APPROPRIATE DESIGNS AND APPROPRIATING IRRIGATION SYSTEMS

Irrigation infrastructure development and users' management capability in Bolivia

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PREFACE

The idea of this research was born while working with the Andean and Valley Irrigation Teaching and Research Program (PEIRAV). At the time, great headway had been made in conceptual development regarding water management in Bolivia, as an outgrowth of different research efforts. However, the practical application of so much expertise was lacking. So, I began to conduct a research program entitled “irrigation system design”. This made it evident that there was an urgent need to take water management knowledge into account for irrigation infrastructure design. This need shaped the profile for this research project.

Subsequently, when I had the good fortune to belong to a team of professionals from PRONAR, I witnessed in greater depth the need to pursue this research, because the results would help link two important aspects of design – management and infrastructure – which are normally developed separately, when irrigation projects are prepared by agronomists and civil engineers, respectively. Another truly crucial issue addressed by this research is to never lose sight of the fact, when designing irrigation systems in Bolivia, that small-farmer irrigation systems are farmer-managed. Remembering this will help ensure irrigation systems’ sustainability.

That idea oriented this research, which became a reality thanks to support by PRONAR; I am deeply grateful to engineers Humberto Gandarillas (Coordinator of the Technical Assistance Component) and Carlos Castrillo (Coordinator of UCEP PRONAR). I would also like to thank Washington Claure for all his support while conducting the entire dissertation. I would also like to thank the following professionals, who directly or indirectly contributed to this research effort: Galo Muñoz, Daniel Vega, Alan Camacho, Alfonso Bottega, Paul Hoogendam, Iván del Callejo, Alfredo Durán, Lía Soto, Luis Carlos Sánchez, Fernando Castellón, Pedro Maldonado, Antonio Oblitas, José Luis Monroy, Domingo Saldías and my friends Jaime Alarcón, Roberto Saravia, Marina Arratia and Silvia Cardona. I am grateful to the small farmers and the PRONAR Staff.

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1 RESEARCH CONTEXT

INTRODUCTION

Except for a small number of systems implemented by the State in the 1940s and 1970s, most irrigation systems in Bolivia were built and are managed by user organisations. In the last few decades, public contributions to investment in the irrigation sub-sector have increased firstly through the national government's Development Corporations, and currently through departmental prefectures. Further, a large number of non-government organisations (NGOs) take up work and even specialise in contracts for irrigation support, because they see it as a major component of rural development. Lately, municipal governments have also joined in, with funds from tax allocations (co-participation), taking scattered initiatives in irrigation development. Much of this investment is undertaken under the umbrella term of 'irrigation improvement', in addition to construction of new schemes.

Along with arguments regarding citizen participation and fundamental rights to community self-management, it is noteworthy that, because of the country's economic and political conditions, irrigation systems must continue to be self-managed and sustainable. This situation implies that any improvements introduced in them must ensure that the system will remain sustainably self-manageable, and remain relevant to users' current and future irrigation management capability. Although most irrigation systems in Bolivia are community-managed[1], there are many "threats" to this self-reliance – partly involving irrigation assistance projects themselves. So far, the results are discouraging. Much of the infrastructure built by intervention projects is not being used as expected by designers or is in bad condition, and farmers have subsequently developed only part of the improvements they anticipated when applying for assistance.

In Bolivia, projects to improve management capacity have often imposed new organisational forms divorced from farmers' communal organisation, which are also unfulfilled. These shortfalls have become a major concern to the responsible Bolivian agencies (PRONAR 1999, Dixhoorn 1996, Arratia et al. 1996, Hoogendam & Montaño 2001, Smulders 1998). Among the several causes of this situation, a major issue is the concept of irrigation system *design* that support agencies have or, more importantly, the lack of more appropriate criteria or approaches for water design and management demanded by these types of irrigation systems. Another central problem lies in unequal power relationships between development institutions and user organisations, which make it difficult to implement irrigation projects on a horizontal, shared basis between engineers and users. Another cause may be the lack of appropriate methodological tools, taking into account the country's cultural, topographical and climatic diversity.

1 There is great diversity in the form of this local management (system size, economic aspects, development history, etc.) but users always have control over water management

In view of the lack of criteria to design and construct irrigation facilities in Bolivia's physical conditions, research has been conducted under the National Irrigation Programme (Bottega & Hoogendam 2004, Monroy et al. 2002, Muñoz et al. 2002, Sánchez et al. 2002a, Sánchez et al. 2002b). This has yielded new technical criteria for design and construction, better suited to Bolivia's conditions. However, research is still required to clarify the interaction between technology and social organisation for irrigation, in order to orient engineers involved in designing irrigation systems.

This book sets out to explore these unforeseen threats from interventions expected to improve irrigated agriculture, and farmers' responses to them, and help learning for the future through detailed case studies of four intervention projects to improve irrigation infrastructure and management. Its objectives are to explore and demonstrate the 'divorce' that is taking place in how critical actors think about irrigation infrastructure design and management, and in how designers often impose their own narrow preferences in infrastructure composition and performance without reflecting on users' preferences and needs. It also sets out to debate what conditions will help new infrastructure introduced into irrigation systems to fit in with management characteristics and potential, in order to guarantee sustainability. To answer this question, it is necessary to address the issue of *irrigation system design,* considering the reality of rural economies and labour dynamics, agro-ecology, accepted irrigation infrastructure and the socio-political institutions of the Andes. The case studies were selected to show these realities.

The study focuses on case studies of irrigation improvement projects. While irrigation rehabilitation and modernisation processes have been conceptualised and studied quite extensively for large-scale systems (Plusquellec 1994, Halsema 2002), the processes of improvement directed at farmer-managed irrigation systems (FMISs) have had less systematic study, especially in Bolivia. Levine and Coward (1986, p.10) have noted how, from the intervention side "…improvement anticipates significant changes in the ability to control and distribute water, and potentially changes in rules for allocation. Occasionally but not universally, there will be increases in the basic supply and as a result extension in irrigated area and numbers of irrigators. In addition there is typically increased use of steel and concrete, revisions expected of irrigation schedules to allow greater response to production opportunities, and development of water user associations". Such transformations can confront users with problems until they work to accommodate them and re-appropriate their systems (Zaag, 1992). This book shows that such design changes are also typical of improvements projects in Bolivia. However, alongside description of the project aims, the case studies also document what farmers have sought from contact with such projects, the benefits they have gained alongside the problems they still face, and their own efforts to re-appropriate and embed their improved systems back into their community.

This study has developed out from a special review of interventions in Bolivian FMISs to address these problems, gaps and challenges (Arratia et al. 1996, Claure & Gutiérrez 1995, Del Callejo & Gutiérrez 2000, Hoogendam & Montaño 2001), in which the author also organised studies contributing to this work. This research has devoted special attention to building analyses of infrastructure, and its relation with management and support organisation. However, this study is not a detailed study of infrastructure hydraulics, or a study of knowledge and biases in design, nor an ethnographic study of social practices. Rather it is set up as a description and analysis of infrastructure, management principles to obtain water using that infrastructure, and intervention support to build both, to show how farmers sometimes despite or against project intervention designs (re)create systems that are functional and sustainable according to their current needs and still provide new possibilities for production and labour deployment. While infrastructure diagnosis and its relation to design is the critical empirical material, the entry and closing debate always relates it back to farmers' production systems.

1.1 BACKGROUND ON THE RESEARCH: DESIGN SHORTFALLS IN THE ANDEAN REGION

Research conducted on irrigation system management has shown that infrastructure design and management design are closely inter-related and shape the operational environment for farmers' production options, not only in the ways water is delivered but in how demands for labour, skills, materials and finance are created (Levine 1980, Miranda & Levine 1978). As Jurriens & Bottrall (1984) put it, they are the two sides of the same coin. However, the value of the coin, or relation, lies in its usefulness to the productive world of users. Infrastructure design, in the creation of physical settings linking structures, landholdings and operational possibilities, needs to be relevant to and operable within the organisational practices that users can agree on for irrigation activities. If we consider practices of Bolivian small farmers[2] (*campesinos*) in building or rehabilitating their irrigation systems, we find that the physical form is defined at the same time as the system management (particularly how irrigation facilities will be operated and maintained and how any conflict resolution may take place). That is, designing an irrigation system is giving a new shape to two elements: infrastructure and management (water rights, distribution of water, maintenance and organisation).

In this regard, Boelens (1998a) mentions that developing a small-farmer irrigation system entails an ongoing process of interaction among three main aspects: generation and reconfirmation of rights (norms), construction and rehabilitation of infrastructure, and creation and strengthening of the organisation relevant to local norms. Farmers redesign this operational environment when they see new production options, through their capabilities to transform organisational and infrastructural dimensions and overcome financial and transactional costs involved. Public agencies have been seen by irrigators as a source to help face these challenges, and not only seek their own projects (Regmi 2004, Narain 2003, Arratia et al. 1996). However, imposition

2 . Rural people / peasants / small farmers. According to Eric Wolf (1968) peasants are farmers somewhere between primitive and modern farming methods. Although these small farmers work their land and exchange products with more primitive farmers, they also deal with the capitalist market as modern farmers do – yet they have important features that distinguish them from both other kinds. These small farmers are differentiated from primitive farmers because they are part of social and economic relationships that force them to provide part of their surplus production to other societal groups. That is, they begin to emerge when social classes and the State appear in primitive society, and they are obliged by social constraints and political power to deliver revenues to dominant groups. Therefore, peasant farmers are a social class within a given structure of social relationships. In the Inca Empire, farmers from communities paid tribute to the Inca State, and during colonial times they had to pay the so-called "indigenous contribution". In Europe, during feudalism, peasants also had to render tribute to the feudal lord. The difference between a peasant and a modern (agribusiness) farmer is that the small farmer practices subsistence farming in which the basic unit – the household – is governed by a ratio of human resources to means of production, defined as labour-intensity (self-exploitation) (Chayanov 1979). This means that peasant farmers do not apply just entrepreneurial criteria to pursuing profit, but mainly aim to meet the family's basic needs (as the "rural economic unit"), and take only surplus produce to market. For the Andean world, several different notions have been discussed. (Harris 1987), for example underscores that people keep circulating products outside the market, and that goods, services but also money acquire, beyond their economic implications, cultural meanings. So, the market economy is adapted to meet household and community needs through exchange based on family-relationship networking.

of too complex infrastructure and organisational models based on performance ideals different from farmers will stall the transformation until farmers can re-appropriate the scheme and its performance according to their own criteria and coping capabilities (Ambler 1993, Steenbergen 2002, Levine 1980).

The study of inter-relationships between infrastructure design and management design has already begun in Bolivia (Claure et al. 2001, Gutiérrez & Hoogendam 1998). An example is the Totora Khocha system in Punata (Claure & Gutiérrez 1995) which yielded clear conclusions: each physical design entails conscious and unconscious assumptions about how the system will work[3]. If intended users cannot operate according to such assumptions, the system is likely not to work well, or users may have to adapt it (and engineers will say, "these small farmers damage my canals"). In the above example, farmers did not use the canals, and broke distribution facilities. The institution responsible for the project had to invest again to "adapt the facilities" to small-farmer irrigation practice and management requirements. As a result institutions devoted to improving rural irrigation systems often judge users harshly, considering that they misuse constructed or improved facilities. So that users will operate facilities properly, engineers prepare operating and maintenance manuals after the infrastructure is built, and then provide training in proper usage. However, users are often not to blame, but rather the assumptions built in from the outset. Recognising that there are intrinsic (imbedded) assumptions regarding future management in each project design (including a new organisation that might be superimposed) leads to the conclusion that before and during the technical and physical design, these assumptions must be questioned, to see how realistic they are. Thus we need commitments and frameworks that help users judge whether they will be in a position to abide by these new assumptions, as they affect farmers' management criteria and production strategies. It is even more important to realise that design is always both technical and social – along with physical aspects, socio-organisational (and management) aspects must also be included (Apollin & Boelens 1996, Boelens 1998b, Claure et al. 2001, Hoogendam & Montaño 2001, Mollinga 1998, Raj Khanal 2003, Shah 2003, Uphoff 1986, Uphoff and Ramamurthy et al. 1991). This book analyses whether it is possible to include, consciously, both aspects in design and, if so, to generate methodological tools to apply this approach.

Given their difficult environments, Bolivian irrigation improvement projects have been required to leave behind durable high-quality water infrastructure in technical construction terms, and irrigators' organisation with the capacity to operate the system self-reliantly. The challenge has been to establish what kinds of improvements in technology and organisation are durable and feasible. Increasingly, there is a consensus that, for users to be able to manage the system, four major conditions must be met: (1) establish clear, socially accepted rights and working rules, (2) users have the organisational capacity to undertake management activities, (3) infrastructure is technically, socially and economically suited to users' management capacity, and (4) water distribution must be accepted by users, with organisational management arrangements suited to the irrigation system's and users' conditions (Boelens & Dávila 1998, Gutiérrez & Hoogendam 1998, Hendriks 1994, Hoogendam & Montaño 2001).

3 For example, dividing the water system into irrigation blocks assumes that there are users who will set up a group with each other, co-operate and set rules of play. Another frequent example is that canals are sized assuming a certain amount of water. In the above study, engineers assumed that water would be delivered at the community level on a multi-flow basis (changing from single-flow). For this reason, the canals designed for each community were smaller than those that users were accustomed to.

Helping enhance users' management capability calls for more than just the work of training, it also includes an activity that must touch on two aspects at once: "participatory design of future management" (activities, agreements, organisation, etc.), and "participatory design of infrastructure" to go along with management capacity. Implementing these two aspects requires great skill to inter-relate infrastructure and management issues, and to view both within the physical, ecological, socio-economic and cultural context of the area. In this regard, Jurriens & de Jong (1989) indicate that design must take into account the possibilities and constraints of all resources – physical, financial, economic and human – since they all come together to form the basis for conceptual design.

In Bolivia, although lately some agencies are beginning to claim that they will include future management in infrastructure design, in practice many actually design the infrastructure first, then build it, and finally turn their attention to future management issues, under the "operation and maintenance" heading. In some cases, the institution sometimes disappears once the facilities are built, leaving bad results in terms of the design, affecting the management of the renewed or built system (Del Callejo & Gutiérrez 2002, Gutiérrez et al. 2002, Maldonado 2002).

A methodological approach that allows for appropriate design of future management is exceedingly important. However, the lack of such a creative, contextualised methodology means that agencies design future management by imitating others' experiences. Common examples include creating uniform water rights and forming standard irrigators' committees or associations (even copying the by-laws and regulations), without any adaptation to the local reality and – importantly – even any analysis of the prevailing water management. The Inter-Valley Irrigation Programme (PRIV) made history in Bolivian irrigation, as one of the first institutions to reflect on its experience in designing and implementing irrigation projects and posing questions about them (Gandarillas et al. 1992). This created a mirror for reflection and self-criticism by other support and implementing NGOs. However, these other entities have seen PRIV's results as a model, but unfortunately they have not reflected on or analyzed the local situation for each irrigation system, nor taken into account the particular features of each working zone. Logically, each system has its own features, set by the larger environment (social, cultural, economic and physical) which creates greater problems for irrigation system management. A common error, for example, is to create specific irrigation organisations in systems where a local community organisation already handled irrigation as one of its responsibilities (Claure & Gutiérrez 1995, Criales et al. 2002, Gerbrandy & Gutiérrez et al. 1996, Gerbrandy & Hoogendam 1998).

Reviewing international literature on irrigation development, we find that, due to irrigation project failures, the issue of "irrigation organisation design" has been emphasised more, with the idea that better institutional structure would ensure operation and maintenance of the built or upgraded system (Ambler 1993, FAO 1991, Horna & Rentería 2000, Pimentel & Palerm 2000, Reinders 1994). However, Coward & Levine (1989) warned that water user associations (WUAs) are fostered for multiple reasons that can include hopes of 'better' organisation of operations, maintenance and collection of fees to cover them. However, they can be ineffective because they fail to relate with local concepts and institutions for equity, which also include how to share power in the group. Authors such as Ostrom (1992) indicate that the rules governing the way that users interact with each other are as important as properly built irrigation facilities. She mentions that, in several self-organised irrigation institutions in which users have developed usage rules, users increasingly want to invest labour and resources to maintain irrigation systems. Although it is wise to question prescriptions, this author presents principles for designing institutions, which could in some cases prove useful for strengthening existing institutions, especially in large systems. However, for many micro-irrigation systems in Bolivia, this study will show that such criteria become irrelevant. Further, they almost fail to consider or pursue the importance of designing adequate infrastructure or the interaction of this design with small-farmer management of the system.

Although many studies have been conducted lately on water management design in the Andean countries (Apollin et al. 1998, Arratia & Gutiérrez 2003, Boelens 1998b, Claure & Gutiérrez 1995, Gutiérrez & Hoogendam 1998, Vega et al. 2002), an issue that has not been explored sufficiently for the region is design of *irrigation infrastructure* from an integrated, interactive approach. Interactive design implies joint decision-making by stakeholders (users and engineers) to reshape or design the initial shape of an irrigation system. An important aspect for interactive design is the attitude of the professional team, fostering users' contributions. Also, as Horst & Ubels (1993) explain, a "consensus-building" approach requires an interactive process, in order to gather the full range of required information and negotiate among stakeholders (Claure et al. 2001, Gutiérrez & Hoogendam 1998, Kimani & Ubels 1993, Raj Khanal 2003, Smulders 1998).

Both globally and in Bolivia, we seldom find authors with civil or agricultural engineering backgrounds who analyze the interaction of engineering with other aspects of irrigation system design, such as water management and the larger environmental context. For this reason, there has been reliance on literature on other regions, which may not be appropriate for irrigation systems in the Andean area. It is also important to bear in mind that projects in Bolivia work to improve existing small-farmer systems, where there is already an irrigation tradition. Moreover, these irrigation systems are located in rugged terrain, i.e. the Andes. This environment is adverse and highly complex, which makes it difficult for the infrastructure constructed to work well.

Literature on infrastructure[4] commonly presents steps for calculating hydraulic design for different types of construction, as a sort of prescription, using coefficients, indices and largely assumed values. Thus, the application of these agronomic, hydraulic and civil engineering indices will mould a specific project. They not only fail to take into account the importance of contextualisation in general, but also lack any analysis to design the irrigation infrastructure system as a whole, placing the process of calculating the project in isolation. The objectives of change relate to the engineers' performance preferences, without reflecting on the outcomes most important to users in terms of system's functionality, operability and maintainability. Engineers continue designing with standards and principles grounded in a conventional theoretical framework and empirical factors, but which are questionable for specific areas such as Bolivia (Horst, 1998a). Design is rarely based on field experience or criteria involving users' management preferences.

For example, Meijer (1992) lists three typical errors in design: 1- using very optimal roughness factor figures when applying Manning's formula to design canals – consequently, flow is impeded and greater maintenance by users is required; 2- hierarchical design of infrastructure (first the main canal, then secondary and finally tertiary) rather than cyclical, so the result is visible only after the design has been implemented; 3- insisting on designing for high irrigation efficiencies, rather than "something more than just water" to facilitate distribution. Meijer states that, when using efficiency rates, one should reflect on whether it is actually necessary to improve efficiency, and analyse possible outcomes. For example, if improving efficiency is necessary to save water,

4 Among others, we can mention Kraatz & Mahajan (1976), Torrez (1992), Villaseñor (1979), and Gayos (1994).

the question is whether the water saved could be used right there or elsewhere effectively, or may be wasted, and finally ascertain the economic and social cost of increasing measurements and the structures required to save that water.

Levine & Coward (1986, p.15) also noted the tendency of public intervention schemes to impose a logic of water efficiency on farmer-managed irrigation systems (FMISs), either because of experience in water-scarce areas or their professional training. However, not all FMISs operated either in settings of real scarcity or gave primary attention to efficiency. Rather it was equity, operationalised through fair allocation and distribution of water that was the fundamental principle, which then shaped collective organisation for labour and inputs needed for related operation and maintenance (Yoder, 1994a). Nevertheless, Levine & Coward (1986) also emphasised how identification of appropriate criteria on which to base changes in FMISs needed special attention while also being challenging in methodology and description. They listed several sets of information that can help bring understanding of equity and farmers' management preferences into design, as discussed in the next section.

Infrastructure must be designed according to the Andean region's topographical and geological conditions. Vincent (1998) indicates that the challenge of irrigation design in the Andes involves three macro physical divisions: high altitudes and plateaus (*altiplano*), steep valley slopes, and valley lowlands. Naturally, there is great variation in the hydrological characteristics of rivers in the Andean zone, many with great seasonal fluctuation, and heavy sediment loads during the times of year when their flow rates are high. Designing for the Andean zone also means adapting technology. In this regard, Yoder (1994b) says that design in mountain areas involves the uncertainty of soil stability, since there is an ongoing process of erosion. Mountain irrigation systems similar to the Andes[5] (Bali, Indonesia, Philippines, Nepal and many others) need their own design principles or criteria for these challenging conditions (Martin & Yoder 1988, Vincent 1995, 1998, Achayra 1985). The main problems of canals built on steep slopes include: slopes prone to landslides, ongoing sloughing, and slopes suffering serious erosion problems (Ford Foundation 1995). Therefore, decisions to build canals and other projects must be based on a "risk assessment" (Yoder 1994b) and applied adapting hydrological, hydraulic and construction calculations. It is also fundamental for this assessment and the plan to mitigate possible risks to involve discussion and negotiation, interactively, with water users. However, in general, systems designed by intervention projects in Bolivia use a conventional conceptual framework, with existing basic information, which is usually insufficient. Consequently, for example, water intakes in rivers are found washed out by high-water flooding, canals are unusable (cut off, left hanging) because of landslides, distributors do not work, and projects are silted up. So one wonders: wouldn't it be better to use design principles or criteria suited to local conditions?

A critical feature for infrastructure in the Andean zone is also the actual "construction". For example, the quality of manpower (experience in construction), availability of material (location of materials depots) and climatic characteristics (frosts in the *altiplano* area), all influence the choice of infrastructure. Such factors are going to determine the choice of what to build and its hydraulic characteristics (Bottega & Hoogendam 2004, Smout & Ward 1987). Aspects of constructive suitability are important, but since technicians who build projects do not often systematise their experiences, such information is almost non-existent in the literature. García (1991) is an author who briefly mentions some technical considerations from his experience

5 The Andes are a young landscape, where there is much natural erosion.

building dams, distributors and canals in Peru and Bolivia. The poor results of many irrigation systems may be caused partly by the construction process.

An exhaustive review of the literature (Del Callejo & Gutiérrez 2002, Diemer 1992, Chambers 1988) also reveals that the classical intervention approach still persists and predominates, emphasizing infrastructure design as a central aspect, to which the other areas (management, agricultural production) must accommodate. This approach gives rise to a sequential intervention, stepwise: 1- design the infrastructure, 2- build it, and finally 3- operate and maintain the irrigation infrastructure to irrigate crops. That is, this approach emphasizes technical aspects as the core of design. Conventional design emphasises infrastructure design grounded in technical data alone (Ali 1980, Luque 1979, Palacios 1980) including the following:

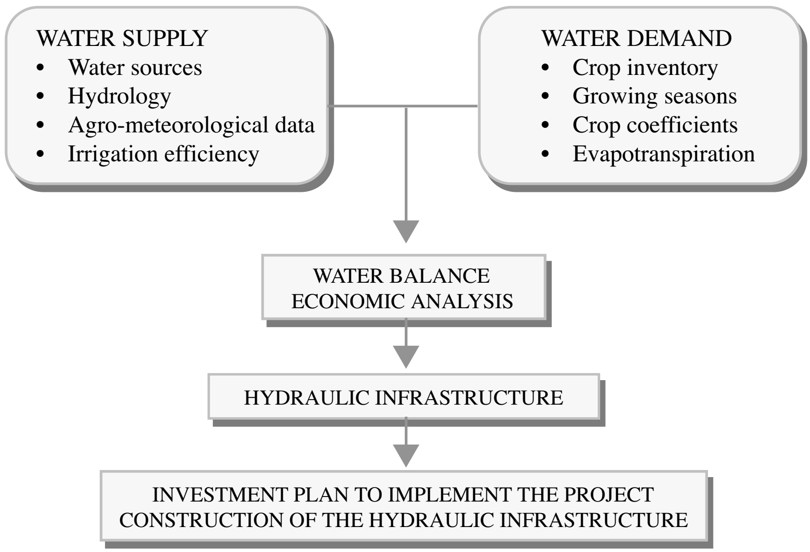
a. An agronomic study, to estimate the area of land to be irrigated, soil characteristics and climatic conditions of the region. These factors will be used to decide about future land use, crops that will thrive and yield profits there, and classify land for irrigation purposes. Topographical and soil maps also enable designers to define canal and structure system characteristics. Finally, a water balance estimates water needs and the amount to be applied to the land.

b. A hydrological study, to assess water sources, quality and space-time availability, potential flow rates and the range of variation in catchment and/or storage from the sources.

c. An economic study, emphasising economic justification of the investment in irrigation projects. Much importance is granted to such economic indicators as the internal rate of return (IRR), net present value (NPR), and cost-benefit (C/B) ratio.

On the basis of this information and successive, increasingly detailed studies, project phases proceed sequentially: reconnaissance, pre-feasibility, feasibility and finally investment. Costs increase in proportion to the degree of detail. This is shown schematically in the figure below:

Figure 1.1 Procedure and phases in designing irrigation systems



Although these technical data are necessary for the design, several assumptions are made about essential aspects of how the irrigation system will work, such as:

- Irrigation efficiencies, which determine the flow rates to be applied, and canal and structure sizing
- Structure functions and performance, i.e. measurement, regulation and division of flows
- Crop systems, defined according to uses for consumption, usually based on production optimisation functions
- Orientation of production (generally planned for as cash crops for market)
- Presence of an adequate commercial and institutional framework for the expected type of agricultural production.

The shortage of reliable information on these points, despite fairly detailed studies, means that designs are substantially based on assumptions, highly dependent on a limited set of technical criteria, met by applying hydraulic theory to available information, as Vermillion (1989) puts it. They are implemented as a single task, rather than a gradual, careful process. So, future management is uncertain, not only for designers, but also for future users. From an analysis of the case studies, a model for interactive design is presented in the conclusions as a new option to replace this classic sequential approach.

Mollinga (1998), when analysing the history of irrigation development, centres his criticism on three key aspects of the conventional approach: treating technology as an unquestioned black box; the limited concept of human agency; and the idea of an absence of power relationships. The conventional approach considers that infrastructure's influence on the irrigation system is neutral. Therefore, many irrigation engineers do not consider social implications. In this regard, Chambers (1988) considers that conventional design has exclusively emphasised construction of physical infrastructure, feeling that "good" infrastructure would in and of itself enable water management and use according to technical design criteria. In other words, conventional design assumes that farmers will simply agree with technical concepts and social and economic assumptions made by the irrigation project. The consequences of such assumptions have been evident years after many of these irrigation systems have been commissioned. The original design forecasts have not played out economically, in terms of management, or even in the use and operation of the physical infrastructure. The engineering approach is complemented by the economic approach underlying irrigation projects, since evidently projects must be "economically sound" to be funded. For example, in Bolivia, to fund an irrigation project, its internal rate of return (IRR) must be over 12%, the net present value (NPV) must be positive (greater than zero) and benefits must exceed or at least equal costs.

By contrast with this reading, a different approach is needed, which has been developed by various researchers, who refer to irrigation as a socio-technical phenomenon (for more detail see appendix 1) in which technical and social aspects interact; this is the foundation for the present study (Kloezen & Mollinga 1992, Mollinga 1998, Uphoff 1986, Uphoff, Ramamurthy et al. 1991). It has been acknowledged that irrigation facility design and construction are more than just a hydraulic and civil engineering issue, because it involves a series of management, socio-economic, production-related, cultural and environmental issues. In the past few years, many studies have researched water issues, in what can be summarised as *Small-Farmer Irrigation Management*[6].

6 Gerbrandy and Hoogendam (1998), Bleumink and Sybrandy (1990), Arratia and Gutiérrez (1997), Mitchell (1994), Oré (1993), Bolin (1994), Seligmann and Bunker (1994).

However, additionally, the researcher is interested in further conceptualising irrigation, and concentrating on irrigation infrastructure, no longer from the hydraulic-construction standpoint itself, but amidst the complex reality of irrigation systems, their management and overall environment. Therefore, this study analyses design and construction, considering how projects operate within the irrigation system's economic-productive and socio-organisational context.

1.2 THE CENTRAL PROPOSAL OF THIS RESEARCH

Because of the physical conditions of the Andean zone, because irrigation systems must be community managed and because of bad results in design and construction, it is necessary to "open the black box", as Horst (1998) put it. It is urgent to analyse all aspects of infrastructure, to be able to establish criteria or guidelines (without resorting to prescriptions) to design and build irrigation facilities *adapted to users' management capability.* In this regard, Jurriens & de Jong (1989) indicate that publications seldom discuss common deficiencies in design and also fail to assess management problems caused as a consequence of poor designs. Although this concern is widespread, irrigation projects do not have the necessary budget or time to reflect on their approach, their conceptual framework, methodology or monitor their outcomes. For this reason, it is necessary to prepare a suitable conceptual and methodological framework for designing irrigation systems in Bolivia that could be replicated in other areas of the Andean region. The main question and sub-questions orienting the research are as follows:

Main question

What characteristics of irrigation infrastructure make it appropriate given the management capability and social and productive settings of farmers in the Bolivian Andes, and how and why have the designs developed by irrigation improvement projects been reshaped by farmers?

Sub questions

1. What diversity in designs, operations and management are found in farmer-managed irrigation systems in different regions and communities of the Bolivian Andes?
2. What designs in infrastructure, water delivery and social organisation have been adopted by farmers during and after irrigation intervention processes, what changes have been adapted and what operational, technical and productive characteristics of infrastructure have farmers re-appropriated?
3. What design and implementation processes shaped these design outcomes, and how were farmers involved in them?
4. What changes in irrigated production systems have been shaped by changes in infrastructure?
5. What changes in costs and labour are associated with the improved infrastructure, and how do these economic and financial requirements compare with the production options of farmers from irrigation and the wider economy?

1.3 AGROECOLOGICAL ZONES, AGRARIAN & ECONOMIC REFORMS AND IRRIGATION DEVELOPMENT IN BOLIVIA

Agro- ecological zones and irrigation systems in Bolivia

Bolivia lies almost exactly in the centre of the South American continent, sharing borders with five neighbouring countries: Peru (to the west), Brazil (to the north and east), Paraguay (to the south) and Argentina and Chile (to the south-west). Bolivia's land area is 1,098,581 square kilometres. It is politically divided into nine departments, each divided into provinces, which are subdivided into sections. Bolivia is one of the least populated nations of South America, with just over 7.5 million inhabitants, with a density of only seven inhabitants per km^2. With increasing mixed indigenous-outside lineage (mestizo, nearly 38%), there are several significant ethnic groups: Quechua (34%), Aymará (22%), and many others in the flatlands (6%). Regarding the four case studies (see below) in general terms, the Condorchinoka case study belongs to Aymara culture, in Caigua live mestizo and Guarani (flatlands) people, and in Naranjos Margen Izquierda and San Roque - Capellanía people are mestizo. Also, the different communities referred In Chapter 2 belongs to Aymara, Quechua and mestizo groups.

Figure 1.2 Map of Bolivia showing Departments and case study sites

Geographically, Bolivia is divided into three major regions, quite markedly differentiated, as described below:

- Two thirds of the territory (to the east) is tropical plains (thick forests and broad savannahs) at altitudes ranging from 230 to 800 metres above sea level, with average temperatures of 25ºC year round.
- In the Andean highlands, there are fertile valleys, at altitudes ranging from 1500 to 2500 metres, with temperatures averaging from 18º C to 20º C (central and southern Bolivia). To the south, the Chaco plains predominate.
- Finally (to the west) are the immense, high-altitude plateaux, between the eastern and western ranches of the Andean mountain range, at altitudes averaging 3800 metres. The *altiplano* features an average temperature of 10º C.

In Bolivia there are three large watersheds: the Amazon basin, the basin of the La Plata river, and the endorrheic basin of the *Altiplano*, which provide surface and underground water resources. However, their spatial and altitude distribution and the enormous micro-regional hydrological variation have a marked effect on water utilisation, which is constrained by the difficulty of obtaining water for farming in the areas where most of the population is concentrated.

Agro-ecological zones

The agro-ecological zones comprising Bolivia's territory feature great altitudinal and climatic diversity. The range of altitudes in Bolivia's territory provides four agro-ecological regions, with 14 zones or sub-regions, which have clearly differentiated climatic characteristics and relatively homogenous predominating vegetation. These sub-regions correspond to a summary of existing units (over 40) and sub-units (about 120) that are in the process of being characterised.

There are agroecological zones where the climatic conditions impose at least six months a year of water deficit. This scarcity of water is the greatest obstacle to pursuing agricultural activities. The zones under such conditions total some 448,700 Km^2, representing almost 40% of Bolivia's area. In these zones, drought and killing frost are the most adverse factors affecting agricultural production. Drought has the greatest negative impact and intensity in the valleys and the Chaco plains, and both factors affect the altiplano. The case studies are located in these areas, Condorchinoka is in the altiplano (very high-altitude region), San Roque Capellanía in the valley (the highlands region), Naranjos Margen Izquierda in the mesothermal valley (Mid-altitude region) and Caigua in the Chaco (Lowlands region)

Table 1.1 Agroecological zones of Bolivia

Nº	Agro-ecological zones	Altitude (metres above sea level)	Total land area		Area under cultivation	
			(Km^2)	(%)	(Km^2)	(%)
1	Lowlands region	(115-700)	721,282	66%	4,609	33%
2	Mid-altitude region	(700-1500)	51,010	5%	1,200	9%
3	Highlands region	(1500-3000)	147,627	13%	5,650	40%
4	Very high-altitude region	(over 3000)	178,662	16%	2,550	18%
	TOTAL		**1,098,581**	**100%**	**14,009**	**100%**

Source: Paz (1992)

Irrigation systems in Bolivia generally cover a small irrigated area, compared with other irrigation systems in the Andean region. According to a national irrigation inventory, there are 4,724 irrigation systems, comprising 217,975 user households, to irrigate 226,564 hectares.

The following table classifies these systems by size:

Table 1.2 Irrigation System Size

Micro 2-10 hectares		Small 10-100 hectares		Medium 100-500 hectares		Large > 500 hectares	
Systems (Nº)	Area (ha)	Systems (Nº)	Area (ha)	Systems (Nº)	Area (ha)	Systems (Nº)	Area (ha)
1,733	10,528	2,616	86,638	326	65,944	49	63,454

Source: PRONAR (2000)

Most systems obtain their water from rivers, and this is also the largest irrigated area. Irrigation systems using dams get their water mainly from rivers and springs; they are few in number, but account for 19% of area under irrigation. Irrigation systems using springs and wells as their source each cover 6% of the irrigated area. The next chart shows the number of irrigation systems, by source of water, and the area irrigated by each category of source.

Table 1.3 Irrigation systems and area irrigated by water sources

	Rivers		Springs		Wells		Dams		Total
	Systems (Nº)	Area (ha)	Systems (Nº)	Area (ha)	Systems (Nº)	Area (ha)	Systems (Nº)	Area (ha)	Area (ha)
Total	3,428	154,582	702	13,869	496	14,159	103	43,470	226,031

Source: PRONAR (2000)

Most of these systems are developed by farmers, or were taken over by farmers after the Agrarian Reform in 1952. A detailed description of irrigation infrastructure used in Bolivia is given in Chapter 2.

Agrarian and Economic Reforms in Bolivia

Prior to colonial times, peasant societies were concentrated in the Andean regions and had developed traditional forms of organisation tied to agricultural production. After colonisation, dominance of large haciendas (ranches) characterised the countryside. The Agrarian Reform Law[7] came into being following the revolution of 9 April 1952, and essentially allowed peasants to

7 This law undermines original community or traditional ayllu organisational structures, by giving rise to rural unions (sindicatos), promoted by political parties and labour organizations. In hacienda areas, these unions were initially an instrument to pressure and advocate against mistreatment by the boss, and ended up eliminating the hacienda system. Once this goal had been attained, rural unions became the basic community organisation in these zones. Unionisation of communities and original ayllus was later and ridden with conflict, which persists to this day. The rural union movement was implemented to reject traditional ayllu organisations. At that time, these changes were welcomed by most communities, who even accepted with the pride of modernisation their new role as "rural workers" organised into unions. (Albo & Ticona, 1997)

claim the land that they had traditionally worked. This law (2 August 1953) gave greater freedom to the Indian population and gave peasant farmers much greater security, starting a new era. However, the size of many peasant plots did not increase as a result of the reform. Local peasant organisations became legitimate and politically acknowledged by the state, strengthening this sector. Unfortunately, however, this social recognition was not tied to parallel structural measures that could consolidate production systems and improve services and productive infrastructure.

In retrospect, Land Reform was more of a social success than an economic one. Although the reform improved income distribution, its main contribution was to transform a feudal society into a market society. Agrarian Reform has remained a goal of successive governments since 1952, but the pace and scope of reform slowed. The original Agrarian Reform Law was amended in 1963 and 1968. By 1986 the government claimed to have redistributed 33 million hectares through the reform process. But although peasants ate better, agricultural production did not increase in the way most government officials anticipated. In addition, the reform process was hampered by price controls, a lack of extension services, inadequate credit, insufficient infrastructure, and regional conflicts between the highlands and lowlands.

Land policy since 1952 also has been marked by the colonisation of the lowlands. Although government policy has encouraged colonisation of these isolated areas since the 1940s, the process did not accelerate until the 1950s. The government created the National Colonisation Institute (Instituto Nacional de Colonización--INC), which typically helped highland families move to newly established government colonies, sometimes completely isolated from other towns. From 1952 to the mid-1970s, the government helped 46,000 families (190,000 people) colonise the lowlands. Other settlers included members of Japanese and North American Mennonite communities who were establishing colonies in neighbouring Paraguay.

