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Analyzing the dynamic complexity of development interventions: lessons from an irrigation experiment in Nepal

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Abstract Improving irrigation systems in Asian countries has been a high priority for the allocation of international aid. Substantial funds have been allocated to adopt the "best practices" of hiring external water engineers to construct modern systems to replace those that farmers built. These expensive investments have infrequently led to long-term improvement in the operation of irrigation systems in Asia. In this article, we examine the process and impact of an innovative irrigation assistance project that was initially undertaken in Nepal in the mid-1980s. We analyze data obtained over three time periods related to changes in system structure and performance over time. We trace the unfolding patterns of improved engineering infrastructure across time depending on the way it interacts with other factors to affect long-term irrigation performance. We examine some of the key variables that are likely to affect the diverse and complex patterns of change. We also undertake analysis of the configural impact of core variables using Qualitative Comparative Analysis (QCA). We find that the initial and later investments in system infrastructure are only one factor that helps to generate short-term improvement. Unless farmers encourage local entrepreneurs and organize themselves, create their own rules or use sanctions, and augment their rules through collective action, infrastructure investment alone is not sufficient to achieve sustainable higher performance.

Keywords Irrigation · Development assistance · Building participatory projects · Nepal

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Introduction

After decades of investing substantial funds in development assistance, analysts who are familiar with these efforts to help the people of developing countries are critical of the simplistic models that are applied repeatedly (Evans 2004; Meinzen-Dick 2007; North et al. 2008; Gibson et al. 2005). Pritchett and Woolcock (2004) graphically described the systematic failure of development agencies to improve services to rural areas including those related to irrigation. They concluded that frequently "the" solution becomes "the" problem confronting those who supposedly have been helped. Rodrik (2008) urged the World Bank and other international development agencies to avoid "the best practices trap." To do so requires "local knowledge *and* creativity. What works in one setting is unlikely to work in another" (2008, p. 20).

Merrey et al. (2007) reviewed extensive efforts to find the best way to provide water for irrigation. They strongly urged policymakers to quit using simplified formulas and to learn how to relate general lessons learned from earlier projects to local circumstances rather than developing specific blueprints. Contrary to repeated warnings, however, development agencies have allocated substantial funds to hire external water engineers to construct "modern" systems to replace the primitive systems in use by farmers. Building new irrigation works has frequently led to temporary improvement, but rarely to longer-term enhanced performance (Chambers 1988; Korten and Siy 1987; Johnson 1991; Lam 1996). Experts who have examined the performance of the systems that have received development assistance rarely give positive reviews (Turral 1995; Meinzen-Dick 2007). Further, systems that have received major external assistance tend to become totally dependent on external help (Araral 2005). Recommendations are frequently made to include more participation and to build local leadership (Gulati et al. 2005; Abernethy and Sally 2000; Meinzen-Dick et al. 2002), but it takes more time to do this than to allocate funds and hire engineers to build new systems.

The argument that engineering infrastructure alone does not bring about better irrigation performance is not new. Prior studies of engineering solutions, however, have tended to be either in-depth historical analysis of a small number of irrigation systems or statistical analysis of variables measured at one time for a larger number of systems. While these studies offer important insights, their static, descriptive orientation has prevented them from adequately capturing the way in which the impact of improved engineering infrastructure unfolds across time depending on other causal processes. Instead of asking whether engineering solutions, as contrasted to other factors, better contribute to irrigation performance, it is more useful to examine how improved engineering infrastructure configures with other factors in affecting irrigation performance, and to identify conditions under which improved engineering infrastructure can make a difference in irrigation performance. Policy analysts have tended to rely on analysis of interventions viewed as simple additive processes rather than complex configural processes. In this article, we intend to examine the complex, over-time processes initiated by an innovative development project that tried to avoid imposing a "best practices" cure-all on local farmers.

The project was initially undertaken more than two decades ago to improve irrigation systems in one district in Nepal. Instead of spending large funds and imposing a top-down planning process, the project extensively involved farmers in deciding what should be done. We also report on efforts to evaluate the performance of this innovative effort over time using both conventional statistical analysis as well as Qualitative Comparative Analysis (QCA) (Ragin 1987). The purpose of this study is not to try to provide one more piece of evidence to show that engineering solutions alone do not work. Rather, we intend to trace and examine the unfolding patterns of improved engineering infrastructure across time depending on the way it interacts with other factors to affect long-term irrigation performance.

We find that the initial and later investments in system infrastructure are only one factor that helps to generate short-term improvement. Unless farmers organize themselves, create their own rules, augment their rules through collective action or by imposing fines on those who violate rules, infrastructure investment alone is not sufficient to achieve sustainable higher performance. We discuss the implications of these findings in the conclusion of the article.

The Water and Energy Commission Secretariat and the International Irrigation Management Institute (WECS/IIMI) project

In 1985, the Water and Energy Commission Secretariat (WECS) of Nepal and the International Irrigation Management Institute (IIMI) developed an ingenious intervention program for 19 irrigation systems located in the central hills of Nepal (Pradhan 1989a, b; Yoder 1986, 1994). The project was innovative in at least seven ways: (1) the farmers chose whether to be involved; (2) the project provided technical assistance but purposively did not provide full funding[1] for all potential 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 had a veto over engineering plans that were not consistent with their preferences; (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 *other farmers* who had developed 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 their system.

