we look at individual systems, the pattern of change of cropping intensity varied across the systems. Ten of the 19 systems recorded an improvement in the period between time slices 2 and 3. Only five systems experienced deterioration in the same period; two systems showed no effect.

In terms of the net effect (comparing the cropping intensities in time slices 1 and 3), nine systems showed a net increase, although the magnitude of the increase in two of the systems was relatively minor. It is noteworthy that, of these nine systems, four showed a neutral short term effect, and one showed a neutral longer-term effect. It means that only four systems showed continual improvement in both time slices. Four systems experienced a net decrease in cropping intensity; one of them experienced a neutral short term effect, and another a neutral longer-term effect. It suggests that only 2 systems showed a continual decrease in agricultural productivity. Three systems experienced a reversal of effect; two of them wound up having a neutral net effect, and the remaining one had a minor improvement.

Several patterns could be identified on the basis of the analysis of the tail end intensity data. First, the effect of intervention on tail end intensity takes time to factor in. Second, most of the systems recorded a positive impact in the longer term, although the magnitude of the improvement varies quite substantially. Third, a high degree of diversity can be found in the trajectory of change in tail end intensity among the systems; many systems have experienced a reversal of effect in the course of development. Obviously, the relationship between intervention and agricultural productivity is not as simple and straightforward as one might want to see. Agricultural productivity tends to be affected by a complex array of factors, whether and how intervention can bring an improvement often depends how it configures with the other factors (Lam and Shivakoti, 2002).

Level of deprivation

A major measure of deprivation is whether some irrigators in the system are consistently disadvantaged in the allocation of water. Table 11 shows the numbers of irrigation systems in which some irrigators are consistently disadvantaged in the three time slices. Before the intervention (i.e., in time slice 1), half of the systems had the problem of deprivation. The number dropped in time slice 2, when only one fourth of the systems had the problem of deprivation. Such a trend continued afterwards. In time slice 3, none of the systems had the problem of deprivation.

While the problem of deprivation has been ameliorated over time, we are also interested in whether equity among farmers in irrigation management has improved. A measure of relative equity is the changing distance between those who are most advantaged and who are least advantaged in water allocation. The information on relative equity for the three time slices is provided in Table 12. In time slice 1, of the four systems for which relevant information is available, the social distance was increasing in one of diem, and remaining in the remaining three. Significant improvement is found in time slice 2, when five out of nine systems witnessed a decreasing distance between the advantaged and the disadvantaged. Two of the remaining four systems had an increasing distance and two others are remaining. In time slice 3, the distance in 12 out of 17 systems was remaining, indicating that the improvement in equity as the result of the intervention has largely persisted.

Making Sense of the Changing Irrigation Performance

Analysis of the changing patterns of irrigation performance of the 19 systems sheds light on how the intervention has affected irrigation performance. First, the effects of intervention on the technical aspects of irrigation management are conspicuous in the short run. Due to improved infrastructure works, the size of irrigated area increased and the technical efficiency of the irrigation systems also improved. Yet these positive effects dissipated, or leveled off, in the longer run. In particular, the analysis suggests that the improvement of technical efficiency has withered away in almost all systems. Second, while better technical efficiency might have helped improve water adequacy in the short run, it is not a factor that explains the persistence of adequate water supplies in the longer run. The analysis suggests that, even after the technical efficiency has leveled off, farmers on many systems have been able to maintain a relatively high level of water adequacy. Third, generally speaking the intervention has brought about consistent improvement in the way that farmers interact with one another. Deprivation has decreased and more equitable water allocation has been attained. Fourth, while one might expect that improved irrigation infrastructure and management might help bring about better agricultural productivity, the analysis portrays a more complicated picture. The impacts of the intervention on tail end cropping intensity vary significantly across the systems. In fact, much fluctuation can be found in the patterns of change of tail end cropping intensity among the systems, suggesting that a variety of factors interplay with one another to affect agricultural productivity.

While the patterns of relationships among the various performance measures provide interesting hints for how the intervention has affected irrigation performance, building a statistical model that explicates and explains the intervention effect on irrigation performance across time is a substantial challenge. Notwithstanding the small N problem, the data we have only describe three snapshots of an unfolding process. Studying these *snapshots per se* might not fully capture the dynamics of the process. Other than data problems, we are also faced with serious methodological problems of using statistical analysis to capture the unfolding effect of intervention. Statistical analysis is variable-oriented. The effect of individual independent variables is assumed to be independent from one another, and the estimate of a variable is calculated by averaging out the effect of the variable across all observations (Ragin, 1987). Obviously a major problem of this assumption is that the effects of particular variables are often contingent. Often it is the combinatorial effects of a number of variables that affect outcomes; and the combinatorial effects are usually not linearly related.[4] Also statistical analysis by its variable-oriented nature cannot adequately deal with the time dimension of social phenomena. Some causes and effects, such as those involved in understanding the effect of intervention, have a long time horizon; it takes a long time for them to unfold and to be discernable (Pierson, 2003, 2004). Particularly, statistical analysis does not provide a very good foundation for dealing with the dynamics involved in the process of institutional change. Notwithstanding the notorious modeling problem of accurately measuring dynamics in statistical models, it is often difficult to specify the complex dynamics of institutional change in a statistical model.

Given the data and methodological problems, in-depth case studies might be a better research methodology to capture the changes and unfolding events in the systems. The fieldwork conducted in 2001 by the NIIS team, as mentioned earlier, was devoted to putting together case studies of the systems. The case studies provide the narratives of major events that have occurred since the intervention; and of the way these events have unfolded and impinged upon irrigation management. To facilitate comparison of the case studies, we will apply the Boolean methodology, which emphasizes the holistic nature of explanation of social phenomena (Ragin, 1987, 2000). Instead of treating an empirical case as a mere collection of values with reference to some variables, the Boolean method treats a case as a configuration of casual and outcome conditions. The basis of explanation is not the correlation of variables, but a systematic comparison of configurations of causes that produce the same outcome.

Coping with Complexity and Change

The case materials suggest that the 19 irrigation systems in the Indrawati watershed took on very different paths of development since the completion of the WECS/IIMI intervention. Some of them have been able to build upon the improved social and physical endowments brought about by the intervention and thrived; some were only able to reap the initial benefits of the intervention and failed to sustain effective irrigation management; some others simply failed to make a good use of the opportunity and have remained poor performers.