In the 1990's the government implemented the Law for the National Institute of Agrarian Reform (Ley del Instituto Nacional de Reforma Agraria INRA), that regulates the legitimacy of land tenure and safeguards a more equitable distribution of land for the population. The fundamental objectives of INRA are, on the one hand, to establish the institutional setting to manage and regulate land tenure nationwide, and, on the other hand, to establish the legal instruments to achieve a more equitable and efficient land use natural capital. In 2005 the INRA was working, but could not achieve the objectives, because of social problems.

The Land and Territory Commission in one of its evaluation documents, rejects the INRA Law for the following reasons:

a. The land is wrongly distributed, because the Agrarian Reform Law has distributed useless, infertile, marginal and small land to the rural people, whereas 70% of fertile, productive land is in the possession of 30% of the population (i.e. agroindustrialists, large landholders, plantation owners) and there is no certainty that they own this land legally.

b. The Law ignores the right to life, because over 2.5 million Bolivians have no land at all, or their smallholding has become insufficient. Some 50 years after the Agrarian Reform, there is plenty of land both in western and eastern Bolivia that is performing no economic or social function, while the rural people are starving.

c. INRA and judicial institutions take the side of large landholders and politicians. The forces of repression, judges and courts persecute and imprison those who defend the rights of the landless and the rural people. INRA has become the worst obstacle preventing small farmers from accessing land.

d. Increasing poverty and the exodus from the countryside, resulting from the 1953 Agrarian Reform, has turned rural people into beggars, street peddlers, and others who are unemployed in the big cities. Fifty years after Agrarian Reform in Bolivia, hunger and extreme poverty prevail and the younger population seek their fortune elsewhere.

This has given rise to the Landless movement and other social conflicts. Therefore, there will be no social peace in this country until such injustice is reversed. The Land and Territory Commission is advocating a law to replace the INRA Law, based on the original vision, incorporating the slogan: "land, territory and integrated rural development".

Land policy and government agricultural policy in general shifted dramatically when orthodox economic policies were implemented in 1985. Supreme Decree 21060 (29 August 1985) started the process of economic structural adjustment, ending an economic model of state capitalism, and beginning an era of market liberalisation. This decree led to the State abandoning the role it acquired after the 1952 revolution; i.e., its role as a regulatory body and the agency in charge of production and the functioning of the economy. Instead, the State focused on the success and profitability of private investment. Setting the economic model of structural adjustment in process allowed the country to develop agreements with the International Monetary Fund and the World Bank. No doubt, the most important things achieved during this period of great transformation were stopping hyperinflation and achieving economic stabilisation. However, important levels of international reserves were also reached; there was an efficient management of the exchange rate, and there was the establishment of real interest rates, as well as control of fiscal deficits.

Since 1993 the government started to implement a number of political reforms, known as the Second Generation Reforms. The main laws were: The Law for Restructuring the Executive, The Law for Capitalisation, The Law for Pensions, The Law for Decentralisation, The Law for Educational Reforms, the Law for Popular Participation[8], the Law for the National Institute of Agrarian Reform and the Agricultural Productive Transformation Strategy. In relation with water, the government implemented the Law for Electricity, and the Law for Drinking Water. All of these have their own norms that regulate the use of water, but they do not take account the Irrigation Sub-sector.

Irrigation development and intervention policy

Governmental intervention in irrigation, through the Ministry of Agriculture (General Directorate of Irrigation) began when the Mexican Mission came to Bolivia in 1938 (Mexico's National Irrigation Commission). At that time, the only two public irrigation systems still in place were built: La Angostura and Tacagua, completed in 1944 and 1961, respectively. After the 1953

8 The Popular Participation Law created Territorial (= Local) Grassroots Organisations (OTBs), comprising representatives of civil society, to share the responsibility of administering resources and social services. The Law grants these OTBs specific rights and obligations within the municipality. OTBs representing the entire urban or rural population of a given local territory are granted legal status. In urban areas, these territories are neighbourhoods defined by municipal governments, and in rural areas they are existing communities. The only requirement is to register according to the procedure set forth in the Law. The Law and its regulations recognise three major categories (aside from more local names, such as "ayllu" or "union" (sindicato) to organise new legally recognised entities once they have registered: indigenous peoples, rural communities, and neighbourhood boards. (Albo & Ticona, 1997)

Agrarian Reform, some small irrigation projects began. Later, in 1966, a decentralised unit was created, the National Community Development Service, which built small projects with funds provided by USAID, the Government and local contributions (labour and construction materials). At the same time, the Ministry of Agriculture created the Division of Soils, Irrigation and Engineering, as the agency to promote, regulate, co-ordinate and implement the country's rural development policy. In 1979, the Ministry of Rural and Agricultural Affairs, through the National Community Development Service, commenced the Altiplano / Valleys Irrigation Programme, which implemented the irrigation systems in Tiraque / Punata (Cochabamba) and Huarina (La Paz), and begun studies for the systems in Culpina (Chuquisaca) and Comarapa (Santa Cruz). The programme was implemented in two stages. In the second, it changed scope, under the name of Inter-Valley Irrigation Programme (PRIV), with the main aim of integrated management for the interconnected lake system of Tiraque – Punata.

Along with development of PRIV, a drought in 1983 moved the Government, with United Nations funding, to pursue Programmes BOL 83/023, BOL 83/024 and BOL 83/025, to upgrade small irrigation systems in the hardest-hit Departments of La Paz, Oruro and Potosí. The result was 558 system upgrades, benefiting 18,600 rural families (Salazar et al. 2005). The intervention experiences of PRIV technical staff and reflections on the "technology package" approach (Gandarillas et al. 1992) generated, within the sector, criticisms of the approach used up to that point.

On the basis of this experience and the conclusion of the PRIV, in 1992 the Inter-Institutional Irrigation Committee was set up, comprising FAO, GTZ, CAF, UNDP and the IDB. This Committee formed a National Irrigation Plan Steering Commission, with external funding, and designed the National Irrigation Programme (PRONAR). In the context of change resulting from the Popular Participation and Administrative Decentralisation Laws, National Irrigation Programme (PRONAR) implementation began in 1996, with Inter-American Development Bank (IDB) and German Government Technical Co-operation (GTZ) funding. PRONAR is currently supervised by the General Directorate of Productive Development and the Water and Soils Unit.

The PRONAR approach (PRONAR 1999) included ways to improve irrigation project interventions, such as:

Redefinition of the role of institutions and users: The central idea here is that the rural organisation is the main stakeholder in system management and project formulation. Institutions are there to provide support and services.

Interaction and advisory process: The interaction process is viewed as a meeting of two parties (institution and users) to negotiate the small farmers' project. Each project requires decision-making by farmers, and the institutions support farmers' decision-making through this interaction.

Levels and opportunities for discussion: Discussions occur at different organisational levels: households, rural communities, irrigators' organisations, or other organisational forms representing the people living there. Further, organisational action is responsive to needs and changes according to actual realities.

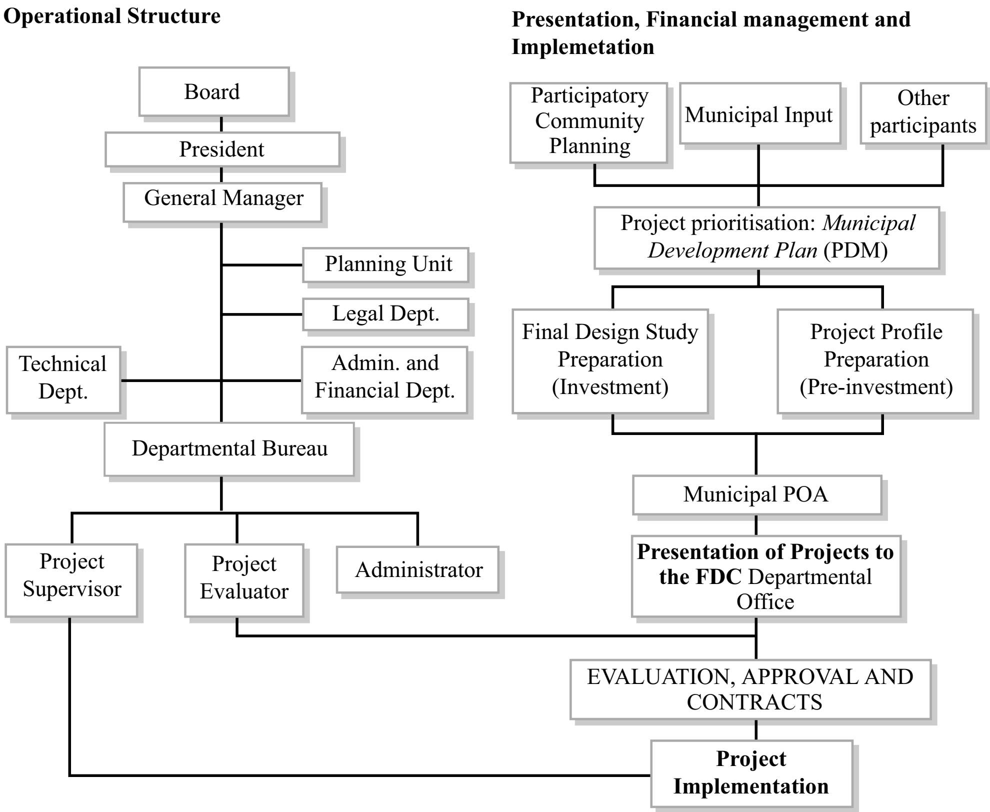
Shared, consensus-based, flexible planning: Consensus-based, shared planning means defining activities that farmers and institutions deem necessary to meet project goals. Consensus-building helps make timeframes flexible and adjust them according to real needs, clearly establishing co-responsibility.

Irrigation system sustainability: An irrigation system's sustainability is the farmer organisation's capacity to adjust, develop and establish arrangements within the irrigation system in response to changes that are introduced. Emphasis is placed on social sustainability (management), financial and environmental sustainability.

PRONAR was to fund small-scale irrigation system rehabilitation or upgrades, for a total cost no higher than $350,000 each, and a cost per hectare no higher than $2500. Funding for the investment component would also be handled by the Rural Development Investment (Fondo de Desarrollo Campesino) (FDC) grant mechanism (which would be responsible for technical and financial evaluation and final approval of project funding).

The organisational chart (Figure 1.3) shows the flows and structure of how the FDC was to work in approving and allocating funds:

Figure 1.3 Organisational Chart of the FDC's Operational and Financial Management Structure.



Source: Maldonado (2002)

For presentation, financial management and implementation, a prerequisite for project formulation was for a project to be included in the Municipal Development Plan (PDM) and inserted into the Annual Operating Plan (POA) under a Municipal Council resolution. Moreover, projects required approval of a 10% cash matching contribution by the municipality (later reduced to 5%). The support agencies and the building companies are not part of the FDC structure; they are hired eventually for the FDC through public bid.

It is under this institutional context, that irrigation projects selected as case studies for this research project and paper were implemented.

Water and Irrigation legislation in Bolivia

In Bolivia, the Law of Water Ownership and Utilisation is based on a Decree of September 8, 1879, which was enacted as a law on November 28, 1906. Several of its articles have been practically repealed by subsequent norms. In order to fill in the gaps left by this law, a number of legislative proposals have been promoted during the last three decades, and there are now 32 versions of draft laws. The last proposed law that the National Congress was analysing has been withdrawn and shelved, due to the conflict that broke out, known as the *"Water War",* waged by societal organisations in the year 2000. This also got the Water Ownership and Utilisation Law of 1906 repealed, and the Government made the commitment to prepare an alternative proposal, changing those norms that were trampling over the rights of small farmers, both indigenous and settlers. A 60-day deadline was set to prepare this draft law.

According to Rico (2003), the main objections to the law were:

- The law did not distinguish between social and lucrative use of water. It established a single system of rights, called water concessions and titles, for companies and business activities, and also for rural communities and other social-type uses.
- There was no mechanism to set priorities in granting concessions, which could favour the more influential, or those best positioned to do the paperwork for permits.
- It was impossible, in practice, to install metres all over the country to verify units of volume versus time.
- Rural and indigenous communities were required, in order to obtain a concession, to demonstrate their customary uses and tradition on the basis of regionalised regulations on uses and customs.
- It would allow small farmers to arrange for concessions on an individual basis, affecting community access rights and generating conflicts within communities.
- Small-farmer irrigation systems were treated in the same category as medium-scale farms and agri-businesses. They were required to demonstrate their ownership of their land by "some suitable means". This posed a problem, because over 90% of the land is not legally titled, "with all documents in order". There are many communities that are legal owners (but without papers) who could be displaced by ex-hacienda owners, speculators, and so on, who do have some sort of document.
- Using the criterion of land ownership to legitimise ownership of water sources is dangerous, because the source could be located in private property, but be used communally.
- All concession holders could charge others to use water. It was clarified that the intention was only to charge in cities, but it was acknowledged that the article was worded in such

a way that any type of concession, even in rural areas, would be included, leading to a nation-wide water market.

- The spirit of the law promoted privatisation and commoditisation of water, to promote a water market and water titles.
- Concessions could be transferred (bought and sold) with the Superintendency's authorisation. This would generate a water rights market, with the danger that a few parties could end up owning all the water sources, as has happened in other countries. The Superintendency would not have the capacity to oversee some 50,000 concessions that would be created.
- It is assumed that all concessionaires pollute water and must therefore pay the pollution fee, unless they can prove that they are treating the water prior to returning it to its watercourse. This affects small farmers and indigenous concession holders and favours companies that would rather pay the pollution fee than treat their effluents. Penalties for pollution, which is not legally a crime, would be only 100% of the permit fee. This would favour oil and mining companies.

To date, four years have elapsed since the "water war", and there is no amended water law yet. However, in May 2000, the Government, through the Ministry of Rural and Agricultural Affairs, began to draft an **Irrigation Law**. On October 2004, the Government released that law. It expresses four fundamental thrusts: 1. recognition and respect for small farmers' uses and customs; 2. a new institutional framework; 3. a decentralized framework of authorities; 4. social participation, expressed through the creation of the National Irrigation Service to administer water issues. The NIS comprises seven representatives of irrigators and two of producing and societal organisations from each sector. This law is innovative, incorporating the spirit of participation. It was drafted by irrigators nation-wide, on the basis of a consensus reached by this sector. It is this context that forms the background to this research.

1.4 CONCEPTUAL FRAMEWORK

This study around irrigation technology applies the sociotechnical approach (see Appendix 1) developed by various authors (Huppert 1989, Kloezen 2002, Manzungu 1999, Mollinga 1998, Pradhan 1996, Raj Khanal 2003, Shah 2003, Halsema van 2002, Uphoff 1986, Vos 2002). It builds on the framework developed by Mollinga (1998) on the "social construction of irrigation technology". Mollinga (1998) saw the social dimension of technology expressed in three dimensions: social requirements for use, social construction, and social effects of irrigation technologies.

Social dimension of technology

Social requirements for use: is what society needs to make the infrastructure work. In an existing or new irrigation system, these social requirements for use become agreements, norms and rules that shape the "new" water management. An analysis of social requirements for use is the foundation for designing the *future water management and irrigation infrastructure*, so that both aspects will match. For example, laying out the route of a canal may require a certain configuration of the irrigation organisation. The choice among various types of division and control facilities may entail different organisational skills and processes, as well as different external relationships to obtain parts to keep the facilities working.

Kimani & Ubels (1993) show that, when technical and social considerations seem not to match viably and coherently, there are three possible courses of action:

- Adapt the technical design so that organisational requirements better fit in social patterns
- Develop new organisational arrangements that link technical requirements and organisational capacities
- Seek certain social or organisational changes that will result in new forms of organisation.

Social construction: irrigation systems can be called socio-technological complexes, because there is an interaction, in irrigation systems, among three sub-systems (Boelens 1998 a, b): infrastructure (concept, construction and rehabilitation), norms (generation and reconfirmation of rights and obligations) and organisation (creation and consolidation of organisational forms). So, irrigation technology is an expression or materialization of norms. Horst & Ubels (1993) are so right when they say that designers often fail to appreciate the effects of a social setting on irrigation system use. As a result, the technical system does not facilitate the use desired by farmers, and/or farmers are not inclined or able to meet the system's management requirements.

An important facet of this topic is participatory or interactive design (Bruns 1989, Oad 1987, Thompson 1989, Vermillion 1989). Interactive design implies joint decision-making by stakeholders (users and engineers) to reshape or design the initial shape of an irrigation system. An important aspect for interactive design is the attitude of the professional team, fostering users' contributions. Also, as Horst & Ubels (1993) explain, a "consensus-building" approach requires an interactive process, in order to gather the full range of required information and negotiate among stakeholders (Claure et al. 2001, Gutiérrez & Hoogendam 1998, Kimani & Ubels 1993, Raj Khanal 2003, Smulders 1998).

Social effects: the simplest way to understand that irrigation infrastructure has social effects is that the purpose of the project is to improve people's living conditions, by assuring better production and providing water for different uses (irrigation, to water cattle and for human consumption). The effects depend on projects' characteristics and operation, including environmental impacts. The environmental impact of irrigated agriculture can be divided into four categories (Guijt & Thompson, 1994): changes in the soil, changes in surface and underground water, socio-economic impacts and effects on wildlife.

Sociotechnical design

The sociotechnical approach also brings a focus on the design of technology. Papanek (1997, p.4) says, design in its most basic sense is ''the deliberate, intuitive effort to impose meaningful order'', involving imagining and representing an artefact also with purposeful action to serve a function, achieve an outcome or solve a problem (Shah, 2003). The design of technology thus involves reflection on the ordering of technical and social knowledge and principles related to its development as well as to the physical composition of its practical parts (Vincent, 2005).

The research framework is based on the fact that irrigation system design has two main dimensions:

1) **The contents dimension,** regarding **results** and involving the following main elements:

a) Infrastructure design, covering the physical setting of irrigation with both structures and their related layout with farm plots (Levine and Coward 1986, Zaag van der 1992);

b) Future water management design, related to the social organisation created to enable irrigation activities (Levine and Coward 1986, Eggink & Ubels 1984). The term 'Management capability' is used here to cover the collective capacity, skills and practices of social organisation for water management, given productive and political settings

c) Design of the agricultural production system under irrigation, which also involves seeing irrigated agriculture in the wider context of production and deployment of household resources (Burawoy 1985).

2) The process dimension, which studies **the ways that decisions are made.** This includes attention to the stakeholders involved in the process, their interests, positions, roles and activities leading to design outcomes.

Whether planning interventions that create new or transforming existing systems, these two dimensions are inseparable. However, for programmatic and methodological reasons, the overall focus of analysis in this research is on the **content dimension** and, within this dimension, specifically **infrastructure design** and how its changes relate with accepted changes in production and social organisation. It builds around the concept of 'appropriateness' of technology, in both how a system is appropriate and suitable to current needs but also how (and whether) farmers can transform a system themselves, or re-appropriate their system after its transformation, to run it themselves as relevant to local principles and practices.

For this purpose, the following main research areas are developed to focus on the operational, material and productive dimensions between infrastructure and management (see Figure 1.4):

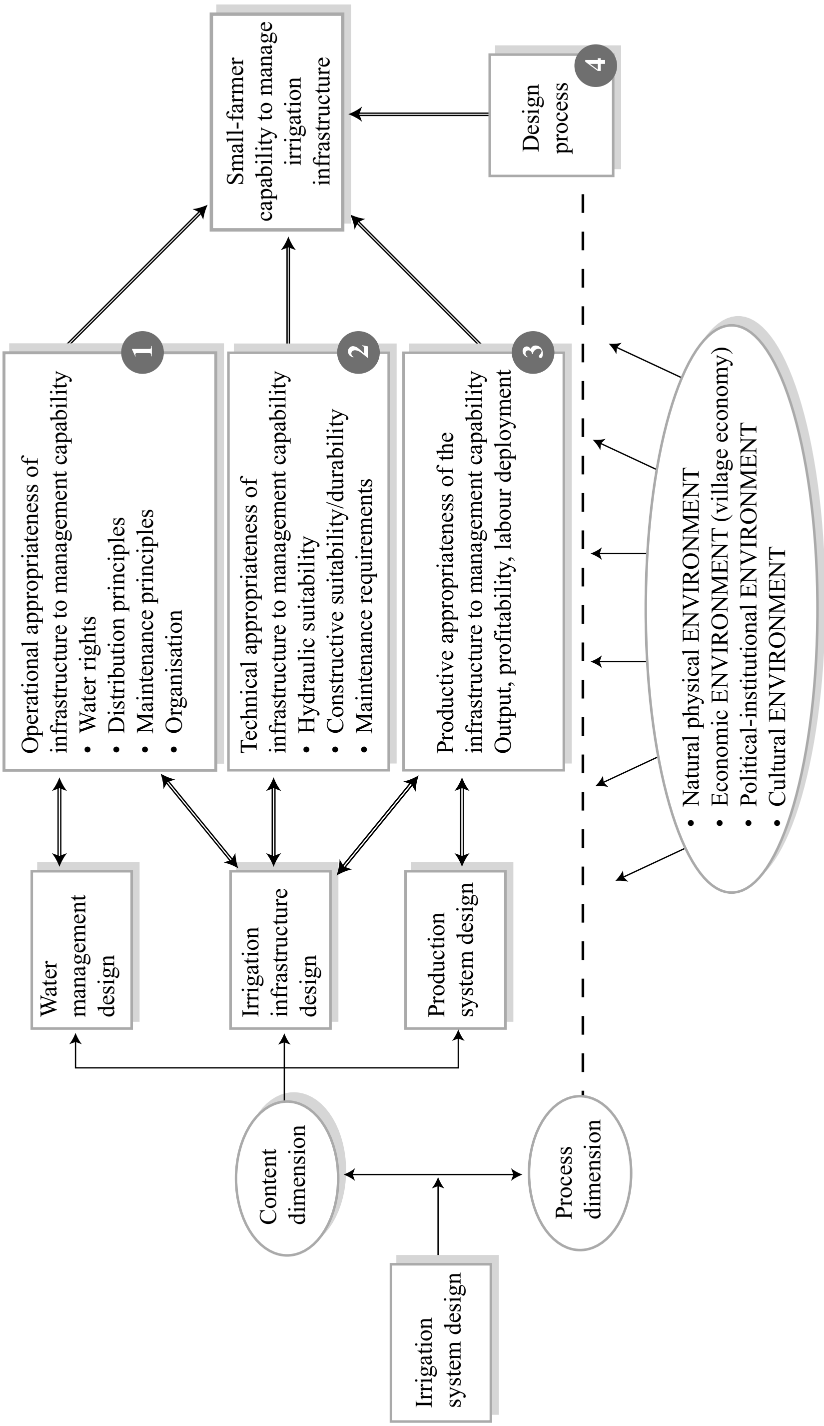
1. Operational appropriateness of infrastructure to management capability (related to operations and functionality of a system). These are the institutional characteristics that are embedded in the infrastructure; appropriateness refers to the requirements for use of infrastructure improvements at system and local device level in relation to users' management capability, especially in rights, rules, roles organizational forms and work needed to ensure water delivery and self-administration.

2. Technical appropriateness of infrastructure to management capability. These are the technical characteristics of improved physical settings in relation to management capability, as reflected in their hydraulic and constructive suitability and potential in relation to the environment, and their maintenance requirements.

3. Productive appropriateness of infrastructure in relation to management capability. This involves the possibilities for inter-related transformations of production options and management institutions with improved infrastructure.

The following figure shows how these concepts inter-relate: how small-farmer infrastructure management capability is related to the content dimension: design of management, design of technical infrastructure, and design of the agricultural production system. Small-farmer infrastructure management capacity is also related to the design process dimension.

Figure 1.4 Outline of the research framework



1.4.1 Operational appropriateness of infrastructure to management capability

This refers to the relationship between the infrastructure and its suitability or relevance from the management standpoint. To determine the infrastructure's appropriateness to management capability, it is necessary to analyze possibilities and restrictions regarding organisational capability, water distribution and necessary maintenance practices regarding the designed infrastructure, to guarantee that the irrigation system can continue to function sustainably under community management. Findings of the research on water management in irrigation systems under small-farmer management lead to the conclusion that each system has a particular water management system. However, there are a series of common water management principles or criteria shaped by aspects of the environment, mainly cultural, social and economic.

These management principles are also design principles, when changes are made in the irrigation system. For institutions that make interventions in small-farmer irrigation systems, it is important to analyse these principles, since the new or renewed infrastructure's appropriateness to management capability will largely depend on whether these principles remain in effect in the improved irrigation system.

To examine this issue, it is useful first to define the concept of "water management", and particularly "small-farmer water management" (*gestión campesina de agua*), as used in this study. Subsequently, I will refer to the "water management capability" concretely.

The concept of water management

Several aspects of water management have been conceptualised, on the basis of numerous studies and various irrigation systems (Arratia & Gutiérrez 1997, Arroyo 1999, Boelens 1998b, Boelens & Doornbos 1996, Dixhoorn 1996, Gerbrandy 1998, Gerbrandy & Hoogendam 1999, Golte & De la Cadena 1983, Gutiérrez & Bustamante 1999, Hoogendam 1999). The definition presented by Gerbrandy & Hoogendam (1998, p. 230) based on studies of irrigation systems in Bolivia is the one chosen for this research, namely:

"Water management is a form of social interaction:

among different stakeholders, using different methods, resources and strategies,

- *about water use and distribution activities,*
- *taking place in a given socio-technical system, consisting of a series of settings for interaction, which have:*
    - *a spatial dimension in terms of the social hydraulic levels of the irrigation system (system, group of households, households), and*
    - *a time dimension, linked to the agro-ecological cycle and the water delivery rate, and*
    - *rooted in the culture, in the agrarian structure, in the institutional infrastructure of public and private entities and in material infrastructure (ecology, technology), continually produced and transformed through interaction."*

Taking this concept into account, in small-farmer irrigation systems in Bolivia, the main domain in which the irrigation system is imbedded is the rural community. Within the community, small farmers live and work together and organise to attain their goals in life and production. Co-ordination of families living together is expressed at the community level, in social relations among co-existing households and in the delimitation of physical space. Most resources in this setting are under members' control, who organise distribution of use and access to resources, or seek to control them. In the case of water, small-farmer water management is shaped by communities' socio-territorial organisation, since the community where the water source is located has the greatest right to use it.

Water management is just one more activity within community management in general. At the community level, water management includes such activities as: defining rights, distributing water, maintaining and reconstructing infrastructure, and organising users. Water management is organised as a community effort, and includes water-related rituals. Rituals are part of the activities of management, and are carried out for and by the users of the irrigation system. Water management capability thus here relates with how farmers chose to build this social organisation and have preferred practices that embed and maintain important social principles and are feasible within local coping strategies for economic survival.

Such collective, community-based, farmer-managed systems have also been referred to as communal irrigation systems (Coward & Levine 1989). Egginks & Ubels (1984) summarise how operational management can be studied through the rights, maintenance and conflict resolution practices in irrigation systems as shaped by specific roles and powerful groups. In the case studies the following concepts will be used to know the operational management: water rights, organisation, distribution & operation and maintenance.

Water rights: linkages between infrastructure and water access

According to Gerbrandy & Hoogendam (1998: page 113) water rights are *"An authorised claim to the flow of benefits from a water source"*. The flow of benefits means the water that can be obtained from a water source. There is the possibility of extracting water from this source, which may be used for all kinds of applications (Ibid.). There are water rights if this removal of water is authorised, that is when a certain group of people have agreed that someone may use it. Therefore, rights are also an institutionalised phenomenon, not just a one-time, one-person matter. In all cases, the action falls within a pattern of agreements with others (Ibid.). In principle, water rights are an abstract concept, a claim to appropriate something, to use an amount of water. Rights may be used personally, traded or sold (Ibid.).

Arratia & Gutiérrez (1997) indicate that water rights are understood as an *"authorised claim"* and *"permitted use"* of water, collectively. This permission is granted on the basis of requirements and agreements established by the community. Rights may be considered, in practice, as a volume of water reaching the community and redistributed on the basis of such agreements.

Gerbrandy & Hoogendam (1998) explain that just having water rights is not enough to be able to use them. Three further things are essential:

- Infrastructure and technical facilities (water intake, canals, etc.).
- Agreements, norms, and rules to regulate different persons' water claims.
- Labour to operate the infrastructure, implement rules and direct the water.

Without infrastructure or technical facilities, water rights are not effective. The water must be obtained and transported. However, infrastructure and technical facilities make water rights complicated. Therefore, there are rights regarding canal usage as well.

Sometimes these rights seem to coincide with the time-frame of water rights: having water rights implies, in such cases, that the canals needed to transport the water can be used. This is not always the case. In many situations, there is a distinction between water rights and infrastructure use rights. If one community refuses to let another through in order to improve its conveyance, for example, this can be seen as water rights without the right to use part of the infrastructure.

Water rights are social relationships between water and people, but above all among people (social relationships). Water rights indicate who can and cannot use water. Therefore, water rights are part of social arrangements about resource distribution. Some people are allowed to use a resource – in this case, water – and others are excluded from this use. In the case of water rights, this relationship is essentially social, so water rights should be considered as part of an overall whole of social relationships at a given time in a community. Water rights acquisition, water rights contents, and water rights distribution are all aspects that are closely related to the prevailing social organisation. Accordingly, it is also clear that water rights reflect community organisation. When somebody speaks of water rights acquisition, the notion immediately relates to the idea of buying and selling, business deals, etc. However, here I am using the term "acquisition" not only in reference to ownership, but also to the different situations by which a family may be authorised by the collective body to use water. These relations are explored further in Chapter 2.

Rights creation mechanisms are related to the concept of water rights acquisition, with the difference that the concept of creating rights refers to change situations in which some action generates new rights. The concept of hydraulic property can help explain rights creation mechanisms. (Abeyrante 1990, Boelens 2001, Claure et al. 2001, Coward 1986a c, Gerbrandy & Hoogendam 2001, Hecht 1990, Pradhan 1987). These concepts are especially important in situations of outside intervention. Every time that irrigation systems are improved the question arises whether the new investment (labour or money) will create new water rights.

Hydraulic property refers to the existence of property relationships between people and irrigation structures (water source, infrastructure and the water itself) and among people sharing access to these irrigation structures. Dams, intakes, canals and so on are the property owned. Creation of property that is owned (through property relations) enables people to acquire ownership rights, rights to use objects and/or rights to exclude other potential users. (Coward 1985, 1990, Gerbrandy & Hoogendam 2001, Pradhan 1987)

To improve most irrigation systems, it is essential for property rights (translated into water rights) to be created during a construction process (creating objects of ownership). According to authors who have applied the hydraulic property concept (Coward 1986a, b, Hecht 1990, Pradhan 1987), if property rights to water and land are clear, users will take full responsibility for the irrigation system (and therefore conserve their rights). Conversely, if these rights are unclear (which often happens in external irrigation intervention projects when future rights are not defined clearly beforehand), existing property rights can be destroyed, leading people to oppose infrastructure construction and to dispute water distribution after the intervention. Conversely, intervention projects can assume new water rights are easily negotiable for new farmers acquiring water in an extended irrigation system: however these also have to be renegotiated.

Water management roles and organisation

Organisation for irrigation depends especially on requirements resulting from water distribution and infrastructure maintenance. In some cases, organisation is mainly geared toward distribution needs and in others toward maintenance needs. However, organisation must be grounded in clear definition of all users' water rights, since these are the normative foundation for user-management of the system. These characteristics enable irrigation systems to be user-managed. One important criterion in water distribution within small-farmer irrigation systems is the possibility for users to wholly control the system. In all cases, the users themselves distribute the water. That is, in most systems, men, women, elderly people and children all know the agreements, rules, and norms governing distribution, which are very clear. Chapter 2 gives a more detailed overview of a framework that studies roles in different fields of water distribution, maintenance and, conflict resolution, and the structure of organisational levels that can emerge in more complex communities managing multiple sources.

Management practices for water distribution: water distribution delivery and operation

Distributing water is the practical expression of the apparently abstract concept of the *operational* part of water management, referring to how the irrigation system works when water is conducted by users from the source and distributed for use. During distribution, water rights are visibly expressed, in practice, revealing agreements and conflicts, and the persons responsible for this management have to act. It is also during distribution that the infrastructure's management or operation can be seen. Taking these aspects into account, Claure & Gutiérrez (1995) define water distribution as follows: Distribution comprises all infrastructure management activities (opening gates, regulating flow, etc.), all social activities that users organise to distribute water (delegating responsibilities, overseeing distribution) and the norms, agreements and criteria governing delivery of water. Two main aspects may be distinguished within this concept: the more evident one, which is generally considered in irrigation projects, directly involves *infrastructure operation.* The other, less perceptible one, which is generally not taken into account in irrigation projects, involves organisation and agreements for *water distribution delivery.*

Water distribution operation, in the control of infrastructure is generally simple and requires no skilled personnel in the small systems of Bolivia.

Water distribution delivery is crucial in an irrigation system, as the time when water use acquires a collective dimension to ensure all farmers can get water to their fields. This is a fundamental issue, not only as a starting point for social analysis of irrigation in Andean regions, but also to resolve the huge challenges posed by rehabilitating or improving existing irrigation systems or creating new ones. It is important to know what concepts or criteria small farmers use to determine how they will distribute water, with what conditioning factors.

Water distribution is system-specific: chapter 2 provides an overview and first attempt to differentiate practices, in relation to (a) water delivery method; (b) small farmer water distribution practices.

Maintenance of the infrastructure

Carruthers and Morrison (1994) say that maintenance is a management response to the deterioration of the physical condition of the irrigation system that threatens to make it impossible to achieve operational targets. Small-farmer irrigation system maintenance is an activity for all users, to ensure that the infrastructure is in a position to get the water from the source to their farms. In most small-farmer irrigation systems, the infrastructure comprises un-lined dirt ditches made of local materials. For this reason, irrigation system maintenance concentrates on "cleaning" ditches, rebuilding intakes and in some cases repairing reservoirs. But when the infrastructure is improved it requires other types of maintenance: preventive maintenance and routine maintenance. Routine maintenance includes all regular work necessary to keep irrigation systems functioning satisfactorily. Preventive maintenance dealing with the causes of maintenance needs to be done before they accumulate to become a major problem. Chapter 2 provides more detailed overview of the maintenance theme.

Water management principle

Management principles are understood here as the basic or fundamental criteria underpinning agreements and activities that shape water management, as expressed in a range of specific rules and practices for each irrigation system. These practices show how small farmers cope in difficult environments, which are often different from practices addressed by engineers seeking to optimize technology performance (Richards 1993; Wahaj 2001). Infrastructure design requirements for use regarding the organisation's management capability are evaluated by analysing those criteria, but needs to address farmers concerns. The criteria found in small-farmer irrigation systems include:

Transparency: An irrigation system is transparent when users (men, women, elderly and often children) understand how the infrastructure works and how the irrigation system is managed. Users understand and undertake the foundations for water allocation, understand and take part in operation / water distribution, and also maintain the irrigation infrastructure. (Gutiérrez & Gerbrandy 1998a, b).

Minimising conflicts: This is the capacity to avoid disputes, a feature that usually has its social and technical expressions in irrigation systems with traditional infrastructure. In this regard, Vermillion (quoted by Yoder & Thurston (1989) says that farmers prefer to minimise the division of canals and levels in system hierarchy.

Equity: There is equity if the existing infrastructure enables people to exercise their water rights under conditions deemed fair by different user groups. In improved systems, there is equity if users are satisfied that the improved or built infrastructure meets their expectations (Levine 1989). It is also important to take into account how obligations are distributed and particularly the responsibilities for maintaining facilities, as a function of the benefit to each user, because this will ensure equity in the improved system. Design must take into account how small farmers understand equity. Horst (1987,1996 b) mentions how negotiation and agreements on water rights must be discussed as a top priority, and infrastructure to distribute water must be based on these water rights conditions.

Usage capability: People's ability to assimilate the technology, which calls for: organisation, knowledge and resources.

Sustainability: The ability to mobilise users' own resources (knowledge, money, labour, material) to meet needs to continue operating and maintaining the improved irrigation system.

A fuller study of all water management practices found in Bolivia is given in Chapter 2.

The following table elaborates the analytical framework used to compare structures of management before and after the improvement projects in the cases studies. It extends the framework of Eggink & Ubels (1984) to study the rules, roles and dominant groups. A new scheme activity is introduced: system operation & distribution.

Table 1.4 Communal irrigation management analyses

Scheme activities / Organisation	Water allocation	System operation & distribution	System mantenance	Conflict management	Construction & rehabilitation
Decisions & tasks	Decisions that users have to make and tasks that have to be executed in order to realize the different system activities				
Formal rules	Formal rules that exist to govern decision-making and task-execution in all system activities				
Participants	The actors who participate in decision–making, task–execution, the needed contribution and the resulting benefits in all system activities				
Logic and informal rules	Logic and mechanisms that govern the actual functioning irrigation system in all the systems activities				

Source: Adapted from Eggink & Ubels (1984).

1.4.2 Technical appropriateness of infrastructure to management capability

This is explored through hydraulic and constructive suitability and maintenance requirements.

Hydraulic suitability in relation to management capability

Hydraulic suitability describes the capacity of the irrigation system's physical structure and of each facility[9] to meet the hydraulic requirements expressed in proper operation, taking into account, especially, the requirements for management and irrigation practices according to agricultural production in a given zone (Bottega & Hoogendam 2004, Gutiérrez, Alarcón &Saldías 2003, Sánchez et al. 2002 a, b). Moreover, a facility is suitable when it makes alternatives possible, both in distribution and in agricultural production. A facility also has hydraulic suitability if it goes along with the physical environment's conditions, reducing operating and maintenance requirements. Chapter 2 gives an overview of the range of water control facilities used in community schemes in Bolivia. To assess the infrastructure's hydraulic possibilities and management requirements, aspects of distribution capability (division and operation) and maintenance capability are analysed.