How the project irrigation systems were selected

The Indrawati River watershed in the central hills of Sindhupalchok District was selected for intervention due to its proximity to Kathmandu, since the project involved a substantial investment of time by the project staff.[2] 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 h to travel on foot to the irrigation systems located in the hills on either side of the Indrawati River. The District was quite similar to others in the middle hills of Nepal in regards to settlement patterns, ecology, and socioeconomic conditions. An inventory of all existing farmer-managed irrigation systems (FMIS) in the area was prepared to fulfill the objective

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[1] The full cost of the project averaged only 3,286 Nepali rupees per hectare (the exchange rate on 1/1/85 was 18 Nepali rupees per U.S. dollar).

[2] This section draws on Lam and Shivakoti (2002, Chap. 8).

of determining relative needs among systems and establishing criteria for selecting final candidates for assistance. Of the 119 irrigation systems identified with canals longer than 0.5 kilometer in the area, 23 FMIS met two criteria:

- Expansion of the area to be irrigated was possible and could have a high impact on food production and be used by additional families.
- The existing users of these systems were willing to allow their systems to expand and to accept additional farmers as members of their water user organization (Yoder 1991, p. 56).

A rapid appraisal study was carried out to collect information on the physical and agricultural aspects of these 23 irrigation systems and on the management practices of the farmer organizations. On the basis of the information from rapid appraisal and discussions with farmers to determine their willingness to participate, a total of 19 irrigation systems were selected for assistance (see Fig. 1).

During the same period, a dialog 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 their desired physical improvements into three groups:

1. The highest priority was placed on improvements necessary for the 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.
3. The third-priority improvements included work that farmers could accomplish using their own skills, labor, and materials (Yoder 1991, p. 57).

The project agreed to allocate funds initially to cover the cost of only those components that were given first priority. The farmers were told 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 with the farmers included a requirement that the farmers 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 farmed;
- 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, p. 20).

During the processes of the dialog, 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, p. 20).

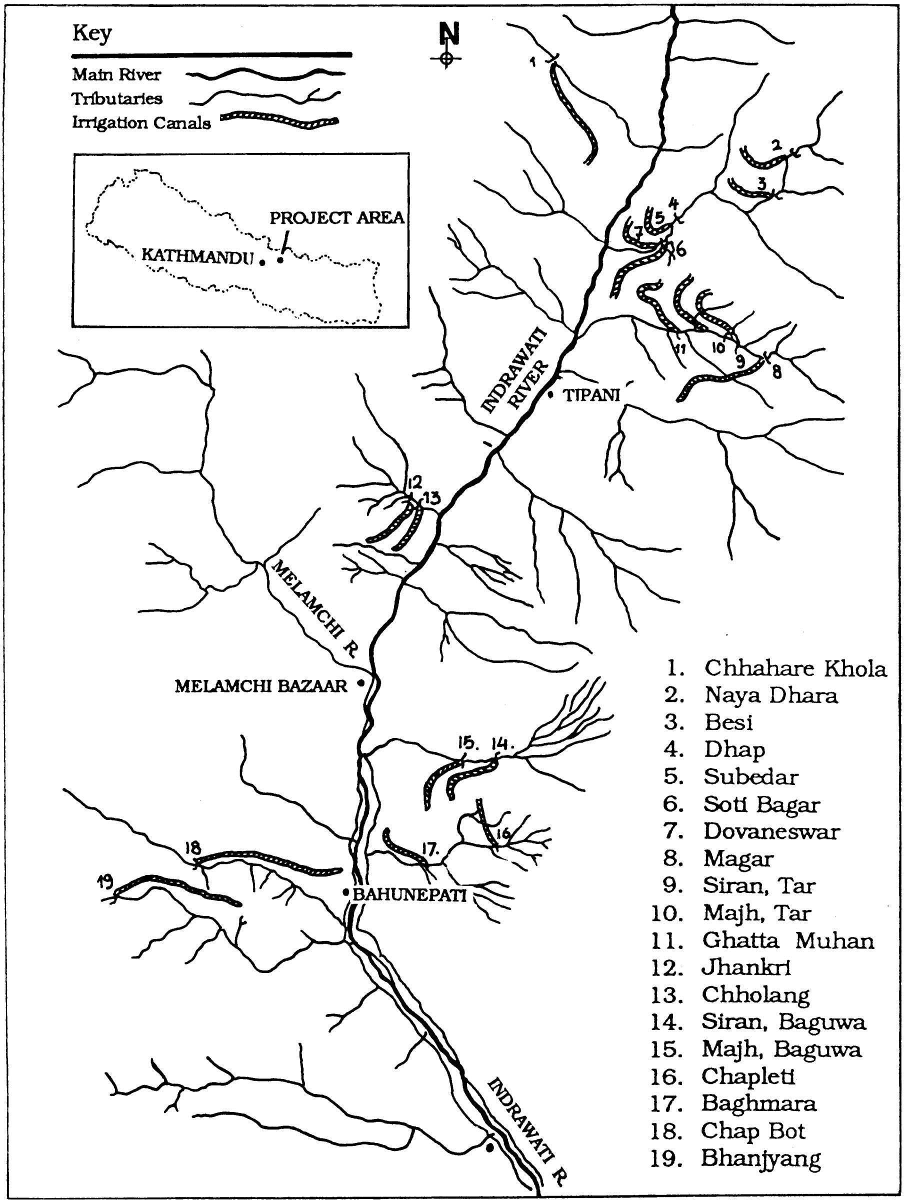

Fig. 1 Project area map showing the names and locations of the 19 systems that received assistance. *Source*: WECS/IIMI (1990 p. 17)

Farmer-to-farmer training

A major problem identified early in the project 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, p. 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 team 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 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" (Pradhan 1987, p. 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. The host farmers from the well-managed system also worked as consultants. These consultant farmers 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 shown the constitution, minutes, attendance records, and the labor contributed by the farmers of the host system. By the end of the second day, the farmers began to relate some of the management problems in their own systems to the ways successful irrigation systems in similar ecological areas of Nepal had coped with these problems. 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.