An interesting question of major policy importance is whether one could identify a set of causal conditions, amidst diverse experiences, that are conducive to the persistence of intervention effect. Based upon the case studies of the 19 systems, we will first identify factors that might explain why some systems have continued a higher level of performance and why there are differences in the longer term effects of the intervention project. Specifically, we will examine how continual assistance to improve infrastructure, the existence of written rules, the imposition of fines and punishment, leadership, and collective action might have affected the sustainability of the intervention effect and hence irrigation performance. We will then apply the Boolean analysis to examine how these causal conditions configure to bring about particular patterns of outcome.

Continual infrastructure investment

Since the completion of the WECS/IIMI intervention project, a number of systems have received external assistance to fix or to further improve their irrigation infrastructure. The improvement works mainly concerned improving the lining and the diversion structures of the systems. The amounts of the funds varied, ranging from 10,000 rupees to 2,300,000 rupees. The sources of funding included local Rural Development Committee, District Irrigation Offices, as well as international donors such as UNDP. For those who think that irrigation management mainly concerns moving water from where it is available to where it is needed, continual investment in irrigation infrastructure is obviously a most important factor affecting irrigation performance. Presumably, continual infrastructure investment can help consolidate the improved physical endowment, hence make the intervention effect persistent.

The data analysis above, however, challenges such a view. The level of technical efficiency in almost all of the systems dropped in the period between time slices 2 and 3. Interestingly, of the two systems that did not experience a drop in technical efficiency in the period, one did not receive any assistance, and the other received assistance worth merely 10,000 rupees, the smallest amounts among all the assistance. So the evidence is that continual infrastructure investment, in general, did not help maintain, let alone improve, technical efficiency. Yet, interesting questions remain as to whether the systems that have received assistance are more likely to sustain a higher level of performance as compared to those that have not; and how continual infrastructure investment might configure with other factors to affect irrigation performance and the sustainability of the intervention effect.

Written rules

A major element of the WECS/IIMI intervention project is that farmers in a system were required to develop their own set of rules for irrigation management after the project was completed. In fact, the farmer-to-farmer training was undertaken with a view to enabling the farmers to develop organizing skills through learning from successful experiences; it was expected that the farmers who have gone through the training could serve as catalysts for the rule-crafting efforts in their own systems. The case materials show that the WECS/IIMI project did trigger rule-crafting efforts in most of the systems. The scope and the comprehensiveness of the rules varied across the systems. While on most systems the rules developed mainly concerned water allocation and maintenance, farmers in some systems worked out extensive rules dealing with such issues as arranging payments from farmers to support full-time watchmen. In particular, systems on which water management served multiple purposes such as generating hydraulic power and grain mills tended to have developed a more sophisticated set of rules with a much broader scope. In the Naya Dhara Kulo, for example, a set of rules was developed for water management for both energy generation and irrigation. The rules not only stipulated how resources are mobilized for regular maintenance and how water is allocated, but also addressed such issues as environmental protection and organizational development for the system. A caveat is warranted, however. The existence of rules does not necessarily mean that the rules are strictly followed at all time. In some systems, written rules existed but were not followed because nobody enforced them; in some other systems, strong leaders were able to coordinate farmers' action that renders strict application of formal rules unnecessary.

There are of course systems on which farmers did not draft a set of written rules for irrigation as required by the WECS/IIMI project. On some of these systems, farmers just failed to work with one another to engage in rule-crafting activities; yet there were also systems on which farmers were able to organize collective action for water distribution and maintenance on the basis of verbal agreements and understanding. On these systems, the norms and common understanding that had evolved over the years already provided a good basis for collective action, and farmers did not see the need to turn these norms into written rules. Particularly on systems where there were strong leaders, the leadership already provided the necessary focal point for collective action.

Fines

The third causal condition that might affect irrigation management is whether farmers have made effort to punish those who violate the rules or free-ride on the efforts of others. Only 9 of the 19 systems had worked out rules imposing fines. A review of the experiences of the system reveals several interesting patterns. First, that a system had a set of written rules for system operation and maintenance does not necessarily mean that the system also had a provision for imposing fines. On many systems where leadership was strong and a good working order was in place, farmers did not see the need for imposing fines. Second, whether and how a fine provision has affected farmers' incentives to contribute to irrigation operation and maintenance depends on the configuration of factors that constitute farmers' action situation. In Dhap Kulo, for example, the water users committee provided an arena for farmers to resolve conflicts effectively, a fine provision was considered unnecessary. In Chhahare Khola Kulo, on the other, although a small group of local leaders were able to maintain a certain level of collective action, the lack of a fine provision was considered to be a major reason why many farmers did not participate in canal repairs and maintenance. Third, the farmers in general did not think of the imposition of fines as a useful means for enhancing collective action. As a farmer in Majh Ko Kulo succinctly put it, "only the honest and sincere people pay the fines". In fact, farmers on most systems were hesitant to impose fines even if there were fine provisions. When asked how they handled the conflicts caused by farmers violating rules, most answered that discussion between the leaders and the rule violators had been the most often used and effective means for conflict resolution.

Consistent leadership

A major factor that might affect the long term viability of irrigation management is whether leadership is consistent and be able to adapt to change. When the WECS/IIMI project was implemented, a group of local leaders were identified and encouraged to participate in the process of project implementation. As discussed above, one of the major elements of the project was to enhance the organizing abilities of local leaders through training, so that they could serve as the catalysts for collective action in the local community. As a result, in almost all systems, a water users committee, or the equivalent to it, was set up to provide leadership.

Local leaders performed important functions. On most systems, water allocation and system maintenance were coordinated by the water users committee. In Ghatte Kulo, for example, the chairperson was a very powerful leader who decided on the order of water distribution for other farmers on the system to follow. In Tallo Jhankri Ko Kulo, canal cleansing and system maintenance were mainly coordinated by the chairman of the water users committee. Moreover, local leaders often served as the arbitrator for resolving conflicts among farmers, or between farmers and outsiders.

Yet the existence of a water users committee does not necessarily mean that leadership exists. Leadership, in the context of irrigation management in Nepal, is embedded in the broader social relationships in the local community. On systems where existing social capital is minimal, the WECS/IIMI project seems to have had limited success in building up leadership. What happened in Bagmara Ko Kulo is a case in point. The community is divided by ethnic issues. Although the WECS/IIMI project helped farmers to set up a water users committee, the committee became inactive shortly after the completion of the project; farmers reported that the committee has not held any meetings ever since.