Distribution capability

To analyse the distribution capability (division and operation) as a function of hydraulic suitability of the infrastructure, the following aspects are considered:

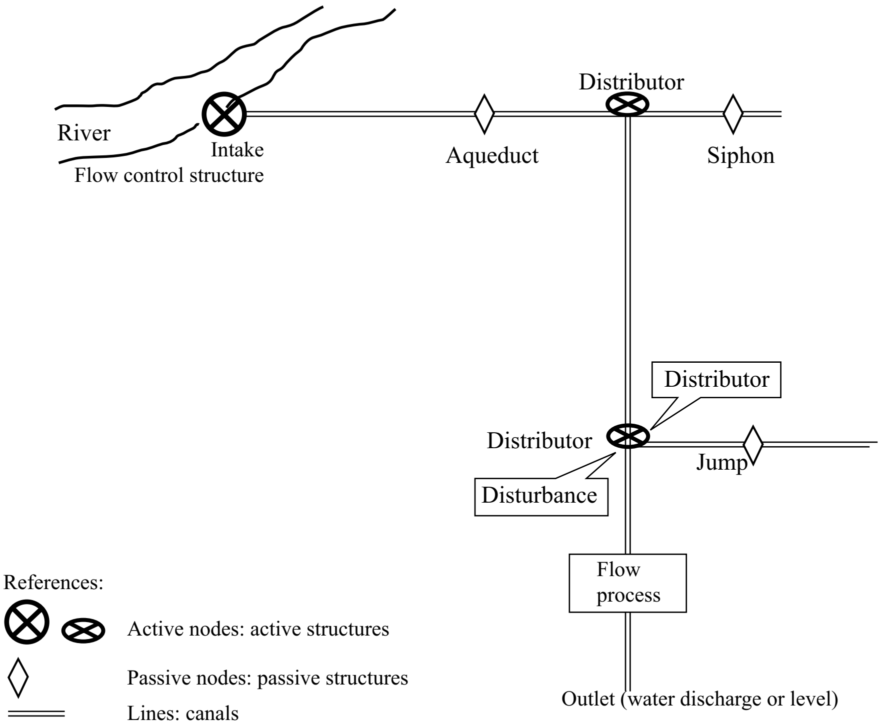
9 A facility is a hydraulic structure to perform different functions. There are regulation facilities (dams and diversion dams), catchment facilities (different types of intakes, undersluice filtering galleries, breakwaters), conveyance facilities (canals, siphons, aqueducts, energy dissipations), division and control structures, measurement facilities (different types of gauges), and protection facilities (silt traps, hydraulic jumps).

The design flow rate and actual flow rate, with the former as the conveyance capacity of the facility. It is common practice for the design flow rate to be the result of calculation of the crop irrigation requirement (Horst 1996b). To calculate crop irrigation requirements, a series of coefficients or indices are also assumed, such as Kc's, efficiencies and so on (Gurovich 1985, Grassi 1988, Lavín 1983, Proyecto Limeta 1997, Proyecto Zapallar 1993, Proyecto Ascapa 1998). In the case of small-farmer irrigation systems in Bolivia, especially in systems with water sources that vary seasonally, the design flow rate is set as the peak flow (maximum supply). Therefore, a project has hydraulic suitability if the design flow rate will cover all irrigation practices required by users and makes it possible to use the infrastructure both during the dry (low-flow) and rainy (high-flow) seasons.

Facility functionality: A facility is said to be functional if its characteristics enable it to work optimally. That is, if facilities have the capacity to conduct water as desired and can be operated according to agreed-upon rules. In Bolivia, as Bottega & Hoogendam (2004) indicate, a facility is functional if it is adapted to the particular conditions of Bolivia's mountainous zone. The particular conditions for irrigation in the mountains concern topography, hydrology and geomorphology.

Operation of the infrastructure as a system: Reviewing "irrigation project" documents, one finds a flaw in failure to conceptualise the "system" of interlinkage in facility design. An infrastructure system comprises nodes and interconnected lines as shown in the following figure.

Figure 1.5 Diagram of irrigation network and flow process



Prepared by the author on the basis of Ankum (1995)

Lines are ducts on which the nodes are located. Under good conditions, nodes may be "passive" or "active". They are passive when they do not affect or influence system operation and active when they do. In irrigation infrastructure, lines are canals and nodes are the facilities located on them. Proper design of linkages indicates that hydraulic operating principles are clear to the designer and can be explained in the field. Active nodes include control and distribution facilities. Water flow through these structures may be called the "control process" (Ankum, 1995). The "result of the process" is the water discharge or level. These points need to be operated or manipulated and thus directly influence system operation. They are necessary to keep the system in a given state. The "regulator" has to guarantee that the water flow rate is not affected by "disturbances". A disturbance is a factor directly influencing flow, meaning that the "regulator" has to correct the flow. Then, the "regulator" influences the control process. The "controller" can be a human operator (intake caretaker) or can be hydro-mechanical or automatic. The "controller" sends appropriate control signals to the "regulator". These "active facilities" interact to influence canals and passive facilities. These passive facilities (siphons, aqueducts, bridges, drops, rapids) have their own characteristics, but do not define the other system elements.

For research purposes, the concept of network system will be useful, in big systems or irrigation zones with more than two irrigation systems, but which have common infrastructure. In small systems, the concept has limitations on its application. Nevertheless, when analysing irrigation infrastructure, it will be analysed as a system, including its operation.

Constructive suitability in regard to management capability

This refers to facilities' capacity to fit in with the physical characteristics of the local area or physical context, so they will work properly and the users will be able to operate and maintain them adequately. Important concepts within constructive suitability are risk engineering, safety and quality:

Risk engineering in mountain zones:

Yoder (1994) defined this as the science and art of providing for considerations of the natural and human process, and tolerable risks caused and affected by the infrastructure.

Risk engineering in the mountains means that design must analyse and assess aspects such as: 1. risks of landslides caused by building irrigation canals and other facilities, 2. losses of economic investments and labour due to natural landslides, and 3. costs per hectare to control erosion / landslides, including facilities to protect the area of influence of the irrigation infrastructure. Analysing these elements makes it possible to select an appropriate route for the physical irrigation system, based on a risk assessment. It also makes it possible to determine how to build the protective infrastructure in order to minimise environmental degradation (Yoder, 1994).

Yoder (1994) also mentions that infrastructure confronts risks and hazards caused by natural forces, and that cost of construction and maintenance are also affected by risks. He proposed two ways to incorporate the issue of risks into economic analysis, to obtain realistic cost-benefit estimates.

Risk factors: This comprises the elements that could keep the physical system and facilities from meeting their hydraulic requirements. Especially in the Andean zone, there are many factors that jeopardise facility operation, such as landslides, sedimentation, and erosion. During construction of the facilities, it is necessary to consider the magnitude of the risk, which may be high, medium or nil. This will orient the builders to take into account the need to build protection facilities, under a prevention plan.

Prevention plan: This refers to construction measures to reduce the construction risk, so that the physical system and facilities will meet hydraulic requirements. For example, within the prevention plan, there is "gully management". This is a major problem arising when building hydraulic projects in the Andean zone. It is also important to consider the high-water levels of rivers, and hillside slopes that may collapse and slough down.

Safety

A project is safe if it is free of all dangers or risks and, if there are failures, they will not cause accidents. Safety is especially important in the mountains, in view of soil instability and high risks of erosion on sloping hillsides when water is dammed up. In this regard, Bottega & Hoogendam (2004) indicate that safety measures in design cover a range, including: locating flow control facilities, reinforcing structures, building protection facilities (e.g. retaining walls), providing pipes for flow through canals in unstable zones, and implementing protective measures to prevent personal accidents. To avoid problems with water damming, design must include "safe drainage routes", to guarantee that no damage will happen even when the system does not work properly.

Quality

Good quality means that projects will be durable and strong enough to withstand environmental conditions. Bottega & Hoogendam (2004) say that it has been proven that most defects in facilities result from deficient construction rather than bad design. They add that it is good practice to involve future users in quality control of projects to ensure that they will influence the construction results. Users usually have a good idea of what could go wrong with projects, because they are involved in the work and are deeply familiar with the local environment; this expertise should be tapped.

Maintenance Capability

To analyse this dimension of the infrastructure, the following elements are considered:

Facility sizing: The facility's dimensions, as well as satisfying the hydraulic design, make maintenance practices possible. For example, too deep a canal will require too much effort by users when they have to clean out sediments manually.

Sedimentation and weed growth*:* Sedimentation is a common problem in irrigation systems. Horst (1998) says that water division structures are generally points of discontinuity in flow rate, and rates decrease in weirs, causing sediment deposition upstream from the structure. The same effect is observed when weed growth reduces the hydraulic cross section of canals.

Completeness of the facility: A complete facility can operate properly and calls for less maintenance. Although this may seem too obvious to mention, many facilities do not have all their elements (e.g. intakes without sand traps, Monroy et al. 2002). This makes it more difficult for the facility and the system overall to operate, and increases maintenance requirements.

Facility location: When a facility is located in the right place, it can perform the function for which it was designed. In Bolivia, this is a key aspect, especially in locating intakes, because of river characteristics. A properly located facility will decrease maintenance requirements.

Relevance: A facility is relevant when it fits the functional needs and environment's physical conditions. For example, a Tyrolian intake is advisable when the river has steep slopes. When the facility is relevant, this reduces maintenance requirements.

Infrastructure criteria that facilitate distribution and maintenance

These are some infrastructure criteria that facilitate management:

Flexibility: This is the capacity of the physical system to adapt in response to users' changing water needs. It must also adapt to future production plan requirements (e.g. new crops). The physical design or infrastructure is flexible when it allows variable water distribution during high- and low-flow periods, as in Andean small-farmer irrigation systems. A system is also flexible if it allows multiple uses of water (agriculture, home supply, livestock watering). Also, as Horst (1998) puts it, *"a good design can adjust to fluctuating conditions of resources available to operate and maintain the system"*.

Idle capacity (redundancy): This refers to the physical system's capacity to enable multiple uses of different water sources and to combine different functions. For example, a canal may be used for conveyance and drainage or irrigation delivery. Along with this concept, there is, for example, the practice of small farmers who leave alternatives when they build facilities, so that the system can continue operating in the event of temporary repairs or partial failures.

Functionality: A facility is functional when it meets the requirements of the small farmers for whom it has been built or improved. For instance, building an intake must avoid the need for labour to continually reconstruct it, which was the case before it was upgraded, or a canal's lining should enable the water to reach land located further from the water source.

Maintainability: This is users' ability to keep the facilities operating properly. Bottega & Hoogendam (2004) indicate that a facility's maintainability is not only an intrinsic characteristic, but also depends on users' capacity to mobilise the necessary resources for required tasks: labour, local materials, cash for outside materials or services, and the necessary knowledge and skills to make repairs. In designing facilities, engineers and users must analyse their future maintenance requirements. It is essential for them to jointly ascertain whether users are going to be able to mobilise sufficient resources to maintain the facilities.

Visibility: This refers to the degree to which users have a clear view of how the facility and the combination of facilities (system) work. For example, a distributor that divides the water into two canals must have at least two gauges, one on each of these canals, so the farmers can be sure that they are receiving the proper amount of water and the facilities are operating correctly.

The applicability of the above indicators for hydraulic and constructive suitability and maintenance has not been tested in Andean irrigation systems so far. In the case studies, **qualitative surveys are described for the infrastructure,** to show both their hydraulic and constructive suitability and maintenance requirements. In addition a resource budget has been costed for maintenance of improved infrastructure.

1.4.3 Productive appropriateness of infrastructure in relation to management capability

This entails the capacity of physical and institutional settings to be reformulated to management capability that also enables new production scenarios, expressed in time and space. Production scenarios are translated into water distribution scenarios, and the physical system limits or enables production scenarios. However both are mediated by the feasibility of institutional change given wider economic, agrarian and political relations, and whether transaction costs of change can be overcome (Steenbergen, 2002). It is the profitability of new production and availability of labour after improvements that shapes how labour and money are invested in local production, in system maintenance, or are taken to other production systems.

One limiting factor in agricultural production in Andean areas is the low availability of water and irregular rainfall pattern during the planting season. For this reason, rural dwellers consider that one of their main needs is to improve their irrigation systems or build new ones. New markets, other work opportunities and new institutional support also influence production.

The characteristics of agricultural production are also determined by farmers' thinking, expressed in their production goals. They will try to cover their self-supply needs (part of their natural subsistence strategy) because they need to make sure that they can live on the output of their own diversified production activities. At the same time, demand for other consumer goods and services that they cannot produce, due to the agro-ecological conditions of their setting and the introduction of new consumption habits, is growing. For this purpose, in general, they exchange part of their production for other goods (or for money), both from other small farmers and from manufacturers, mainly through market mechanisms. However, there are economies that are highly inserted in the market, which calls for cash crop production. In this case, the production approach will be conditioned (among other factors) by the market's economic forces. Farmers' thinking and production decisions are not static, but vary as their relations with the wider economy and environment change. In this case, they influence, among others, through greater market insertion, production of market-oriented crops, migration and other agrarian and economic transformations.

In this process, the (greater or lesser) availability and access to resources (land, labour, capital and water) will "shape" the construction of the new "production scenario" and will determine, among other factors:

- expansion (or not) of land area under irrigation
- the degree of diversification of agricultural production
- favourable modification of growing schedules
- increase (or not) in yields

In this way, irrigation projects influence or shape new production scenarios. Moreover, access to and availability of water contribute to preventing risks (resulting from pests, adverse climatic factors and fluctuation of market prices) by changing growing seasons and enabling production diversification. These new scenarios are shaped by access to resources and local production modes, procedures and techniques (such as using appropriate inputs, production technologies and work organisation) to produce new crops (diversifying production). In conventional irrigation project design, many assumptions involve the availability of agricultural inputs, services, prices, transport, communications channels, etc. Some decisions during the design may be based on those assumptions. However, usually such assumptions are not realistic. As Ellis (1993) points out, in "developing" countries, markets are imperfect and incomplete. Therefore, mechanisms regulating supply and demand do not work adequately, and farmers may face a series of hurdles in input or spare part supply, as well as restrictions on sale of their produce, through low prices, inadequate services, or simply lack of information.

Farmers also make choices in how they invest new earnings or labour availability into irrigated agriculture, or other income-generating activities. They may invest in new equipment to assist irrigation, such as pumps, or new tools and inputs from cultivation. Many projects assume that new income can be reinvested in the system, through payments of fees for water that assist maintenance or cover new administrative costs. However, there can be high transaction costs in getting people to contribute funds where earlier only labour was contributed, especially as political and agrarian relations change (Steenbergen, 2002), while high inflation, lack of banks and security questions also limit people's faith in maintaining bank accounts. Farmers' actions and decisions are thus considered as rational responses (rational from their own point of view and under their particular production conditions) to their problems, according to available resources (including local and outside expertise regarding farm management) and according to their production and reproduction goals. They make decisions on the basis of their experiences and those of others, seeking solutions to production and socio-economic problems that are appropriate according to their perception and interpretation of phenomena.

These conditions structuring small-farmer economies have been summarised, according to Boelens (1998c), as:

- Insertion in the overall economy
- Heterogeneity of farmers and their production strategies
- Reproduction of the family unit and community
- The household as a unit for work, production and consumption
- Diversification of activities and outputs within the household and community
- Interdependence of production activities.

Given the earlier emphasis on the communal and local characteristics of the small-farmer economy, in the field of irrigation it is germane to explain why is it so important to thoroughly understand the interaction between the "market" and the "community" in rural economies, and the consequences for sustainable reproduction. Irrigation projects are usually geared toward future cash crops, in terms of bought-in inputs and produce for market. Boelens 1998, pp. 250-256 writes *"… because of the internal logic of development assistance, they are merely obliged to project this transformation toward the market, simply because only projects deemed profitable are funded (those that can produce the economic means to recover both O&M costs and investment costs). This often results in blaming the farmers when economic outputs are not as (unrealistically) high as expected. Still, it is not always and necessarily problematic for small holders that irrigation leads to greater market involvement. Small farmers' own strategies also require dealings with the market, in order to supplement the resources they need for their families' and communities reproduction. Therefore, those farmer strategies that seek to maintain control over their own management amidst insertion in market relations are grounded in a) strengthening "local control" over designs of why, how, where, and when to deal with the market, b) materialising concrete potential for collective, equitable, organised market access, and c) striking the required balance in interaction between the market and the community, considering that the latter is the fundamental foundation, both for reproduction of the collective body and its parts, and for dealing with the market without losing self-management capacity".* (Ibid. 1998: pp. 250 –256)

Irrigation projects project future economic income on the basis of assumed future agricultural production. Consequently, they plan operation and maintenance and justify economic investments on this basis. For this study, it is useful therefore to evaluate what changes improved irrigation systems have meant for agricultural production, expressed in irrigated area, crop profile, agricultural calendar, yields and income.

Thus to evaluate the productive appropriateness of infrastructure to management capability, the study analyses:

- The productive scenario promoted and local community economy;

- **Achievement of farmers' production goals** in terms of positive changes in the production scenario, through water distribution scenarios and an analysis of constraints on or possibilities for achieving them, resulting from the infrastructure.

- Household net income and labour availability increment, regarding increased net income and labour released from maintenance due to improved irrigation systems, enabling them to contribute economically to maintain the infrastructure. The net household income from irrigation is related with local income necessary for basic needs, to explore whether farmers might invest income further into irrigation and new maintenance or deploy their resources elsewhere to increase their livelihood options.

1.5 RESEARCH METHODOLOGY

The research context

To understand this study's methodology, it is necessary to look back at how this effort developed. The story began when I had been accepted by the Department of Irrigation of Wageningen University for my doctorate. Unfortunately, for reasons unknown to me, the Agronomy Department of St. Simon University (Universidad Mayor de San Simón) did not authorise me to pursue this plan. This situation forced me to resign as a researcher / university teacher in the PEIRAV Programme (an agreement between St. Simon and Wageningen Universities) and continue with my plans under support from Wageningen University, who raised funding for my research.

Once my proposal was approved, I returned to Bolivia, with the idea of continuing, but with no budget to conduct the research. Fortunately, the activities that PRONAR was implementing included an Applied Research subcomponent, so they opened a competitive selection process for a research director. I applied and was chosen. I began work by preparing the Research Programme, with four themes, each covering several issues, a total of 27 research studies. For each research effort, I was responsible for preparing the proposal, hiring the researchers, monitoring fieldwork, reviewing information and jointly preparing, along with the researchers, the documents resulting from the research.

Conducting the different studies under the four themes enabled me, while doing my work as Applied Research Officer, to also gather my own research information. This situation set the format of my work, because I did not remain with any of the cases for a long period of time, but visited them repeatedly for shorter periods. On the contrary, every time I had the opportunity to go somewhere for one study or another, I took advantage of the occasion to collect information. This is why the dates appearing in the document are so varied. The information collected covers a three-year period (2000 - 2002). Additionally, the information obtained by researchers engaged for other topics as referred to in the studies. For example, in the Caigua irrigation system, several studies were conducted, including: determination of the crop coefficient and reference evapotranspiration rate (ETo), design and construction criteria for intakes, the greater environment for water management, mathematical models for irrigated agriculture, and the effect of irrigation projects on agriculture. This research yielded information relevant to the present study (infrastructure, water management, agricultural production) which was put to good use.

Fortunately, the fact that the research programme had different themes also put me into contact with researchers from other specialties. In this case, my dealings with civil engineers were significant, enabling me to discuss irrigation infrastructure issues with them. In summary, I was privileged to have input from various researchers generating data and the good fortune of PRONAR's support, enabling me to do my work while conducting my own research. Moreover, PRONAR will also publish this thesis in Spanish. For this research I have also used wider information on small farmer irrigation that I have gathered over years of professional practice. This field information has been used to prepare Chapter 2.

The methodology

The methodology selected for this research undertaking is the case study. This method was chosen because case studies are useful when research seeks to answer questions about "how" and "why" and to understand phenomena that have not yet been researched thoroughly, as is the case here (Yin, 1984).

To select cases, the following aspects were taken into account: 1. Location in different agro-climatic zones (*altiplano*, valleys, mesothermal valleys and *chaco*). 2. Overall diversity of facilities. 3. Working systems. 4. Access to gathering information[10].

Under these indicators, eight cases were first selected, and information was gathered. Subsequently, because eight cases would have been unwieldy, four cases were chosen for more extensive analysis, bearing in mind the initial selection criteria (see table 1.5).

10 Due to problems with the INRA law, people are quite sensitive and hesitant to give information (mainly in the *altiplano* and valleys of Cochabamba). Two systems were selected in Tarija because people were so willing to provide information.

Table 1.5 Irrigation systems researched

Description	Condorchinoka	San Roque - Capellanía	Naranjos Margen Izquierda	Caigua
Agro-ecological zone	Altiplano	Valley	Mesothermal valley	Chaco
Key Infrastructure	Filtration gallery, lined canal, distribution points	Intake modified by users, lined canal, aqueduct, stoplogs	Direct intake, lined canal, siphon, aqueducts, distribution points	Derivation dam-type intake, lined canal, siphon, aqueducts
Distribution Principles	Free delivery in rainy season. Rotation with one flow in dry season. Functions continuously	Free delivery in rainy season. Rotation with one flow in dry season. Functions continuously	Free delivery in rainy season. Rotation with one flow in dry season. Functions continuously	Free delivery in rainy season. Rotation with one flow in dry season. Functions continuously
Basic normative system	Local normative	Local normative	Local normative	Local normative
Local community organisational system	Sindicato[11]	Local Grassroots Organisation OTB	Sindicato	Local Grassroots Organisation OTB

One very important aspect of the methodology used was to carefully establish the methodological framework in great detail, taking into account that this research needed to gather different kinds of information: irrigation management, infrastructure, agricultural production and the intervention process. For each aspect, variables were determined, indicators for the variables, and the technique to be used to gather information. Once the technique was decided, the instruments were prepared for use, with field data sheets for each aspect to be studied.

11 In areas where there were haciendas, the community took over the territory that the hacienda had occupied. In each community, there is some sort of local organisation, which in most cases today is the agrarian union (*sindicato*). At least 70% of communities are organised into agrarian unions. This union, in most places, is the basis for national organisations. In their community assembly, they make all major decisions. Rural unions are generally grouped into sub-central committees, which sometimes follow canton boundaries. These sub-committees in turn are grouped into central committees. Most central committees comprise the sub-central committees of a province, but there are also special central committees that do not follow provincial geographical political boundaries. Central Committees (currently over 200 organised and active) are grouped into Federations. There are nine departmental federations, 26 regional or special federations and several national ones, all of which come together in the Single Union Confederation of Rural Workers of Bolivia (CSUTCB).

To provide relevant information, different techniques were used, including data collection techniques such as interviews and observation in the field and with key actors, and group workshops, as outlined below.

- Interviews of two types: 1) open-ended, asking key informants about facts, opinions about them and suggestions; these interviews also helped identify main issues; and 2) focused, following a sequenced set of questions in order to cover specific issues; many of these questions were then opened out to elicit opinions more freely, whereas others remained more structured.
- Casual meetings, informal conversations and other meetings attended. These activities helped generate ideas and elaborate on ideas emerging from interviews.
- Workshops with all users to know about agricultural production
- Field observation with users, mainly to learn about the characteristics of facilities and their operation.
- Review of files, to examine characteristics of the design process and irrigation system intervention. Different files were used, including project documents with final designs, compilations of memoranda and minutes, books with changes in orders, operation and maintenance manuals, by-laws and regulations.
- Field infrastructure inventories, compiled from system walk-through with representatives
- The minutes from irrigation system meeting
- Operation and maintenance manuals and by-law and regulations of local system management
- Measurements of water flow
- Literature research

Access to secondary information was important, since this research required internal information from PRONAR and FDC, which is generally not available to the public, such as books recording changes in orders during infrastructure construction. Also thanks to PRONAR's carefully organised files, it was possible to access projects' Final Designs. This was not the case with the project document for San Roque - Capellanía.

The structure of this book

In this first chapter the topic of irrigation system design is reviewed, also the analytical framework to study it. To contextualize the research, the characteristics of the study zone and the general characteristics of irrigation in Bolivia are presented. The methodology that guided this research is also explained. Chapter 2 introduces the characteristics of traditional infrastructure and explains the management characteristics (water rights, operation and distribution, organisation and maintenance) on small-farmer irrigation systems, taking into account the four case studies and especially other irrigation systems in different areas of Bolivia. The objective of this chapter is to provide more information to understand the case studies in the following chapters. Chapters 3, 4, 5 and 6 present the cases researched, presenting the irrigation infrastructure, the agricultural production system, water management before and after the intervention, irrigation project proposals regarding future management and the design process in general. These issues are used to analyse, in each case, the appropriateness of infrastructure to management capability. Chapter 7 investigates the appropriateness of infrastructure to management capability, taking into account the results of the case studies using the three dimensions conceptualised: Operational appropriateness in relation to management capability, Technical appropriateness of the infrastructure to management capability and Productive appropriateness of infrastructure to management capability. In closing, Chapter 8 presents the research findings, reflecting on the analytical framework and also presenting some recommendations for intervention practice.

2 TRADITIONAL INFRASTRUCTURE AND SMALL-FARMER IRRIGATION MANAGEMENT IN BOLIVIA

INTRODUCTION

In this chapter two major aspects will be discussed as a framework for this study: traditional infrastructure and small-farmer irrigation management. The issues addressed under each heading characterise irrigation systems in Bolivia in general and the wider experiences which the case studies document in more detail. In this context, irrigation projects intervene to improve existing irrigation systems.

2.1 TRADITIONAL IRRIGATION INFRASTRUCTURE

Irrigation infrastructure in traditional[1] systems is seen by farmers as a system. The irrigation system is constructed in response to availability of water, at maximum and minimum flow rates, i.e. summer and winter, respectively. During the dry season, since water availability decreases considerably, crop areas are smaller than during the rainy season. The infrastructure also enables to different irrigation practices in each zone. For example, when land is flooded to prepare it by depositing topsoil silt, which calls for high flow rates. In turn, the system can also be used for crop irrigation, at lower flow rates (e.g. vegetables) or high flows (e.g. maize and forage that is flooded). Irrigation infrastructure is oriented toward various and multiple uses: irrigation, watering livestock, washing vegetables, driving mills, and drainage.

The system is laid out, first of all, to benefit as many families of the community and the greatest land area possible. For this purpose, they locate the intake upstream, as high as the physical and social conditions (territory) will allow. On this basis, they normally define the number of users with water rights. However, the system is also dynamic, because as users increase and land is brought under cultivation, the network extends gradually. Findings of numerous research studies show that, if there are several water sources in a single zone, it is common to find them using a single system, but avoiding any mixing of water. For this purpose, they set up shifts, to take turns using the infrastructure, thereby minimising conflicts and emphasising transparency. Infrastructure matches social organisation. That is, each community has points of water delivery and canals identified by community members and neighbour communities. The system also goes along with the zone's physical characteristics. A community could have one or more points of delivery, with their respective canals.

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1 The word "traditional" in this thesis is used not as a concept that refers to ancient, static or folkloric properties, but to contemporary and dynamic and small-holder systems that have their roots in Andean management traditions.

Traditional irrigation infrastructure may be grouped into storage, catchment, conveyance and distribution facilities.

Storage facilities commonly built by small farmers are reservoirs, *atajado* reservoirs (small ponds) and larger dams (lakes[2]). *Dams* are normally built at spots where there are natural reservoirs, where they pile stones and sod to increase the storage capacity. To release water, they leave an opening that can be closed using sods, stones and dirt. *Reservoirs* are generally built when the source is a spring, with a low flow rate, too little to irrigate crops directly. These facilities store water for a while in order to release a greater flow rate, enough to get water to croplands. Reservoirs are made with stones and sod. To release water, an opening is left, that is closed with sod, stones and/or logs. In some cases, when they can afford it, reservoirs are made with stonework masonry.

A*tajados* are reservoirs used to store water from hillside runoff, located on sloping land. To build such a reservoir, they dig into the earth, and construct the sides with the excavated dirt. To waterproof the walls, they pack them, sometimes using clay or plastic to prevent seepage. There are also *atajado* reservoirs that take advantage of water from small creeks. For this purpose, they build walls crosswise to stop the water's flow. This is most common in the Tarija region. To release water from atajado reservoirs, they siphon it out with hoses or pumps.

Photo 2.1. *Atajados* in Totora - Cochabamba

Catchment facilities, to abstract water from rivers, small farmers generally place their intake on the creek or river bank. The structure consists of an opening and a canal diagonal to the watercourse. The canal is made of local materials (clay, branches, and stones). Normally, when the water level is high, this damages the structure, and users must continually invest labour to rebuild it. These needs are also found in new facilities materialising through improvement projects, as it will be seen in the case studies presented in this book.

In the altiplano of Potosí and Oruro, rural people have developed an ancient technique to obtain underground water from rivers. This is kind of a filtration gallery, but located right at the surface, in the form of a buried canal. These galleries are called "poteos" and are built with stones piled one on top of the other, forming a vault crossing the river.

Conveyance facilities include canals and aqueducts. Canals or "ditches" are mainly not hierarchically organised, so they are used for conveyance, distribution and application. Canals take radial[3] directions, and users avoid mixing water from different sources. Canals generally

2 In Spanish, farmers call them lagunas.

3 In large systems, where there are two or more communities, although they have one intake, each community wants to have its own channel if the topographic conditions allow. So, there are many channels (one for each community) from the same intake like the spokes of a bicycle wheel.

have an irregular[4] cross-section throughout their length. There is water lost through filtration, but this depends on the soils from which they are built. Ditches use different local materials, mainly dirt and dry masonry. User groups would all like to have lined canals, for which purpose they are always looking for outside funding as presented in the case studies. Depending on land slopes and/or soil characteristics, canals are subject to problems of canal bed erosion. Aqueducts conduct water in places where the terrain requires them, and connect directly with the earthen canal. They are built of different materials: wood, sheet metal, 200-litre metal tanks, and occasionally concrete. Additional aqueducts are a common feature of improvement projects, as presented here in Naranjos Margen Izquierda, Caigua, San Roque - Capellanía.

Distribution facilities. In traditional systems, water is generally distributed by a single flow. There are normally distribution points, used to direct water flow from one canal to the next. These points are normally located at the headwater entrance to the community, the irrigation zone, and the irrigation group. Sometimes these distribution points may be used as water division points. Since they are located on the earthen canals, distribution facilities are part of them, as openings that instead of gates are covered by sod, stone, or sandbags. So, in traditional systems there are no gates.

2.2 SMALL-FARMER IRRIGATION MANAGEMENT

Taking into account that one of the most important aspects of this research is to analyse infrastructure in regard to management capability, it will be useful to first present in detail the concrete characteristics of irrigation management. For this purpose, different cases studied by the researcher over a number of years will be used, emphasising aspects involving water rights and distribution. Organisation is examined in terms of its significance, in particular, for water distribution. Maintenance is also touched on, because the systems studied all clean ditches and commonly build / rebuild the intake.

However, management is also moulded by overall environmental conditions (economic, social, cultural, institutional, and physical). To demonstrate this, examples show how the cultural setting and the economic situation have shaped water management in two different irrigation zones.

2.2.1 Water rights

The concept of water rights and all the elements that are implicit inside this concept were presented in chapter 1 (1.4.1). Here more detail will be given about the concrete aspects related with water rights: water rights as social relationships, acquiring water rights, creation of rights, expression of water rights, variety of rights, rights and access to water.

Water rights as social relationships

The concept of water rights in an irrigation system is influenced by the organizing characteristics of the community. In traditional organizations such as *ayllus* and *capitanías*, management decisions are made on a consensus basis, led by captains, chiefs, *jilacatas*, mayors, and judges, who rotate through these positions. They grant top priority to the community's overall well-being, caring for both the people and their farms.

4 The canal is not the same size throughout its whole length, or the same shape.

Private property has only barely entered these *capitanías* and *ayllus*. Only land has, partially, individual owners[5]. Water is not individually owned. Resource distribution is based on coexisting with resources, without distributing them precisely. Therefore, water belongs to everyone, with distribution agreements that do not assign exact volumes or times to anyone. That is, they share their scarcity, with each family planting a fairly similar amount of land, depending on water availability, so that there will be enough to go around for all.

By contrast, in former hacienda communities (Condorchinoka case study), organisation is based on the agrarian union [*sindicato*] (although there are also aspects of family-type organisation). There is more of a notion of individual land-ownership. Water rights are more individualised, more specific and quantified. They are related to land ownership and land tenure as a consequence of the Agrarian Reform.

However, there are communities organised on the basis of the agrarian union although they were never part of haciendas. They have similar criteria to the ayllu and capitanía systems in regard to water ownership. This is the case of systems, for instance, in the zone of Arque, Cochabamba. This would suggest that, although there are indeed concrete associations between the type of organisation and water rights, they are neither definitive. The concept of rights moulds the different aspects that the water rights will entail, as it will be seen in the following points.

Acquiring water rights

In systems with their original organisation, such as ayllus in the altiplano and capitanías in the chaco, “de facto rights” are usually found. That is, no member of the community who has established a household is deprived of water; in exchange, the family must meet obligations set by the community, which may or may not be related to irrigation. (Gerbrandy & Gutiérrez et al. 1996, Gutiérrez & Cardona 1998a, Gutiérrez & Hoogendam 1998, Guzmán 1997, Oblitas et al. 2001).

The most usual ways to acquire water rights are: by being born in the community and starting a family, by inheritance, by planting, by taking part in construction projects or helping improve the infrastructure, by occupying positions and by donating land for community projects. In other systems, in addition to these ways, rights are purchased or earned by providing services.

Expression of water rights

Since the concept of water rights is somewhat abstract, the phrase “expression” can be used (Arratía & Gutiérrez 1997, Gerbrandy & Gutiérrez et al. 1996, Gutiérrez & Hoogendam 1998) to refer to the practical way that water rights are manifested when a given family uses the water. Water rights may be expressed in different ways. In some cases, they may be defined quite specifically and quantified, whereas in others they are not quantified.

In those cases in which water rights are quantified, they may be expressed: as a fraction of the total water flow over a certain amount of time (minutes, hours); an amount of time (minutes, hours) with the whole flow; in some systems with a reservoir, rights may be expressed by volume; in other systems, water rights are linked to land tenure and the right is expressed as water use over a given surface area (Gutiérrez & Cardona 1998b, Luján 1997).

5 In the altiplano, individual property is known as sayaña.

In other systems, although water rights are quantified and may be expressed in terms of time, this is not perceived as property. This is the case in the systems of Aiquile (Novillero, Zomora, and Tipapampa in the mesothermal valleys of Cochabamba) where, if the user finishes watering his or her plot in less time than the allotted right, the water is passed on to the next user anyway. In other systems, such as in the zones of Sacaba, Punata, Tiraque and Tiquipaya (valleys of Cochabamba), and in the case studies, where water delivery is by time, the irrigation time allocated for the water right belongs to the family, who may make use of their right as they see fit (irrigating, selling, lending, etc.) (Escobar 1998, Maldonado 1997, Montaño 1997, Sáenz 1997, Vega 1996).

In those cases in which rights are not quantified (e.g. most ayllus and capitanías), water rights depend on belonging to the ayllu or capitanía. In these systems, not only people have water rights, but the fields themselves. Each field that has been planted has the right to be irrigated, and each person has the right to irrigate his or her field until finished, providing the water judge and/or Jarrero[6] rules that it should be irrigated.

Variety of rights

Variety of rights refers to the fact that, within a given system, not everyone irrigates with the same amount of water, regardless of how rights are expressed. That is, there are distinctions among the rights of different users, as it will be seen in the case studies. In some irrigation systems, especially where there were haciendas, varied rights can be found as a consequence of Agrarian Reform, which established agrarian unions to give former settlers land and water – they generally irrigate more than new families (Apollin & Eberhart 1993, Salazar 1994).

This variety of rights may be manifested in different ways: When water is delivered on a time basis, some may irrigate longer (titular users) than others (additional users). There may also be varied rights when flow varies; each shift may last the same time, but the flow wanes. This happens in the irrigation system of Viloma (lower Cochabamba valley): some irrigate with one sixth of the flow, others with two sixths and others with three sixths. In other cases, variety of rights is manifested through differentiated volumes delivered from reservoirs; for example, some irrigate with two reservoirs-full, others with only one, as in the irrigation system of Waychapata (Arani - Cochabamba).

Also, water rights may have different meanings at different times of the year. During times of plenty, rights may not be quantified, whereas during the dry season strict norms may apply, on the basis of crops, land area or persons, as in the case of common waters and *mitha*[7] waters, in various systems fed by river or spring water, mainly in the lower and central valley of Cochabamba. In other systems, especially in ayllus and capitanías, there is no variety of rights, because fields are irrigated when they are seen to need irrigation (Greslou, 1990). For example, in the case of Sullcayana, the Jarrero visits the plots requesting irrigation every day and organises water delivery on the basis of crop status (Medrano & Rafael 1996).

6 The jarrero is the person responsible for determining the order of daily water delivery, according to the water requirement status of the crops that people ask to irrigate.

7 Mitha is a way of delivering water on the basis of a listing established during the hacienda period. This list is made up every year. Each user knows when it is his/her turn, without having to be notified by the water judge or other authority.

Collective and individual level of rights

In each irrigation system, certain collective or communal activities are carried out, such as maintenance, oversight of common flow, and decision-making. Especially when a group of community members conducts water flow to their sector, some speak of collective rights up to a certain level (e.g. from the dam down to the intake). Within the sector, tasks may be directed by individual rights: each family must care for water conveyance to their own plots (Maldonado 1993, Gutiérrez & Cardona 1998 b).