Evaluating impact

In our effort to understand the impact of this intervention, we entered the data collected by the WECS/IIMI team in a database we had already created, called the Nepal Irrigation and Institutions (NIIS) database (Lam 1996, 1998). In our NIIS database, we were already coding variables related to various physical and institutional features as well as irrigation performance of the systems we were able to study in the field. By augmenting the data collected by the WECS/IIMI team in 1985 about the systems before the intervention, this "Time Slice 1" serves as a benchmark against which the impact of the intervention can be assessed.

In 1991, members of the NIIS research team visited these same 19 systems to conduct a second round of data collection using the coding instruments developed for the NIIS database. The collected information describes the action situations of the systems a few years after the intervention, which constitutes the "Time Slice 2" data. In an earlier paper, Lam and Shivakoti (2002) compared performance at Time Slices 1 and 2 and found that looking at the intervention as a one-shot process of transferring resources to the farmers did not fully explain the patterns found in 1991. A better explanation was generated by looking at both the direct and mediating effects of an intervention. Their analysis corroborated the argument that intervention should "enhance" rather than "replace" the efforts of local farmers in irrigation management (Shivakoti and Ostrom 2002; Shrestha 1988).

In order to assess the long-term sustainability of the intervention effect of the WECS/IIMI project, the NIIS team visited the 19 systems again in 1999 (8 years after the second visit). Using the same coding forms, the team collected information on the physical and social aspects of the systems, as well as performance measures.[3] The information collected constitutes the core of the "Time Slice 3" data reported on herein. 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 qualitative interviews. 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.[4]

Patterns of change of irrigation performance

The availability of structured information on the 19 systems in three time slices plus in-depth information on diverse processes allows us to study how irrigation performance has changed over the years. Particularly, the data provide useful information on both short-term and long-term effects of the intervention, which allows for an analysis of temporal patterns of performance. We measured the short-term effect by the change in performance from Time Slice 1 to Time Slice 2, and the long-term effect by 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 examine five key measures of irrigation performance: size of irrigated area, technical efficiency of irrigation infrastructure, water adequacy, tail-end cropping intensity, and levels of deprivation in a system. The patterns of change of these performance measures can shed light on the way the effect of the intervention has unfolded over time.

Size of irrigated area

Table 1 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 37.1, 52.58, and 58.84 ha,

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[3] During the initial period of project development and our first revisit in 1991, the Maoist insurgency had not yet erupted in Nepal. During the later visits, the region was divided between those villages near the road that were under the control of the Nepali army and relatively peaceful. The systems located in remote areas were under Maoist control and were also relatively peaceful. The villages served by one of the systems in the middle—Majh Baguwa—did face considerable challenge as villagers were divided in their loyalty and faced army patrol during the day and Maoist patrols at night. While very disruptive of social relationships since the villagers were themselves divided, this disruption did not adversely affect the overall performance of this system due in part to its setting and the relative ease of obtaining water and needing only a minimum level of repair and maintenance. Only modest "out migration" from this rural setting occurred during the time of our study, and thus few external remittances were introduced.

[4] The qualitative interviews aimed at capturing the process of institutional change as well as major developments that had occurred in the systems since the intervention in 1985. In order to provide a coherent framework for collecting and recording the interview information, the NIIS team designed a set of questions that focused on the governance and operation of the systems. Colleagues who conducted the interviews were required to write up each interview following the checklist format, which allowed the first author of this article to code the interview information systematically for QCA analysis.

Table 1 The size of irrigated area of the irrigation systems

Name of system	Size of irrigated area over time (ha)			Impact of intervention
	T1 (1985)	T2 (1991)	T3 (1999)	
1. Chhahare Khola	126	163	151	Expanded—fluctuating
2. Naya Dhara	55	110	110	Expanded
3. Besi	65	85	85	Expanded
4. Dhap	70	50	60	Deteriorated—fluctuating
5. Subedar	40	40	60	Expanded
6. Soti Bagar	19	30	32	Expanded
7. Dovaneswar	2	12	6	Expanded—fluctuating
8. Magar	100	143	140	Expanded—fluctuating
9. Siran, Tar	18	24	48	Expanded
10. Majh, Tar	71	87	71	No change—fluctuating
11. Ghatta Muhan	23	33	35	Expanded
12. Jhankri	18	31	31	Expanded
13. Chholang	23	37	37	Expanded
14. Siran, Baguwa	18	37	50	Expanded
15. Majh, Baguwa	13	33	65	Expanded
16. Chapleti	8	23	15	Expanded—fluctuating
17. Baghmara	3	9	12	Expanded
18. Chap Bot	12	17	18	Expanded
19. Bhanjyang	21	35	40	Expanded

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 and that this expansion leveled off after the initial increase.