For systems that had strong leadership at the beginning, how to cope with leadership change so as to maintain a consistent leadership poses a great challenge. What happened in Magar Kulo is illustrative. When the WECS/IIMI project was implemented, a water users committee was formed under the leadership of Mr. Batan Singh Tamang. Mr. Tamang was instrumental not only in the process of implementing the intervention project, but also in sustaining farmers' collective action in managing irrigation operation and maintenance. His leadership was so effective that farmers did not see the need to put the rules in the written form. The death of Mr. Tamang in 1998 presented a big shock to the system. While there were some potential leaders, farmers failed to agree on a successor. Since then, the chairmanship of the water users committee has been kept vacant; and the irrigation working order unraveled rapidly. With the committee defunct, water delivery was left coordinated and farmers appropriated water whenever they needed it; no organized maintenance activities have been conducted ever since. Farmers in the system see the problem but don't know how to cope with it. What happened in Magar Kulo is not unique, on other systems, such as Chapbot Ko Kulo and Dovaneswar Kulo, the demise of old leaders often caused confusion and bewilderment. In fact, the general situation is that the more frequent the leadership has changed, the less effective the water users committee has become. Systems that have been better able to maintain a good working order and good performance are often characterized by the existence of a core group of active leaders who provided a level of consistency in leadership.

Co-management existed in three systems. In the 1990s, hydraulic power generating facilities were constructed on Dhap Kulo and Naya Dhara Kulo. As water was no longer used for irrigation purposes only, an integrated management framework was put in place. A water resource committee was set up to replace the existing water users association; the new committee was given the authority to oversee both the energy and irrigation matters. Expanding the scope of water management brought in both opportunities and constraints. On one hand, bringing two groups of users (irrigation and energy) under the auspice of one institutional framework inevitably increased the likelihood of conflicts. While the farmers would like to have the flow of water under control, the energy users would prefer continual flow of a large volume of water in the canals. Farmers reported that the conflict between farmers at the head end and the energy users was particularly severe. On the other hand, bringing in the energy users also brought about some sort of checks and balances. The energy users had the incentive to see to it that the operation and maintenance of the water system was in good shape, and that a set of rules for water delivery and canal repair be developed -- and followed. More importantly, leaders of the energy sector have been proven to be a valuable asset for water management; farmers commented that, since the new institutional framework was put in place, the leadership has improved, which in turn has brought about improvement in agricultural productivity.

Co-management could take another form, however. In Besi Kulo, the water users association was abolished in the 1990s, and the responsibility of irrigation management was shifted to the Ward, a local general-purpose political-administrative unit. The Ward chairman was given the responsibility of "supervising" the operation of the system. As one would expect, the chairman was not likely to spend too much time and effort on irrigation management. A result was a rapid unraveling of management order for irrigation. Since the institutional change, no meetings have been held to discuss about irrigation management; the management of the system was, in farmers' words, "on an individual basis". Ironically, although a set of written rules for irrigation operation and maintenance existed in the system, most farmers were not even aware of its existence.

Collective action

The existence of written rules and active leaders are not likely to bring about good performance if farmers are not willing to be involved in collective action for system operation and maintenance. The importance of collective action is not only about farmers' effort *per se,* but more importantly the building of trust and common understanding among farmers in the process of working with one another, which in turn could serve as the foundation for collective problem-solving in other contingencies. The success of collective action hinges upon a variety of factors; moreover, collective action often impinges upon irrigation performance in combination of other variables. On Magar Kulo, for instance, the lack of leadership resulted in the unraveling of collective action among farmers; and brought about low levels of technical efficiency of the system. On Majh Ko Kulo in Thangpal, however, farmers were able to maintain a certain level of collective action despite a lack of leadership in the system.

Maintaining a certain level of collective action among farmers is always a challenge. A seemingly minor event could trigger the unraveling of collective action easily. What happened in Siran Ko Kulo in Baguwa is a good case in point. When the WECS/IIMI project was first implemented, farmers in the system were enthusiastic about the endeavor and were willing to engage in collective action for irrigation management. As farmers recollected, it was the time when "an environment of trust" prevailed, that enabled them to attain a high level of technical efficiency of the system. The effective working order began to fall apart when some farmers at the head end stopped participating in collective maintenance works, arguing that a continual flow of water in the canals could adversely affect their lands. It was unfortunate that the leadership in the system was also going through changes at the time, and the new leaders failed to resolve the conflict between the farmers at the head end and their neighbors at the middle and the tail ends. The situation deteriorated rapidly, and farmers have become dependent on the water users association for system maintenance. Conflicts have become a frequent occurrence, particularly during dry season from March to June when water is scarce. As the farmers put it, a "crisis of trust" is worsening the technical efficiency and agricultural performance of the system.

Configurations of Causal Conditions that Sustain Intervention Effect

As argued above, the five casual conditions did not operate independently to affect irrigation performance in a linear manner. To understand how the five causal conditions configured to affect the sustainability of intervention effect, it is necessary to identify possible configurations that lead to particular outcomes, and to specify the necessary and sufficient causal conditions. In this section, we will employ the Boolean method to help compare the configurations of causal factors leading to sustainable intervention effect identified in the 19 systems. As discussed above, the Boolean method emphasizes the holistic nature of explanation of social phenomena. Instead of treating a case as a mere collection of values with reference to a set of variables, the Boolean method looks at a case as a configuration of casual and outcome conditions. The basis of explanation is not the correlation of variables, but a systematic comparison of configurations of causal conditions that produce the same outcome.

All causal conditions, or variables, in the Boolean analysis are dichotomized. A condition is coded as being either present (TRUE) or absent (FALSE). Such simplification helps focus the analysis on the structure of relationships among causal conditions, rather than on the competition among variables to explain the outcome. In our analysis, we want to know what configurations of causal conditions accounted for the persistence of intervention effect. The outcome, or the dependent variable, is whether persistent improvement in irrigation performance existed in a system or not. In this analysis, we will examine two measures of irrigation performance, namely, the adequacy of water at the tail end of the system in winter season, and agricultural productivity at the tail end. We focus on performance measures at the tail end because irrigation at the tail end faces a more challenging task environment and hence should be most sensitive to any change in the causal conditions.

The two outcome variables are meant to capture not only whether there was an improvement in irrigation performance fifteen years after the intervention, but also whether the improvement had been persistent. The coding for "water adequacy at the tail end in winter season" *(JO)* was based on the information provided in Table 9b. We coded a system as TRUE if the net intervention effect on water adequacy at the tail end in winter was positive, *and* there was no reversal in intervention effect. For all other situations, we coded them as FALSE. For example, the intervention brought about a short term positive impact on water adequacy in Magar Kulo, followed by a negative impact in the longer run. Although the net effect was positive, we coded the system as FALSE. To provide a simplified notation, we adopted the convention of using the upper case letter (D) to indicate a TRUE value and the lower case letter (d) to denote a FALSE value (see Table 13).