Groups of families may hold rights to a source as a group as well. For example, a group of households may claim water rights over a source because it is located inside their territory. As a group, they hold rights to this source's water, without dividing rights among the different group members. Another example is the situation in Sullcayana, where the collectivity holds water rights over the river during the daytime hours, whereas the other ayllus have rights during the night-time. Within Sullcayana other rules govern water distribution to families, based on criteria of equity among users.

Rights and access to water

Water rights are defined here as an authorised claim to the beneficial flow from a water source. Despite this, in many irrigation systems, it is not always necessary to hold water rights in order to irrigate; conversely, holding rights does not always guarantee that holders can make use of these rights. Therefore, it is necessary to differentiate between rights and access to water. Access indicates something about the possibility to make use of water rights in practice, and the possibility of access to water without any rights. The most frequent cases of access without rights happen when someone needs to irrigate when it is not their turn. In such a case, they can purchase or borrow (all or part of) a turn from another person or another system, or can steal part of the flow. The advantage of this system is that there is great flexibility for users to "round out" their access to water as required. (Soto 1997)

Especially during the dry season, water flow may decrease so much that the users furthest from the intake can no longer use their rights, simply because the water flow runs out along the way to the community or plots. In such cases, they often rent out their rights, or sell their turns to other persons whose plots are closer to the water source.

The distinction between access and rights can also be important in gender analysis. Most water rights are family-based and held in the name of males, as heads of household. However, any family member can use the water rights. Moreover, in many communities shifts and land are not divided for succeeding generations. That is, different family generations share water and land. In cases studied by the author in Bolivia, no families headed by women have been found to be prevented from using their rights, e.g. because they could not safely irrigate at night (Arratía & Gutiérrez 1997, Escobar 1998, Gutiérrez & Cardona 1998a,b,). Moreover, in the case of ayllus, women act as water judges and/or *jarreros*. Therefore, they perform their duties by day and by night. By contrast, other authors indicate that in other regions of the Andean zone, such as Ecuador, women cannot have access to water although they have rights, because of the danger of irrigating at night. (Arroyo & Boelens 1997, 1998, Boelens & Zwarteveen 2001). This shows that gender (in)equality in access to water cannot be assumed a priori, but must be ascertained empirically.

Irrigation systems located in ayllus and capitanías feature few cases in which there is any difference between water access and rights. In most systems located in ayllus and capitanías, rights are not expressed in fixed shifts, but as overall rights for farms.

Nevertheless, it would be necessary to monitor water use in detail, recording those who irrigate, where and how long, as the only way to discover whether, in practice, there is discrimination in access to water among different community members.

2.2.2 Distribution: operation and water delivery

Distribution of water means to operate the infrastructure and water delivery inside the irrigation system. Though these activities are narrowly interrelated, for greater clarity this will be separated in this presentation.

Operation

Operation activities in summary are regulating flow and monitoring flow and structures so that the water will flow as expected. One particular aspect happens when the irrigation system has storage facilities, such as dams, reservoirs or *atajados*, which call for regulation activities (opening and closing), which creates more work (labour-intensity) in operation tasks, compared to irrigation systems with other water sources.

In irrigation systems with intakes in the river (not permanent), operating tasks during the season when water is most available involve monitoring water flow(s) to prevent infrastructure damage and also protect plots near intake facilities.

When the infrastructure is improved, operational activities in different types of work are related with regulating flow, as it will be seen in the following paragraphs.

Catchment facilities. There are two groups of these facilities: with regulation and without regulation. Facilities *with regulation* make it possible to regulate the source flow. These facilities that enable regulation include dams, ponds and diversion dams *(atajados*). This feature, that these facilities can be regulated, is a factor that strongly influences water delivery practice. Facilities such as dams, ponds and diversion dams *(atajados*) make it possible to regulate flow and thereby increase operating requirements. Nevertheless, when regulation facilities are small, as in most irrigation systems in Bolivia, the facility is simple enough that specialized personnel are not required for these tasks. The intake and reservoir are operated simply by opening and closing the gate.

The situation is different when regulation facilities are large dams, as in the Cochabamba irrigation systems, (e.g. Totora Khocha dam in the Punata area). Totora Khocha System has a dam that irrigates two provinces in the department of Cochabamba and operates on a batch delivery basis[8]. The distribution of water divides volume between the two provinces, so users must know the height-volume ratio to operate the dam. Moreover, one of the provinces has three different agro-climatic zones, each comprising an irrigation block with different irrigation requirements. This means that each block will irrigate independently at different times, respecting their water-right entitlements, which are expressed in terms of flow rate and time, and converted into volume.

8 This delivery of water by batches is discontinuous. Each batch is the time period when water runs between when the dam is opened and closed.

The other province has 55 communities in eight irrigation blocks. Since the blocks do not finish irrigating at the same time – each has a different number of users – during each batch period the gate controller regulates facilities twice. These distribution conditions make operating tasks more complicated, because they require regulation and calculation of volumes along the dam's height (head) / volume curve.

These types of facilities (dams, ponds or diversion dams) increase the system's regulation capacity, thereby granting greater flexibility in water distribution, compared to unregulated irrigation systems. They can adjust to changing dynamics in water supply and demand. It is also possible to irrigate discontinuously, either by batches released from dams or daytime irrigation in the case of ponds. Dams also make it possible to estimate the amount of water available for a given growing season, which is a key to planning water distribution. Turn duration can even be adjusted, on the basis of water rights.

Catchment facilities *without regulation* make it easier to get the water flow and require fewer operating tasks, like in the case studies (see photo 2.2, 2.3, 2.4.2.5)[9]. With this type of intake, users seldom regulate them at all, unless the river floods, forcing them to close the intake to prevent damage to infrastructure and the irrigation area downstream. This is not the case with rustic intakes, because they are designed to fail so that damage will be kept to a minimum. These features increase maintenance (rebuilding) work. Occasional addition of water at the source often cannot be used, since it exceeds the intake's capacity, which limits water availability.

These facilities without regulation deliver water continuously, so irrigation should be done day and night, without any interruption. Although intakes are designed and built to operate automatically, there are situations such as with derivation dams in which, due to the characteristics of rivers in Bolivia, sediment tends to build up, upstream from the weir. If this silting is not removed, it prevents the intake from working properly. This makes it necessary continually to rebuild a rustic approach canal to keep it working, as with a traditional intake. This means that, for the intake to work right, users must do specific complementary activities to clean the sediment or to build the rustic approach canal.

Photo 2.2 Filter Gallery in Condorchinoka irrigation system

Photo 2.3 Intake in San Roque-Capellanía irrigation system

9 The intakes shown in photo 2.3 and 2.4 are called toma directa. The intake in photo 2.5 is called toma tipo presa derivadora.

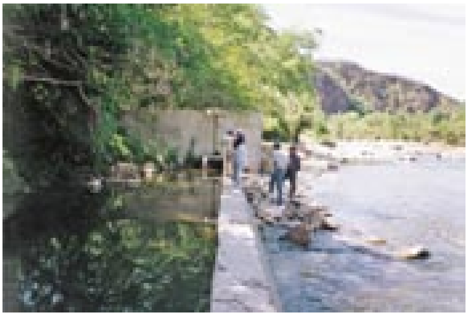

Photo 2.4 Intake in Naranjos Margen Izquierda irrigation system

Photo 2.5 Intake in Caigua irrigation system

Or it may happen, as in the Vidriera Candelaria system, that the renovated intake is useful only when water availability is high. During the dry season, the facility is too high above water level. So, to obtain water, users build a rustic intake downstream from the rebuilt intake, and splice this into the improved canal.

Regulation facilities are quite important, especially to prevent damage to infrastructure and the irrigated land area when flow rates are unusually high and may get out of users' control. These structures are generally fixed, such as orifices and overflow spillways. Therefore, their operating requirements are practically nil. Generally, they are located at the systems' catchment section, which is often distant, and therefore impractical for users to adjust entry flow rate anyway. On occasions, during extreme events, regulation facilities overflow. Then, users are faced by a greater maintenance workload and may even have to make emergency infrastructure repairs.

Despite the importance of regulation facilities, some systems have built no regulation structure. In such cases, for example, users have to use the self-cleaning gate of the silt trap for regulation. Out of 20 cases researched regarding design and construction criteria for intakes *toma tipo presa derivadora* in the departments of Oruro and La Paz, 85 % have no side spillways for surplus water (Monroy et al. 2002). When the spillway is not well designed, as in the Rosillas system, it lets more flow through than the canals can hold. This increases gate regulation tasks, especially when the river rises, forcing users to close intake gates

Sediment control facilities include silt traps, which are usually part of the catchment system. However, they are also indispensable at the entry point into siphons and pipes, to keep them from plugging up. These facilities play their sediment retention role automatically when water is distributed, and therefore require no operation. Although this type of structures facilitates system operation, in many cases we find deficiencies that force users to do additional work to keep them operating. Silt traps generally have a gate that must be operated for the trap to clean itself. This task of opening and closing the gate can be done by any user, if it is properly built.

Basic conveyance facilities include canals, these facilities are used for various purposes: irrigation, drainage, and water supply (for humans and livestock). An activity that is characteristic of unlined dirt canals during irrigation is that users must *conduct the water*, which takes a lot of work. However, as lined canals often have stones and sediments inside, especially at distribution points, they also require this type of activity. This water guiding is generally done by members of the family whose turn it is to water.

Finally, irrigation systems in Bolivia normally have no specific drainage infrastructure. Irrigation canals also play this role, combining for this purpose with the natural flows in irrigation areas and gullies. This reduces operating tasks, because there are few flow control points.

Special conveyance facilities include siphons, gully passes and aqueducts. Although *siphons* do not require operation, because they are automatic, when users irrigate with muddy water (to enrich their land with waterborne silt, *lameo*) or when there is plenty of vegetation in the area, siphons can plug. For this reason, users must operate more carefully, specifically when controlling the flow entering the system. Some siphons, especially longer ones (e.g. in the Totora Khocha Tiraque system, have operating problems, restricting total irrigation flow. This forces users to constantly (about every three hours during the community's irrigation turn) purge the siphon valve. This is much more complicated, since the concrete lid of the box protecting the valve must be lifted, and it is so heavy that several men have to lift together.

Gully passes need no operation. *Aqueducts* are common structures to conduct water acroos a dip in the terrain. These facilities work more transparently than siphons, with visible water flow, and operate automatically, although they may cost more to build than a siphon, because they require foundations.

Distribution facilities. In Bolivia's farmer managed systems, there is generally no need for flow division structures, because when there is more pressure on water use, water is delivered without dividing the flow, in a single discharge. Therefore, no structures are required to "precisely" divide the flow. Existing distribution facilities are openings in the canal, which may be regulated by a gate[10] or simply have no regulation at all. The most common distribution points are a combination of gates. These operate in the "open – shut" mode characteristic of single-flow systems, as in the cases studied.

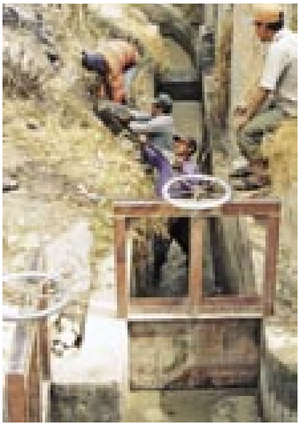

Photo 2.6 Sliding gate

Photo 2.7 Rode gate

Finally it can be concluded that facilities do not require complex activities to be operated if they are functional. The functionality of facilities determines operating requirements, as will be seen in subsequent chapters.

10 In the case studies two types of gates are mentioned: Photo 2.6 Sliding gate (compuerta de gusano in Spanish) and Photo 2.7 Rode gate (compuerta de oreja in Spanish).

Delivery of water

Since water distribution is system-specific, it is difficult to prepare a conceptual framework. However, to provide tools for description and analysis, some general aspects will be presented below that have been encountered during the research. This will grant insight into how water is distributed in small-farmer irrigation systems in Bolivia.

Water delivery method

Water distribution is primarily determined by water availability at the source. When water supply is high, water is normally delivered on demand. If the water begins to wane, then it is delivered by order and, finally, when water availability is even lower, and demand higher, turns are established.

Free water delivery on demand is common, especially in irrigation systems fed by a river, but depends on whether it is raining. When the free delivery on demand mode is in effect, anyone living in the area of influence of the source can irrigate, without any control over whose turn it is; each can irrigate as long and as much as they like.

This distribution mode is associated with continual supply and divided flow, due to high water availability. Unlike what is usually meant by free delivery on demand in the classical irrigation literature, in which users have water available whenever and in whatever amount they like, in small-farmer systems in the Andes, free delivery on demand is in effect only for a short while, such as in river-fed systems when the river is flooding. Therefore, there is no security of frequency or duration.

In general, when irrigation is free upon demand, water flows continually through canals, and is returned to the river when unused. During this water delivery mode, flow control tasks fall to the user who is irrigating, and must ensure that the flow does not cause problems downstream (flooding plots, silting up canals or damaging irrigation facilities).

Moreover, the boundaries of the area of influence of area irrigated during such a period may vary considerably, compared to the area of influence during the dry season, although in other systems this is not the case, because it is physically impossible to irrigate more with existing infrastructure.

In some irrigation systems fed by rivers, when it is not the rainy season but there is still considerable water flow, water may be **delivered "by order**". When this method is in effect, each user may irrigate until finishing their plot, and then it is the turn for the next farmer, so everyone gets a turn. This is the case, for example, in irrigation systems studied in Mizque (Bañados, Taqo-taqo) and Aiquile (both in Cochabamba).

This delivery mode is not very widespread. Normally after water is delivered freely upon demand, the next mode is delivery by taking turns. Water is normally **delivered by turns** in the dry season or when the water supply is less than the demand. For this water delivery mode, agreements are generally established to operate systems and share the water deficit during water distribution, as will be seen in the case studies.

There are different ways to distribute water by turns, which may be grouped as turns by time, turns upon request, and turns by date. (Gerbrandy & Gutierrez el al. 1996, Gerbrandy & Hoogendam 1998, Vega et al. 2003) . In **turns by time,** water delivery is expressed in time units (minutes, hours) which may be fixed or variable. This type of delivery requires someone to monitor time.

There could be a fixed person responsible for this monitoring, or the user could be responsible for his or her own turn. In **turns upon request**, users apply to the corresponding authority, normally the water judge, for permission to irrigate. The water judge receives all requests and orders water delivery. In some systems, the water judge orders water delivery sequentially by order, to prevent water jumps. However, in other systems, this is not done and there are water jumps, wasting water left in the canals. Some other systems use a combined system, in which users apply to the water judge, but the request is granted within an established schedule of turns.

Most of the above turns may be fixed or with a regular sequence among users. However, there are also irregular turns. In this case, each time the user must apply for water, and the person responsible (water judge, commissioner) prepares a list of users for a given period (a day or a week) of water use. This is called turns by annotation. Each system has different rules for who can and cannot be noted on the list, when they can be listed, and for how long in advance the list of turns is made.

For example, in El Paso (Cochabamba), each user is listed for a turn one day in advance, indicating where the water will be used. Then the water judge assigns the exact time of the turn, grouping families who have requested turns by zones, to avoid water jumps in the system. The number of hours of irrigation per family is recorded cumulatively, so that no one will exceed their allotted assignment of hours to which they are entitled. The same principle governs the Cala Cala system, in Oruro, which has a dam. In many irrigation systems with a small reservoir, such as the several ones in the ayllus of Oruro, water is distributed according to the day's notation, so that users who want to "register" for the day's listing must gather at the reservoir early in the morning, for the water judge to assign turns. In the irrigation system of Iskaypata in the lower Cochabamba valley, the listing system is used only in the period of common waters (May to August, dry season) to distribute irrigation water at night. There, the water judge also prepares a list on the basis of registrations, signed up the night before the irrigation date.

In **turns by dates,** water is delivered on fixed dates, as in El Paso, Tiquipaya and the mitha in Punata (Cochabamba). In these systems, every year users get their turns on the same calendar date. This is usually not organised too elaborately, since irrigation is an institutionalised custom and does not require leaders' intervention. By contrast, in the system of Iskaypata, Vinto / Pairumani (lower Cochabamba valley), turns move every year and, for different allocations, work days and weekends are taken into account (some allocations irrigate only Saturday or Sunday). For this reason, every year, before beginning the mitha season, the two water judges are responsible for preparing the list of all allocations.

Water shares, as used in the reservoir systems of Punata (Cochabamba), are part of a system listing fixed-duration turns. Each time water is released from the dam, a share represents a certain amount of time with the right to use water. In other systems with ponds, such as "El Comando"(lower Cochabamba valley) the time of each share indicates the total time that a family can use water, and that family decides how to divide this time among four releases.

Turns by volume are used in irrigation systems with a small reservoir, the volume of which is assigned to a single user or group of them. In these cases, the user whose turn it is to irrigate can use the entire reservoir volume, normally wherever he or she wishes. When the reservoir runs dry, the outlet valve is closed; at a given time, or when the reservoir is open again, the next user will open that valve again.

Small-farmer water distribution practices

To distribute water in the different irrigation systems, there are various mechanisms or practices by which small farmers deliver water. They are used only when the water delivery mode is by turns.

Rotation and rotation of rotation: In many small-farmer systems, water delivery is by "rotation" on different levels. If an irrigation system comprises two or more communities, the full water flow normally reaches one community and then the other, until all communities in the system have irrigated. Within the community, or if the system is a single community, the water rotates from one canal to the other, or from one sector to the next. In a given canal, water delivery from one user to the next is also by rotation, one after the other. That is, the user has the entire flow for a given time: users prefer this, as will be seen in the case studies.

The practice of "rotating the rotation" evens out any inequalities due to position in the list of turns or spatial location. For example, in the systems of Punata, a community that has received water first, will be the last next time. In this way, they can enjoy the advantage of being last, because they will have access to the tail water or trickle[11]. Also, in the community, the rotation involves canals or sectors and, if there is only one canal, rotation is done by starting at the top one time and at the bottom the next time. Rotating rotation also ensures that it will not always be the same users who irrigate in the daytime or at night. (Arratía & Gutiérrez 1997, Gutiérrez 1990, Gutiérrez & Bustamante 1999, Gutiérrez & Gerbrandy 1998 a, b)

Water delivery by a single flow: In most irrigation systems water delivery is by single flow and rotation, as in all the case studies. It is possible to find flow division when a single infrastructure conducts water from two or more systems but, once the water belonging to each system has been divided, the water is delivered to users by single flow. When the water source is a river and it has successive intakes, there is division of flow among intakes according to established agreements, but once the water enters a given intake, water is delivered by single flow and rotation. (Maldonado 1993, Maldonado 1997, Sáenz 1997)

Only in some cases it is possible to find a division of flows belonging to a single system. This is the case in the systems of Punata, such as the Laguna Robada system, which divides flows into two parts for two irrigation groups. In the Totora Khocha system there is a division into eight parts for the eight irrigation groups.

The literature indicates that division in half seems to be genuinely Andean, because it includes division of society into the *hanan* and *urin* parts[12] (bi-partition) and the consecutive division into left and right. (Greslou 1990).

Losses and compensations in water distribution: In most small-farmer irrigation systems, since their irrigation infrastructure is generally un-lined, communities' location in the system and users' location within the community is compensated for at the system and community level by using different mechanisms.

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11 Because of the distance between the dam and the irrigation zone, when the dam closes its gates, the canals still contain water. This is called the "tail" or "trickle".

12 In many communities, also after the Toledo reductions and the Spanish urban pattern that was imposed, the Andean bipartite division between Hanan and Urin still prevails, with a sound hydraulic basis. This division between two halves of the community and ecological levels controlled and represented by their members corresponds to an opposition (or tinkuy) between upper and lower, in which water plays a unifying role. (Greslou, 1990)

Compensation may be in time or in flow. For example, in the Totora Khocha system in Punata - Cochabamba, when the water arrives, they wait for two hours to begin using it by turns, so that the water will wet the canals of communities, calculated in practice, and communities are assigned additional time on their turn. For example, in the Querarani system of Oruro, the community of Villapata receives 17 additional hours, to compensate for losses due to location.

Internally, within communities or sectors, there is also compensation for wastage. For example, in Poquera – Capinota - Cochabamba, the irrigation list begins to be counted only when the water reaches the last user, which is normally after 12 hours. When irrigation begins from the top, losses are also compensated for in time by granting each user additional time, which is normally about half an hour per unit (*pegujal*). In irrigation systems in the ayllus of Oruro, there are no loss or tolerance times, since they distribute water by allowing each farmer to completely irrigate his or her plot, which implicitly compensates.

Groups to distribute water: The presence of groups in the community to distribute water are evident in some irrigation systems. Grouping may be due to topographical conditions, family relationships, or system size. This grouping facilitates community control over water distribution, so it is clear for everyone that each receives the water they are entitled to, under the same conditions as the rest.

In systems such as Punata, grouping also facilitates control over leaders' performance, because it is clear to see who is doing a proper job and judge the quality of their performance. (Arratia & Gutiérrez 1997, Claure & Gutierrez 1995, Gutiérrez 1990, Gutiérrez & Gerbrandy 1998 a, b)

Factors determining how water is distributed

There are different factors determining how water is distributed in an irrigation system, which are even elements of management. Along with infrastructure and water rights, other factors include types of flow, types of use and social organisation.

Types of flow and their influence on water distribution: Although there are many different water sources, it would be able to say that there are two "types of water flow": dammed water and continual flow. Water that is dammed up in reservoirs, *atajados* and ponds can be regulated in more ways, both in terms of frequency and volume. Dammed water in large (multiseason) dams is normally released according to the volume stored during the rainy season. According to the amount of water stored, users define when the dam should start operating, and when water should be released each time. So, for example, if the stored water is insufficient for *miska* crops (requiring more irrigation), it can be used to prepare the soil for annual, or *chaupi miska* crops[13].

When water flows continually, as in water from rivers and springs, the situation is more unpredictable. It is harder for small farmers to plan the type of crop they will choose to plant. The water distribution remains the same, and can hardly be changed (e.g. in terms of frequency of water delivery) until the rains resume and free delivery upon demand is again possible (Gerbrandy & Gutiérrez et al. 1996, Luján 1997, Vega et al. 2003).

Water uses and their influence in water distribution: In small-farmer irrigation systems, water is used for different purposes: to irrigate, for domestic consumption, and to water animals. These different ways of using water define water distribution to some degree. For example, in some

13 For miska crops planted in June and July, land is prepared in April and May. Chaupi miska crops are planted in August and September, and annual crops in October and November.

altiplano irrigation systems, such as in Huaraca (Oruro), some are water users only for domestic purposes, and others only to water their livestock. This calls for a certain frequency of water delivery in this system.

In some irrigation systems in Yucasa and Mallcoca, located in Huari (Oruro), hide dealers have the right to wash their skins in ditches, although the chemicals they use are harmful. In this same zone, the brewery uses irrigation water and the factory's effluent is used by small farmers to irrigate. Such complex water distribution must be taken into account when designing the irrigation system. (Gutiérrez & Hoogendam 1998)

Relationship between the type of irrigation application and water distribution: Generally speaking, in traditional irrigation systems (except for those with reservoirs), including those with dams, there is no relationship between the irrigation purpose and water distribution. Distribution remains unchanged, and no greater flow is used to prepare land or lower flow to irrigate crops. Nor is there any perceivable variation in irrigation frequency. Water distribution practice is routine, which ensures transparency and member acceptance.

In river-fed systems, when the water is high and irrigation water is free upon demand, water is used mainly to prepare land and even to fertilise it by depositing water-borne silt. Irrigation systems with reservoirs – common in the altiplano – allow members to use the water as they please. That is, they can regulate the outlet flow and use high flow rates to prepare / fertilise land and flow rates when irrigating crops.

2.2.3 Organisation

The irrigation organization is based on water rights, since these are the normative foundation for user-management of the system. Rights may be operational and/or for decision-making (Beccar et al. 2001). Operational rights have to do with the right to use part of the water, the right to use the infrastructure, and the right to occupy positions in managing tasks. Decision-making rights involve the right to take part in decisions on system management, on inclusion / exclusion of users, on changing the hydraulic infrastructure and selling or transferring water or canals.

Each user and group of users seeks a certain degree of autonomy. These characteristics are manifested through different distribution mechanisms applied to users in irrigation systems (Gutiérrez & Gerbrandy 1998 a, b). However, weak organisation can cause water distribution problems, since users cannot be sure that water will be available for them to use, because there are some users who do not respect agreements or ignore established rules.

Organisational levels of distribution and water distribution responsibilities

In systems comprising several communities, such as in the valleys of Cochabamba, there are different levels of water distribution organisation, each with its own responsibilities. For example, in Punata there is the Association of Irrigation and Services of Punata (ARSP) which combines three dam committees (Totora Khocha, Laguna Robada and Lluska Khocha). The ARSP, along with its counterpart in Tiraque, simply defines the volume from the Totora Khocha dam corresponding to Punata and Tiraque. In the other two dam systems (Laguna Robada and Lluskha Khocha), the ARSP has no influence on water distribution (Blanco 1996, Montaño 1995). Each dam's water committee is responsible for operating and distributing water in each irrigation system independently.

For all three dams, the irrigation committees are responsible for getting water from the dams to the intake. At the intake, water is turned over to each community committee, and the latter is responsible for getting the water from the intake to the community. In the community, the family is responsible for getting water to the plots that it deems most suitable. So, each community has its own agreements to deliver water to its members, and the community is decentralised from the committee.

Overseeing water distribution

In irrigation systems for which the water source is far from the irrigation zone, the quality of supervision will determine how much water reaches the plots. In some systems, the community organisation or irrigation committee is responsible for monitoring water conduction from the source to the irrigation zone. For this purpose, they have roles (intake watchers, *ronderos* who make their rounds, guiders, caretakers, etc.) played by users, who rotate these duties. This is the case in Punata's dam systems. Normally, the points most prone to theft are identified and that is where supervision concentrates.

In other systems, the users themselves are responsible for watching over the water. For this purpose, they often have to hire people, if their family members are not sufficient, as in the Achocalla system in Sacaba. Supervision is one of the most time-consuming activities and is difficult, especially when irrigating at night. In Punata, to receive 30 minutes of irrigation water, a family must devote 18 hours to monitoring, following and accompanying their water.

In small systems, there is surveillance as well, but it is less evident, since distances are shorter and there is less tendency to steal, because it is easier to identify the thief, as in the case studies. In both cases, there are penalties to punish thieves, but since need is greater than fear of punishment, many steal and pay the fines and those whose water was stolen remain unsatisfied, pointing out that they cannot water their crops with the fine money. There is great competition for water.

Community participation and the system of roles

As mentioned, there are roles with various names in different systems. The number of roles also varies, but in almost all irrigation systems there is a water judge or mayor. In general, the water judge is a position in the community organisation. The water judge's main duty is to settle problems regarding water distribution and organise water delivery and infrastructure maintenance.

In some systems, in addition to the water judge position, there are other roles. For example, in Sullcayana, besides the water judge and/or mayor, who ensures justice among people and makes water distribution decisions, there is the "jarrero" or "jarreador", who assesses crop status and water needs (Gutiérrez & Cardona 1998a, Medrano & Rafael 1996).

In Punata, water released from the dam is distributed by the following officials: water judge, guiders, intake watchers, *rondero* watchpersons, timers, and "accompany-ers". These are the positions within the community and community members perform these functions while their community has its turn to receive water. Aside from these community positions, there is also a general system intake watcher, who is responsible for distributing flow from different water sources among relevant communities. The duties assigned for distributing water in Punata especially call for surveillance, so that they will all help guarantee that water reaches them all.

In all Andean irrigation systems, as will be seen in the case studies, playing these roles is a duty for all users and a prerequisite to have irrigation water rights (Cahuana 1991, Castro 2001, Claros

2002, Gelles 2001). In some cases, performing these tasks is a weighty obligation and may mean a great sacrifice and investment of time. That is why not all positions are very desirable, although some systems (e.g. in Poquera – Capinota – Cochabamba, each user contributes ten cents of a US dollar a month) do provide some compensation to the water judge for the time invested. Not only the person designated (usually the head of household) has to perform these duties, but sometimes every family member who takes part and assumes responsibilities. Therefore, in water distribution practice, men, women, and children are seen contributing to water management.

Irrigation responsibilities feature different modes. There are irrigation systems in which the necessary duties for water distribution are rotated every 12 months. In others, the position is performed only during the irrigation event (e.g. the Poquera (Cochabamba) irrigation system, in which the water judge rotates each irrigation turn). However, there are also examples of systems in which specific tasks, requiring special knowledge and skills, are performed by people with greater experience, who remain in those positions for longer. For these reasons, such positions cannot be rotated. There are cases in which a water judge can remain in that position for several years, such as in Combuyo, Cochabamba.

2.2.4 Maintenance

Infrastructure maintenance is a requirement for access to water. In some irrigation systems in which water rights are quantified, taking part in maintenance is required to maintain water rights. In systems without quantified water rights, it is sufficient to participate in cleaning and rebuilding facilities in order to use water during a planting season. Those who do not participate cannot use water during that period.

Normally, dates for canal cleaning are fixed. In Cochabamba valley they clean out canals twice a year, before the rainy season (to take advantage of high-water flows) and again prior to setting up turns. In the Oruro altiplano, they generally clean out canals once a year. The work consists of shaping the canal, removing material that has settled in the ditch, removing weeds and shaping the canal's berms. To reconstruct irrigation facilities, there are no set dates, but this is done whenever needed. In river-fed systems, intakes are usually destroyed by high flows, by users of other systems that get water from the same river, or by animals – all entail emergency repairs.

In general, all users take part in cleaning canals, assigning each a stretch measuring one *suyo* (a *suyo* varies from system to system, from about two to as much as five metres). Some systems require male presence for this activity (especially in Tarija). Maintenance is usually organised by the water judge or mayor. In many irrigation systems, canals are cleaned on holidays, since this is when the work can be shared, along with food and beverages. But, when irrigation systems are improved, there are new requirements to maintain the infrastructure, and it is not enough only to clean, users should pay fees for maintenance, as it will be seen in the case studies.

2.3 IRRIGATED AGRICULTURE: THE OVERALL ENVIRONMENT FOR WATER MANAGEMENT

Irrigation systems are moulded by their environment. This is everything around the system, which is potentially able to influence system management. An irrigation system may be seen as an open system in continual interaction with its environment.

Social interaction for irrigation management, expressed at the system level, operates within a larger setting, which for clarity can be divided into several specific contexts. Each has a specific influence on the way that irrigation management is organised in each irrigation system. They include: the physical ecological environment, the political, administrative and legal environment, the economic and socio-economic environment, the technological environment and the socio-cultural environment. Section 1.3 has already presented a brief outline of the legal setting and water policies. National legislation and official policies have even less impact on actual local irrigation system management than in any other Andean country; systems are managed by the users themselves.

Since little or almost nothing has been studied in Bolivia on the influence of environments to explain water management characteristics, it is necessary to present more extensively what has been found in the research[14] (Arratia & Gutiérrez 2002, Criales et al. 2002, Gutiérrez & Cardona 1998 a, Oblitas et al. 2002). Findings show how the particular conditions of water management in altiplano and valley irrigation systems, which are basically subsistence production-oriented, are strongly shaped by the cultural environment. Elsewhere, in irrigation systems that are primarily market-oriented (as in the mesothermal valleys of Santa Cruz and the valleys of Tarija), it is the economic mercantilized environment that strongly moulds irrigation management.

2.3.1 The agro-centred Andean culture and water management

People in most altiplano and valley irrigation systems have strong roots in Andean culture. In the Andes, all of life hinges on caring for the farm, so the Andean culture is agro-centric. Farming lies at the heart of this worldview. Farming is at the centre of Andean economies and social life, religion and culture. This agro-centred culture is linked to integrated management of the ecosystem. This entails the coexistence of a broad diversity of economic activities, all structured around agricultural demands and needs. Activities involving agriculture harmonise the other cycles of life: including festivities and migrations (Van Kessel & Condori 1992), Choquehuanca (n.d), Grillo et al. 1994, Arratia 2001)

Although each irrigation system has a particular way of managing their water, there are criteria moulded by the Andean culture that are manifested especially during water distribution, namely: equity, transparency, autonomy, flexibility and collective decision-making / control, among others. To present the first four concepts, the descriptions by Gerbrandy & Gutiérrez (1998) will be used.

Equity

The difficult thing about a concept like equity is that the way the concept is defined depends on the perception we have of the phenomenon that we want to describe. Equity is related to equality, but is not quite the same. Equity means "equality of intention" whereas equality means that things are the same. Equity is also related to justice.

The way that equity is expressed depends on the culture. Bleumink & Sijbrandij (1990) in Punata indicate that justice entails three main factors:

14 Studies were directed and conducted by the researcher. Many cases were analysed, in the Oruro Altiplano and the valleys of Cochabamba, mainly Punata, the Chaco area of Tarija and the Mesothermal valleys of Santa Cruz).

- Participation by all members, and mutual control.
- Transparency in understanding operating decisions by all members.
- Equality. This is expressed by egalitarian distribution of benefits and problems among members of a society.

According to Coward & Levine (1989), irrigation users perceive a pattern of water allocation as equitable, if water claims are based on principles that are accepted as just and correct by users as a whole.

The difference is significant between the equity definitions by user-managed irrigation systems and those of systems managed by outside (governmental) institutions. This also shows the difference in perception by small farmers and employees of irrigation system projects. Small farmers apply the concept of equity, first of all, to the members of society and their land tenure. By contrast, projects deal much more with a concept of water resource usefulness. Therefore, they relate equity with crop water requirements and crop yield.

Authors who have written about water distribution norms in the Andes also refer to concepts of equity. Valderrama (1989), describing irrigation systems in the Colca valley (southern Peru), says that equity is manifested when the amount of water received by a user during water distribution is based on the amount of work invested in building and maintaining the system. Equity in water distribution is when each user has access to water according to their rights. Equity in water distribution is actually expressed in a family's right to use water, and the degree to which they can really use this right.

This brief outline of equity concepts shows that different irrigation systems, in their respective cultural contexts, define the concept differently. In the Sullcayana ayllu of the Oruro altiplano, and in Chilijchi in the inter-Andean valleys of Cochabamba, for example, the water use right is assigned to all community members and to all irrigable land. In Punata and in the cases studies (as it will be seen in next chapters), these water rights are directly proportionate to the time that a family has invested in building infrastructure. Here, it is possible to speak of the creation of rights, independently of the amount of land a family owns. However, only members recognised by the community organisation and by the irrigation association have access to water rights.

Transparency

Gandarillas et al. (1992, p. 198) say that transparency is demonstrated in distribution norms and rules: a system is transparent because "distribution norms and rules are visible for all users and they can distinguish any change made in the system".

In the case studies and in other systems in general, a first signal of transparent distribution is that water is distributed through rotation, in which a single water flow rotates among the different users. Total rotation, until coming back to the first user, lasts a reasonable time to be able to cover crop requirements. If the number of users is too great to enable them to irrigate one by one, groups of users are assigned turns, and they decide how to distribute the water (by turns, or by dividing the flow).

In compound irrigation systems, with different types of water (from different sources), each with their own rights, the single-flow system guarantees that users will not confuse different types of water. For example, in Punata different types of water reach the main intake at the same time.

There, the water flows are separated and each has its own turn, so that two types of water will not be flowing in the same zone at the same time. So that users can ensure water distribution equity, the system is transparent for all users. So, in Punata, there is great transparency in water distribution, since there is no need to administer much. Each group of irrigators handles the distribution, operates gates and supervises the water from their source. The group with the turn takes over the water from the intake, walks along with the water toward the community, and when the turn is over, the next group comes to take it over. It is forbidden to combine an individual turn with the turn of another community. The unit of measurement is known and fixed. The flow delivered to the community and to the user is the whole flow. The system is transparent, because they know when the irrigation turn begins and ends. Users know what each may use.

Flexibility

Bleumink & Sijbrandij (1990) mention that in the irrigation systems of Punata flexibility is the possibility of changing or diversifying the operating system, in response to regional / national changes and/or individual goals. There are two levels of flexibility: (1) “system flexibility” that materialises in the user’s possibilities of choosing when and where to apply how much water; and (2) “general flexibility”, the system’s capacity to adapt to changes in social, climate and production. The irrigation system makes it possible to change agricultural production, to use crops with different water requirements. The fact that community members in Punata can be users of different systems (lake 1, lake 2, well, or *mitha*), which reach the community at different intervals, enables them to access water at different times, meeting the requirements of different crops. An irrigation system’s flexibility also involves possibilities of selling, buying or exchanging water turns. This, and the existence of different systems, enables users to arrange their access to water turns, to meet their crop requirements in volume and frequency. The system of rotating single flows also enables flexibility in where the water is used and therefore to irrigate different areas, as was found in the case studies.

Autonomy

Unlike centralised operating systems, water management in most Andean systems is highly autonomous at the communal level. This means that conditions are favourable for users to participate. There is autonomy because systems are managed and administered by the users themselves, as will be seen in the case studies. Autonomy is also expressed by the community’s independence from others in setting turns, monitoring and deciding about how to distribute water within the community. Distribution is done by the community itself and it is responsible for maintenance from the intake to the community.

Communities’ irrigation system autonomy is also reflected in the small number of operating levels (no more than one level above and one below the community level). Therefore, irrigation actions operate on a very routine basis, with decentralised operating responsibility (at the communal level, not at higher levels).