A note of caution is warranted. While the intervention succeeded to expand the systems in general, the magnitude of the expansion varied among the systems. 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 diversity. During the period between Time Slices 1 and 2, 17 of the 19 systems showed an expansion of irrigated area; one system shrank in size and one system had no change. 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. Both the short-term and long-term effects of the intervention on the size of irrigated area are statistically insignificant at the 0.1 level.

Overall, 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 long run.

Technical efficiency of irrigation infrastructure

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 database, technical efficiency is

Table 2 Technical efficiency of irrigation infrastructure

Name of system	Technical efficiency[a]			Impact of intervention
	T1 (1985)	T2 (1991)	T3 (1999)	
1. Chhahare Khola	2	4	2	No change—fluctuating
2. Naya Dhara	3	4	3	No change—fluctuating
3. Besi	3	3	2	Deteriorated
4. Dhap	2	4	3	Improved—fluctuating
5. Subedar	2	4	2	No change—fluctuating
6. Soti Bagar	2	4	3	Improved—fluctuating
7. Dovaneswar	3	4	3	No change—fluctuating
8. Magar	3	3	3	No change
9. Siran, Tar	3	3	2	Deteriorated
10. Majh, Tar	3	4	2	Deteriorated—fluctuating
11. Ghatta Muhan	2	4	2	No change—fluctuating
12. Jhankri	2	4	2	No change—fluctuating
13. Chholang	3	4	2	Deteriorated—fluctuating
14. Siran, Baguwa	3	3	2	Deteriorated
15. Majh, Baguwa	3	4	3	No change—fluctuating
16. Chapleti	1	3	3	Improved
17. Baghmara	4	4	2	Deteriorated
18. Chap Bot	2	4	2	No change—fluctuating
19. Bhanjyang	3	4	2	Deteriorated—fluctuating

[a] Technical efficiency coded as (1) highly ineffective, (2) moderately ineffective, (3) moderately effective, (4) highly effective

measured by a four-point scale. Table 2 provides information on the levels of technical efficiency of the systems in the three time slices. The coded values of technical efficiency in the three time slices are: 4 = highly effective; 3 = moderately effective; 2 = moderately ineffective; and 1 = highly ineffective.

The short-term effect of the intervention is obvious. Of the 19 systems, 14 showed a short-term improvement in technical efficiency, while five showed no impact. Given that engineering improvement work was 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 devices 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 long-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, 13 of the 19 systems have gone through a reversal of the intervention effect—they experienced an improvement in technical efficiency in the initial years after the intervention, which was then followed by a deterioration of efficiency in the long term. The differences between Time Slices 1 and 2, and between Time Slices 2 and 3, are statistically significant at the 0.1 level. In terms of the net effect, only 2 of the 13 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. 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 long run. Chapleti (system 16) 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 can actually get it. That a system has a high level of technical efficiency is no guarantee that farmers actually receive water when they need it. It is not uncommon that water is efficiently 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 (Burns 1993; Gill 1991).

The average levels of water adequacy at the head end and the tail end across all systems in three different seasons are shown in Table 3. The short-term effect of the intervention on water adequacy is obvious. 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,[5] at both the head end and the tail end in all seasons. The data also suggest 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 at the 0.1 level.

When comparing the pattern of change of water adequacy with that of technical efficiency, one can see 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 wore 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, only two of them experienced deterioration in water adequacy in the period between Time Slices 2 and 3 (see Table 4) and 12 of them showed consistent improved water adequacy. This suggests that improved infrastructure may help to launch farmers' collective action for irrigation management; after the launch, however, as long as a good management order can be maintained, farmers may be able to attain a high level of water adequacy even with less well-constructed or maintained infrastructure.

Tail-end cropping intensity

A common measure of the agricultural productivity of an irrigation system is the cropping intensity at the tail end of the system. Table 5 shows the tail-end cropping intensity of the systems in the three time slices. The data suggest that the short-term effect of the intervention on tail-end intensity was mixed. Only 6 of the 18 systems for which we had

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[5] The values of the four-point scale are (1) abundance, (2) limited, (3) scarce, (4) nonexistence.

Table 3 Average water adequacy for 19 systems

	T1 (1985)	T2 (1991)	T3 (1999)
Spring tail end	2.36	1.54	2
Winter tail end	2.06	1.26	1.25
Monsoon tail end	1.64	1	1
Spring head end	2	1.37	1.43
Winter head end	1.8	1.2	1.1
Monsoon head end	1.53	1	1

Water adequacy as coded for individual systems: (1) abundance, (2) limited, (3) scarce, (4) nonexistence

Table 4 Water adequacy at the tail end in winter

Name of system	Tail-end water adequacy[a]			Impact of intervention
	T1 (1985)	T2 (1991)	T3 (1999)	
1. Chhahare Khola	2	2	1	Improved
2. Naya Dhara	2	1	1	Improved
3. Besi	2	1	1	Improved
4. Dhap	2	1	1	Improved
5. Subedar	2	2	Missing data	Unknown
6. Soti Bagar	2	1	1	Improved
7. Dovaneswar	Missing data	1	1	Unknown
8. Magar	3	1	2	Improved—fluctuating
9. Siran, Tar	2	1	Missing data	Unknown
10. Majh, Tar	2	1	1	Improved
11. Ghatta Muhan	Missing data	1	Missing data	Unknown
12. Jhankri	2	1	1	Improved
13. Chholang	2	2	1	Improved
14. Siran, Baguwa	2	2	1	Improved
15. Majh, Baguwa	2	2	1	Improved
16. Chapleti	4	1	1	Improved
17. Baghmara	1	1	4	Deteriorated
18. Chap Bot	1	1	1	No change
19. Bhanjyang	2	1	1	Improved