The coding for the "Cropping Intensity at the Tail End" (7) was based on information provided in Table 10. Again, the coding was intended to capture not only whether there was a net improvement in tail end cropping intensity across time, but also whether the improvement had been consistent. Unlike water adequacy which is mainly determined by irrigation management, tail end cropping intensity is affected by an array of factors other than whether the irrigation system is well maintained. As a result, a small change in the tail end cropping intensity might reflect more the effect of other contextual factors than the effect of the intervention. So in our coding, we imposed a higher standard for what we mean by an improvement. If a system had a persistent increase in tail end intensity but the net increase was less than a quarter of a crop, we coded it as FALSE. These cases are indicated with a "S" in Table 10.

There are five causal conditions in the analysis, namely whether a system has received further infrastructure assistance since the completion of the WECS/IIMI project *(A)*, whether farmers on a system have been able to develop a set of written rules for irrigation operation and maintenance *(W)*, whether farmers have worked out provisions for imposing fines *(F)*, whether the leadership in a system has been able to maintain continuity and to adapt to the changing environment *(JO)*, and whether farmers have been able to maintain a certain level of collective action in system maintenance *(C)*. Coding for these causal conditions is based upon the case studies of the 19 systems. By reviewing what happened in the systems a decade and a half after the intervention, we sought to identify major events and their impacts on irrigation management, and also to understand the processes and dynamics of change. The causal conditions are coded as either TRUE or FALSE. Again, the upper case letter denotes a TRUE value and a lower case letter a FALSE value (see Table 13). For some causal conditions, such as *A* and *W*, the coding is rather straightforward. But for some other conditions such as *L* and *C*, delineating a TRUE value from a FALSE value requires careful interpretation of the local history of the systems, as well as an exercise of judgment. Fortunately in the case studies, farmers did offer vivid descriptions of events and their comments; which has provided a good basis for our coding.

The Boolean analysis starts with constructing a Truth Table, which lays out all the configurations of the five causal conditions that exist among the 19 cases. The Truth Table for water adequacy at the tail end in winter (D) is shown in Table 14. Eight configurations generate D, two configurations generate d, and one configuration generates contradictory outcomes. For this study, we are only interested in configurations generating D, so only the configurations that generate D will be used for subsequent analysis. A problem, then, is how to handle the configuration that generates contradictory outcomes. Practically, the contradiction might suggest that there were some other causal conditions affecting the outcome that we did not take into account in our analysis; or it is simply a result of randomness. The Boolean convention in dealing with contradictions is to adopt a threshold value for deciding whether the particular configuration is more likely to generate D or d. We adopted the 50% threshold, meaning that unless a particular configuration generates more D than d, we will not consider it as a configuration generating D. Accordingly, the configuration that generates contradictory outcomes failed to pass the threshold, and were not included in our analysis. In Table 14, the configurations used for analysis are shaded.

The fsQCA software was used to minimize the configurations generating D to come up with an equation that succinctly describes the relationships between D and the configurations of casual conditions:

$$D = ACW + alCf + A1WF + LCWF \qquad (1)$$

Two questions are of major policy interest. First, how important continual infrastructure investment is for sustaining adequate water supply in the systems? Is it a necessary condition? If not, what are the contexts for it to be present for water adequacy to occur? Second, it has often been argued that experiences of collective action are the basis for the accumulation of social capital. One of the major objectives of the WECS/IIMI intervention, in fact, was to encourage and enable farmers to participate more fully in irrigation management. Exactly how collective action relates to water adequacy? What are the supporting conditions with which collective action can bring about water adequacy?

To address these questions, we rearrange the equation (1) to:

$$D = AW(C + IF) + C\ (LWF + alf) \qquad (2)$$

In Boolean algebra, addition is equivalent to the logical operator OR; multiplication means the conjunction of causal conditions. Equation (2) is composed of two groups of configurations, meaning that if any one of two groups of configurations is obtained, there will be persistent improvement of water adequacy. The first group of configurations concerns the situations in which a system has received continual infrastructure investment. A always comes with W, meaning that continual infrastructure investment can bring about persistent improvement in water adequacy only if farmers have been able to develop a set of written rules for system operation and maintenance. The existence of AW is not sufficient, however; it has to be in a context where either farmers are able to engage in collective action, or fines be imposed.

The second group of configurations in Equation (2) concerns situations in which a system has not received any infrastructure assistance since the completion of the WECS/IIMI project. Without continual assistance, collective action of farmers is a necessary condition for D to occur. Collective action by itself, however, is insufficient. In some systems, collective action has to be supported by consistent leadership with a set of written rules and fine provisions. In cases where both consistent leadership and assistance are lacking, collective action is effective only if it is not organized on the basis of punishment.

Now we turn to the analysis of configurations of causal conditions leading to persistent increase in cropping intensity at the tail end. Again, the analysis starts with constructing a Truth Table as shown in Table 15. Two configurations generate T, seven configurations generate t, and two configurations generate contradictory outcomes. Again, the configurations that generate contradictory outcomes were dealt with by the 50% threshold. Only one of the two configurations that generate contradictory outcomes was included in our analysis. In Table 15, the shaded configurations are those we include in the analysis.

The fsQCA software was used to generate an equation that lay out the relationships between T and the configurations of causal conditions:

$$T = aCWf+LCWf \tag{3}$$

We re-arranged the equation to:

$$T = CWf\,(a + L) \tag{4}$$

Equation (4) provides a succinct statement about the relationships between the configurations of the causal conditions and the existence of persistent increase in tail end cropping intensity. The term CWf is the necessary element of configurations for T. The presence of collective action, the existence of a set of written rules for system operation and maintenance, and the absence of a provision of fines are the basic conditions for sustained improvement in agricultural productivity. What we have found is consistent with the finding of prior research that effective irrigation management hinges upon a good working order sustained by farmers' continued involvement and a set of rules (Ostrom, 1990, 1992; Lam, 1998). With collective action and the rules in place, formal punishment would not be necessary, or could even be harmful to collective action.