Decision-making and collective control

In small-farmer irrigation systems in general and in the case studies, a criterion governing water distribution is collective decision-making, based on shared agreements, which enables a high degree of societal enforcement of agreements. Although this does not guarantee social justice for all groups, there is usually an ongoing dialogue among all users regarding these agreements. Distribution is dynamic and rules are continually renewed. These renewals involve changes in the community itself (each generation of families has a different composition) and changes in the environment (river patterns, land tenure, types of agricultural production, etc.). Irrigation systems can react flexibly to these dynamics.

These principles are mainly shaped by culture and livelihood conditions. In this case, the agro-centred culture of rural communities and ayllus demands collective involvement to guarantee that life will go on. In the case of water, it is not possible to irrigate individually, because its different aspects require everyone's participation (Castro 2001, Gelles 2001, Golte & De la Cadena 1983). Therefore, the individual self is always projected onto the collective body, for example in altiplano systems and many systems in the valleys of Cochabamba. These are important principles that should be taken into account by irrigation projects, since they guarantee the sustainability of the irrigation systems. If irrigation projects ignore these principles the results are not encouraging, as will be seen in the case studies in the next chapters.

3.3.2 Markets, migration, production relations and irrigation management: an illustration

Although Bolivia has irrigation systems managed mainly according to principles based on Andean culture and customs (as outlined in the previous section), there are also irrigation systems managed mainly according to economic, market - oriented principles, as in the irrigation systems of Santa Cruz and some of them in Tarija. To illustrate the influence of the economic setting on water management, the irrigation system of La Colonia, located in Los Negros, in department of Santa Cruz (Arratia & Gutierrez, 2002) will be presented.

La Colonia features groups of migrants from widely diverse origins, a complex mosaic in social and cultural terms. In Los Negros there are people from different places: Santa Cruz, Valle Grande, Pasorapa, Oruro, Chuquisaca, La Paz, Potosi, etc. The residents who are clearly of Quechua or Aymara origin (partly temporary residents) are called the "peasants".

Over half the persons farming have no land. Consequently, to gain access to land and therefore to irrigation water, these farmers make a range of agreements (rental, *antichresis*[15], sharecropping, tithing[16]) with landowners or bosses in order to be able to farm. There are also many day labourers who offer cheap labour in order to work with those who gain access to land and water as indicated.

Because of these production characteristics, there are two water access modes: through "delegation" and through "ownership". Sharecroppers, *antichresis* and rental tenants, etc. become "delegated" users and owners make up the group of "owner" users.

15 This kind of transaction to access land works like this: a family gives an amount of money equivalent to approximately 30% of the cost of the land to the landowner family. The owners, after one or two years (depending on the timing that the parties agree to) return the full amount of money received from the family who used the land.

16 Diezmeros ["tithers"] are people who gain access to land and farm with their own inputs, tools and labour. The production is divided by furrows: 9 for the diezmero and 1 for the landowner.

To distribute water, there are eight irrigation groups. Each group has a given number of members, and each group has a turn lasting a certain time. The times assigned to groups are different, because of different numbers of group members. Each user gets a six-hour turn and turns are distributed on a rotation basis. This approach to water distribution does not change much, since sharecroppers, tenants, etc. adopt the turns assigned to land they are cultivating temporarily and owners let them know on what dates they are entitled to use their turns.

Organisation for distribution is by groups. Each group has a head. There are two water judges, one with three groups and one in charge of five. Water judges are responsible for water distribution, in co-ordination with group heads. The position of water judge cannot be occupied by rental or *antichresis* tenants or sharecroppers, but they can be group heads.

There are two types of maintenance, ordinary and extraordinary. Users participate in ordinary maintenance by groups. The eight groups are notified by the group heads, who are notified by the water judges. Canal cleaning is done by *suyos*. The water judge distributes these *suyo* units by measuring the stretches of canal for each group. This ordinary canal-cleaning maintenance work, digging out silt deposits, lasts all day. Sharecroppers provide their labour according to the turns that they receive. Participation by rental and *antichresis* tenants is different, since they must participate in silt cleaning and also make cash contributions for extraordinary maintenance work.

These contributions vary according to contract duration. For example, tenants with contracts for a single growing season do not make cash contributions, but do have to help clean out canals. *Antichresis* tenants with long-term contracts are considered like owners and, when landowners are not present, they must perform all obligations, in labour and cash contributions, just like owners, but they are not allowed to vote in irrigation system meetings.

The La Colonia irrigation system has a user organisation, comprising about 100 landowner users. Election of officers must be done yearly according to the norms, but this does not happen, since it is very difficult to call users together for such elections. Users do not attend meetings, because they want to avoid being elected to positions.

Although landowners are called to participate in irrigation committee meetings, most do not attend, but send their sharecroppers or workers (day labourers). However, the latter have no decision-making powers. They usually attend the meetings only so that the owners they represent will not be fined for not attending, and to report back on what was discussed in the meeting. Sharecroppers have no decision-making power, but may be group heads, and are also part of the “latent organisation” (Huppert, 1989), since they are part of the available labour force for maintenance work and distribution activities. Moreover, owners – precisely because they are no longer personally working their land – gradually lose their linkages with the irrigation organisation and are slipping away from their responsibilities as users. Gradual disconnection from the land and agricultural activity by owners has generated a lack of interest and a power gap. This stresses water management organisational patterns. Lack of representation and delegation prevents enforcement of irrigation management, which makes it necessary to turn to other outside authorities, such as the police.

An irrigation organisation, comprising owner-users along with delegate users, operates on the basis of “asymmetrical complementarity” for irrigation management, which subordinates delegates to owners (according to production and land tenure relations). For example, when tenants are chosen to head the water distribution groups, they are able to enforce norms only partially, to avoid confronting “bosses” who demand that they follow the rules[17].

Owners’ lack of interest in local production has also undermined active participation in organising and overseeing revenues, such as dues, fines, and so on. Therefore, the lack of transparency in fund management seriously jeopardises irrigation system performance, since there is no investment for collective demands or interests, such as irrigation infrastructure maintenance, which is a prerequisite for the system’s physical sustainability.

Consequently, this analysis has emphasised some main features that show how certain elements of the overall environment (e.g. the market and migration) mould new production relationships, which affect the way that water is managed. In this case, it can be seen that migration and intensive cash cropping lead to conflicts regarding watershed management, increasing pressure on access to water; further, at the system level we find a heterogeneous group of users, which stresses water management.

Heterogeneity of user groups

In most Andean zone irrigation systems studied by other researchers, each organised user group shares elements of common or similar cultural practices and world-views. This means that they have strong social cohesiveness, community control and a feeling of belonging to the community and its organisations. Nevertheless, these forms of coexistence, based on water, are continually re-created under the influence of structural changes and dynamics. At any given time, most of these village economies are weakly or partially incorporated into the market.

In the irrigation system of La Colonia, the user group comprises people of different cultures, classes and ethnic groups, of greater and lesser prestige. This establishes intercultural relationships, and asymmetrical power relationships in daily life and production relationships.

Societal groups who refer to themselves as “*cambas*” or “*vallegrandinos*” are identified as “bosses” who have the economic resources, know-how and power. Consequently, the attitude of “migrants” in relation to these “bosses” is somewhat submissive, denying their own cultural worth. This relationship of subordination is legitimised by economic relationships.

It is significant that the cheap migrant labour supply, under various production modes, has enabled owners to accumulate more capital. As a consequence, increasing socio-economic differentiation has accelerated the outflow of rural people from their farmland. At the same time, this situation causes the inflow of migrants returning to the rural sector as labourers.

Consequently, these groups have different resource management interests. For example, owners do not participate directly in production processes, but focus their interest on the results. On the contrary, sharecroppers, tenants, etc. participate more directly in production processes and therefore are more interested in resource management. Day labourers, in turn, are most interested in maximising their earnings by selling their labour.

17 A sharecropper may work with different landowners from one year to another.

Asymmetrical complementarity among owners and delegate users in water management

Water management is possible thanks to the contributions and participation by owners (of land and water) and renters. The former provide economic inputs to maintain infrastructure and take part in decision-making and occupy positions. Their participation in practical water management activities (watering, upkeep, canal cleaning) tends to be less and less. The latter participate fully in practical activities. They also take part by occupying positions, in one of two ways. One is by direct delegation, when appointed in a users' assembly; the other is indirectly, when the owner transfers his position to his tenants. Nevertheless, even if renters take part in meetings and occupy positions, they have no decision-making power at meetings, and their authority is partial in performing their duties. For these reason, they are viewed as "delegate users", and their "manoeuvring room" (Long: 1989) is restricted.

Therefore, in the interaction between these two user groups for irrigation management, there is "asymmetrical complementarity". It is asymmetrical because there is a relationship of subordination, due to production relationships and ownership of the means of production. Then it makes sense to ask: Who are the actual users? Only those with water rights? Those who should be beneficiaries of an irrigation project?

Absence of delegation and representation in water management

Efficient, productive irrigation management requires effective arrangements for collective action among water users. The problems that we find in the La Colonia irrigation system can be understood as a lack of accountability. In this regard, Mollinga (1998) says that accountability has two elements: One is "representation and delegation" and the other is "rationality". In this case, the lack of interest in occupying positions reveals a lack of "representation and delegation"; that is, there is no one who will take responsibility for governing and implementing water management's practical and administrative tasks. The second element, "rationality", expects and assumes that those who are involved will arrive at arrangements for collective action on the basis of agreements rather than, for example, through violence or other forms of force. However, in the case analysed, although the few who do attend meetings do establish rules "rationally", they are not enforced, because there is a lack of social consensus and authority, which makes it necessary to resort to other outside authorities, such as the police, for enforcement.

Institutional regulation and power relationships in water management

Irrigation systems' sustainability depends partly on the transparency and clarity of management rules, because accountability commitments are underpinned by power relationships. Social power can be defined as the ability to influence the behaviour of others. Accountability depends on who has to oversee whom, who has to decide about others' behaviour, and how. Accountability is basically the way that authorities are institutionally regulated. Using this power goes beyond irrigation actions, because it is expressed and reproduced in the broadest social relationships. As already discussed, some 50% of farmers are "delegate users" and have direct economic relationships of depending upon "users with decision-making power". That is, these relationships are based on mutual but asymmetrical inter-dependence.

There is a dual bond: bosses are important because they can grant access to land and water; and renters make it possible for bosses to cultivate their land and obtain greater income while engaged in other activities, which are not necessarily agriculture, and which yield greater income, at a lower risk than farming. Such a situation leaves owners with no other choice than to involve renters in some practical activities of management, but not in decision-making. Because they are dependent, tenants avoid conflict and perform their duties as group heads only half-heartedly, because enforcing norms and rules would require them to confront their bosses. The lack of transparency in accountability is an important source of problems with performance in this irrigation system.

Solving such problems of re-establishing balanced performance of the irrigation system would imply confronting the inherent features of the local agrarian structure and the market, not only supposedly internal issues of administration and management. This shows that water management is strongly influenced by outside environments.

Therefore, interventions in irrigation systems in such contexts may tend to deepen this differentiation of rural roles. Accordingly, assessments of irrigation management must be analysed from a broader perspective, examining the entire agrarian structure, and the local power structure, which are heavily influenced by their environments.

Tension between collective control and individual strategies

In comparison with La Colonia, in Bolivian Andean zone irrigation systems (altiplano, valley headwaters and valleys), collective control of resources generally is better, as are their co-operation relations, and their sets of rules guiding water use. In La Colonia there is the tendency to lose community control. Although it was a principle that bosses knew about water management and made decisions, the incorporation of “delegate users”, and decreasing participation in water management by “owner users” who are losing interest, are placing water management under stress. This also gives rise to individualistic market-oriented strategies and responses.

This development has occurred because owners of land and water have become economically differentiated and diversified their economy. Agriculture is no longer their main income source. Land use intensity is also leading to greater capital investment, for ever-less-profitable agricultural production. On this basis, we can see that, on the one hand, possibilities of reinvesting money to improve and maintain infrastructure tend to decrease and, on the other hand, shrinking organisational entities and activities for agreement renewal jeopardise the system’s sustainability.

Decreasing irrigation system reinvestment and sustainability

When an irrigation system is implemented, it requires investments of users’ work and capital in order to be maintained over time. In the case of La Colonia, although it is a relatively young irrigation system, a break is emerging between infrastructure and the responsibility to maintain it by reinvesting. Evidently, greater investment in irrigation system improvement will yield greater economic returns, by enhancing production and productivity, which in turn enables reinvestment in the system. This principle is in question in La Colonia, because owners prefer to invest their profits in other areas and “delegate users” have no obligation to invest in the irrigation system, because they have no water rights. Consequently, there is no investment to meet collective demands or interests, as required for an irrigation system to be sustainable. Rather, the tendency is to satisfy individual interests and needs.

In addition to the system's physical sustainability, organisational sustainability is also endangered. Users are losing interest and becoming less diligent, not only in investing labour and money to improve irrigation infrastructure, but also in participating in the organisation in order to make decisions. In the case studies, there are problems with the fees for infrastructure maintenance but there are also other reasons for it, as will be seen in the next chapters.

To conclude, this case studies responds to new challenges regarding the development of conceptual and methodological frameworks to orient irrigation interventions, with the perspective of obtaining better results in regard to infrastructure design, agricultural production design, and water management design, which are evidently influenced strongly by their environments. A look at irrigation management in a broader, more integrated context, as is presented in the following chapters of this research, will make it possible not only to identify whose projects actually benefit irrigators, but also what settings most influence water management and how a project can fit into such dynamics.

3 SEARCHERS FOR WATER: THE CONDORCHINOKA SYSTEM

INTRODUCTION

Condorchinoka has been selected as a case study because it is located in the agro-ecological zone of the *Altiplano*. Also because the intake is a filtration gallery, the use of which is more widespread in areas such as Oruro and Potosi in this region.

Condorchinoka is a community comprising 55 households, belonging to the Cercado province of Oruro Department. They have little tradition of outward migration, having kept their population significantly, since this zone has long grown vegetables, which requires plenty of labour. Unlike the other families living around this area in 2001, Condorchinoka's families did not seem to be living in extreme poverty. Their housing, access to the media (radio and television) and dietary habits (noodles, rice, coffee, tea and other bought-in foods) reflected some purchasing power. This lifestyle may be thanks to a favourable microclimate because of its location at a foot of a hill that protects the crops from frosts. Condorchinoka also has different sources of water that farmers can use to reduce the frost damage[1]. This micro-climate has enabled them to specialise in vegetables, such as onion and carrots. Other families who do not belong to this community envy these conditions. Life in surrounding communities is typical of the *altiplano* (3760 metres altitude), with a cold climate that enables them to grow only the typical rain-fed crops of that region (barley, wheat, potatoes and other tubers). Other communities in the *altiplano* suffer from exposure to frosts and scarcity of water, because they are located on the high altitude and plain. This prevents them from growing cash crops, so these neighbouring communities are poorer.

The distance between Condorchinoka to Oruro (capital of the department) is 32 km by road; 15.5 kilometres of which are paved[2], while the rest is earth road. Near Condorchinoka there is a spa with thermal water and the paved and earth road are kept in good condition throughout the year. The distance between Condorchinoka and the city of Cochabamba is 220 km. Both cities are good markets for commercial production by Condorchinoka's farmers. As vegetable growers, the population in general (men and women of different ages) have all had to develop skills to deal with the business world, such as speaking Spanish and Aymara, as part of these strengths. It is no accident that Condorchinoka has a school located right in their community. However, despite their strong ties with the market, this community maintains various principles of their Andean culture (deities, rituals and beliefs) which are visible in their organisational forms, recognition of authority, collective work and system of reciprocity (*ayni*).

1 Heat conduction and storage in the soil depends greatly on its water content. This is because water stores plenty of heat and conducts heat more readily than dry soil. Research has shown that it is important, prior to killing-frost risk periods, to keep the soil water content near field capacity, so that the soil surface temperature will be as high as possible (Soza, 2002).

2 This road was built in 1940 and paved in 2000.

A particular aspect of this community is the ways that families invest their earnings from cash crops, which are higher than in surrounding areas. They mostly spend on improving the quality of life for their younger generations (education and health care) rather than reinvesting in their production system. Otherwise, families' priorities are consumer goods (vehicles and electronic appliances) (interviews, April 2000).

All the families that live in Condorchinoka received lands through Agrarian Reform. After the Agrarian Reform people organized in a *Sindicato* and each family obtained land as owners. However, as a result of hereditary succession, the agricultural plots[3] size has reduced greatly, with problems of "minifundio" emerging. The holding size varies from 0.8 ha to1.14 ha.

Community members reported that most are engaged in farming. Temporary migration to other places is not significant, since farming keeps workers busy most of the year. During months when there is little farm work, most prepare their land. People who migrate mostly leave for good. Greater cropping intensity has reduced out-migration, because labour is continually in high demand, for cultivation, irrigation and land preparation, with peak demand at harvest and planting times, some of which are staggered (interviews, April 2000).

The production system in Condorchinoka in 2001 reflected a process of change over several decades, beginning after the 1953 Agrarian Reform. With the organisation of the *Sindicato* community members began using surface water from the Tolapalca river, using a rustic intake. This water was conveyed and distributed through an earthen canal for irrigation. All families that belonged to the *Sindicato* had a water right, and each user could irrigate until finishing their plot, and then it was the turn for the next farmer. It is difficult to know how many people and how many plots were originally involved in irrigation. *Campesinos* said that since water belongs to everyone who planted and remained in the community, performing his or her community obligations, the number of people and the plots changed each year. The flow in the river fluctuated from 0 l/s in June and July to 85 l/s in January. The water was enough to produce crops such as potatoes, barley and wheat.

As irrigation water became increasingly scarce because the community began growing vegetables (onions and carrots), irrigation users decided, first off, to set up a system to take turns using water (in 1973). Later, to obtain more water, they sought financing to improve their irrigation system. Finally, in 1983, with the assistance of the Oruro Development Corporation (CORDEOR), they built a filtration gallery on the riverbed. Engineers chose this technology because there was no perennial flow in the river during the dry season, but there was sub surface water flow.

Notwithstanding these collective efforts, water availability fell short of demand, so in 1984 they dug a communal well in the riverbed, 9 metres deep and protected by rings. As the water of the gallery and the communal well was not enough, they also dug another five group wells in the riverbed, for the use of "groups" who had invested their labour and money in building them. These groups are authorized by the community to make use of the groundwater, because the communal well had and has a yield of only 4 - 5 l/s and this flow is not permanent, since the wells are not deep. Each user of the wells, including the communal one, has his o her own pump (*motobomba*) and pays the costs of operating the pump (these wells are not used for drinking water). Each user used to have on average during the year access to 9 to 11 l/s in total[4]. During this time users were

3 There are plots from 500 m2 to 1000 m2.

4 This includes the water from the gallery and the well. Though it is a manageable flow for irrigation, this was not enough, because during one period of irrigation (7 days) with this flow (10 l/s) in 29 ha on average the application depth is 20 mm.

organized in the *sindicato*, and the water judge was responsible for controlling irrigation system distribution and maintenance.

Even with these different additional water sources, expansion of vegetable growing demanded more water through the years. This drove users to continue fund-raising efforts with governmental and private institutions to further improve their irrigation system. The situation was worse in 1991, when the shortage of water was especially intense. So the idea of improving their irrigation system with a new project was born in a community meeting (July 1992) after a drought in the previous growing season (1991-1992). All families vowed to obtain greater support, regardless of the source. At the time, the gallery had a flow rate of 2-3 l/s due to the drought, which was not enough to water their crops, and led to tensions among families. This need was intensified by the intention of increasing the area under cultivation, mainly for onions and carrots, which had become more important for this zone. Families were also vying with each other for access to water in order to improve their social status. This led to a feverish search for other alternatives to gain access to more water. However, since the drought the gallery has also experienced decreased flow due to greater silting, which farmers did not know how to tackle.

The original proposal by users for this new project was to line the main canal, to reduce losses during water conveyance and distribution. They then realised that such lining would not substantially increase the amount of irrigation water available. Since they already had a filtration gallery in their zone, they looked into the possibility of building another, about 200 metres upstream from that one. They applied for funding to numerous institutions. Finally, in 1998, they got support from the National Irrigation Programme (PRONAR). Funding from the IDB[5] (Inter-American Development Bank) was earmarked for this purpose.

The improved irrigation system began operating in 1999, doubling the amount of water available at critical times from 12 l/s to 25 l/s[6] (flow measurements in 2000). This made it possible to expand the irrigated area from 20 to 54 hectares, improving yields and only slightly changing the range of crops, since they were already growing vegetables with irrigation. It is important to indicate that crops are under-irrigated.[7] In the first growth phase vegetables (carrots, onions) are irrigated every seven days; in the remaining phases the interval is between 15 and 20 days. For potatoes, *campesinos* irrigate 4 or 5 times. Barley receives 1 or 2 irrigations during its cycle. Alfalfa is irrigated only if excess irrigation water is available and sometimes receives one irrigation in a year.

Prior to the project intervention funded by PRONAR, 36 households had surface water rights, because they had worked to build the first gallery in 1983. Nine families did not use irrigation, because some of them did not believe that it was possible to have water through a filter gallery and others because they were not present in the community when they built the old gallery. So they did not work with the system and consequently they did not have water rights. Afterwards, 42 families had water rights and access. The new users with water rights accessed water because

5 This IBD-PRONAR fund was administered by the Rural Development Fund (FDC). This made the FDC a stakeholder in the intervention process.

6 It was designed for 40 l/s

7 Water scarcity restricts application to meet full water demand. Farmers appear to have established the basic understanding of deficit irrigation themselves. If they have water they prefer to irrigate 2 plots instead of one optimally, because they have proven that the yield of both plots will be more. For information on water requirement by crop stage and "deficit irrigation" when soil water need not be fully replenished for crop growth, see Doorenbos et al. (1979).

they were sons or daughters of the original 36 users. They did not allow inclusion of members from the nine families, because they did not want to change the irrigation interval[8]. So, despite the widespread interest in access to irrigation water, not all families in the community have irrigation water. The nine families have no water, and grow only rain-fed crops; consequently, their earnings are lower. No families can irrigate from groundwater alone.

In 2001 (during the research), the Condorchinoka system used the water collected by both galleries (which came together in the initial section of the main canal), the water from pumping and the conveyed water from high flows, which was all conveyed by the same main canal and each user can irrigate with this water. The wells are seen as part of communal water resources. As all different sources are combined there is a single institutional principle for managing the irrigation system. The water is distributed through the irrigation turns. New users really only receive part of their parents' turns. The irrigation interval to complete the 27.5 six-hour turns is 6 days 21 hours

In order to obtain both projects, the irrigation leaders contacted the irrigation authorities in the department of Oruro. In the earlier project they contacted the Oruro Development Corporation (CORDEOR) and in the latter one, the Prefecture of Oruro. In the first project CORDEOR made the intervention directly with its own funds and its own technicians. In the second case the Prefecture of Oruro put them in contact with the Oruro Micro-Irrigation Project (PMO), but the PMO replied that they had no budget to improve the Condorchinoka system. However, the PMO put the community in contact with the Technical Assistance Component of the National Irrigation Programme (CAT-PRONAR), who agreed to help.

In the context of this background on the community, the present study focuses on the stage of improving the irrigation system with PRONAR funds, in which the intervention process, dynamics and outcomes are readily visible. To facilitate understanding, first the infrastructure characteristics and agricultural production system in 2001 are reviewed. Then, irrigation management before the intervention is described, to provide a baseline to analyse water management proposals under the project. Next, the intervention process is described. Finally, all these aspects make it possible to draw conclusions, *analysing the suitability and adaptability of the improved infrastructure to management capability*.

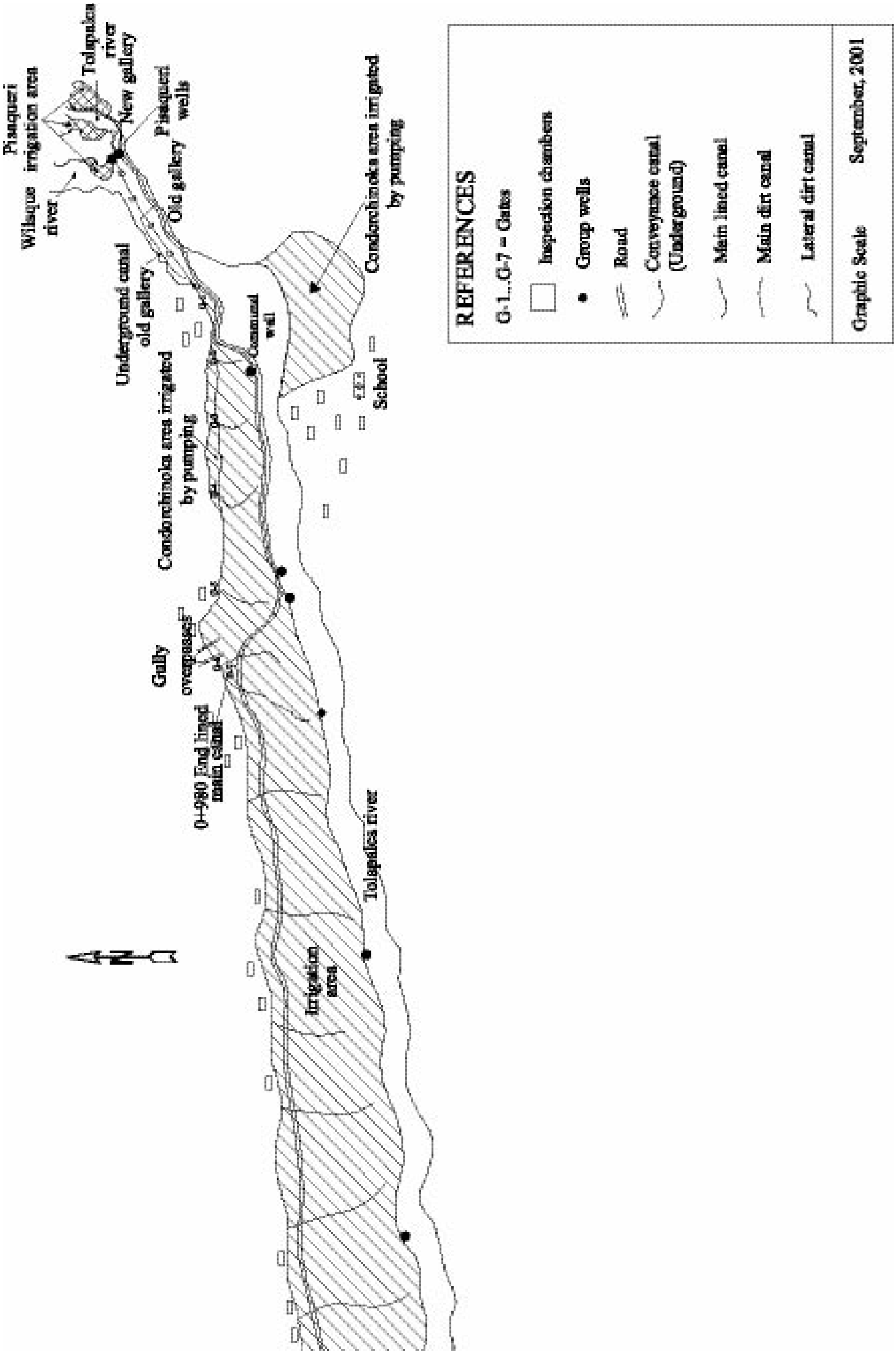
3.1 IRRIGATION INFRASTRUCTURE

The intake infrastructure of this irrigation system uses a filtration gallery. A gallery is a subterranean conduit built in the permeable bed of a river. The objective is to tap the sub surface (underground) water flow that drains through the permeable bed material of the river. The water enters the conduit through loopholes. This water is led to the conveyance canal through a channel situated in the lower part of the gallery. The gallery functions throughout the year. In the dry season the flow is rotated from one user to another according their turns, used at their respective distribution points. During the rainy season water is used freely.

Before the intervention, the irrigation system had only one filtration gallery, and a lined conveyance canal. The rest of the infrastructure was traditional. To better understand this local context of technology, this section presents a description of the infrastructure in its current state, i.e. after the intervention.

8 To increase the number of users would mean to lengthen the irrigation interval

Figure 3.1 Map of the Condorchinoka irrigation system



Intake

The engineers designed an infiltration gallery in order to replace the old one. The new filtration gallery was built in the Tolapalca riverbed, which is also the roadway to communities upriver. Therefore, heavy trucks necessarily drive over the gallery, endangering its stability. This new filtration gallery is located in the territory of the neighbouring Pisaqueri community, next to Condorchinoka. Consequently, the use of surface and underground water, a few meters from the gallery, is not clearly defined. So, Pisaqueri community members pump out surface and underground water, decreasing the amount available for the Condorchinoka system.

Previously there were settled relations between both communities, because, although both use the water of the same river, Pisaqueri had always the "right of head" by being located upstream. The problem arose with the location of the new filtration gallery. Residents of Pisaqueri resent the new gallery's location in their territory. The fact that there is no definitive agreement between these two communities on water use makes relations tense between them. The final project document shows no mention of this conflict, perhaps because it was not deemed significant. However, it jeopardises the improved system's sustainability.

This gallery was built in 1999, with two parts, one crosswise and one lengthwise in terms of the river's flow direction (see Appendix 2), at an angle of 86° between the axes of the two. Their main features are:

Table 3.1 Characteristics of the crosswise and lengthwise galleries

Crosswise gallery	Lengthwise gallery
• Catchment length 28.8 m • Inside dimensions: 0.8 * 1.35 m. (WxH). • Material: Cyclopean concrete[9], with reinforced concrete covers. • Loopholes: PVC drainpipe, diameter (D) = 3", placed in three rows in the upriver wall. • Filter: Only in the upriver wall. • Two inspection chambers located at the two ends, one on the left bank of the river and the other on the riverbed near the right bank.	• Catchment length: 19.6 m. • Inside dimensions: 0.8 * 1.05 m. (WxH). • Material: Cyclopean concrete, with reinforced concrete covers. • Loopholes: PVC drainpipe, diameter (D) = 3", placed in three rows in both walls. • Filter: In both walls and on top. • One inspection chamber, located at the top upriver end.

To check how the new gallery was operating, a group of engineers of PRONAR including myself inspected this gallery accompanied by the community delegation in September 2001, with the following findings:

- The facility was physically in good condition, except for the gabions that were placed on the "supposed filters"[10] to protect them, which had been undermined where the river water now runs. The undermining depth considered in the gabion design was minimal,

9 Cyclopean concrete is a variety of concrete, made by adding massive stones of irregular shape and size to ordinary concrete.

10 "Supposed", because the filters were not built with sufficient operational capacity.

and the gallery was shallow (it did not touch the bedrock). These two factors resulted in this early undermining. Users said they have no experience in repairing the gabions.

- The filtration gallery was built of cyclopean and reinforced concrete. The gallery and entry / inspection chamber covers were too thick (15 cm), oversized. They were handled very little, because they were too heavy for ready access to inspect and clean inside. One had to pass an iron bar through the iron hooks on the cover so that four people could haul on it. This meant that women and elderly people could hardly handle them, because it took a group of strong men to move them.
- An inspection of the gallery and a test pit dug up water from the main part showed that the filters were saturated, and could not be adjusted, due to a construction flaw, as the building company did not follow the technical specifications of the construction of the filter. Consequently, over 80% of the loopholes were out of service, silted up. Users did not know how these filters work, either, or that they must be maintained.
- The inside of the gallery had a low slope, so fines collect that must be cleared away often by users. This is awkward due to the gallery's dimensions.

The old infiltration gallery did not have filters and loopholes. Water flowed through the existing spaces among the stones piled one on top of the other. As the old gallery did not have filters almost all these spaces were covered by sediment and the resulting flow was low. The project document mentioned that the gallery had 5- 6 l/s in September and October 1997. In April 2000 the flow measured was 12 l/s. This gallery had been maintained by users who cleaned the sediments out of the channel situated in the lower part of the gallery. At the beginning they used to clean almost each month. But even after they cleaned, the water flow was low.

For the new gallery, while the estimated design flow rate was 40 l/s, in April 2000 the flow was 26 l/s, showing that the gallery was functioning at 65% of its estimated capacity. If all the loopholes operated properly, the gallery would be able to extract approximately 140 l/s, five times more.

Conveyance canal

The gallery is connected to the conveyance canal. The canal is cyclopean concrete with reinforced concrete covers, and is buried in the riverbed. It is rectangular in shape, measuring 0.5 x 0.32 m with a slope of 0.0013 m/m. Its rated capacity is 40 l/s. The canal has five inspection chambers. These were built at the same time as the conveyance canal. The engineers' idea was that users would clean the sediments through these chambers. When the inspection was made, the underground canal was silting up, although there were the inspection chambers to clean out such obstructions.

The conveyance canal was in good condition, and generally well finished. However, the last section (between the old gallery and the open canal) opened into the Wilaque gully branch. This opening had worn away the canal slabs by abrasion, so the canal wall was exposed where the water had eroded the earth. In 2001 the conveyance canal was working effectively, without cracking or leakage problems.

Main canal

After the conveyance canal is the main canal, 2300 m long, of which 980 m was lined. The 980 m lined section is rectangular, 0.5 x 0.4 m WxH, with a slope ranging from 0.0005 to 0.002 m/m.

It has 7 distribution points, with a side spillway and two gully overpasses. The dirt section is 1320 m long, is irregular in shape, and its slope ranges from 0.001 to 0.0124 m/m. This canal is used to convey and distribute irrigation water. Water is delivered not only through the distribution points, but is also pumped to plots above the canal that cannot receive water by gravity flow from the canal.

The main canal accumulated silt from the gallery intake and local environment, and its walls were algae-covered. The left edge of the canal has become a pedestrian walkway for users along almost its entire length. Where there are crumbling slopes, rock fall has caused a partial break in the canal slope. No work has been done on the slope to prevent these destructive effects[11]. The damage caused to the canal slope by a boulder has been repaired by users.

The section exposed to the slope and to the riverbank is a latent threat, because successive overflows have undermined the riverbank. The canal also shows different levels of construction quality, and some places are not built well. Users explained that this was because sometimes when the canal was poured, the temperature was too low for the concrete to set properly. Others blame poor-quality concrete mix. They also mentioned that, during construction, the company changed builders often, and the three different builders each applied their own experience – but users feel that none of them was a good mason.

Lateral distribution points

Users said that the project designers and building company had no idea where to locate the distribution points. During construction, the *Jilakata* (community delegate) located the gate sites with the technicians, taking into account that each gate's area of influence should be as extensive as possible and benefit more than one user. Therefore, the traditional distribution points, which irrigated very small plots and benefited a single user, were not considered. As a consequence the lined system has a total of seven distribution points, each with two rod gates. Not all gates are easy to operate; some require a tool to open them or must be jarred to close them tight. Engineers chose this type of gate because they are cheaper than sliding gates. Almost at the end of the canal there is a take-off point with no gate, because (according to the water judge) they were one pair of gates short during construction.

All gates were in relatively good condition, although they were not being maintained (greased). So, they are hard to operate, and must be hammered closed. Evidently, siting of distribution points was not optimal, although the *jilakata* was involved. Engineers explained to the users that they could not put gates on all the traditional distribution points because there was not enough money. Users accepted this proposal, so distribution points that irrigated very small plots and benefited a single user were not considered. There was a case where one gate was located lower than the land level, so the user made a dirt canal next to the side slope outside the lined canal to conduct water to a point where the water could reach his plot. Thus, once the canal was built, some users realised that the gates did not benefit them, and that the gates allocated to their plots would not work either, so they made holes in the canal's left wall (10-15 cm in diameter), which they cover with a wooden plug when not using them. Irrigation organisation leaders mentioned that they have instructed users who made these holes to plug them with cement and stones, because they affect the lined canal's stability. None of the users has followed such instructions.

11 The project budget did not contemplate construction of this type of works.

3.2 THE AGRICULTURAL PRODUCTION SYSTEM WITH IRRIGATION

In the past (up until two generations ago), almost all farming was rain-fed, growing mainly potato, *quinua*, barley and wheat. At present, the irrigation system makes crop diversity possible, with vegetables predominating, so the system can be defined as diversified horticulture. Potatoes are grown on small areas, due to the high risk of frost and hail damage, which harms potatoes more than other crops. Despite this risk, potatoes are still grown here, mainly for family self-supply. The zone is strongly oriented toward vegetables, with onions, carrots and other crops covering 53% of cultivated area. This is more significant in production and economic terms, since over 90% is for market. The farming calendar in this community begins in May to July, preparing the land (*cusupi*). By late July, some people transplant their first onions, but most begin by early August, transplanting onions and sowing carrots and fava beans. (See Figure 3.2).

All crops inside the irrigation zone are irrigated, at least once. As water is scarce, the order of priority to water crops is as follows: vegetables, fava beans and potatoes. Barley, alfalfa and in some cases wheat receive irrigation if there is excess water after supplying the other crops. There is no fixed irrigation scheduling; usually carrots and onions receive irrigation water every 7 to 14 days. The first irrigation in case of potato and fava beans is 2 months after sowing. The intervals for irrigation are variable; the most important are when the crop is flowering (see footnote 5). Crops such as barley, wheat and alfalfa receive at least one irrigation, in some cases two or three, depending on precipitation and availability of irrigation water. During the rainy season, when water may be freely used, the field application method is by wild flooding. During the dry season, in almost all the crops application is by furrow. Border irrigation is usual in alfalfa and cereals.