[a] Water adequacy coded as: (1) abundance, (2) limited, (3) scarce, (4) nonexistence

complete data had an increase in agricultural productivity between Time Slices 1 and 2, six systems had a decrease, and six showed no effect.[6]

If we look at individual systems, the pattern of change of cropping intensity varied across the systems. Of the 19 systems, 10 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

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[6] In terms of the average tail-end intensity, there was a slight increase from 244.22% to 246.16% during the period, but the difference is not statistically significant. The average cropping intensity dropped from 246.16% in Time Slice 2 to 241.76% in Time Slice 3; the drop is statistically significant at the 0.1 level. It suggests that, generally speaking, the intervention effect on agricultural productivity could not be sustained.

Table 5 Tail-end cropping intensities

Name of system	Tail-end intensity			Impact of intervention
	T1 (1985)	T2 (1991)	T3 (1999)	
1. Chhahare Khola	200	192	200	No change—fluctuating*
2. Naya Dhara	200	200	205	Improved*
3. Besi	200	235	210	Improved—fluctuating*
4. Dhap	250	250	290	Improved
5. Subedar	250	270	300	Improved
6. Soti Bagar	150	215	300	Improved
7. Dovaneswar	300	200	300	No change—fluctuating
8. Magar	190	200	210	Improved*
9. Siran, Tar	255	250	Missing data	Unknown
10. Majh, Tar	300	230	230	Deteriorated
11. Ghatta Muhan	271	270	Missing data	Unknown
12. Jhankri	200	270	300	Improved
13. Chholang	220	220	300	Improved
14. Siran, Baguwa	300	285	250	Deteriorated
15. Majh, Baguwa	280	300	300	Improved*
16. Chapleti	Missing data	300	200	Unknown
17. Baghmara	300	300	100	Deteriorated
18. Chap Bot	270	270	300	Improved
19. Bhanjyang	260	220	115	Deteriorated

*Small magnitude of change

increase in two of the systems was relatively minor. 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 long-term effect. Only two systems showed a continual decrease in agricultural productivity.

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 long term, although the magnitude of the improvement varies substantially. Third, considerable 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 sometimes thought. Agricultural productivity tends to be affected by a complex array of factors; whether and how intervention can bring an improvement often depends on how it configures with the other factors (Lam and Shivakoti 2002).

Levels of deprivation

A major measure of deprivation is whether some irrigators in the system are consistently disadvantaged in the allocation of water. Table 6 shows the number 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

Table 6 Levels of deprivation

Are there appropriators who are consistently disadvantaged in irrigation?	Time slice		
	1 (1985)	2 (1991)	3 (1999)
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

deprivation. This positive trend continued. In Time Slice 3, *none* of the systems had the problem of deprivation.

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, 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 long run. In particular, the analysis suggests that the improvement of technical efficiency has withered away in almost all of the systems.

Second, while better technical efficiency might have helped improve water adequacy in the short run, it does not explain the persistence of adequate water supplies in the long run. The analysis suggests that, even after the technical efficiency leveled off, farmers on many systems were able to maintain a relatively high level of water adequacy. Third, generally speaking, the intervention 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. 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 instead of a single cause.

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. Our data describe only 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 conventional statistical analysis, which is variable-oriented, to capture the unfolding effect of intervention. The effect of individual 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 effect of particular variables is often contingent.

Often, it is the combinatorial effects of several variables that affect outcomes. The combinatorial effects are usually not linearly related.[7] Also, statistical analysis by its variable-oriented nature cannot adequately deal with the time dimension of social phenomena.

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[7] 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.

Some causes and effects, such as those involved in examining the effect of intervention, take a long time for them to unfold and to be discernable (Pierson 2003, 2004). Notwithstanding the notorious modeling problem of accurately measuring dynamics in statistical models, it is also difficult to specify the complex dynamics of institutional change in a statistical model.

Given these methodological problems, the in-depth qualitative interviews are an important complementary 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 asking farmers in-depth questions about the governance and operation of these systems over time. In response to the checklist of questions, farmers responded with narratives of major events that have occurred since the intervention, and of the way these events have unfolded and impinged upon irrigation management. In order to synthesize the in-depth responses, we will apply the Boolean algebra, which emphasizes the holistic nature of explanation of social phenomena. Instead of treating an empirical case as a mere collection of values related to some variables, the Boolean method is case-oriented, treating a case as a configuration of causal and outcome conditions. The basis of explanation is not the correlation of variables but a systematic comparison of configurations of causes that produce a similar outcome. “Rather than focus on the net effects of causal conditions, case-oriented explanations emphasize their combined effects” (Ragin and Sonnett 2005, p. 180). Unlike conventional small-N qualitative case study methods, however, the Boolean method extends the holistic analysis to the studies of a larger number of cases, and allows a more systematic distinction between necessary and sufficient causal conditions (Rihoux 2008).