The necessary elements *per se* are inadequate, they can bring about sustained improvement in agricultural productivity only if either one of the two additional conditions exists—the presence of consistent leadership and the absence of continual external assistance for infrastructure improvement. Obviously these two additional conditions are consistent with and complementary to the necessary' elements. As we have found in the case studies, local leaders have played an important role in enhancing and maintaining farmers' collective action in the 19 irrigation systems. They have not only provided a locus for coordinating collective action, but also served as an arbitrator in resolving conflicts and disputes among farmers. In fact, leadership is particularly important in the context where farmers tend to be hesitant to resort to formal punishment, and consider discussion and arbitration as a better means for conflict resolution.

The analysis also offers a note of caution to those who think that continual assistance for infrastructure improvement is an essential means to sustain improvement in agricultural productivity. Our finding suggests that continual assistance is either irrelevant, or, in some cases, the absence of it is imperative for persistent improvement in agricultural productivity. Prior research has long warned against the possibility of intervention projects building in the recipients a dependent mind-set (Amatya et al, 2004). More importantly, improving irrigation infrastructure without paying attention to how it might affect farmers' incentive could bring about counterintuitive outcomes, and could be detrimental to farmers' collective action (Ostrom and Gardner, 1993; Lam, 1996b, 1998).

Conclusion: Sustainable Human Artisanship and Sustainable Irrigation

Prior research and assistance experiences have suggested that technological fixes alone are not likely to improve irrigation performance. An intervention project stands a chance of success only if it could help develop robust local institutions to support the operation and maintenance of engineering infrastructure, and enhance social capital that has already existed in the local community. While the principle for designing successful intervention project seems to be straightforward, turning the principle into the design of intervention projects is not as simple as some might expect. In particular, how to keep the intervention effect last and sustained in the long run poses a significant challenge.

In 1985, the Water and Energy Commission Secretariat (WECS) of Nepal and the International Irrigation Management Institute (IIMI) initiated an intervention project to assist 19 farmer-managed irrigation systems located in the Indrawati watershed in Nepal. The project was designed with a view to developing and testing methods for delivering assistance that could enhance farmers' organizing ability for irrigation operation and maintenance at the same time as the irrigation infrastructure was improved. In this paper, we have drawn upon several rounds of data for the systems involved in the project to assess and understand how the intervention has affected the operation and performance of the systems in a decade and a half after completion.

Before one asks the question of what can be done to help the farmers in the Indrawati watershed, or for that matter farmers in Nepal in general, to improve irrigation performance, one has to appreciate the challenges and complexity involved in managing irrigation in a region where the natural environment is hostile and the material condition is in general austere. Torrential rains, flooding, and landslides are common occurrence in monsoon season, which often damage the primitive irrigation infrastructure that farmers have struggled to construct, and render system maintenance extremely difficulty and costly. It is not surprising that, in many instances, when government officials and donors came in to try to "assist" the farmers, fixing the engineering infrastructure was often the first thing that came to their mind.

Our analysis of the experience of the WECS/IIMI intervention, however, has shown that infrastructure fixes can improve technical efficiency only in the short run. In most of the cases, the improvement in technical efficiency as the result of intervention withered away soon after the completion of the intervention. Such a situation should come as no surprise. For farmers who engage in constant struggle with the tough environment, working together to fix and rebuild their systems in simply part of irrigation management. In fact in some irrigation systems in Nepal, the diversion structure was built of primitive materials intentionally so that during the monsoon season water could be stopped from getting into the system to flood the canals and farmers' fields (Lam, 1998). Given the challenging environment, to maintain a high level of technical efficiency by continual infrastructure investment is not, and should not be, a realistic objective to be sought after.

In fact, our analysis has shown that continual infrastructure assistance, in general, cannot sustain a high level of technical efficiency.

Does it mean that infrastructure fixes are irrelevant to efforts helping farmers to improve irrigation management and performance? The answer is negative. Our analysis has suggested that, in most of the 19 systems involved in the WECS/IIMI project, the improved technical efficiency of irrigation infrastructure did bring about an improvement in water adequacy, which has persisted even after the improved technical efficiency withered away. As discussed above, the WECS/IIMI intervention was designed to get farmers involved in the processes of planning and implementing the infrastructure works to the extent possible. The infrastructure improvement works provided not only incentives for farmers who could see for themselves how their effort could make a difference, but also precious opportunities for farmers to develop working relationships with one another. As long as a good working order can be maintained, a high level of water adequacy can be achieved.

Maintaining a good working order, of course, is no less a challenge than coping with the capricious physical environment. It requires a mastery of human artisanship—the abilities and skills required for working with one another for mutual betterment. A major focus of the WECS/IIMI intervention was to equip farmer with such abilities and skills. Through farmer-to-farmer training, getting the farmers involved in project implementation, identifying local leaders, and helping farmers to work out rules, the intervention set the momentum for farmers' self-organization.

Given the different history and social-political backgrounds, the 19 systems have taken on different paths for self-organization. Some have been able to build upon the momentum and thrived; others have failed to sustain a good working order. It would be naive to think there is a recipe for developing human artisanship. Yet our analysis has suggested that as long as farmers are willing to maintain a certain level of collective action, and a corps of local entrepreneurs exist to provide leadership and be able to adjust to changes, it is possible for the farmers to build on the momentum set forth by the intervention to attain consistently high levels of performance.

Table 1. Relationships between Intervention Types and Physical Condition of Irrigation Systems

Types of Intervention	Physical Condition			
	Excellent	Moderately Good	Poor	Total
Intervention with High Level of Farmers' Involvement (WECS/IIMI)	12 (63.2%)	7 (36.8%)	0 (0.0%)	19 (100.0%)
Intervention with Moderate Levels of Farmers' Involvement (ADB/N and ISSP)	9 (13.6%)	45 (68.2%)	12 (18.2%)	66 (100.0%)
Intervention with Low Levels of Farmers' Involvement (DIO, MLD, and Multi-service Agencies)	6 (22.2%)	16 (59.3%)	5 (18.5%)	27 (100.0%)
FMIS without Intervention	6 (8.7%)	54 (78.3%)	9 (13.0%)	69 (100.0%)
AMIS	4 (8.4%)	22 (45.8%)	22 (45.8%)	48 (100.0%)
Total	37 (16.2%)	144 (62.9%)	48 (20.9%)	229 (100.0%)

Table 2. Relationships between Intervention Types and Economic Efficiency of Irrigation Systems