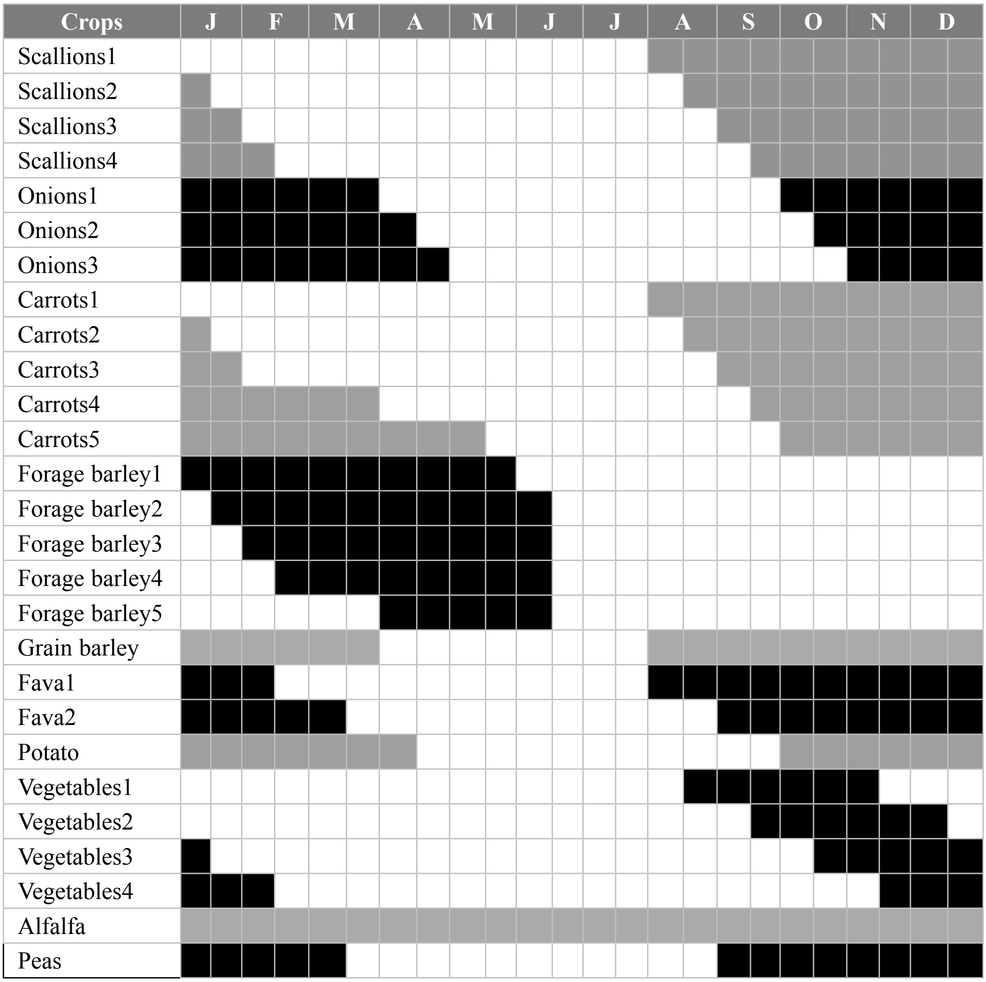
Staggered planting is common in this area, so there is no single planting date. Users plant twice a month for several months. Onions are transplanted until early November, carrots are planted until early October, and lettuce is transplanted from mid-August through November. Farmers indicate that this is the best time to transplant lettuce. They could transplant earlier but they do not, because they would have over-ripening problems, losing quality and possibilities for marketing. Fava beans are grown from late July through early September, also with staggered planting dates. Potatoes are planted from October through early November. Barley for grain is planted in early August, and harvested by May. Barley for forage is planted from early January through February. It requires no cultivation, but is simply broadcast after harvesting onions or carrots.

Onions are harvested from early December through April, and carrots through May (even if they were ready long before that, because they can be left in the ground without over-ripening). Farmers attribute this to the low temperatures in the zone and the longer intervals between waterings during this phase of the crop (every two, three or even four weeks). Different vegetables are also harvested on a staggered schedule. Wheat is planted in January and harvested and threshed in May. Alfalfa is first cut the second year, and thereafter may be cut two or three times a year, depending on the climate and watering.

Farm labour is mostly based on family members. Farmhands are hired to transplant onions and lettuce, or families help each other by "*ayni*", specifically for transplanting. Male farmhands can be hired for US$ 3.25 a day (wages are US$ 2.49 for women, who are preferred for transplanting). On average each family living in the community has six members: father, mother and four children. In some periods this is enough to cultivate the crops, but in others they need more people. The holding size for irrigated crops varies from 0.8 ha to 1.14 ha. Each peasant has several plots located in different parts of the irrigation zone. When potatoes were grown on larger areas, they used the *minka*[12] to plant and harvest them. This way of organising mutual access to labour is now being lost (Field interview, 2001).

Sheep are also raised in this community for wool and meat. Families average 15-20 sheep each, handled by the women or children. Sheep are pastured at higher altitudes during the day, to keep them out of the crops. In some cases, when not required to plough, bulls are also taken up to pasture. An average family has two or three bulls or oxen. Some have small livestock such as chickens and guinea pigs. This animal raising mainly produces meat for the family table.

Figure 3.2 Farming calendar in the irrigated area



Field survey, 2000

The improved irrigation system increased available water from about 46,000 m³ to 105,000 m³·. This made it possible to change production in terms of irrigated area, crops chosen and yields. Area under irrigation and changes in crops are shown in the following table:

12 Minka is a work modality in which workers are not paid in cash but in kind.

Table 3.2 Comparison of irrigated area (hectares) and crops

Crop	Before the project	In 2000	% of area under cultivation (2000)
Carrots	8.00	7.85	14.54
Onions	11.00	13.04	24.15
Scallions	0.00	5.29	9.79
Fava beans	2.00	8.07	14.92
Potatoes	2.00	1.25	2.30
Vegetables (lettuce)	0.00	2.78	5.15
Barley for grain	6.00	2.58	4.78
Barley for forage	0.00	6.86	12.69
Alfalfa	0.00	5.24	9.69
Peas	0.00	1.10	2.03
Total irrigated	**29.00**	**54.06**	**100.00**

Source: Field survey, 2000.

Yields and income have also varied thanks to the project, as shown in the two tables compiled from the workshop hold with all users in 2000, carried out by PRONAR under the author's supervision:

Table 3.3 Average yields with and without the project in tonnes / hectare

Crop	Yield (t/ha) before intervention	Yield (t/ha) in 2000
Carrots	12.00	24.15
Onions	12.00	20.26
Scallions	12.00	18.40
Fava beans	6.50	10.35
Potatoes	4.80	4.11
Lettuce	0.00	31429**
Barley for grain	0.80	1.47
Barley for forage	0.80	5.25
Wheat	0.93	0.65
Alfalfa	0.00	11.83
Peas	0.00	1.72
Quinua	0.70	0.70
Rain-fed potatoes	4.50	4.50

** Heads of lettuce

Source: Workshop Evaluation of the Condorchinoka irrigation system National Irrigation Programme 2000.

Changes in the production scenario have changed irrigating families' economic income, as shown in the following table:

Table 3.4 Net average income from irrigated production per hectare

Crop	ha	Cost/ha	Total cost	Income/ ha	Total Income	Net value US$
Carrots	7.9	1,952.4	15,327.0	3,195.9	25,088.3	9,761.2
Onions	13.0	2,051.5	26,756.6	2,463.3	32,128.1	5,371.4
Scallions	5.3	2,010.1	10,642.4	2,283.8	12,091.6	1,449.2
Fava beans	8.1	503.3	4,059.9	856.4	6,908.9	2,849.0
Potatoes	1.2	563.2	701.3	641.4	798.6	97.3
Lettuce	2.8	385.2	1,072.0	436.9	1,215.9	143.9
Barley for grain	2.6	337.5	872.3	364.9	943.1	70.8
Barley for forage	6.9	134.0	919.2	325.5	2,232.5	1,313.3
Alfalfa	5.2	341.1	1,786.3	419.6	2,197.2	410.8
Peas	1.1	158.0	173.6	976.0	1,072.2	898.6
Total	**54.06**		**62,310.64**		**84,676.34**	**22,365.70**

Source: Workshop, Evaluation of the Condorchinoka irrigation system. National Irrigation Programme. 2000.

The final project design document for Condorchinoka (1997) shows an average pre-project net yearly household income of US$ 258. With the project, the 42 user families should increase their average income to nearly US$ 533 / family / year. In 2000 after the project, income was US$ 414 / hectare under irrigation. This income is less than the project specification because the projections in area and types of crops were not achieved in reality. For example, engineers projected that users would cultivate 18 ha of carrots, 16 ha of onions, 4 ha of fava beans and 16 ha of potatoes. When a project is designed it must be profitable, so engineers project areas that justify the economic investment. The actual reality is always different, sometimes less, sometimes more.

3.3 WATER MANAGEMENT

All the information about management was collected through interviews in 2000 and 2001, based on a form elaborated for this purpose (see Appendix 3).

Water rights

Condorchinoka community members have traditionally used water from the Tolapalca river since the hacienda period. Agrarian Reform granted ex-settlers water rights, which became more visible in 1973 when community members decided to organise irrigation turns during times when water was at its lowest level (August through December) to avoid conflicts among users during that time. As the introduction of vegetables was growing, there were also increasing conflicts regarding access to the water. During that time there were 36 users. User rights were reaffirmed when the first filtration gallery was built in the Tolapalca river in 1983 by CORDEOR. At that time, all users invested the same number of workdays to consolidate their water rights, even though their water shifts were of different duration. After completing the construction work, the system comprised 36 users with differentiated rights, expressed in irrigation turns for two, three or six hours of irrigation. The irrigation turns were established in proportion to each user's landholding.

Irrigators' organisation

Before building the new gallery, the only irrigation system authority was the Water Judge, also called the *Jilakata*, who delegated some functions to an assistant. This position was part of the communal syndicate[13] board, although both (water judge and assistant) were chosen by the users as an irrigation committee. The syndicate board was composed of a president, vice president, treasurer, recording secretary and water judge. The communal syndicate was responsible for carrying out all community activities; irrigation was one more of its activities. The water judge controlled water distribution and organised maintenance of irrigation infrastructure. His assistant would replace him when he was absent. All community members were obliged to serve in these positions as authorities in the syndicate on a rotating basis.

Since 2001, the water user association president performs the duties that the water judge had, although he receives greater support from the board. Now there is supposedly a recording secretary, treasurer and another member to help. More information about the current organization is given below.

Water distribution

Water distribution before and after the intervention is the same. There have been no changes in distribution arrangements since improving the irrigation infrastructure. There are still two modes of water delivery during the year, one when water may be freely used (during the rainy season) and the other by turns (during the dry season). Distribution is the same because even though there are more users, the six new users[14] irrigate on their parents' turns. Before, there were 27.5 six-hour turns, now it is the same. The water delivery interval is still seven days. Users did not want to modify this interval, so they did not make any change in distribution. Now they have more water, and with each turn of water they can irrigate more area. Remember that they under-irrigate crops because they prefer to have more area planted. The difference is that now each user opens and closes the gates when s/he has the turn. They are using the wells as before.

When taking turns, water is delivered on a single-flow basis, by order on the list: this means that they do not divide water among users. When water is low users have a meeting and they decide to begin the institution of turns. The definite roster is drawn up by the water judge. The water judge makes sure that users respect their turns. During a turn, users decide where to water. However, since their plots are scattered[15] through the community, the rule is to start irrigating with the plot nearest the intake (top down). However, this rule does not prevent long water leaps. In this

13 After Agrarian Reform, ex-settlers were grouped into communities, organised into agrarian unions or syndicates.

14 Now they are on the list of users but they use part of their parents' turn.

15 Agrarian Reform gave each settler the same amount of land, but divided according to soil quality, so that each would get both good and poorer land. For this reason, family plots are scattered throughout the irrigation area and even elsewhere.

case, the tail water remaining in the canal (since it is cut off upstream), is for the user who was irrigating up until the change. During the driest period (October through December), each user has the option of increasing the flow by pumping water from the community well to the main canal. Each user pumps during their own turn, with their own pump. Sometimes, relatives may loan each other pumps, but in general each user has one. It is common to see users irrigating plots above the main canal by pumping water up from this canal. Users with water rights to several group wells can mix the water from these wells with water from the gallery and the community well, to increase available irrigation flow, especially when water is most scarce.

Maintenance

Before building the new gallery, users did only routine maintenance of their infrastructure, cleaning out their irrigation canals early each month. Estimated labour costs for maintenance were US$ 702 / year before the new gallery, entailing an investment of a fraction of one workday per user per month. All users with water rights participated obligatorily in maintenance. The water judge monitored attendance and organised the work. All users contributed the same amount of labour independent of rights, e.g. cleaning out the canals. Since 1983, they have cleaned the old gallery and underground canal only twice. Aside from that, no other cash contributions have been made for maintenance. The table 3.5 summarises the characteristics of irrigation management before project intervention.

Table 3.5 Condorchinoka irrigation management analysis I – Before project

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision at a general meeting of the syndicate to decide: 1. Water rights are obtained by doing workdays to build the infrastructure. 2. Everyone contributes the same number of workdays, although rights vary.	Decision at a general meeting of the syndicate to: 1. Begin delivering water by shifts and free on demand. 2. Elect the water judge and his assistants.	Decision at a general meeting of the syndicate so each user would contribute one workday / month to clean infrastructure.	Decisions at syndicate meetings to establish penalties for non-fulfilment of agreements and obligations.	Decision at syndicate meeting to organise activities involving construction.
	Activities involving keeping a record of days worked.	Activities involving preparing the roster of shifts, so all will enjoy the benefit of irrigating by day and the difficulty of irrigating at night.	Activities involving cleaning canals.	Activities involving supervision of fulfilment of norms and obligations.	Activities involving organisation of construction: work groups, scheduling.
Formal rules	Fulfilment of workdays. Rules establishing the relationship between rights and obligations: attending meetings, serving in positions on a rotating basis.	Only people with water rights irrigate in the dry season. Delivery is by rotation of the full flow to users (who decide which plots to irrigate). The delivery interval is no longer than 7 days. Water from different sources is mixed including the new gallery, to increase the flow.	Rules obliging participation: keep to the schedule, do tasks efficiently, take your own tool.	Rules punishing: failure to respect the irrigation schedule, to attend canal cleaning, to attend community meetings, and to perform tasks given the community.	Rules establishing the work schedule, age and sex of users allowed to do the work.
Participants and roles	The syndicate, overseeing agreements, and the users' group, abiding by agreements.	Water judges preparing roster of shifts and enforcing it, and group of users with water rights during the dry season, and the whole community during the rainy season.	Water judge to oversee group of users with water rights to clean the infrastructure.	Water judge to oversee distribution and maintenance. President of the union to oversee attendance at meetings and delegated tasks, and users who fail to follow established rules.	Users with water rights.
Logic and informal rules	Logic of community control. Each user sees how many workdays he works and the number of contributions by other users.	Logic of community self-control (transparent and predictable). Users know when their turn comes, and irrigate their different plots until their turn is over. The shift user cuts his predecessor's water off in the earthen canal.	Logic of community self-control. Each user comes with his own tool to the head of the system to distribute distances that each user will clean.	Logic of community self-control. Distribution conflicts are solved by following a chain: between users, water judge, irrigation committee meeting.	Logic of community self-control.

3.3.1 Irrigation project proposal regarding future management

To explain the project's proposal for water management, it should be taken into account that projects address this subject at two stages: pre-investment and investment. The first stage results in the project's final design document. The second happens during the construction process. It should result in an "operating and maintenance manual" and the "by-laws and regulations" to run the improved irrigation system. The work done during the second stage is called support or backstopping *(acompañamiento*). It is also important to realise that each stage has different players.

The project was prepared during 1997; the final design document was submitted in February 1998. Improvement of the infrastructure began in November 1998 and finished in October 1999. The support entity began to work on the irrigation system in October 1999. The project proposal regarding future irrigation management in the improved system is in Table 3.6 and the following paragraphs.

Pre-investment stage

Reviewing the project document, the following proposals regarding the different components of irrigation management were identified:

Water rights. The project proposed to increase the number of irrigation system users, from the original 36 to 55, i.e. all members of the community syndicate. This would mean that 19 community members would have to acquire water rights over the source by means of the project.

Irrigation organisation. During project preparation, no changes were proposed in organisation.

Water distribution. It was proposed to divide the flow into four parts (during the dry season), so four users irrigate at the same time, for six hours each. Putting such distribution into practice would have caused many problems among users, since their plots are scattered around the canal area, with different plot size and different crops on each. This would obviously cause different demands for water, requiring greater control over water distribution and more work, as well as making the system less transparent. It would also have required measuring structures for such division, which the project did not include.

Maintenance. The project proposed to incorporate new maintenance tasks, consisting of cleaning the gallery, twice a year (July and November), cleaning the riverbed over the new gallery whenever necessary, preferably before and after the rainy season, and changing filters in the gallery every three years. Engineers did not quantify and cost these requirements. This proposal focused attention on eliminating sediments, neglecting such aspects as repairing concrete facilities, replacing joints, repairing side walls, and fixing gates.

Evidently, during the pre-investment stage the needed adaptation of the social organization, or "water management design" was not emphasised. Therefore, many results of current water management are a consequence of users' own decisions, either during the construction process or afterwards.

Table 3.6 Condorchinoka irrigation management analysis II – Project Proposal

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision by the irrigation committee about: 1. Contributing 171 workdays per 6-hr irrigation shift (based on estimated cost of projects). 2. Acquiring water rights for 19 new users.	Decision at the irrigation committee to: 1. Elect the irrigation committee. 2. Delegate a paid person (supervisor) to oversee irrigation times.	Decision at irrigation committee meeting to: 1. do routine and preventive maintenance activities. 2. Define maintenance fees.	Decisions at irrigation committee meeting to enforce by-laws and regulations.	Decision at irrigation committee meeting to: 1. Define community labour input equivalent to 20% of total cost of the new infrastructure.
	Activities involving supervision of workday performance.	Activities involving water delivery to fields in order and not by water shifts. Activities involving opening and closing gates for water delivery.	Activities involving preventive and routine maintenance.	Activities involving fulfilment of by-laws and regulations.	Activities involving organisation and monitoring of work: groups, periods, tasks.
Formal rules	Rules related to performing obligations: maintaining infrastructure, attending meetings, using only water to which one is entitled.	Water is delivered in order, plot by plot. Main canal flow is divided among 4 users irrigating simultaneously	Rules establishing that each user must contribute US$ 2.40 for a 6-hr shift and the necessary workdays.	Rules fining those who do not meet established norms and obligations.	Rules establishing planned work: work schedule, periods, amounts.
Participants and roles	Engineers noting each user's contribution, irrigation committee recording workdays, and community members doing their work.	Group of users with water rights, and a "supervisor".	President, treasurer and group of users with water rights.	Authorities from irrigation committee to enforce by-laws and regulations and users who follow.	The construction committee organising the work, engineers directing the work and users with rights following plans.
Logic and informal rules	Open-system logic to incorporate new users with water rights.	Logic of irrigation efficiency.	Logic of monetary investment to ensure project sustainability.	Logic of enforcement by punishment.	Logic of farmer investment to guarantee irrigation system sustainability.

Investment or support stage

According to PRONAR, support service should be provided during and after the construction phase. However, due to excessive delay in the bidding process for support, the consulting firm awarded this contract began working after commissioning by the Rural Development Fund (FDC) and Prefecture provisionally delivered the infrastructure to users (October 1999). Therefore, tasks that should have been done during project implementation (e.g. participation in the tender process, user training during implementation and meetings to explain different stakeholders' roles during project implementation) never happened.

The consulting firm prepared an operation and maintenance manual outlining future maintenance work to be done by users and how to care for facilities during operation. The contents of the manual regarding water distribution and maintenance are presented in this section, but this also shows the state of the art in irrigation management, accepting some support entity suggestions but totally discarding others.

Water distribution

The consulting firm proposed, to make water delivery technically "more efficient", avoiding losses during a user's turn (tail waters or wetting of the canal), and to irrigate from head to tail or downwards by plots, rather than by fixed user shifts. Apparently, this proposal would improve water distribution, but users felt that it entails many disadvantages, including the following:

- All week long, users would have to be alert to when their turn might come, which would prevent them from planning their time for other activities.
- They would invest much more time in controlling irrigation of their plots, since they have several plots scattered in different locations along the canal.

The implementation of this proposal needs to have a person who continuously registers each user's time of irrigation in order to make sure that they irrigate only for the time consistent with their water rights. However, the water judge is present at irrigation only if there are problems. Judges are not present non-stop.

These disadvantages were users' reasons not to accept the changed distribution mode. However, their main reason to choose the current distribution arrangement is that it is "transparent and predictable" as will be explained below.

Before building the new gallery, user turns lasted the following times:

Table 3.7 Number of users and duration of irrigation turns before building the new gallery

Number of users	Duration of turns
21	6 hours
10	3 hours
3	2 hours
2	3 hours (sharing 1 hour with another user, every other turn)

Source: Final Design Document, "Condorchinoka Irrigation Project" 2000.

This arrangement kept the irrigation interval fixed, determined by the total duration of one cycle through the irrigation turns. In 2001, although there were a greater number of users, the number of turns (and therefore the total duration of a turn) did not change. Six new users really only received part of their parents' turns. The irrigation interval to complete the 27.5 six-hour turns is 6 days 21 hours, which means that, each time around, the new cycle begins three hours earlier. This situation enabled all users to irrigate sometimes by day and sometimes by night. Under the arrangement proposed by the support entity, there would be no way to predict when one's turn would come up, because it would be a function of the characteristics of the plot to be irrigated (type of soil, size, type of crop, type of irrigation). This would make it less transparent. Also, since all users know the distribution system, they can know when they will get water again, in order to plan their other activities more conveniently.

Other reasons making any other distribution system difficult to accept were that the system has a single conveyance canal (not split), and users' production strategies, such as staggered planting and production of crops such as onions, carrots and other vegetables requiring frequent, reliable irrigation. This latter reason led users to decide to maintain the irrigation frequency, so that the entry of new users would not lengthen the interval between each user's turns.

Another aspect to mention regarding distribution and water availability is that project implementation increased the total flow to distribute. Nearly 50% of the main canal was improved and the flow intake was increased. By lining part of the main canal, "*descorreduras*"[16] tail water times and water leaps were reduced, which helped make water use more efficient during each user's turn.

Maintenance

After building the new gallery and lining part of the main canal (October 1999), the support entity and users agreed to perform the following maintenance work. (Minutes of the community of Condorchinoka, December 1999):

Table 3.8 Maintenance work proposed after completing the project

Type of maintenance	Physical facilities	Description of activities/tasks
Routine	Main canal (lined and dirt) Inspection chambers (underground canal) Inspection chambers (underground canal) Filtration gallery	Cleaning, the first day of each month. Inspecting infrastructure (by the president / water judge). Cleaning, first days of the month, quarterly. Cleaning collection canal and silt trap chamber, first days of the month, quarterly.
Preventive	Gates Main canal Main canal Lined canal, chamber covers, edges, etc. Filtration gallery	Painting and greasing gates twice a year. Highlighting meter markings on the lined canal. Building crown ditches to prevent erosion and damage. Patching any cracks and breakage. Unclogging filters and cleaning openings, every two years. Building walls to protect the gallery.

Source: Operating and maintenance manual by the support entity.

Out of the tasks indicated in this chart, only monthly ditch cleaning is done regularly. At this time of writing (2004), the inspection chambers (gallery and conveyance canal) and gallery collection canal

16 *Descorredura* is the time that the water remains in the canal, once the water delivery has been cut off at a given point.

should have been cleaned, and the gates greased, but users have not done either. Users did not give reasons why they do not clean the gallery and conveyance canal even though they agreed to do this.

Many users mentioned that gates have no adjustment mechanism (rod gates). When well greased, they will shut by themselves, under their own weight, damming up water that ought to be flowing to irrigate. For this reason, they prefer for gates to be un-greased and hard to operate, so they will not close accidentally during irrigation. This problem is caused by the infrastructure, affecting maintenance and operation.

During the support stage, users agreed to pay dues for maintenance, overall US$ 66.50 per user a year (which is equal for all, despite unequal water shares), to purchase materials for maintenance work. This means US$ 2.40 per six-hour turn. This does not include the workdays that each user should contribute to the different jobs. As of 2004, users have not paid this agreed fee. The irrigation system organisation is voluntary, with no punitive authority, and the water judge cannot force users to pay the fees. Any agreement has to be determined at users' meetings, but, as most of them do not contribute their fees, this issue is not discussed at meetings. This is a great problem because irrigation system sustainability is at risk.

Organisation

The support entity, H & S, a consulting firm hired by the FDC through a public bid, promoted formation of the Condorchinoka Irrigation Association, as a way to strengthen user organisation, adding new positions and roles to the existing irrigation committee. Suggestions by the support entity on setting up this irrigation association were reinforced when leaders, along with some other users, visited the Batallas irrigation system in the Department of La Paz. That system had recently implemented an irrigation project, and its users had decided to organise into an irrigators' association. This helped persuade Condorchinoka users to adopt that type of organisation.

The Condorchinoka Irrigators' Association was set up as follows:

Table 3.9 Positions and duties on the Irrigation Association board

Position	Duties
President (Water Judge)	- Organise the beginning of turns - Resolve conflicts - Organise maintenance
Treasurer	- Manage finances - Support the president's work
Secretary	- Keep minutes - Support the president's work
Member	- Notify users, leaders and outside the community - Support the president's work

Source: Minutes of the community of Condorchinoka November 1999

This organization has existed since 1999. Users feel that it is a positive change for the water judge to be supported by a recording secretary, treasurer and other member to help. On the old irrigation committee, the water judge received little or no assistance in performing his duties. After the project, the other members including the treasurer support the president's work, especially when he is not present in the community.

The association's board is chosen every January, which is when the water judge was traditionally renewed. All users of the system are eligible to serve on the board, and may be re-elected if users feel that they have done a suitable job. Users pay no dues to the irrigation organisation, because they believe that they do not need money in order to manage the irrigation system. For them to be the authority is an obligation that all users should carry out in rotation, without receiving any remuneration, but everyone must attend monthly meetings (on the fifth of each month) held together with the whole community's syndicate meetings. Treasurers, secretaries and members have the duties indicated above in the syndicate, which shows how the irrigation association is inserted within the community's overall organisation, as was the old irrigation committee. The change here is more a re-labelling than a change in the essence or organisational form regarding irrigation.

Proof that the organisation has not changed under the new name of "irrigators' association" is that previously the water judge was responsible for distribution before Agrarian Reform, and this role was called *Jilakata*. In 2001, the irrigators' association president was called water judge or *jilakata*, because users felt that they all mean the same and the duties had not changed.

Water rights

As in most irrigation projects, which base water rights on workdays or money invested, work to improve the Condorchinoka system made it possible to formalise water use for another six users, who received a fraction of their parents' water rights.

Although everyone worked equally to build the old gallery, a new criterion was applied to build the new gallery and line the canal: users decided that each one should contribute work in proportion to their own water rights. (171 days of work for a turn of 6 hours). Those who irrigate for a longer time worked more and those who irrigate for a shorter time worked less. This agreement was obeyed by everyone, during the meetings that users had with the design engineer. During the support phase users decided that the contribution for maintenance would be the same for everybody, without taking account the variety of water rights

This shows that decision-making is collective and dynamic. Any rule set by community consensus may be changed when situations change, such as production conditions. Therefore, water rights are valued quantitatively higher when production is intensive and priority is given to watering vegetable crops for market. This grants greater economic value to water rights for whoever irrigates more, earns more, and must therefore contribute more. Nevertheless, each user makes the same contribution to maintenance.

Obligations and penalties regarding the conservation of water rights, currently in effect in this system, are shown in the following table:

Table 3.10 Obligations and penalties in the irrigation system

Obligations	Penalties for non-fulfilment
Workdays for canal maintenance (one per month).	Fine: US$ 7.
Workdays to change new gallery filters (2 days every 2 years).	
Dues paid for maintenance (US$ 66.50./ year / user).	Fine: US$ 3.
Meeting attendance (the fifth of each month).	
Using water only during each user's turn.	Fine: US$ 29 (and loss of the turn).

Source: Minutes of the Condorchinoka community's minutes, December 1999

Fines are not levied in practice; they are only a threat. Building the new gallery increased each user's workdays required for maintenance, to change gallery filters and clean inspection chambers. Each user must also pay a yearly maintenance fee (they do not pay), which was not the case before these new facilities were built. Other rules and penalties regarding water rights are not directly related to the irrigation system, but were established in the community minutes. They are now included in the Condorchinoka irrigation association by-laws. Although regulations are in writing, they are also flexible, and are mainly used to support the community's rules and practices. Penalties are seldom or never applied, because users say this is unnecessary. These apparently superfluous regulations may have been introduced because, during truly critical periods during intervention (1983 and 1993), they helped regulate access to water and resolve conflicts.

Water rights are family-based. All family members use water on their plots, which are also family-owned. Due to the shortage of water, new users are not admitted. This is a closed system. When children form their own families, their parents give them a fraction of their own water rights and land. The rule maintains the 27.5 six-hour turns. Obligations and penalties related to conserving water rights are also the responsibility of all family members.

Although the project tried to change them, irrigation management characteristics have remained just like before the project intervention, as presented in Table 3.12.

3.4 THE DESIGN PROCESS

The project took a long time (8 months) to obtain funding for implementation, as shown in the following chart:

Table 3.11 Timetable for project implementation funding approval

Activity	Date
Final design document submission	February 1998
Approval by CDAP	4 May 1998
Approval by CAF	11 May 1998
Contract signing, FDC-Promoting entity	20 May 1998
Contract with the building firm	28 October 1998

Source: Condorchinoka project procedural manual.

After FDC and the promoting entity (in this case, the Oruro Prefecture) signed the contract, it was finally possible to begin the tender process for project implementation and supervision. According to the contract, the Prefecture would be responsible, with FDC support. The tender required the longest time. The contract with the building firm was finally signed on 28 October 1998[17].

17 The project was included in the Municipal Development Plan (PDM) and the Annual Operating Plan (POA) for 1998 in the municipality of Cercado-Oruro, District 6.

Table 3.12 Condorchinoka irrigation management analysis III – After Project

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision at the committee meeting: 1. Everyone contributes 171 workdays per 6-hr water shift to build the infrastructure (differentiated contribution). 2. No new users are allowed to acquire water rights, aside from dividing up their parents' rights.	Decision at the general irrigation committee meeting to: 1. Begin delivering water by shifts and on demand. 2. Elect irrigation organisation positions.	Decision at the union meeting for each user to contribute 1 workday / month to clean infrastructure and contribute US$ 2.40 / year per 6-hr shift, for maintenance.	Decisions at the committee meeting to establish penalties for failure to fulfil agreements and obligations.	Decision at the irrigation committee meeting to organise a construction committee to monitor workdays, quality of new infrastructure, and organise construction tasks.
	Activities involving workday records.	Activities involving preparing the roster of shifts, so all will have the benefit of irrigating by day and the difficulty of irrigating by night.	Activities involving cleaning sediments from infrastructure.	Activities involving monitoring fulfilment of norms and obligations.	Activities involving work organisation: scheduling, groups.
Formal rules	Rules establishing the relationship between rights and obligations: attending meetings, holding positions on a rotating basis, paying maintenance dues.. The work of minors is not recognised.	Only people with water rights irrigate during the dry season. Delivery is by rotation and full flow to users (who decide which plots to irrigate). Delivery interval no longer than 7 days. Water from different sources is mixed, including the new gallery, to increase the flow.	Rules enforcing participation: abide by the schedule, do work efficiently, take your tool, contribute US$ 2.40 a year.	Rules fining for failure to fulfil established norms and obligations.	Rules establishing the work schedule, age and sex of users allowed to do work.
Participants and roles	Construction committee to monitor workdays and users to complete their workdays.	Water judge to prepare and oversee roster of shifts. Users' group with water rights in dry season and the entire community in rainy season.	Water judge to monitor and users' group with water rights to clean.	President (water judge) to enforce penalties and users who do not fulfil their obligations.	The building company, directing the work, the construction committee monitoring quality, and users contributing work.
Logic and informal rules	Logic of community control. Each user monitors how many workdays he contributes and others contribute.	Logic of community self-control (transparent and predictable). The president prepares the water shift roster. Users know when their shift is, and irrigate their plots until completing their shift. The one with the shift open and close the corresponding gates.	Logic of community self-control. Users come with their tools to clean canals. They partially do routine maintenance but no preventive maintenance. They give no O&M fees.	Logic of community self-control. Distribution conflicts are settled in order: between users, water judge, union meeting. No fines. No penalty for failing to pay O&M fees.	Logic of community self-control based on inclusion and exclusion because of investment in construction. Users do not contribute workdays when the building company demands labour.

The amount approved for project implementation was based on the eligibility criteria set by PRONAR, i.e. US$ 2500 per additional hectare brought under irrigation and US$ 4000 per beneficiary family. In Condorchinoka, the amounts calculated did fall within the range of these indicators, but estimated and real costs differed (as shown in the following table):

Table 3.13 Comparisons between the values of projected and actual eligibility indicators

Indicators	Eligibility criteria	Project estimate (US$) 1997	Real Amount (US$) 1999
Cost per additional hectare	Under US$ 2500.	2,386.64	3,021.12
Cost per family	Under US$ 4000.	1,345.20	2,229.87

Source: Final design document, "Condorchinoka Irrigation Project" and Condorchinoka project procedural manual.

Regarding the first indicator, the actual project cost increase put the cost per additional hectare over the established ceiling. The project document estimate was under this limit. Even the full amount (US$ 2500 / hectare) would not have been enough to line the entire canal. Moreover, the table shows that the investment per family was not a constraint, because the US$ / family ratio fell within the established limit. So, the criterion that more severely restricted investment in this irrigation project was the maximum cost per incremental hectare. This factor reflects the great importance of a good analysis of alternative ways to improve this system, to find the best possible way to increase the amount of irrigation water available, for the least investment. But, in this case it was impossible to cover all the work required to improve this system, such as lining the whole main canal (another 1132 metres) plus some lateral canals that were identified as benefiting from lining.

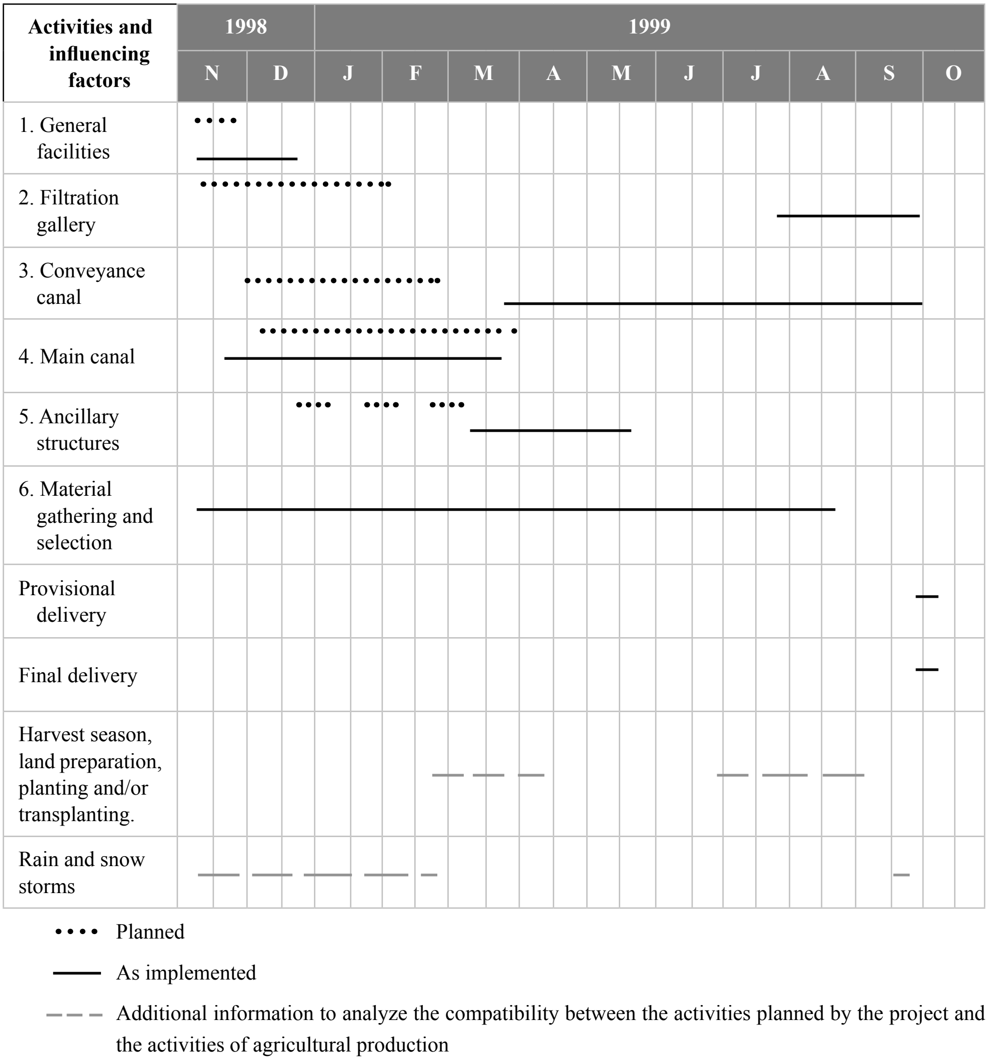
3.4.1 Project implementation

For this phase, the Oruro Prefecture played the roles of promoting entity (PE) and project implementer, signing an agreement with the FDC on 20 May 1998. Under this agreement, the FDC would provide the disbursements to build the facility according to the project timetable, and to supervise the project until completion. The Prefecture was to take all actions required to build the project according to FDC regulations (tender and contract procedures). The Prefecture (PE) would then sign a contract with the beneficiary community (BC), which would make the community contribution to the construction work. The contract between the PE and the contractor entity (CE) to whom the project contract was awarded was signed on 28 October 1998. This document set implementation deadlines, technical specifications, and so on for the CE, and the cost for the work.