Coping with complexity and change

The information provided by farmers in the qualitative interviews suggests that the 19 irrigation systems in the Indrawati watershed took different paths of development after the completion of the WECS/IIMI intervention. Some of them were 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; others simply failed to make 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 the intervention effect. Based upon a review of the literature as well as the qualitative interviews conducted with farmers from the 19 systems, we identify five factors that may explain why some systems have continued a higher level of performance and why there are differences in the long-term effects of the intervention project. Specifically, we will examine how (1) continual assistance to improve infrastructure, (2) the existence of written rules, (3) the imposition of fines and punishment, (4) leadership, and (5) collective action may 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 further external assistance mainly to fix or further improve the lining and diversion structures of the systems. The amount of funds varied, ranging from Rs. 10,000 to Rs. 2,300,000. The sources of funding included a 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 an important factor affecting irrigation performance. Presumably, continual infrastructure investment can help consolidate the improved physical endowment, hence making the intervention effect persistent.

The data analysis presented earlier, however, challenges this 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 (Magar [system 8] and Chapleti [system 16]), one did not receive any further assistance, and the other received continued assistance worth merely Rs. 10,000, the smallest amounts among all those assisted. Thus, the evidence shows 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 continuing 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 was that farmers in a system were required to develop their own set of rules for irrigation management after the project was completed. The case materials show that the WECS/IIMI project did trigger rule-crafting efforts in most systems. The scope and the comprehensiveness of the rules, however, varied across the systems. While the rules developed for most systems mainly concerned water allocation and canal maintenance, farmers in some systems worked out extensive rules dealing with issues such as arranging payments from farmers to support full-time watchmen. In particular, systems on which water management served multiple purposes, including generating hydraulic power and grain mills, tended to develop a more sophisticated set of rules with a broader scope. In Naya Dhara (system 2), for example, a set of rules was developed for water management for both energy generation and irrigation. A caveat is warranted, however. The existence of rules does not necessarily mean that the rules are strictly followed. In some systems, written rules existed but were often not followed because of a lack of enforcement. In other systems, strong leaders were able to coordinate farmers' action that rendered strict application of formal rules unnecessary.

On some of these systems, in which farmers did not draft a set of written rules, farmers just failed to work with one another to engage in rule-crafting activities. Yet, systems existed in 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. Farmers did not see the need to turn these norms into written rules. Particularly on systems in which there were strong leaders, the leadership already provided the necessary focal point for collective action.

Fines

The third condition that may affect irrigation management is whether farmers have made efforts 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 systems reveals several interesting patterns. First, systems that had a set of written rules for system operation and maintenance do not necessarily also have a provision for imposing fines. On many systems in which 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 situations.

In Dhap (system 4), for example, where the water users committee provided an arena for farmers to resolve conflicts effectively, imposing fines was considered unnecessary. In Chhahare Khola (system 1), on the other hand, although a small group of local leaders was able to maintain a certain level of collective action, the lack of a provision for fining violations 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 Baguwa (system 15) 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.

Consistent leadership

A major factor that may affect the long-term viability of irrigation management is whether leadership is consistent and able to adapt to change. When the WECS/IIMI project was implemented, the designers were well aware that building up strong leadership in the irrigation systems was important for the project's success. Systems that were chosen for the project were in general free from major conflicts that could prevent building effective leadership. In particular, the Time Slice 1 data in the NIIS database show that, although a certain degree of ethnic heterogeneity existed in all the 19 systems, they did not affect effective communication among farmers in any of them.[8] As discussed earlier, 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 of 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 Ghatta Muhan (system 11), for example, the chairperson was a very powerful leader who decided on the order of water distribution for the other farmers on the system to follow. In Jhankri (system 12), 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 a few systems in which existing social capital might not be as solid, the WECS/IIMI project seems to have had limited success in building up leadership. What happened in Baghmara (system 17) is a case in point. Over the years, ethnic issues have escalated to affect the solidity of the community.

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[8] The Time Slice 2 data show a similar pattern as the data for Time Slice 1. The ethnic composition for Time Slice 3 has missing values that prevent us from drawing conclusive patterns. Despite that, the data of Time Slices 1 and 2 are sufficient to support the argument that ethnic issues were not a confounding factor affecting irrigation performance.

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 (system 8) 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. As a result, the irrigation working order unraveled rapidly. What happened in Magar is not unique; on other systems, such as Chap Bot (system 18) and Dovaneswar (system 7), the demise of old leaders also 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 consistent leadership.

Collective action

The existence of written rules and the presence of 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. Collective action helps build trust, norms, and common understanding among farmers in the process of working with one another. Improvement in trust and common understanding can, in turn, serve as the foundation for collective problem solving in other contingencies. The success of collective action hinges upon a variety of factors. On Magar, 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 Tar (system 10), 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 (Dietz et al. 2003). A seemingly minor event could easily trigger the unraveling of collective action. What happened in Siran Baguwa (system 14) 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, which enabled them to attain a high level of technical efficiency of the system. The effective working order began to fall apart on this system 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. 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. 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 effects

As argued earlier, the five causal conditions do not operate independently to affect irrigation performance in a linear manner. In order to understand how the five causal conditions combined to affect the sustainability of intervention effects, 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 effects identified in the 19 systems.

All causal conditions, or variables, in the Boolean analysis are dichotomized.[9] A condition is coded as being either present (PRESENT) or absent (ABSENT). 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 effects. The outcome, or the dependent variable, is whether the persistent improvement in irrigation performance existed in a system. In this analysis, we will examine two measures of irrigation performance, namely, the adequacy of water at the tail end of the system during the 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, especially in winter, which has the least amount of rainfall. Hence, these two measures should be most sensitive to changes in the causal conditions.