Types of Intervention	Economic Efficiency			
	Excellent	Moderately Good	Poor	Total
Intervention with High Level of Farmers' Involvement (WECS/IIMI)	16 (84.2%)	3 (15.8%)	0 (0.0%)	19 (100.0%)
Intervention with Moderate Levels of Farmers' Involvement (ADB/N and ISSP)	21 (31.8%)	41 (62.1%)	4 (6.1%)	66 (100.0%)
Intervention with Low Levels of Farmers' Involvement (DIO, MLD, and Multi-service Agencies)	9 (33.3%)	18 (66.7%)	0 (00.0%)	27 (100.0%)
FMIS without Intervention	14 (20.3%)	53 (76.8%)	2 (2.9%)	69 (100.0%)
AMIS	6 (12.5%)	25 (52.1%)	17 (35.4%)	48 (100.0%)
Total	66 (28.8%)	140 (61.1%)	23 (10.0%)	229 (100.0%)

Table 3. Relationships between Intervention Types and Water Supply at the Tail End of Irrigation Systems

Types of Intervention	Water Supply at the Tail End				
	Adequate and Predictable	Adequate and Unpredictable	Inadequate and Predictable	Inadequate and Unpredictable	Total
Intervention with High Level of Farmers' Involvement (WECS/IIMI)	15 (78.9%)	1 (5.3%)	2 (10.5%)	1 (5.3%)	19 (100.0%)
Intervention with Moderate Levels of Farmers' Involvement (ADB/N and ISSP)	37 (58.7%)	4 (6.3%)	17 (27.0%)	5 (7.9%)	63 (100.0%)
Intervention with Low Levels of Farmers' Involvement (DIO, MLD, and Multi-service Agencies)	7 (26.9%)	1 (3.9%)	14 (53.8%)	4 (15.4%)	26 (100.0%)
FMIS without Intervention	35 (50.7%)	0 (0.0%)	26 (37.7%)	8 (11.6%)	69 (100.0%)
AMIS	5 (10.6%)	1 (2.1%)	24 (51.1%)	17 (36.2%)	47 (100.0%)
Total	99 (44.2%)	7 (3.1%)	83 (37.1%)	35 (15.6%)	224 (100.0%)

Table 4. Relationships between Intervention Types and Agricultural Productivity of Irrigation Systems

Types of Intervention	Agricultural Productivity	
	Cropping Intensity at the Head End (%)	Cropping Intensity at the Tail End (%)
Intervention with High Level of Farmers' Involvement (WECS/IIMI)	252.42 (N=19)	246.15 (N=19)
Intervention with Moderate Levels of Farmers' Involvement (ADB/N and ISSP)	235.89 (N=64)	229.10 (N=65)
Intervention with Low Levels of Farmers' Involvement (DIO, MLD, and Multi-service Agencies)	247.40 (N=25)	233.08 (N=25)
FMIS without Intervention	255.75 (N=60)	251.03 (N=57)
AMIS	211.54 (N=46)	196.22 (N=44)
Total	239.03 (N214)	230.18 (N=210)

Table 5. Irrigable Area and Cost of Improvements to FMIS in the Indrawati Watershed

Name of Irrigation Systems	Existing Command Area (ha.)	Command Area Expansion (ha.)	Total Irrigable Area (ha.)	Project Grant (NRs)	Cost per Irrigable Hectare (NRs)
Chhahare Khola Ko Kulo	126	37	163	126,615	777
Naya Dhara Khola Ko Kulo	55	55	110	139,720	1,270
Besi Kulo	65	20	85	119,839	1,410
Dhap Kulo and Subedar Ko Kulo	30	35	65	85,000	1,308
Soti Bagar Ko Kulo	19	11	30	150,699	5,023
Dovan Swar Ko Kulo (Dobhan Swar Kulo)	2	10	12	74,807	6,234
Magar Kulo	100	43	143	160,805	1,125
Siran Ko Kulo (a) (SThangpal)	18	6	24	136,789	5,700
Majha Ko Kulo (b) (Thangpal)	71	16	87	114,321	1,314
Ghatta Muhan Ko Kulo (Tarali Ko Kulo)	23	10	33	124,321	3,767
Bhanjyang Tar Ko Kulo	21	14	35	65,178	1,862
Tallo Jhankri Ko Kulo	18	13	31	91,707	2,958
Chholang Khet Ko Kulo	23	14	37	116,066	3,137
Chap Bot Ko Kulo (Beltari Fant Ko Kulo)	12	5	17	71,630	4,214
Baghmara Ko Kulo	3	6	9	44,433	4,937
Siran Ko Kulon (c) (Shikharpur)	18	19	37	57,488	1,554
Majha Ko Kulo (d) (Baguwa, Shikhapur)	13	20	33	113,541	3,441
Tallo Chapleti Kulo	8	15	23	78,065	3,394
TOTAL	625	349	974	1,871,024	
Average Cost /Irrigable ha.					1,921
Consultant & WECS Supervision					1,192,747
Tools Supplied					82,182
Farmer Training					55,000
Average Cost of Supervision / ha.					1,356
Total Cost of Improvement / ha.					3,286

Source: WECS/IIMI (1990:29)

Table 6. Head End and Tail End Cropping Intensities Immediately Before and After Intervention

Name of Irrigation Systems	Head End Cropping Intensity		Tail End Cropping Intensity	
	Pre	Post	Pre	Post
Chhahare Khola Ko Kulo	200	167	200	192
Naya Dhara Khola Ko Kulo	200	200	200	200
Besi Kulo	200	235	200	235
Subedar Ko Kulo	250	270	250	270
Dhap Kulo	250	290	250	250
Soti Bagar Ko Kulo	150	215	150	215
Dovan Swar Ko Kulo (Dobhan Swar Kulo)	300	200	300	200
Magar Kulo	190	194	190	200
Siran Ko Kulo (a) (Thangpal)	255	200	255	250
Majha Ko Kulo (b) (Thangpal)	300	230	300	230
Ghatta Muhan Ko Kulo (Tarali Ko Kulo)	271	290	271	270
Bhanjyang Tar Ko Kulo	260	300	260	220
Tallo Jhankri Ko Kulo	200	270	200	270
Chholang Khet Ko Kulo	220	235	220	220
Chap Bot Ko Kulo (Beltari Fant Ko Kulo)	270	300	270	270
Baghmara Ko Kulo	300	300	300	300
Siran Ko Kulon (c) (Siran Ko Kulo–Shikharpur)	300	295	300	285
Majha Ko Kulo (d) (Baguwa, Shikhapur)	280	300	280	300
Tallo Chapleti Kulo	250	300	NA	300