Building began on 10 November 1998. The contract set a deadline of 180 calendar days (6 months)[18], so the provisional delivery date was initially 3 May 1999. The implementation timetable differed quite a lot from the final design document's plans, for several reasons, including: precipitation (the rainy season) and low user participation in work during certain stages, according to the building company. These challenges are analysed below.

18 The final design document for the Condorchinoka project planned to implement the work over five months' time. However, this timeframe was extended to six months in the contract with the construction company.

Figure 3.3 Comparison of planned and real building schedules and the influence of other factors



The planned schedule shown in the chart is taken from the final design document. (The building firm's schedule was not available.) As mentioned above, they were given another month. The construction actually took 338 days. Provisional delivery was 11 October 1999, 158 days behind schedule regarding the initial delivery deadline accepted by the builders. Users provided very little assistance for construction work during those times when they had to prepare their land, transplant / sow and harvest. The construction journal shows that, during these periods, there were several days when no community members at all came to help. Another factor that prevented community members from helping was when they went to neighbouring communities' fairs to peddle their produce.

The Building Firm organized only one work group to begin the work. Users complained, saying that this caused delays. Users asked the contractors repeatedly to organize more work groups in order to conclude the construction quickly to avoid interference with their agricultural activities. The construction committee and farmers prioritized the activities of agricultural production; they could not postpone these activities.

The supervisor then suggested that the company include an additional work group to build canals in order to stay on schedule. A new work group was finally included on 6 March 1999; the company later added a third group to build gabions (on 2 June 1999). Users were also uncomfortable with the contractors because they delayed construction of the works. The Building Firm began work without a resident engineer to organize the work. According to the contract the construction should be concluded in six months. It was the Prefecture's responsibility to guarantee that the community made its contribution to building, but the Prefecture's technicians were not present in the zone during implementation to organise the work.

In addition, a document review (Final design document, "Condorchinoka Irrigation Project" and Condorchinoka project procedural manual) and interviews, during construction, revealed the following problem situations:

- The final design document said to start building with the filtration gallery, then the conveyance canal, and finally line the main canal and ancillary structures. Due to rainfall, the Tolapalca river rose. The supervisor authorised the builder to build in exactly the opposite order.
- Building began without an on-site engineer. The project supervisor and users insisted strongly, and met to decide to apply a fine of US$ 20 per day without the resident engineer. This is a common problem during irrigation project implementation, when building firms promise a qualified professional for this job only to win the tender. When they are awarded the contract, they look for a replacement, often less qualified for the job (or, in this case, non-existent), which harms the quality of work.
- Users complained that the lined (main) canal was too small for future flood flows, and asked to have it enlarged. This suggestion was approved by the supervisor, who authorised higher canal walls (from 35 to 40 cm) making the walls thinner (15 rather than 20 cm) to compensate for this increase in height. Users readily got their way, because their proposal was coherent with the criterion of considering the new gallery as a source of additional water, rather than a substitute for the other gallery and river water.
- The supervisor ordered a change in the initial angle of the conveyance canal from the intake and the addition of two inspection chambers on this canal for technical reasons and to facilitate cleaning. The canal's starting angle was changed to match a change in the orientation of the gallery, and the two additional inspection chambers were added primarily in response to the change in direction of a stretch of conveyance canal because of a rocky riverbed. The supervisor also felt that the chambers were too far apart to properly maintain the facility in the future.
- Users suggested a change in the last stretch of the conveyance canal, aligning it to avoid interfering with the old gallery's conveyance canal. They also objected to demolishing their old gallery, saying that they would do so later (which they did not). The users actually never felt that the new gallery was to replace the old one. This was

clear, and the resident engineer understood this and approved the non-demolition.

- The supervisor and CAT-PRONAR Oruro advisors ordered a change in the orientation of the gallery's crosswise part. This was because they felt that the original angle between the river and this part was too acute (under 90°).
- The supervisor decided to pour concrete into frameworks between 10:00 am and 3:00 pm, because the winter is so cold. This is important, because a few days earlier the supervisor had authorised casting from 9:00 to 4:00, which meant that the concrete mixes were not setting properly during two days of work on the conveyance canal. Users complained that the canal was going to crumble.
- The community objected to placing gabions where the supervisor had indicated, although the latter ultimately got his way. Community members felt that the gabions should be placed to protect crop areas (alongside the river) that are harmed by flooding. The supervisor's priority was to protect the built facilities, mainly the first stretch of the main canal, which is quite near the riverbed, and consequently the fields near this stretch. Maybe the supervisor overrode the users' opinion here because there were too few gabions to protect both the facility and their fields. The last high-water period washed away whole fields just below the area protected by gabions.
- Users began watering their crops from the main canal long before the provisional delivery of the facility, because the crops needed the water. They used the same water distribution arrangements as before the intervention. The main canal lining was finished, but the gates had not been put in, which was why they had been told not to use the canal. Users ignored these instructions and began preparing their land and watering for planting / transplanting purposes. The company complained about this when they were installing the gates, and made users promise not to use the canal until they finished with the gates.
- One flood period silted up 350 metres of the conveyance canal, which was ready for final inspection. Users said that it almost always snows in the mountains when this happens. They told the resident engineer not to uncover the canal that was protected. The engineer ignored this suggestion and uncovered the canal for inspection. Users complained about this attitude, because they had to clean the canal again.
- Rain rushed the company's placement of filters in the gallery. This resulted in poor selection and placement of the filters, which are now totally clogged. Another negative factor was the lack of continual supervision during this work. Users did not complain, probably because they did not understand how important filters are in this type of facility.

3.4.2 Evaluation of project stakeholders and roles

The main stakeholders who took part in the project design process were:

Rural Development Fund (FDC)

The theoretical roles of the FDC during project implementation were: disbursements according to the agreed schedule and supervision of and support for construction. The building firm had no complaints about the disbursement schedule. The manager said that there were some delays in FDC disbursements, but they were not significant. The company operated with its own funding, which prevented delays in work when disbursements were late. The problems involved supervision. The FDC had no suitable mechanism for project supervision that would guarantee good results.

Supervisor

The supervisor[19] was hired by the FDC, under terms of reference framed by the FDC. During construction, he was responsible for all changes in the original design, and for the quality of work. He had to authorise or not any changes suggested by the community or the building firm, and accept or reject completed work. He was the technical person who interacted most with the community, although not enough, because site visits ranged from 2 to 25 days apart during the construction period. Visits were more frequent when they started building the filtration gallery. The supervisor was contracted not only to supervise this project; he also had the obligation to supervise other irrigation projects and other projects that FDC was financing in the area, for example roads.

The supervisor made repeated observations regarding the alignment of the main canal, the quality of stretches of the conveyance canal affected by winter cold, and the quality of concrete, insisting on taking test pieces and rupture test certificates, which the builder did, but not promptly (interview 2000). The supervisor's role in project implementation was important. He made practically all the key decisions during this stage, listening to suggestions and complaints by direct participants in the construction (users and building firm) and by the institutions overseeing his work. The supervisor also had to stand in for the support entity, which should have begun work during implementation.

Prefecture of Oruro – Oruro Irrigation and Soils Area (ARSO)

The Prefecture, as promoting entity, had to oversee the supervisor's work and help supervise. This was done from a distance, as the project log reports only two visits by ARSO technicians during the entire construction period.

Another responsibility of the Prefecture's was to guarantee that the community made its contribution to building. The only action it took for this purpose was to sign an agreement with the users in which they promised to do their part. During implementation, the building firm complained often about this and the supervisor had to mediate meetings to get community members to help. Because of his own time constraints, such meetings were not frequent. The direct relationship between the Prefecture and the building firm was their contract, signed before construction. However, this contract actually was of no importance, since the FDC paid the firm and authorised change orders and addenda, approved by the supervisor (also part of FDC).

Condorchinoka irrigation system users

During construction, users contributed "unskilled" labour and collected local materials (stone, gravel and sand) as the project beneficiary community counterpart input to the project. The number of workdays put in by each user was different, according to the number of irrigation hours

19 The supervisor was a civil engineer from Oruro, who had worked as supervisor of different public works (roads, irrigation, etc) for almost 10 years in diverse institutions. When he finished his work in Condorchinoka, in 2000, he took the post-graduate course on Irrigation System Management organised by PRONAR.

each was entitled to. The reference investment was 171 workdays per six hours of irrigation turn. Users actually invested more workdays than they had promised prior to beginning the project, which was 128.5 workdays per six hours of irrigation.

The number of community workdays was increased because construction began at a bad time, when rain washed away much of the material gathered by users near the river (mainly gravel and sand), and because of the additional work to clean the conveyance canal, which totally silted up when the river overflowed. Other reasons were the lack of consideration for the item of stone excavation for the main canal, which users had to do; and increased volumes of digging by hand in the gallery and conveyance canal, due to landslides caused by digging with machinery on the riverbed.

Users' work was intermittent. Many days, community people did not come for work, or only a few appeared, not enough for the promised work. The building firm complained to the supervisor about this continually. Users were organised in a construction committee whose role was to register the workdays of each user. Also they were responsible for presenting to the engineers the claims about problems in the new infrastructure.

Building Firm

The company responsible for building the system began work on 10 November 1998 (without a resident engineer). The latter finally appeared on 15 January 1999. Users complained that having only one work group caused delays. A new work group was finally included on 6 March 1999; the company later added a third group to build gabions (on 2 June 1999). The company also applied for five deadline extensions, which FDC approved. During construction, the company complained often about lack of compliance with community input. The company's only interaction with users was for such complaints – users were never asked about design or construction.

PRONAR Oruro

PRONAR participated as an advisory entity to prepare the project and also as outside inspectors, supporting the Prefecture. PRONAR's departmental operator's supervision involved deadlines, but also made some suggestions to improve the work, which the supervisor and building firm accepted and applied.

One great constraint for the PRONAR departmental operator's inspection work during construction was that the operator and the FDC supervisor belonged to different institutions. Therefore, any observations by the operator[20] had to follow formal channels, to wit: the departmental operator reported to the National Co-ordinator of UCEP[21] (Programme Co-ordination and Implementation Unit), which forwarded this report to the FDC-PRONAR (investment) Co-ordinator, who in turn forwarded it to the National FDC Director. He submitted this report to the FDC Departmental Head, who shared it with the Supervisors' Co-ordinator, who then showed the report to the project supervisor.

This lengthy process for the operator to make any observations or suggestions about construction was quite a limitation. If he had not had good personal relations with the supervisor (which was

20 The operator was hired by PRONAR. He was responsible for supporting the departmental Prefecture by inspecting implementation of all projects in Oruro.

21 A component of PRONAR.

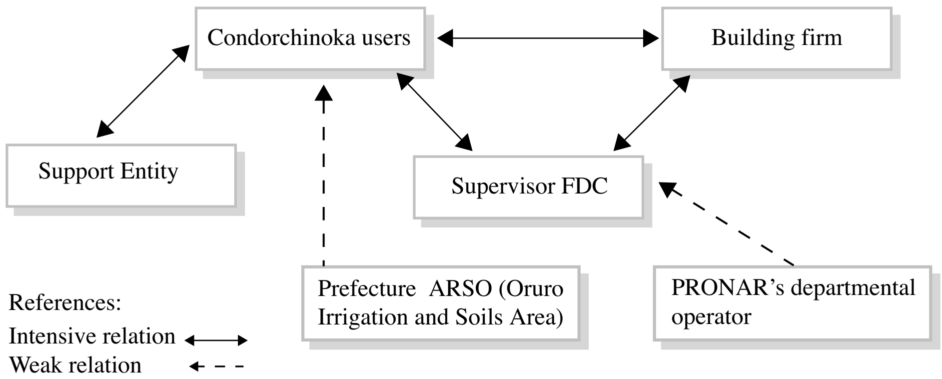
the case), the latter would have had no obligation to take any suggestions into account that did not follow the above pathway.

To conclude, this overview of stakeholders' roles shows that there were quite a few players, but they had little to do with each other and did not reinforce communal work. In a few cases, because of the formal mechanisms imposed by PRONAR and FDC, the former was prevented from any direct, prompt intervention or oversight of outputs. This made PRONAR and the Prefecture passive onlookers during implementation. Relations between them and users were not clear and had no effect on construction decisions.

The main players were the FDC (through the supervisor) and the building firm, who were mainly interested in users' labour input. Users never took part as co-designers. Although users did influence some design changes (as indicated above) this was on their own initiative, when they saw problems. Not all their change requests were accepted by the supervisor. Users were organized in a Construction Committee in order to oversee work quality, but the supervisor deprived them of authority, so the Building Firm did not take their complaints into account. The irrigation association began to work when the construction finished. The syndicate was not active during the implementation, because there was a construction committee.

In general, there was no interactive design either in project preparation or construction, or horizontal relations among stakeholders. During the design phase, users were only the designers' 'key informants'. During the construction stage, users were viewed by engineers mainly as labourers who had to provide manpower. The following diagram summarises who connected with whom and who did not.

Figure 3.4 Relationship among actors



3.5 APPROPRIATENESS OF INFRASTRUCTURE TO MANAGEMENT CAPABILITY

On the basis of this description of how the irrigation system intervention proceeded, it is possible to analyse how suitable and appropriate the infrastructure is to management capability. However, first it is important to examine the design, to help understand many of the project outcomes, and how "design" outcomes in the field differed from proposals.

In this case study problems were present in both crucial stages in the design, in content and process.

First, the assessment for project formulation of improved infrastructure required not only imagination, creativity or sound engineering knowledge, but also capacity and aptitude to understand the relationship between irrigation system management, irrigated agriculture and the role of existing infrastructure.

Some aspects of these relationships are:

- The demand for water is covered, according to “overall water available” at the source. However, limitations regarding water availability should be understood as a result of how the overall water supply is handled – the amount of water to which each user is entitled (according to the water right). That is, how water distribution is related to crop demand and plot layout, or irrigation demand in general (not necessarily just crops’ physiological demand, since water is required to prepare land as well and plots may be spread out).
- What the present infrastructure requirements for use are, and what changes the proposed infrastructure could entail.
- How facility functions and features meet users’ needs and interests.
- What criteria users have regarding water demand and the function of infrastructure in covering that demand. In this case, an example is the designers’ and users’ different concepts about facilities’ functions. Engineers viewed the intake (new gallery) as the only way to increase the water flow back to the higher levels from previous years, never considering the possibility of repairing the old gallery. Users saw the need (and got their way) to keep the old gallery (to provide water supply security during construction and in case the new gallery worked out badly) and also direct intake from the river with canals that could use surface water and pumping from the river into the canal. This shows that users saw the new gallery as an additional water source, not a replacement.

The second important stage was implementation, which encompassed the only process element of the design and where supervision played a crucial role. Key questions for the supervisor could be: Is the work done according to specifications or specific requirements for this type of facility? Each facility will require a specific intensity and quality of supervision during different stages. (For instance, a filtration gallery will mostly require careful supervision during filter placement, which was when this project received the least attention.). In this case the supervisor was not able to organise supervision properly because he had insufficient time; he had more obligations besides this project. Something that engineers should ask themselves is: How does the construction process fit users’ skills and capacity, so they can subsequently operate and maintain the facilities? Engineers seldom ask this question, although it is a key question, as shown in chapter 7. When users do not understand the facilities they cannot imagine how they will operate or maintain them. When they understand the project, they can object if it will be problem. In this case, engineers ignored problems of the new gallery in its hydraulic operation.

During (or before) the implementation stage, the building firm’s technical capacity and equipment are also crucial. Selection must be rigorous to avoid improvisations or deficient work quality or delays that may affect the overall output / infrastructure. The building firm did not want to spend money to hire a resident engineer and also did not want to hire a foreman to direct the work of other work groups. Summarising, FDC did not have sufficient authority and responsibility to oblige to the building firm to comply with the specifications established in the contract. It is clear that in the FDC there were institutional problems (administration and methodological framework) with effects that can be seen in the rehabilitated irrigation system.

With these considerations and taking into account Tables 3.5, 3.6 and 3.12, the three key dimensions of appropriateness of infrastructure can now be reviewed.

3.5.1 Operational appropriateness of infrastructure to management capability

Operational appropriateness of infrastructure is directly related to users' capability to distribute (operate) and maintain the built infrastructure.

Since canals are not arranged hierarchically, the facilities are simple and users prefer to rotate a single flow of water, so users have the capacity to operate the system. There is no conflict in water delivery, because it is transparent for all community members. The support institution's proposal, to distribute water by groups, would have caused transparency problems. The project proposed to distribute water by groups, but did not design or build measurement devices at the distribution points, so users could be sure to receive the right amount of water. In this respect, the project did not relate infrastructure and operations with local water distribution preferences.

However, in this case, infrastructure does go along with some of the local users' concepts regarding equity. They feel that the new infrastructure has satisfied[22] both the users at the head of the irrigation zone and those at the tail. The new lined canal (in one section) gets water from the intake to fields at the end of the system faster, so farmers there can enjoy their water rights as well as the rest.

Regarding users' maintenance capability, this is limited. During the support and construction periods, engineers never trained users or even discussed maintenance requirements with them, so the facilities in general cannot be efficiently maintained. They said what to do but never "how" to do. Users were not trained to carry out the maintenance of the new works. The filtration gallery is the worst problem, since users do not know how to place or maintain filters (users do not know what a filter is or how it works), and only react to emergencies. Consequently, water catchment capacity is reduced, decreasing water availability and jeopardising the irrigation system itself. The old gallery does not have filters, so the problem is serious. Farmers never had the knowledge or practice about how a gallery should be maintained. When engineers designed the new gallery they never asked themselves why the old gallery was not functioning properly, and never related the problem with maintenance. As said earlier, the problem is the divorce between infrastructure design and management requirements, in this case maintenance requirements.

Users think that they can maintain the infrastructure only by cleaning; they do not pay fees. There is a contradiction: they want new technology but they do not respond to new maintenance requirements. Possibly they think they will try for another new project when this infrastructure deteriorates.

Further, since the facilities were built on the basis of users' labour investments, they feel that this was fair. Where problems could arise is in regard to money for maintenance, since there is no proportional relationship between water rights and the fees, which are the same for all. This

22 Users are not happy with the main canal section, but do feel that the canal has not been improved solely to satisfy some group, but for all users.

situation may change over time, because day-to-day users realise that water has an economic value. When they built the old gallery, everybody worked the same number of days, even though they had different water rights. Changes happen over time, in a process that responds to the users' interests. The irrigation association only implements users' decisions.

In conclusion, this irrigation system's usability, from an operational standpoint, is fairly certain, whereas maintenance capacity is restricted. Infrastructure maintenance could be assured as long as the facilities built did not require any additional work beyond users' technical capability, labour availability and economic contributions.

Unfortunately, if users are not taught and made aware of the need to maintain the filtration gallery and other facilities, this system may become unsustainable over time. The system's sustainability is also affected because of a latent problem with the neighbouring community, whose members question the location of the filtration gallery in their territory. This situation logically weakens this irrigation system's management capability. This is a case that shows how technical criteria[23] override users' management criteria in design and construction, specifically in social territorial issues.

3.5.2 Technical appropriateness of infrastructure to management capability

This case shows that the designers made no analysis of the "irrigation infrastructure" as a whole or a system, but simply made isolated calculations. For example, the lack of systematic analysis of the infrastructure could have turned out badly, since the filtration gallery (with a proper filter) could have taken a larger flow (140 l/s). However, this would make the covered conveyance canal operate under pressure, which it was not designed for (designed capacity of the canal was 40 l/s).

Another deficiency in design and construction is the lack of functionality. The new filtration gallery cannot perform its rated work, because the badly placed filters limit its intake capacity. Similarly, canals have restricted conveyance capacity, too little to conduct larger flows, when heavy seasonal rainfall increases flow. When the canal was designed, engineers apparently were unaware that the existing canal carries water from the filtration gallery, from wells and from the river (through the existing traditional intake) and that water is often mixed. So, they calculated the canal just for the water from the new filtration gallery. During the design there was no interactive process; users did not participate sufficiently in the design. During the construction, users could see clearly the limited canal capacity and complained about it, but it was too late, because the investment budget was already finalised. There was no more money for adaptations of the infrastructure. The problem is that both users and engineers have different concepts of project phases, as will be shown in chapter 7.

In sizing the infrastructure structurally and in terms of capacity, engineers should have taken into account:

- The use and function that the infrastructure would have. For example, the main canal seems to have been sized by a mechanical design of crop water demand versus

23 The infiltration gallery was located in order to connect with the existing main canal, in order to keep the irrigated area of influence the same size.

estimated water availability, rather than actual irrigation demand and practice during the rainy season, which requires higher flow rates.

- A balance between practical operation and maintenance of the infrastructure and structural security, which obviously affects investment and maintenance costs.

Similarly, to adapt the facility to local conditions, basic information such as geological, hydrological (flood levels, silt entrained), soil and topographical studies are fundamental for design. In Condorchinoka, no detailed geophysical study was made of the filtration gallery deployment site. For this reason, part is on permeable alluvial material, which prevents it from intercepting all the water. It would have been more appropriate to improve the existing filtration gallery rather than build another new one, especially if there was no certainty of optimal site conditions. Designers should also have investigated how the existing filtration gallery was being maintained, and adapted the technical proposal to these existing conditions.

This case shows that water availability will not necessarily be increased by building new projects or larger, more sophisticated ones. Rather, it is possible to improve those already existing, on the basis of analysing whether elements of how they work (properly) are altered, or what factors jeopardise that operation. As already mentioned, it probably would have been good enough, in view of the river's flow characteristics, to improve the existing filtration gallery, analysing:

- Whether the project per se can still take in the underground water beneath the riverbed (which depends on the river's flow and the geological characteristics and facility conditions).
- Whether the filters (an essential element of this type of catchment facility) are still operating (or even exist or not) and how well they can be returned to optimal operating condition.

Another weak aspect of the construction process is that formwork could be poured only for a few hours a day during the winter, which prolonged the planned construction period. The lack of machinery and equipment made the construction process very difficult and slow, causing design changes (gallery depth and filter quality). These examples show us that design must take into account a prevention plan, with special attention to the necessary construction equipment and machinery, to avoid construction problems. That is, the prevention plan must take the measures that will reduce construction-related risks.

In conclusion, all these deficiencies in designing and constructing facilities produce serious technical deficiencies, affecting infrastructure functionality. This situation and the fact that users do not pay fees for maintenance, jeopardises maintenance requirements, and reduces users' management capability to meet these requirements.

3.5.3 Productive appropriateness of infrastructure in relation to management capability

There are several reasons why users do not properly maintain the improved infrastructure: One reason why users do not pay fees is because they do not have the habit of saving cash resources for their future life: animals are usually used as their savings bank. When there is an emergency they sell their animals. Irrigation organisations for small irrigation systems usually do not work with cash contributions. Collective action is expressed in the contribution of labour.

Further, the local organisation cannot enforce payment, because it is flexible and has no coercive power.

Another reason involves users' preference, to invest their earnings for family goals, such as children's education, purchase of consumer goods, etc. This reduces the possibility of contributing for common goods such as irrigation infrastructure. This may also reflect their two experiences of obtaining external financing to improve their irrigation infrastructure. So they will look for another new grant for future rehabilitation of their system. When asked why they do not pay fees, they say that they will pay later on.

The possibility that users do not pay their fees because they do not have enough cash revenue was also considered. Users' ability to contribute was analysed as a function of the economic revenue yielded by the new infrastructure. To analyse how appropriate the infrastructure is economically, the annual costs of maintenance and the economic earnings from irrigated agricultural production were compared.

In this case, annual estimated maintenance costs are US$ 1066 (Table 3.14), which means that each user family should contribute US$ 25.40 / year, since they agreed that all families would pay the same fee, regardless of their different water rights. The table was compiled considering the type of material, infrastructure dimensions and the maintenance needs for each kind of facility.

As shown in Section.3.3 above, average income with the improved irrigation system was US$414 / year / family. Excluding labour cost, the annual maintenance cost is $US 297. This means that each user should contribute US$ 7/year. Comparing the irrigated agricultural income before the project and the current income, users now have an additional US$ 156. Such an estimate might lead to the conclusion that income is easily enough to cover cash requirements for maintenance, and that labour can still be given for maintenance.

In order to understand why users do not give fees an estimate was made of how much money they need to live. According to the Bolivian Statistics Institute, average household spending in the *altiplano* is US$ 77 / month, equivalent to US$ 924 / family / year. Comparing the new income with the amount required to support a family, irrigated agricultural income covers only 45 % of the required amount. While they have some subsistence needs provided, they must also work elsewhere in this intensifying production system, so farmers do not want to contribute additional labour for maintenance (an additional requirement of 6 days per family). They prefer to put this labour into the additional activities that help build adequate living standards not covered by irrigation income alone. For similar reasons, few people would become employed as a full time maintenance worker.

This leads us to ask: if users cannot afford to maintain their improved infrastructure, shouldn't projects be designed and built with better quality, to require less money for maintenance and last longer? Otherwise, improved irrigation systems actually reduce self-management capability.

To finish, this case study proves that there is a clear relationship between infrastructure and irrigation management that was not considered by stakeholders who designed and implemented this project. There were weaknesses in both design content and process, including inappropriate works, which have operation problems, and lack of users' knowledge about how to maintain the works. Also, users did not comply with commitments to maintain facilities, although their income is better with the improved irrigation system.

Table 3.14 Annual maintenance costs in Condorchinoka

Activity	Frequency	Cost of materials and inputs (US$)					Cost of labour			Total (US$)
		Item	Unit	Unit price	QTY	Total	Nº days	Unit price	Total	
INTAKE										
Inspect intake	monthly	Notebook and pen	PI	0.63	2.00	**1.26**	1.50	3.25	**4.88**	**6.14**
Clean chambers	3times/year	Torch (flashlight)	PI	0.25	2.00	0.50				
		Batteries	PI	0.50	6.00	3.00				
		Builder's buckets	PI	0.90	5.00	4.50				
		Ropes	m	0.02	6.00	0.12				
						8.12	42.00	3.25	**136.50**	**144.62**
Change filters and loopholes	Every 2 years*	Rental fee backhoe	PI	150.00	1.00	150.00				
		Gasoline for pump	l	0.46	15.00	6.90				
						156.90	42.00	3.25	**136.50**	**293.40**
Protect gallery	Every 2 years*	Gabions	m^3	17.00	5.00	**85.00**	10.00	3.25	**32.50**	**117.50**
Subtotal 1						**251.28**	**95.50**	**3.25**	**310.38**	**561.66**
CONVEYANCE AND MAIN CANAL										
Reviw canal	2times/year					**0.00**	1.00	3.25	**3.25**	**3.25**
Clean canal	3times/year	Shovels	PI	0.10	42.00	**4.20**	126.00	3.25	**409.50**	**413.70**
Canal repair and maintenance	Annual	Cement	Sack	4.73	4.75	22.47				
		Stone	m^3	4.00	1.48	5.92				
		Sand	m^3	4.00	0.95	3.80				
						32.19	10.00	3.25	**32.50**	**64.69**
Patch canal	1time/year	Cement	Sack	4.73	1.00	4.73				
		Tar	Kg	1.00	1.00	1.00				
						5.73	2.00	3.25	**6.50**	**12.23**
Remarking stations	Annual	Paint	l	1.50	0.50	0.75				
		Brush 2.5"	PI	0.50	1.00	0.50				
		Wire brush	PI	2.00	1.00	2.00				
						3.25	1.00	3.25	**3.25**	**6.50**
Subtotal 2						**45.37**	**140.00**		**455.00**	**500.37**
Maintain gates	Annual	Rust-prevention paint	l	1.00	0.50	0.50				
		Brush	PI	0.50	1.00	0.50				
		Sandpaper	m	0.30	1.00	0.30				
Subtotal 3						**1.30**	**1.00**	**3.25**	**3.25**	**4.55**
TOTAL						**297.95**	**236.50**		**768.63**	**1066.57**

*This activity should be done every 2 years, but the calculation takes into account only the price for one year.
PI : per item
Source: Field infrastructure inventory (2002).

4 USERS, THE FORGOTTEN ACTORS: THE SAN ROQUE – CAPELLANIA SYSTEM

INTRODUCTION

The San Roque –Capellanía irrigation system is located in the “valley zone” in the community of San Juan del Oro. The community’s total area is 50 ha and includes several irrigation systems, among them San Roque-Capellanía, discussed here. This community is located in the municipality of Las Carreras and belongs to the province of Sud Cinti in the department of Chuquisaca. It is a valley with a dry climate, so demand for irrigation water to ensure agricultural production is great. The annual average temperature is 16.5ºC and the average annual total rainfall is 271 mm. This system has an intake with a long weir (30m) and a lined canal with a varying cross-section.

Most of the families living in this region have agriculture as their main livelihood. The zone at 2328 metres altitude grows a diverse crop range, predominantly maize and onions. Fruits such as grapes, peaches, pomegranates and figs were important in the zone up until a few years ago, but have lost ground to the new vegetable crops. Irrigators feel that horticulture is less risky, since fruits were plagued by pests and diseases, so they have profoundly changed their production system. This community uses land intensively (over 50% of the arable land area is also used during the dry season). Although maize covers much area, the higher-profit crops are vegetables, since their production is entirely market-oriented.

Because of the San Roque-Capellanía zone’s geographical location, it is closer to Tarija (111 km) and further from the department capital of Chuquisaca (400 km). The community is connected to both capital cities of department through a mainly unpaved road that joins the departments of Tarija and Chuquisaca. Tarija influences people’s life style greatly, with habits of consumption (wine), the Spanish language, clothing (bright colours, light garments), beliefs (Catholic religion) and Chapaco[1] cultural traditions.

Before Agrarian Reform, the community of San Juan del Oro was populated by small land owners settled in those lands. In this zone, one can find many traces of the Spanish conquest, in place names, practices and even home aesthetics. Most have *“potrero”* gardens next to their homes and larger fields further from home around the community. The influence of Tarija and therefore Argentina are referents of well-being for the people in this region. However, since their earnings from agricultural production are insufficient, there is a major migratory flow, particularly from San Roque-Capellanía to Argentina. Young, single people migrate most (40%). The rural families overall suffer low living standards and their houses are built with clay and straw, which makes it possible for vermin bearing diseases (such as “*chagas*” disease) to invade them. Among all these deficiencies, the people feel that the worst is the “lack of water to irrigate”, although the community does have drinking water.

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1 Chapaco/a refers to the people living in Tarija valley.

The San Roque- Capellanía irrigation system taps water from the Las Carreras river, which is fed by tributaries Tárcana and Lime, and then in turn joins the San Juan del Oro river. Along this river there are several rustic irrigation intakes, each of them autonomous[2]. The only link among these systems is that they have a single water judge. One of this intake is called "Lourdes", and is used by farmers from Las Carreras. There is minor overflowing at this intake, which increases the flow entering the San Roque – Capellanía intake. This overflowing occurs only when the rustic intake cannot capture all the water due to construction problems – it is not an entitlement.

The San Roque - Capellanía irrigation system did not provide water continually, because the intake was always breaking down, calling for additional labour to repair it, and users at the tail end of the system could not receive water under favourable conditions. Therefore, irrigators decided in 1994 to seek outside help to improve their system. It took almost five years to get a project approved to begin building, in 1998. In 2001, the irrigation system's area of influence was 31 hectares. Part of this area was also watered by two other main ditches, one that taps water from the Las Carreras river (Bramadal ditch) located at the end of the system, and the other waters the head of the system, tapping water from the Las Carreras river (San José canal).

This case was approached as a purely technical project. The final project design document broadly described the zone with general data (demographics, basic services, education, topography, ecology, climate, etc.). By contrast, there was very little mention of the central issues required to formulate an irrigation project, namely agricultural production, system management and existing infrastructure, as shown below. This situation, unlike the other cases, makes it impossible to know accurately what effect the project had on water management and the production scenario. The scanty information available in the final design document suggests that the project increased water availability from 198,000 m^3 / year to 360,000 m^3 / year. With this water supply, 37 families irrigated in 2001.

To show the thinking that guided intervention in this system the infrastructure characteristics at the end of the intervention are presented first, followed by the water management prior to and after system renovation, and the project's proposal for future water management. Finally the issue of the design process is addressed. Each of these elements leads to conclusions about the *appropriateness of the infrastructure to management capability.*

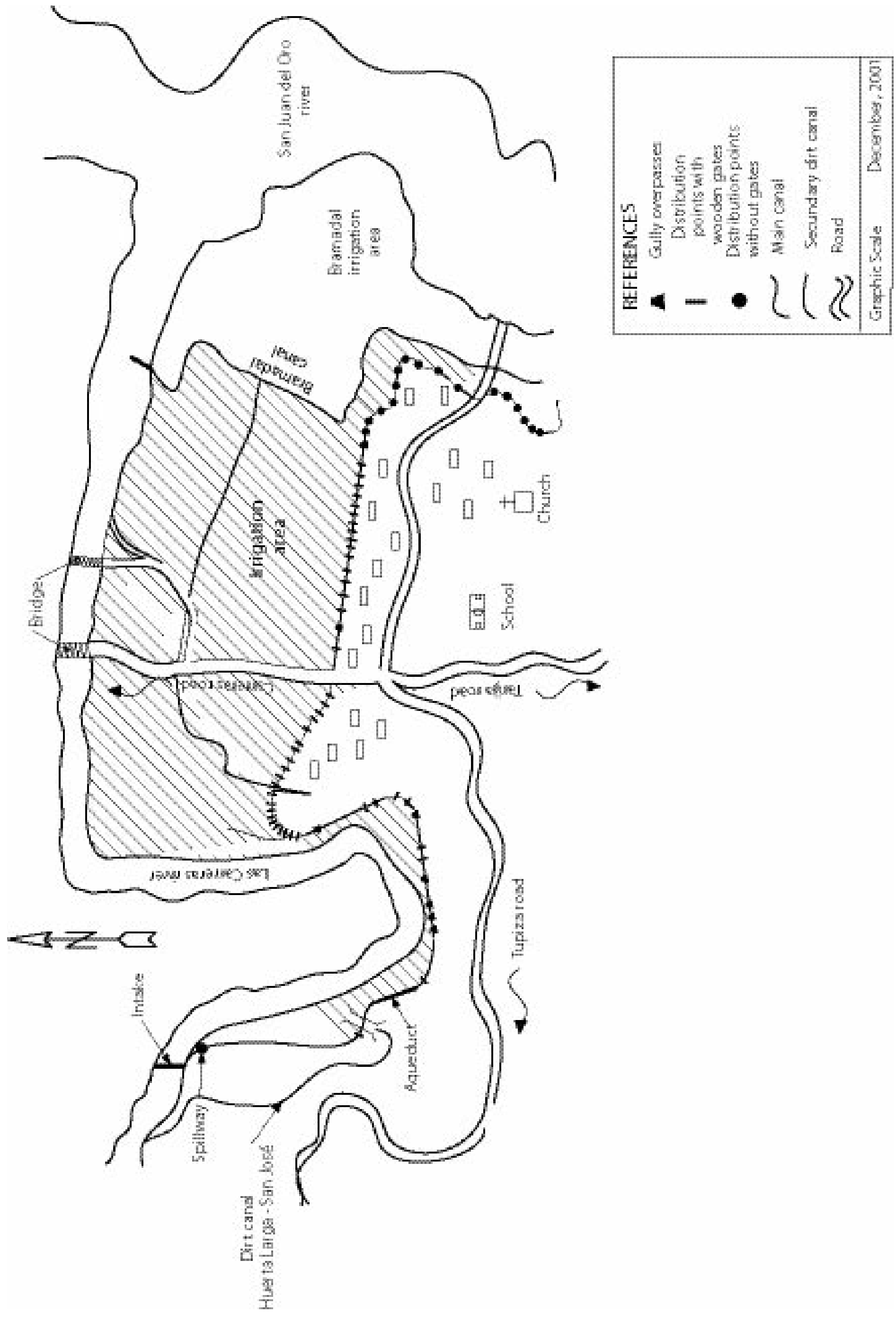
4.1 IRRIGATION INFRASTRUCTURE

Prior to the intervention, the irrigation system had a traditional intake (built of clay, branches and stones), tapping water from the Las Carreras river. The water was conveyed to the fields through earthen canals. Overall, the infrastructure was rustic, except for the aqueduct, which was built by the users in 1996 with funds from the Prefecture of Chuquisaca. After the intervention, the irrigation infrastructure had other features, described below. These features were inventoried during the field study in 2000 and 2001.

The operating principles of the system are as follows: the water is diverted through the intake, then conveyed through the canals and delivered through the different distribution points to the users in rotation and with all the flow. During the dry season they distribute the water, taking into account the turn list. In rainy season water use is open to everyone who wants it.

2 Each irrigation system has a commissioner. The commissioner is responsible for organising water distribution during the period of irrigation by turns, and maintenance work in each irrigation system.

Figure 4.1 San Roque – Capellanía irrigation system



Intake

The new intake is located at the rustic intake site that the system used originally. It has a protection wall and a guide wall about 30 m long on the right side. This protection wall has been raised in some stretches by users, after the system was built. Users made this decision because the river overflowed and flooded part of their fields, just in the year that the project was completed. The intake features a roughly finished weir (a kind of creager weir). The weir performs its role adequately, since the flow rate admitted into the canal is small (100 l/s in the first stretch). However, it silts up, requiring regular cleaning by users, to lead water to the canal entry point. Here also a grating is placed to catch water-borne debris, which can clog the grating and block out water unless cleared away regularly.

Flooding brings abrasive material, which has worn the weir, leaving the stones of the cyclopean concrete visible. This wear, though not large-scale, is significant, taking into account that the structure was made only a few years ago. Moreover, without any structure to buffer water action at the bottom of the weir, it is being undermined downstream. This undermining is not of any great magnitude, but considering that this damage happened during its first year of duty it gives concern for future maintenance activities. Water entry into the canal is controlled by a grate and gate for the open canal. The gate is operated by the commissioner and is hard to open and close (and does not close completely). The finishing of the weir, the entry structure and the intake quality are low overall. (Due to deficiencies in the cyclopean concrete, some sections are deteriorating). The structure is at risk of flooding, which affects surrounding areas, the intake and canal.