The two outcome variables are meant to capture not only whether there was an improvement in irrigation performance 15 years after the intervention in 1985, but also whether the improvement had been persistent. The coding for "water adequacy at the tail end in winter season" (*W*) was based on the information provided in Table 4. We coded a system as PRESENT if the net intervention effect on water adequacy at the tail end in winter was positive, *and* there was no reversal or fluctuation in intervention effects. For all other situations, we coded them as ABSENT. For example, the intervention brought about a short-term positive impact on water adequacy in Magar (system 8), followed by a negative impact. Although the net effect was positive, we coded the system as ABSENT. In order to provide a simplified notation, we adopted the convention of using the uppercase letter (W) to indicate a PRESENT value and the lowercase letter (w) to denote an ABSENT value (see Table 7).

The coding for the "Cropping Intensity at the Tail End" (*T*) was based on information provided in Table 5. 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 ABSENT. These cases are indicated with an asterisk in Table 5.

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[9] The dichotomized nature of the causal conditions is not a function of the QCA method but of the researcher. QCA can also handle continuous variables.

Table 7 Notations used in coding and Boolean analysis

Dependent variable	Symbol	PRESENT	ABSENT
Persistent improvement in water adequacy at the tail end in winter	*W*	W	w
Persistent and significant increase in *tail-end cropping* intensity	*T*	T	t
Causal condition			
Continual *assistance* on infrastructure improvement	*A*	A	a
The existence of a set of formal *rules* for irrigation operation and maintenance	*R*	R	r
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

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 formal rules for irrigation operation and maintenance (*R*), 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 (*L*), and whether farmers have been able to maintain a certain level of collective action in system maintenance (*C*). 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 PRESENT or ABSENT. Again, the uppercase letter denotes a PRESENT value and a lowercase letter an ABSENT value for the systems for which we have relevant data (see Tables 8 and 9). For some causal conditions, such as *A* and *R*, the coding is rather straightforward. But for some other conditions such as *L* and *C*, delineating a PRESENT value from an ABSENT value requires careful interpretation of the local history of the systems, as well as an exercise of judgment. Fortunately, in the qualitative interviews, farmers did offer vivid descriptions of events and their comments, which have 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 (*W*) is shown in Table 8 for all the 15 systems for which we have complete data. Eight configurations generate W, two configurations generate w, and one configuration generates contradictory outcomes. Note that there are only 11 unique configurations for these 15 systems in the truth table because several configurations predict water adequacy for more than one system (as shown in the last two columns of Table 8). For this study, we are only interested in configurations generating W, so only the configurations that generate W 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 W or w. We adopted the 50% threshold, meaning that unless a particular configuration generates more W than w, we will not consider it as a configuration generating W. Accordingly, the configuration that generated contradictory outcomes failed to pass the threshold and was not included in our analysis. In Table 8, the configurations used for analysis are italicized.

Table 8 Truth table for persistent improvement of water adequacy at tail end in winter

Five causal conditions					Number of systems	
A	*R*	*F*	*L*	*C*	W	w
ABSENT	PRESENT	ABSENT	PRESENT	PRESENT	1	1
ABSENT	*PRESENT*	*PRESENT*	*PRESENT*	*PRESENT*	*2*	*0*
PRESENT	*PRESENT*	*ABSENT*	*PRESENT*	*PRESENT*	*2*	*0*
PRESENT	*PRESENT*	*PRESENT*	*PRESENT*	*PRESENT*	*2*	*0*
ABSENT	*ABSENT*	*ABSENT*	*ABSENT*	*PRESENT*	*1*	*0*
ABSENT	*PRESENT*	*ABSENT*	*ABSENT*	*PRESENT*	*1*	*0*
ABSENT	ABSENT	PRESENT	PRESENT	PRESENT	0	1
PRESENT	ABSENT	ABSENT	ABSENT	ABSENT	0	1
PRESENT	*PRESENT*	*PRESENT*	*ABSENT*	*ABSENT*	*1*	*0*
PRESENT	*PRESENT*	*ABSENT*	*ABSENT*	*PRESENT*	*1*	*0*
PRESENT	*PRESENT*	*PRESENT*	*ABSENT*	*PRESENT*	*1*	*0*

Table 9 Truth table for persistent increase in cropping intensity at tail end

Five causal conditions					Number of systems	
A	*R*	*F*	*L*	*C*	T	t
PRESENT	*PRESENT*	*ABSENT*	*PRESENT*	*PRESENT*	*2*	*1*
ABSENT	*PRESENT*	*ABSENT*	*PRESENT*	*PRESENT*	*2*	*0*
ABSENT	PRESENT	PRESENT	PRESENT	PRESENT	0	2
PRESENT	PRESENT	PRESENT	PRESENT	PRESENT	1	1
ABSENT	*PRESENT*	*ABSENT*	*ABSENT*	*PRESENT*	*1*	*0*
ABSENT	ABSENT	ABSENT	PRESENT	PRESENT	0	1
ABSENT	ABSENT	PRESENT	PRESENT	PRESENT	0	1
PRESENT	ABSENT	ABSENT	ABSENT	ABSENT	0	1
PRESENT	PRESENT	PRESENT	ABSENT	ABSENT	0	1
PRESENT	PRESENT	ABSENT	ABSENT	PRESENT	0	1
PRESENT	PRESENT	PRESENT	ABSENT	PRESENT	0	1

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

$$\mathrm{W} = \mathrm{ACR} + \mathrm{alCf} + \mathrm{AlRF} + \mathrm{LCRF} \tag{1}$$

Two questions are of major policy interest. First, how important is continual infrastructure investment 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 does collective action relate to water adequacy? What are the supporting conditions with which collective action can bring about water adequacy?