Table 7. The size of irrigated areas of the irrigation systems

Name of Irrigation Systems	Size of System Areas (Hectares)	Short-Run Effect	Longer-Term Effect	Net Effect	Pattern of Change
Chhahare Khola Ko Kulo	15 163 151	↑	↓	↑	F/I
Naya Dhara Khola Ko Kulo	55 110 110	↑	–	↑	I
Besi Kulo	65 85 85	↑	–	↑	I
Subedar Ko Kulo	40 40 60	–	↑	↑	I
Dhap Kulo	70 50 60	↓	↑	↓	F/D
Soti Bagar Ko Kulo	12 30 32	↑	↑	↑	I S
Dovan Swar Ko Kulo (Dobhan Swar Kulo)	5 12 6	↑	↓	↑	F/I S
Magar Kulo	160 143 140	↓	↓	↓	D
Siran Ko Kulo (a) (Siran Ko Kulo (a)–Thangpal)	35 24 48	↓	↑	↑	F/I
Majha Ko Kulo (b) (Thangpal)	46 87 71	↑	↓	↑	F/I
Ghatta Muhan Ko Kulo (Tarali Ko Kulo)	35 33 35	↓	↑	–	F/U
Tallo Jhankri Ko Kulo	30 31 31	↑	–	↑	I S
Chholang Khet Ko Kulo	25 37 37	↑	–	↑	I
Siran Ko Kulon (c) (Siran Ko Kulo–Shikharpur)	16 37 50	↑	↑	↑	I
Majha Ko Kulo (d) (Baguwa, Shikhapur)	10 33 65	↑	↑	↑	I
Tallo Chapleti Kulo	- 23 15	-	↓	-	-
Baghmara Ko Kulo	5 9 12	↑	↑	↑	I
Chap Bot Ko Kulo (Beltari Fant Ko Kulo)	35 17 18	↓	↑	↓	F/D
Bhanjyang Tar Ko Kulo	30 35 40	↑	↑	↑	I

Pattern of Change: (I) Improved; (D) Deteriorated; (F) Fluctuating pattern; (S) Small magnitude of change

Table 8. Technical Efficiency of Irrigation Infrastructure

Name of Irrigation Systems	Technical Efficiency	Short-Run Effect	Longer-Term Effect	Net Effect	Pattern of Change
Chhahare Khola Ko Kulo	2 4 2	↑	↓	–	F/U
Naya Dhara Khola Ko Kulo	3 4 3	↑	↓	–	F/U
Besi Kulo	3 3 2	–	↓	↓	D
Subedar Ko Kulo	2 4 2	↑	↓	–	F/U
Dhap Kulo	2 4 3	↑	↓	↑	F/I
Soti Bagar Ko Kulo	2 4 3	↑	↓	↑	F/I
Dovan Swar Ko Kulo (Dobhan Swar Kulo)	3 4 3	↑	↓	–	F/U
Magar Kulo	3 3 3	–	–	–	U
Siran Ko Kulo (a) (Siran Ko Kulo (a)–Thangpal)	3 3 2	–	↓	↓	D
Majha Ko Kulo (b) (Thangpal)	3 4 2	↑	↓	↓	F/D
Ghatta Muhan Ko Kulo (Tarali Ko Kulo)	2 4 2	↑	↓	–	F/U
Tallo Jhankri Ko Kulo	2 4 2	↑	↓	–	F/U
Chholang Khet Ko Kulo	3 4 2	↑	↓	↓	F/D
Siran Ko Kulon (c) (Siran Ko Kulo–Shikharpur)	3 3 2	–	↓	↓	D
Majha Ko Kulo (d) (Baguwa, Shikhapur)	3 4 3	↑	↓	–	F/U
Tallo Chapleti Kulo	1 3 3	↑	–	↑	I
Baghmara Ko Kulo	4 4 2	–	↓	↓	D
Chap Bot Ko Kulo (Beltari Fant Ko Kulo)	2 4 2	↑	↓	–	F/U
Bhanjyang Tar Ko Kulo	3 4 2	↑	↓	↓	F/D

Technical Efficiency: (1) Highly Ineffective; (2) Moderately Ineffective; (3) Moderately Effective; (4) Highly Effective
Pattern of Change: (I) Improved; (D) Deteriorated; (U) Unchanged; (F) Fluctuating pattern; (S) Small magnitude of change

Table 9a. Average Water Adequacy

	T1	T2	T3
SPRING TAIL	2.36	1.54	2
WINTER TAIL	2.06	1.26	1.25
MONSOON TAIL	1.64	1	1
SPRING HEAD	2	1.37	1.43
WINTER HEAD	1.8	1.2	1.1
MONSOON HEAD	1.53	1	1

Water Adequacy: (1) Abundance; (2) Limited); (3) Scarce; (4) Non-existence

Table 9b. Water adequacy at the Tail End in *Winter*

Name	Tail End Water Adequacy	Short-term Effect	Longer-term Effect	Net Effect	Pattern of Change
Chhahare Khola Ko Kulo	2 2 1	–	↑	↑	I
Naya Dhara Khola Ko Kulo	2 1 1	↑	–	↑	I
Besi Kulo	2 1 1	↑	–	↑	I
Subedar Ko Kulo	2 2 .	–	.	.	.
Dhap Kulo	2 1 1	↑	–	↑	I
Soti Bagar Ko Kulo	2 1 1	↑	–	↑	I
Dovan Swar Ko Kulo (Dobhan Swar Kulo)	. 1 1	.	–	.	.
Magar Kulo	3 1 2	↑	↓	↑	F/I
Siran Ko Kulo (a) (Siran Ko Kulo (a)–Thangpal)	2 1 .	↑	.	.	.
Majha Ko Kulo (b) (Thangpal) 50617	2 1 1	↑	–	↑	I
Ghatta Muhan Ko Kulo (Tarali Ko Kulo)	. 1 .	.	.	.	.
Tallo Jhankri Ko Kulo	2 1 1	↑	–	↑	I
Chholang Khet Ko Kulo	2 2 1	–	↑	↑	I
Siran Ko Kulon (c) (Siran Ko Kulo–Shikharpur)	2 2 1	–	↑	↑	I
Majha Ko Kulo (d) (Baguwa, Shikhapur) 50625	2 2 1	–	↑	↑	I
Tallo Chapleti Kulo	4 1 1	↑	–	↑	I
Baghmara Ko Kulo	1 1 4	–	↓	↓	D
Chap Bot Ko Kulo (Beltari Fant Ko Kulo)	1 1 1	–	–	–	U
Bhanjyang Tar Ko Kulo	2 1 1	↑	–	↑	I

Water Adequacy: (1) Abundance; (2) Limited); (3) Scarce; (4) Non-existence
Pattern of Change: (I) Improved; (D) Deteriorated; (U) Unchanged

Table 10. Tail End Cropping Intensities

Name	Tail End Intensity	Short-term Effect	Longer-term Effect	Net Effect	Pattern of Change
Chhahare Khola Ko Kulo	200 192 200	↓	↑	–	F/U S
Naya Dhara Khola Ko Kulo	200 200 205	–	↑	↑	I S
Besi Kulo	200 235 210	↑	↓	↑	F/I S
Subedar Ko Kulo	250 270 300	↑	↑	↑	I
Dhap Kulo	250 250 290	–	↑	↑	I
Soti Bagar Ko Kulo	150 215 300	↑	↑	↑	I
Dovan Swar Ko Kulo (Dobhan Swar Kulo)	300 200 300	↓	↑	–	F/U
Magar Kulo	190 200 210	↑	↑	↑	I S
Siran Ko Kulo (a) (Siran Ko Kulo (a)–Thangpal)	255 250 .	↓	.	.	.
Majha Ko Kulo (b) (Thangpal) 50617	300 230 230	↓	–	↓	D
Ghatta Muhan Ko Kulo (Tarali Ko Kulo)	271 270 .	–	.	.	.
Tallo Jhankri Ko Kulo	200 270 300	↑	↑	↑	I
Chholang Khet Ko Kulo	220 220 300	–	↑	↑	I
Siran Ko Kulon (c) (Siran Ko Kulo–Shikharpur)	300 285 250	↓	↓	↓	D
Majha Ko Kulo (d) (Baguwa, Shikhapur) 50625	280 300 300	↑	–	↑	I S
Tallo Chapleti Kulo	. 300 200	.	↓	.	.
Baghmara Ko Kulo	300 300 100	–	↓	↓	D
Chap Bot Ko Kulo (Beltari Fant Ko Kulo)	270 270 300	–	↑	↑	I
Bhanjyang Tar Ko Kulo	260 220 115	↓	↓	↓	D

Pattern of Change: (I) Improved; (D) Deteriorated; (U) Unchanged; (F) Fluctuating pattern; (S) Small magnitude of change

Table 11. Levels of Deprivation

Are there appropriators who are consistently disadvantaged in irrigation	Time Slice		
	1	2	3
Yes	8 (50%)	5 (26.32%)	0 (0.00%)
No	8 (50%)	14 (73.68%)	17 (100%)
Total	16 (100%)	19 (100%)	17 (100%)

Chi Square = 11.02
P-Value = 0.004

Table 12. Changing Distance between the Advantaged and the Disadvantaged

The distance between the advantaged and the disadvantaged	Time Slice		
	1	2	3
Increasing	1 (25%)	2 (22.22%)	5 (29.41%)
Remaining	3 (75%)	2 (22.22%)	12 (70.59%)
Decreasing	0 (0.00%)	5 (55.56%)	0 (0.00%)
Total	4 (100%)	9 (100%)	17 (100%)

Chi Square = 14.49
P-Value = 0.006

Table 13. Notations Used in Coding and Boolean Analysis

Causal Condition	Symbol	TRUE	FALSE
Persistent and Significant Increase in Tail End Cropping Intensity	***T***	T	t
Persistent Improvement in Water Adequacy at the Tail End in Winter	***D***	D	d
Continual Assistance on Infrastructure Improvement	***A***	A	a
The Existence of a Set of Formal Rules for Irrigation Operation and Maintenance	***W***	W	w
The Existence of Provisions of Fines	***F***	F	f
The Existence of Consistent Leadership	***L***	L	l
The Existence of Collective Action among Farmers for System Maintenance	***C***	C	c

Table 14. Truth Table for Persistent Improvement of Water Adequacy at Tail End in Winter

CAUSAL CONDITIONS					OCCURRENCE	
A	***W***	***F***	***L***	***C***	D	d
FALSE	TRUE	FALSE	TRUE	TRUE	1	1
FALSE	TRUE	TRUE	TRUE	TRUE	2	0
TRUE	TRUE	FALSE	TRUE	TRUE	2	0
TRUE	TRUE	TRUE	TRUE	TRUE	2	0
FALSE	FALSE	FALSE	FALSE	TRUE	1	0
FALSE	TRUE	FALSE	FALSE	TRUE	1	0
FALSE	FALSE	TRUE	TRUE	TRUE	0	1
TRUE	FALSE	FALSE	FALSE	FALSE	0	1
TRUE	TRUE	TRUE	FALSE	FALSE	1	0
TRUE	TRUE	FALSE	FALSE	TRUE	1	0
TRUE	TRUE	TRUE	FALSE	TRUE	1	0

Table 15. Truth Table for Persistent Increase in Cropping Intensity at Tail End

CAUSAL CONDITIONS					OCCURENCE	
A	*W*	*F*	*L*	*C*	T	t
TRUE	TRUE	FALSE	TRUE	TRUE	2	1
FALSE	TRUE	FALSE	TRUE	TRUE	2	0
FALSE	TRUE	TRUE	TRUE	TRUE	0	2
TRUE	TRUE	TRUE	TRUE	TRUE	1	1
FALSE	TRUE	FALSE	FALSE	TRUE	1	0
FALSE	FALSE	FALSE	TRUE	TRUE	0	1
FALSE	FALSE	TRUE	TRUE	TRUE	0	1
TRUE	FALSE	FALSE	FALSE	FALSE	0	1
TRUE	TRUE	TRUE	FALSE	FALSE	0	1
TRUE	TRUE	FALSE	FALSE	TRUE	0	1
TRUE	TRUE	TRUE	FALSE	TRUE	0	1

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Notes

[1] This section draws heavily from Lam and Shivakoti. 2002. "Farmer-to-Farmer Training as an Alternative Intervention Strategy," in Ganesh Shivakoti and Elinor Ostrom (eds) *Improving Irrigation Governance and Management in Nepal*. Oakland: ICS Press. Chapter 8

[2] The information is available in the project report produced by WECS/IIMI.

[3] The values of the four-point scale are (1) abundance; (2) limited; (3) scarce; (4) non-existence.

[4] While theories could help identify broad mechanisms of how contextual variables affect human choices, theories usually cannot predict the direction of these mechanisms, as well as how different mechanisms interact with one another to result in particular outcomes.