In order to address these questions, we rearrange Eq. 1 to[10]:

$$W = AR(C + lF) + CLRF + Calf \tag{2}$$

In Boolean algebra, addition is equivalent to the logical operator OR; multiplication means the conjunction of causal conditions. Equation 2 is composed of three groups of configurations, meaning that if any one of three groups of configurations is obtained, there is persistent improvement of water adequacy. The three groups are configurations where, respectively, continual infrastructure investment must be present (A), may be present or absent (i.e., *A* is irrelevant), and must be absent (a).

The first group of configurations suggests 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 presence of *A must* come with the presence of *R*). This suggests that the debate about whether physical infrastructure or social infrastructure is more important is misplaced; neither of them would work without the other. The existence of these two factors alone, however, is necessary but not sufficient; it has to be in a context where either farmers are able to engage in collective action, or fines be imposed for rule violations with a lack of strong leadership. The policy implication of such a finding is that intervention projects might help bring in infrastructural investment (A) and put in place formal rules (R) in an irrigation system; these two factors by themselves are not sufficient to bring about effective outcome. Either they have to be complemented by a certain degree of collective action among farmers based upon common understanding and norms, or, in systems in which farmers' collective action does not exist, they have to be backed up by strict implementation of fines without a strong leader dominating the management of the systems.

The second group of configurations in Eq. 2 concerns situations in which continual infrastructure investment is irrelevant to irrigation performance. In systems in which there are written rules, consistent leadership, a certain degree of farmers' collective action, and also strict implementation of fines, one can find persistent improvement in tail-end water adequacy in winter no matter whether there has been infrastructure investment. This pattern suggests that, to make up for the positive impact of continual infrastructure investment, *all* the other factors have to be present to sustain the positive impact of the intervention. An implication is that there is a limit as to the positive impact of continual infrastructure investment that can be substituted. The third group of configurations refers to 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 becomes a very important factor affecting irrigation performance. Moreover, the analysis suggests that the 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 8. 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 9, the italicized configurations are those we include in the analysis.

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

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[10] For Eq. 2, both the solution coverage and the solution consistency are 1.

$$\mathrm{T} = \mathrm{aCRf} + \mathrm{LCRf} \tag{3}$$

We rearranged the equation to[11]

$$\mathrm{T} = \mathrm{CRf}(\mathrm{a} + \mathrm{L}) \tag{4}$$

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 CRf is the necessary element of configurations for persistent increase in tail-end cropping intensity. It means that the simultaneous existence of collective action, written rules, and the absence of a provision of fines are the necessary conditions without which sustained improvement in agricultural productivity would be impossible. Such a pattern 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 (Lam 1998; Ostrom 1990, 1992). With collective action and the rules in place, formal punishment would not be necessary, or it could even be harmful to collective action.

The necessary elements per se are insufficient. They can bring about a sustained improvement in agricultural productivity only if either one of 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 qualitative interviews, local leaders have played an important role in enhancing and maintaining farmers' collective action in the project irrigation systems. Not only have they provided a locus for coordinating collective action but they 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.

Lessons learned

What are the lessons we have learned from this innovative project? The lessons are general and cannot be picked up and applied routinely to other settings without knowledge of these settings; for example, the existence of extreme storms may make continued assistance necessary. We hope that our findings provide insights to how it is possible to help farmers help themselves to maintain better irrigation facilities and greater agricultural outcomes without massive infusion of funds.

While developing robust local institutions to support the operation and maintenance of engineering infrastructure should not be viewed as a panacea, it needs to be part of the design of projects intended to have a long-term, positive impact on a high proportion of systems that receive external assistance. Further, the designers of projects can learn from, as well as contribute to, the knowledge base of local farmers. When farmers have no voice in the design of systems that are supposed to help them, we can expect few successes over time.

The WECS/IIMI intervention project to assist 19 farmer-managed irrigation systems located in the Indrawati watershed in Nepal 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

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[11] For Eq. 4, the solution coverage is 0.86 and the solution consistency is 1.

improved. In this article, 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 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 occurrences in monsoon season, which often damage the primitive irrigation infrastructure that farmers have struggled to construct, and render system maintenance extremely difficult 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 is simply part of effective irrigation management. In fact, in some irrigation systems in Nepal, the diversion structure is intentionally built of primitive materials 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. 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 earlier, the WECS/IIMI intervention was designed to involve farmers 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 effective 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 help farmers improve such abilities and skills and to avoid swamping them with expensive works that might make them dependent on external aid. 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. The project avoided the "best practices trap" of relying primarily on infrastructure improvement designed entirely by external experts.

Given their different history and social-political backgrounds prior to the intervention, 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 the physical improvements achieved early in the process. It would be naïve to think there is a single 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 core of local entrepreneurs exists to provide leadership and adjustments to changes, it is possible for the farmers to build on the momentum introduced by the intervention to attain consistently high levels of performance over time.

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