Main canal

The canal is lined up to survey station 2+255 and then only dirt up to station 2+400. The lined part is cyclopean concrete, rectangular, with variable sizing. Variations in the canal shaping are given below:

Table 4.1 Characteristics and variations in the cross-section of the lined canal

Section	Survey stations (m)		Length (m)	Slope (m/m)	Base (m)	Height (m)
1	0+000	0+050	50.00	0.0014	0.50	0.45
2	0+050	0+439.5	389.50	0.0004	0.50	0.40
3	0+439.5	0+529	89.50	0.0009	0.60	0.60
4	0+529	0+889.7	360.70	0.0014	0.40	0.40
5	0+889.7	2+053	1163.30	0.0028	0.40	0.30
6	2+053	2+255	202.00	0.0016	0.30	0.30

Source: Information gathered during fieldwork (2001)

The slope ranges, in the different stretches, from 0.0004 m/m to 0.0028 m/m, the most common slope being 0.14 %. Due to these changes in slope, the capacity is also variable, although the canal size is also smaller. It has a 250 l/s capacity in the first section and the end can carry only 30 l/s (flows measured, April 2001). Users complain about this situation, because it prevents them from obtaining the flow rate they require, forcing them to build up the sides of the canal with sod every time they need to conduct more water than the canal flow capacity.

During irrigation, the sod is washed away by the water and dams the canal elsewhere, causing hydraulic instability. The canal layout is irregular, and has curves and counter-curves. While lining the canal, formwork was placed only on the inside faces, leaving the outside faces without any plaster seal, and therefore more prone to cracking and leaking. This means that clods of dirt probably also got into the concrete mix, making it poorer and "contaminated".In addition to the main canal, which also plays the roles of conveyance and distribution, there are two unlined secondary canals called "Esquina" and "Pajcha", 255 m and 695 m long, respectively. The "Pajcha" canal is also known as the "Counter ditch" because it is located parallel to the main canal.

Distribution points

In this case the distributions points are stoplogs. They have different dimensions: 37 have gates 30x40 cm, 10 have gates 20x30 cm and 17 have no gates. Gates are wooden, placed in the main canal to bring water to fields by opening the intake, or at the intake when the field is not to be watered.

Other ancillary structures

To maintain a depth that will not overflow the edge of the canal, there is a lateral spillway at survey station 0+045, 5 m long. When the canal crosses gullies, there are 8 canoe culvert type passes. The pass over the Camargo – Tarija roadway uses a box-type culvert, with reinforced concrete covers. As already indicated, the system has an 89.5 m aqueduct to cross a gully, designed and built by users to shorten the water's pathway at the beginning of the system. This was constructed with a contribution of 200 sacks of cement by the Chuquisaca Prefecture and each user's labour input (equivalent of 31 workdays per *suyo* of water used). Its capacity is 100 l/s, which shows, to some degree, the users' expectation in terms of flow rate, especially to carry water during the rainy season.

4.2 THE AGRICULTURAL PRODUCTION SYSTEM

Most farm labour is performed by family members. When this is not enough, they hire hands on a job or day-labour basis. In 2001 a day's work cost US$3.25 for men, US$ 2.60 for women and US$1.6 for children. The criterion for this cost difference, according to users, is that women and children can make less physical effort than an adult male.

Generally, hired labour from neighboring[3] areas is mostly used for vegetable crops and for labour-intensive tasks. Because there is so much migration from this zone, farmers make production arrangements with landowners who leave for extended periods, sometimes never to return to their land. There are two production modes: rental and *compañía*. Under the former, the owner provides the usufruct of his land, in exchange for a variable amount of money, which the tenant pays annually. Often, owners never come back, in which case a purchase process begins. *Compañía* consists of sharing expenses and work between the owner[4] and the person[5] interested in cultivating under this mode. Generally, older owners (elderly persons[6]) use this arrangement, because they cannot cover labour requirements personally. They make such arrangements with young married couples, who do not have much land and are willing to work in exchange for 50% of the harvest during a growing season.

3 Labour availability is high, hence the lower wages in this zones.
4 The owner provides the land, water and part of the inputs.
5 The compañero provides work and inputs for cleaning the ditch.
6 5% of the community is older.

As mentioned before, agriculture in this zone is diversified, as shown below:

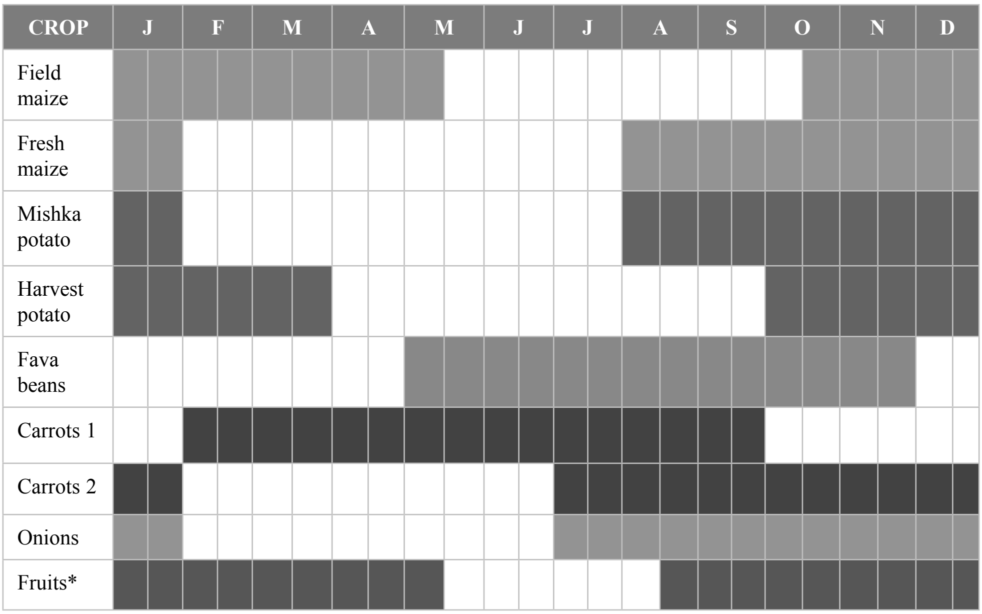
Table 4.2 Irrigated Crop range

Crop	Area (ha)	% of area
Alfalfa	0.24	0.9
Beets	0.05	0.2
Onions	3.23	12.1
Fruits	2.94	11.0
Fava beans	4.14	15.5
Fresh maize	3.34	12.5
Field maize	7.77	29.1
Mishka potato	1.84	6.9
Harvest potato	0.21	0.8
Tomato	0.21	0.8
Carrot 1	1.82	6.8
Carrot 2	0.91	3.4
Total*	**26.7**	**100.0**

* The rest 4.3 is not arable
Source: information gathered during fieldwork (2001)

The agricultural calendar for growing the above crops is shown below:

Figure 4.2 Agricultural calendar



* grapes, peaches
Source: Information gathered during fieldwork (2001)

Irrigated agricultural products, mostly for market, are vegetables (onions, carrots and tomato – although tomatoes are not grown in large quantities and are mostly sold locally). Growers in the zone usually sell their produce at their farm, especially vegetables. Intermediaries range around in trucks, gathering the products from different places. Farmers say that there are one or two local persons who take their produce to larger markets (Tarija, Potosí, La Paz, and even sometimes Santa Cruz).

Livestock activity in San Juan del Oro is supplementary to the main activity, which is arable production. Because of the zone's characteristics, large livestock are limited to 1-3 draught animals, used for ploughing. Moreover, only 10% of families raise these cattle, so growers who do not have their own team of oxen rent one, or barter labour for the use of one, or – if worse comes to worst – rent a tractor, although this is not common. Raising sheep, goats and pigs is not intensive, but most families have a few of these animals, supplying meat locally and to the town of Las Carreras, which is half a km from San Juan del Oro.

The project increased irrigation water availability from 198,000 m^3/year to 360,000 m^3/year. Other changes, such as increased yields, changes in the crop assortment or planting schedule, have not been verified, because the data reported in the project document are ambiguous or simply absent. The project document mentioned three goals regarding agricultural production: 1. to increase yields in five main crops (see Table 4.3), 2. to guarantee family self-supply of food and raise the volume of surplus for market, by changing the crop range and increasing production of the main crops (according to standard family farm models). 3. to improve irrigation infrastructure for 50.7 ha[7] of cropland in the San Juan del Oro community, supplying water uninterruptedly and increasing the available amount for irrigation from 0.40 l/s/ha to 1.75 l/s/ha.

The project document mentions 50.7 ha as the area to be irrigated, but the net area irrigated, measured by aerial photography, precisely digitising the system's area of influence, is no more than 31 ha, which is the total physical land area under the San Roque –Capellanía system's influence (of which some 26 ha are estimated to be arable). Apparently the project considered the total land area of the San Juan del Oro community, which includes other irrigation systems not part of this project

The project document presents no explanation of how the proposed production changes would be addressed or achieved. Actually, the only data presented are shown in Table 4.3, giving increases in average yield per hectare in the zone, and increases in production volumes[8] for two farm models. Although changes in crop range are mentioned as an expected effect of the project, the document presents no range for before or after the project. Yield increases of 33 to 107% are assumed, but without any technical support for such claims. Yields for carrots and onions are also reported of 4.5 to 6 tonnes/ha for the situation prior to the project and 9 tonnes/ha afterward. However, yield measurements in the zone have shown over 30 tonnes/ha for onions and carrots (see table 4.4), which are normal yields for these crops. For fresh maize, the project document mentions yields of 0.5 to 0.71 tonnes/ha, whereas the research found yields of 1.5 to 2.2 t/ha (Field survey 2001). Moreover, the project document mentions wheat. However, interviews in the zone and the crop survey conducted found no wheat anywhere. This crop is grown at higher altitudes, but not in the San Juan del Oro zone.

7 This area is for the entire community.

8 The project gives data in tonnes, apparently production volume data, but without specifying the land area unit, or actually explaining anything at all.

Table 4.3 Increased yields proposed by the project

Average increase				
Crops	With irrigation		Increase	
	Deficient (t/ha)	Improved (t/ha)	t/ha	%
Winter carrot	4.5	9.2	4.8	107.2
Early carrot	5.0	9.8	4.8	96.3
Fresh maize	0.5	0.71	0.21	42.0
Field maize	0.9	1.4	0.5	50.0
Onions	6.0	9.0	3.0	50.8
Potatoes	4.6	9.0	4.4	96.0
Wheat	1.0	1.3	0.3	33.3
Family farm A				
Crops	With irrigation		Increase	
	Deficient (t/ha)	Improved (t/ha)	t/ha	%
Winter carrot	1.8	5.55	3.75	208.3
Early carrot	2	5.85	3.85	192.5
Fresh maize*	165	80	-85	-51.5
Field maize	0.09	0.21	0.12	133.3
Onions	2.1	3.6	1.5	71.4
Potatoes	0.83	1.35	0.52	62.7
Wheat	0.05	0	-0.05	-100.0
Family farm B				
Crops	With irrigation		Increase	
	Deficient (t/ha)	Improved (t/ha)	t/ha	%
Winter carrot	3.15	7.4	4.25	134.9
Early carrot	3.5	7.8	4.3	122.9
Fresh maize*	330	240	-90	-27.3
Field maize	0.28	0.21	-0.07	-25.0
Onions	3.6	6.3	2.7	75.0
Potatoes	1.161	4.05	2.889	248.8
Wheat	0.09	0.05	-0.04	-44.4

*dozens of ears

Source: Final project design for San Juan del Oro 1995

The proposed goals and the above table may be analysed in different aspects showing inaccuracies or unfounded assumptions, above all in regard to yield increases. If they are compared with the data in Table 4.4, there is clearly no relationship.

Table 4.4 Yields in 2001

Crop	Yield (t/ha)
Field maize	1.5
Fresh maize	2.2
Mishka potato	6.7
Year potato	6.7
Onion	33.5
Carrot1	41.9
Carrot 2	35.0
Tomato	21.9
Fava beans	3.4

Source: Evaluation of the San Juan del Oro irrigation project. National Irrigation Programme 2001

As for the model farms, no criteria are given for differentiating between the two standard types, aside from the average hectares under cultivation as the differentiation criterion. For each of the farm models, different yield increases were assumed, apparently expressed as production volumes. The differential increases were not explained, in either case. Maize crops show decreased yields (production volumes). However, the first part of the table shows yield increases, so it is assumed that the decreased production volumes for each farm model is due to a substantial decrease in the land area planted in maize. The project document gives no explanation for this decrease.

Average net income from agricultural production with irrigation

For conditions in 2001, Table 4.5 shows the gross and net values of production. The greatest income comes from onion and carrot crops (72% of total net income) although they account for only about 20% of land area. Another crop with a high gross and net income per hectare is tomatoes. However, since little land is planted in tomatoes, this accounts for only 1% of total net income. Maize, the crop covering the most land area (50% of annual growing area) brings in only 7% of net income.

Table 4.5 Gross and net value of production

Crop	Situation in 2001					Net value US$	Net value %
	ha	Cost/ha	Total cost	Income/ ha	Total Income		
Field maize	7.83	309.01	2,419.57	412.02	3,226.09	806.52	7%
Fresh maize	3.36	278.49	935.73	457.78	1,538.16	602.42	5%
Mishka potato	1.86	495.78	922.14	858.35	1,596.53	674.39	6%
Year potato	0.22	488.15	107.39	858.35	188.84	81.44	1%
Onion	3.25	1,542.01	5,011.53	3,261.98	10,601.43	5,589.90	46%
Carrot 1	1.83	1,507.39	2,758.52	3,218.68	5,890.18	3,131.66	26%
Carrot 2	0.91	1,476.87	1,343.95	2,687.83	2,445.92	1,101.97	9%
Tomato	0.22	2,426.70	533.87	2,985.75	656.86	122.99	1%
Fava beans	4.17	263.82	1,100.13	286.13	1,193.18	93.05	1%
Total			**15,132.84**		**27,337.19**	**12,204.35**	100%

Source: Evaluation of the San Juan del Oro irrigation project. National Irrigation Programme 2001

The table also shows a total net income of about US$ 12,200, an average net income of some US$ 516 per hectare under cultivation, i.e. US$ 329 per family. However, since not all have the same water rights, and they cultivate different amounts of land[9], their estimated income also varies, as shown below:

Table 4.6 Annual income per household

Number of families	5	11	9	4	5	3
Income in US$/year	73.22	149.78	298.33	457.66	598.01	894.98

Source: Based on the evaluation of the San Juan del Oro irrigation project. PRONAR 2001

As already mentioned, information was too limited in the project's final design document to determine household income before the irrigation system was renovated.

4.3 WATER MANAGEMENT

Water rights

The improved infrastructure is used by 37 owners of land in the irrigated zone who acquired water rights by inheritance or by purchasing land including the water rights. There is no precise information about when these rights originated, or how. However, interviews with users suggested

9 The range of farm holdings is 0.4 to 2 ha.

that this was based on the work invested in building and maintaining the irrigation infrastructure, some six or seven decades ago. It is interesting that many farming families in the zone were landowners long before Agrarian Reform. There were no haciendas in San Juan community, but only small and medium landowners. They bought their land before Agrarian Reform.

Water rights in the community are expressed as a "*suyo*" of water. A *suyo* is enough water to irrigate for 12 consecutive hours during the dry season. Each *suyo* is divided into four "*cuartillas*" of water, with a variety of rights, depending on the relationship between the land area each user owns and the water turn (*suyo*). Those who have more irrigation turn time have larger land areas than other users. Under this criterion, there is a diverse range of rights, expressed in terms of variable water turns, as shown below:

Table 4.7 Varied water rights in the system

Number of users	5	11	9	4	5	3
Irrigation turn (hours)	1.5	3	6	9	12	18

Source: List of irrigation turns.(field work 2001)

Since approximately the late 1980s, farmers in San Roque – Capellanía have grown grapes and peaches. At that time, a water *suyo* lasted 24 hours, enough to irrigate four "*ollas*"[10] of land. Later, with the shift from fruit to vegetables, they cut the duration of each *suyo* in half, to increase the frequency of irrigation, as required by vegetables.

Water rights are family-owned and linked to the land. If a user wanted to sell his or her land, they would also implicitly have to sell their water rights along with it. Water rights are also acquired by inheritance when the owner dies. In this case, the land and rights can be divided among the heirs. It is also possible to increase the amount of water that a user receives, by an application that is analysed and discussed among system owners at the community assembly (field information, 2001). To make such a request, users must have met all prerequisites, namely meeting all system maintenance workday requirements set by the commissioner for one year prior to the request; having paid the equivalent of 31 workdays per *suyo* of water used to build the aqueduct; and having paid an annual fee to remunerate the "commissioner". Only someone who feels that the amount of water is too little for their land size can make such an application. If approved by the other members, only one additional "*cuartilla*" of water can be granted.

To conserve water rights, each user must necessarily work on infrastructure maintenance and provide the days of work established on the basis of their *suyo* of water.

Water distribution

Water distribution was not changed after the project. Users maintain two distribution modes: free on demand (during the rainy season) and by turns (during the dry season). When water is scarce (generally starting in August, until the rains resume) users distribute water by irrigation turns (*suyos*). There is no fixed date to begin the turns. However, the "commissioner" verifies water availability regularly and agrees with users on when turns will begin. The single flow is distributed from the head of the canal downwards. Each offtake has the right to use the whole

10 The local land area unit of measurement has been the "olla" [a pot or cauldron] of land, the equivalent of about 4000 m2, according to local farmers

supply in rotation. The water delivery interval is every 11 days. Nevertheless, the interval for watering a given crop may vary (some vegetables, such as onions, require more frequent watering) by lending a few hours of irrigation among neighbours, who then repay the “loan” in kind. Sometimes, the flow is increased when it rains and/or there is runoff from intakes upstream. When there is this extra water, turns are disregarded, and irrigation scheduling shifts. The commissioner and users decide together about the beginning and stopping, when this happens.

During the rainy season (generally starting in January) each user can irrigate as long as they feel their field and/or crop needs it. To irrigate, they must first apply to the commissioner, a day or two in advance. If two or three persons want to irrigate at the same time, the flow is divided into equal parts. During this period, if a person does not conclude the irrigation, during the time they applied for, they can continue irrigating the next day, providing they let the commissioner know and no one else has asked for water at that time. During this period the flow (single and multi-flow) available may range from 30 to 100 l/s. However, the “thread” of water[11] or small flow left running for livestock and varied domestic uses (laundry, etc.) must be left, especially to the end of the canal.

Organisation

Current irrigation organisation remains the same as prior to the intervention. Before the project, there was no formal structure, such as a committee or other organisational form. It was simply called an “irrigators’ organisation” for a given canal, irrigating a certain identifiable sector or area of the community – in this case study, the “San Roque - Capellanía” ditch, irrigating the sectors of the same name.

In the community of San Juan del Oro there are four ditches or systems operating autonomously: “San José”, “Bramadal - San Roque”, “San Roque - Capellanía” and “San Pedro”. The only link among these four systems is that they have a single “water judge” who is responsible for resolving conflicts within and among systems. He also organises and legitimises the appointment of the “water commissioner” in all the systems. The commissioner is responsible for organising water distribution during the period of irrigation by turns, and maintenance work in each irrigation system. The water judge is a user who can belong to any of the systems. The commissioners are users who belong to that respective system.

The community is organised in a Local Grassroots Organisation (OTB[12]) and all users from the different systems also belong to this organization. There is a close relationship between the OTB and the irrigators’ organisation, since requests for institutions to make system improvements are ultimately implemented by the OTB. However, in the internal irrigation system management the irrigators’ organisations are independent. Each system is also independent from the community’s drinking water supply system. There is no overlap between the irrigation system and the drinking water system.

The commissioner’s duties are stipulated in the memorandum formalising the appointment of each new commissioner, normally every year in July. The main duties are to organise and enforce

11 The “thread” of water is a small flow that must be left running continually during the rainy season throughout the entire canal, and users respect this. This flow is used for watering livestock and, before the drinking water supply system was built, people also drank it.

12 This form of organisation (OTB) was created by the Popular Participation Law, April 1994.

all users' contributions of workdays required for maintenance, on the basis of each user's *suyos,* to guarantee that water flows to the end of the system; to oversee distribution of irrigation turns during the dry period; and to distribute the water by order of application during the rainy season. The water judge and commissioner each serve a one-year term. They are appointed by consensus at the annual assembly, regularly in July. They may be ratified for a second term if they did their job satisfactorily. The community pays the commissioner a compensation for these duties by collecting dues (US$ 2/suyo/year) from all users. The commissioner also has one *suyo* of grace, i.e. one less in irrigation infrastructure maintenance obligations. After the project, an "irrigation committee" was set up at the request of the support entity. However, as shown below, this form of organisation is not operating; rather, the original form continues.

Maintenance

Before the project, ditch upkeep work was divided into "*paleos*" and "*tomeos"*, depending on the type of infrastructure to be maintained. Both activities were collectively organised on the basis of the *suyo* and/or water *cuartilla* that each user had the right to. *Paleos* consisted of manually cleaning the main ditch, usually three times a year (August, February and April – the end of the growing season). Depending on the amount of work this could last from one to three days. Users' attendance at cleaning work was mandatory. Everyone had to attend or hire a worker in their place. *Tomeos* consisted of rehabilitating the rustic intake, which would be damaged by river flooding during the rainy season. The frequency of *tomeos* depended on rainfall in any given year. Users would be called together at dawn on a given day, and all would have to come and work until the intake was fixed, which could take three or four days, depending on the damage. Users said that each of them used to work, on the average, 30 days/year to maintain infrastructure. The water commissioner was responsible for calling, overseeing and enforcing this maintenance work. In turn, each user was obliged to work the number of days established to conserve his or her water rights. The commissioner used to call the users roll in order to know how many people were present, to organise the work, and who was absent, but they did not have any special records for this work.

In 2001, with the improved infrastructure, *paleos* were simpler cleaning, to remove sediment, stones and other debris from the canal. This took about a day. *Tomeos* were no longer significant, since the intake is no longer damaged by high water levels. All that was required was to remove any deposits. Though the quantity of days needed for maintenance has diminished, labour is still necessary for maintenance, and is recorded by the commissioner.

In 2001, irrigation management for the San Roque – Capellanía system operated just as before the intervention. The characteristics of the irrigation management before the intervention is presented in table 4.8.

Table 4.8 San Roque - Capellanía irrigation management analysis I - Before project

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision in general meeting of irrigators' organisation: 1. Water rights are obtained by contributing workdays proportionally to the water rights, to build the infrastructure.	Decision in irrigation organisation meeting to: 1. begin delivering water by shifts and free upon demand. 2. in the dry season, the roster of shifts applies, and people use water in order during the free on demand period. 3. Elect the water commissioner on a rotating basis every July.	Decision in irrigation organisation meeting so each user can participate with workdays proportional to their water right, to rehabilitate the intake and clean canals.	Decisions at the irrigation organisation meeting to set penalties for those who fail to meet norms and obligations regarding operation, distribution and maintenance.	Decision in irrigation organisation meeting to organise activities involving construction and permanent reconstruction of the intake.
	Activities involving recording days worked during construction.	Activities involving preparing the roster of shifts on the basis of user applications. And delivery of orderly turns during the free on demand period.	Activities involving organising permanent reconstruction of the intake and cleaning of canal sediments.	Activities involving establishment and monitoring of norms and obligations involving distribution and maintenance.	Activities involving organisation of construction and reconstruction.
Formal rules	Rules establishing: Fulfilment of workday commitment and obligations regarding water rights.	Rules establishing: 1. During the free on demand period water is delivered in order, and during the dry season by shifts, with an interval of 11 days. 2. During the free on demand period the leftover water is left for other uses.	Rules establishing users' obligation to take part in the maintenance: keep to schedule, perform tasks efficiently, and take your own tools.	Rules penalising failure to respect irrigation turns and non-attendance at canal cleaning and intake reconstruction.	Rules establishing labour availability during emergencies due to continual destruction of facilities.
Participants and roles	The irrigators' organisation oversees days worked and fulfilment of agreements and the group of workers participates in construction.	The commissioner, who prepares the roster of turns in the dry season and the orderly delivery of water during the free on demand period, and monitors compliance. Users group with water rights.	Commissioner to monitor and users group with water rights to clean.	The water judge is responsible for resolving conflicts among systems and within the system and users group not meeting agreements.	The commissioner organises work and users with water rights do the work.
Logic and informal rules	Logic of community control Each user monitors his own days worked and those of others. Users may apply to the organisation for increased rights.	Logic of community self-control (transparent, predictable and flexible) Rotation, single flow.	Logic of community self-control. Each user comes to the intake with his tools and materials to rebuild the intake. The commissioner organises and oversees the work.	Each irrigation system is independent and autonomous. Conflicts within the system are resolved between users or in the irrigators' organisation.	Logic of community self-control Users rebuild the intake continually, using local materials.

4.3.1 Project proposal for future management

To examine the project's proposal for water management, it is necessary to analyse two stages in the project cycle: pre-investment and investment. The results of the first stage are materialised in the final design document. The second stage should theoretically happen during the construction process. The work done during the second stage is called "support" and should result in an "operation and maintenance manual" and the "by-laws and regulations" to make the renovated irrigation system work. Moreover, the two stages involved different stakeholders. Table 4.9 and the following paragraphs summarise the irrigation management proposal.

Pre-investment stage

This stage did not address the issue of water management. As proof, there is no mention of water management in the final design project document, to serve as a basis for future management design. It simply mentions that there is an irrigation organisation with formal officers (president, secretaries and members). However, as outlined above, irrigation users did have and still have only two authorities, the water judge and commissioner. Not deeming management issues to be an important part of design, the design engineer did not address water rights, distribution or system maintenance. Nor did they present any proposal for future irrigation system management. The project document mentions only that users should be trained for system operation and maintenance. During this stage, the Integrated Agriculture Project for Southern Chuquisaca and a civil engineer were involved, and the latter made the project design.

Investment or support stage

Despite plans otherwise, support was provided only after construction was over, when the building company had already left. Support was provided by workshops with users, one to three days per topic. These workshops covered two main topics: operation and maintenance of the new system, and preparation of by-laws and regulations to improve user organisation operation and the irrigation system in general.

Water rights

The support entity gave each user a certificate (like a Certificate of Ownership) mentioning the user's name, the workdays contributed and their water rights. In this case users decided to contribute the workdays in cash (US$ 200 per *suyo).*These certificates were signed by the irrigation committee, although the idea was to have the Mayor sign them too. For logistical[13] reasons, this was not possible. This type of certificate may be useful in the event that any conflicts arise or there is a lack of clarity regarding the water rights of new users, or if the intention is to legitimise users' water rights vis-à-vis outside entities.

Organisation

A support entity, CEIBO, was hired by the FDC through a public bid and took some actions to change the existing organisation. It set up an irrigation committee, although the by-laws and regulations mention an "irrigators' association".

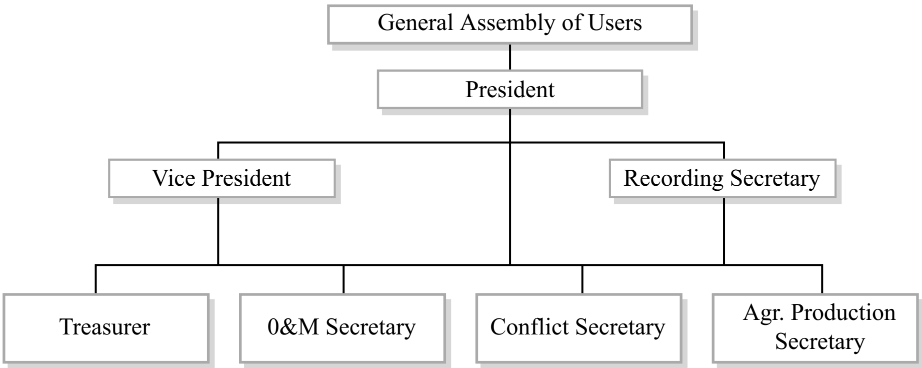
13 There was no car available.

Table 4.9 San Roque - Capellanía irrigation management analysis II - Project Proposal

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision in irrigation association meeting for each user to contribute economically to improve the irrigation infrastructure, proportionally to their water rights.	Decision in irrigation association meeting to decide to keep operation and distribution the same as before.	Decision in irrigation association meeting for users to contribute US4 / suyo for maintenance.	Decisions at irrigation association meting to approve by-laws and regulations for conflict management.	Decision in irrigation association meeting to contribute economically and not with labour to building the system.
	Activities involving recording economic contributions.	Activities involving preparing the roster of turns on the basis of users' applications. And orderly allocation of turns during the free on demand period	The project did not specify maintenance tasks.	Activities involving establishing and monitoring by-laws and regulations.	Activities involving construction and collecting users' fees.
Formal rules	Rule establishing that each user will contribute US$ 200 / suyo in cash as community contribution.	Rules establishing water deliver as before, but recorded in an operating manual.	Rules involving fee payment.	Rules to enforce by-laws and regulations.	Rules to enforce the economic contribution.
Participants and roles	The irrigation association monitors users' economic contribution.	Secretary of O&M who organises and monitors distribution. Group of users with water rights.	The treasurer collects fees and users pay them.	The irrigation association board enforces the by-laws and regulations and the users group fails to abide by the by-laws and regulations.	The irrigation association, collecting fees, users paying fees, and the building company, building.
Logic and informal rules	Logic of economic contribution.	Logic of organisations to make irrigation work. Establishes an O&M secretary.	Economic logic.	Logic of an administrative system for large irrigation systems.	Logic of economic investment.

The new organisational form proposed by the support entity for the San Roque-Capellanía system comprised a board of directors with specific areas of responsibility, as shown in figure below.

Figure 4.3 Organisational chart for the San Roque – Capellanía irrigation committee proposed by the support entity



In the above organisational structure, the position of committee president is currently not functional, because the commissioner and the water judge remain the organisation's top authorities. The former heads the system and the latter is the community authority responsible for resolving conflicts about water. Evidence that the proposed system simply does not exist in practice is that users still talk about the Commissioner and Water Judge, and their duties remain the same as before the project. The support entity tried to maintain the commissioner's role with a new name, "Secretary of Operation and Maintenance".

As for the system's operating norms, the support entity prepared the by-laws and regulations for the irrigation system on the basis of the rules established by the users themselves. However, these new documents are quite lengthy, complex and detailed. For example, the by-laws comprise six sections, 10 chapters, and a total of 67 articles, covering issues of organisation, water shares, members, how to run assemblies, the duties of each member of the Board, requirements for advisory support, etc. The internal regulations have 27 articles, grouped into nine chapters and eight sections, dealing with fees, members, governance and structure, administrative and financial systems, and so on.

This organisational form, and these by-laws and regulations are strongly influenced by the model in the Upper Valley of Cochabamba, concretely the Punata irrigation association. As part of its work, the support entity organised a trip to share experiences and visit the Punata[14] system, so it could "serve as an example" for the users from San Roque - Capellanía.

Distribution and maintenance

The result of the "operation and maintenance" workshops was, overall, to keep the traditional water distribution system. The support entity did no specific activities to ensure that users would have the capacity for system maintenance. The only change introduced by the support entity was the agreement for users to pay annual fees (US$4 per *suyo*) for infrastructure upkeep. According

14 Many other projects visited Punata as a reference point, but Punata is an area with different irrigation systems. For example, Totora Khocha irrigation system irrigates 4200 ha in Punata and 2800 ha in Tiraque.

to a former leader, payment of these fees by users is only partial. However, cleaning activities of the works are done with regularity. After improvements the maintenance activities decreased from 200 days to less than 40, which means that the demand for labour has diminished by 80%, and users appreciate this situation. Despite project attempts to change management, it remained the same, except for maintenance, as outlined in Table 4.10

4.4 DESIGN PROCESS

4.4.1 Identifying and preparing the final design study

The project idea started with the irrigation system users, who demanded improvement of the infrastructure. This demand emerged at a planning workshop held by the Integrated Agriculture Project for Southern Chuquisaca[15] (PSC) with the community in 1994, also attended by a representative of the Sud Cinti Provincial Development Council. The PSC had a permanent presence in the zone, because the engineers were working support farmers with activities related with agriculture production. Both institutions promised their support to arrange the means to satisfy this demand (irrigation project), although the Southern Chuquisaca project actually materialised this support more strongly.

Field interviews (February 2001), showed that users' main goals for this improvement were 1. To enhance canal efficiency or conveyance efficiency. This would especially benefit the users at the end of the canal. 2. To reduce and facilitate system infrastructure maintenance work. According to farmers' criteria, the intake construction was proposed to decrease maintenance work and not to improve catchment efficiency.

The PSC hired a Consultant Firm (Incotec) in order to make the irrigation project document. Once the consultant firm did the first studies, the project profile was ready in 1994. Then, using this profile as a referent, a civil engineer (the brother of an official with the former Chuquisaca Development Corporation) did the final design studies free of charge. Users said that they sought the support of other institutions that were working in the zone. In this manner they also got logistical support from a Dutch co-operation entity working in the zone, which covered the costs of stationery, maps, printing, etc.

The main infrastructural design proposals were to build an improved intake instead of the traditional one and to line 2913 m of canal (the full length of the system's main canal). The project document described the cross-section dimensions and lengths of the main canal, mentioning an irrigation module for each stretch of canal (but no design flow rate). Formulas to calculate each type of structure are also included, but the actual calculations are missing. The ancillary structure plans describe "standard structures" without specifying their location along the main canal.

15 The Integrated Agricultural Project for Southern Chuquisaca was part of the former Chuquisaca Development Corporation.

Table 4.10 San Roque - Capellanía irrigation management analysis III - After project

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision in irrigation organisation meeting for each user to contribute economically to improve the irrigation infrastructure, proportionally to their water rights.	Decision in irrigation organisation meeting to: 1.Begin delivering water by shifts and free upon demand 2. In the dry season the roster of turns is used and water is assigned in order during the free on demand period. 3. Elect the water commissioner on a rotating basis every July.	Decision in irrigation organisation meeting for: 1.Each user to work days proportional to their rights 2. Each user to contribute US$4/suyo for maintenance.	Decisions at the irrigation organisation meeting to establish obligations and penalties regarding operation, distribution and maintenance.	Decision in irrigation meeting to: 1. Contribute US$ 4141.91 to build the new infrastructure. 2. Set up a construction committee.
	Activities involving recording economic contributions.	Activities involving preparing the roster of turns and delivering water in an orderly fashion.	Activities involving organising maintenance and canal sediment cleaning.	Activities involving establishing and monitoring obligations regarding distribution and maintenance.	Activities involving collecting community contribution and overseeing construction.
Formal rules	Rule establishing: 1.Each user contributes US$200 / suyo cash as the community counterpart. 2. Compliance with obligations involving water rights.	Rules establishing : 1. During the free on demand period water is delivered by order and in the dry season by turns with an 11-day delivery interval. 2. During the free on demand period the leftover water is respected for other uses.	Rules establishing users' obligation to participate in maintenance, observe the schedule, work efficiently, and take their own tools.	Rules penalising failure to respect irrigation turns and non-attendance at canal cleaning and intake reconstruction.	Rules establishing payment of economic contributions.
Participants and roles	The irrigation organisation monitors contributions and obligations met, and users contribute as agreed and meet obligations.	The commissioner, who prepares the roster of turns in the dry season and the water delivery order during the free on demand period, and monitors compliance with the roster. Users group with water rights.	The commissioner to oversee and organise the work and the users group with water rights to clean the canals.	The water judge resolves conflicts among systems and within the system and users group failing to meet agreements.	Construction committee, overseeing construction, building company building.
Logic and informal rules	Logic of community control Users may apply to the organisation to increase their rights.	Logic of community self-control (transparent, predictable and flexible) Rotation, single flow.	Logic of community self-control. Each user comes to fix the intake and clean canals. Maintenance fees are partially paid.	Each irrigation system is independent and autonomous. Conflicts in the system are resolved among users or in the irrigators' organisation.	Logic of community self-control and economic investment.

The final design document with only technical data was approved by the PSC, the Mayor's Office of Las Carreras and the Provincial Development Council of Sud Cinti. According to users, most of them did not know who designed the project, much less the proposals included in that document. That is, they did not know how their irrigation system would change after the project, or what new water management requirements there would be. The designer himself admits: "*Regarding management and O+M we have talked, we have discussed a bit with the users, but that was all*" (interview, 2001).

The project document was concluded by late 1995 and immediately sent to the Rural Development Fund (FDC) to negotiate funding. The Southern Chuquisaca Project, through its formal relations and especially through the informal relation among engineers of Southern Chuquisaca and FDC, got this project considered for funding by the FDC. In February 1996, the project was included in the Annual Operating Plan (POA) of the Las Carreras municipality. Subsequently, in May 1996, FDC personnel visited the area to assess the implementing entity (EE[16]) and beneficiary community (CB), in this case the Municipality of Las Carreras and the community of San Juan del Oro, respectively. After this evaluation, they concluded that the project would be socially and technically feasible (FDC report, 7 May 1996).

Several subsequent evaluations examined the final project design document and the beneficiary community. The former was done by the FDC of La Paz[17] in mid- 1997, who rejected the project, since the evaluators concluded that landowners did not live in the zone. The Rural Development Fund – National Irrigation Programme (FDC-PRONAR) evaluator also rejected the project, because of serious reservations[18] regarding the final design document. A third evaluation by the FDC Chuquisaca programme officer had observations on the project and suggested that the consultant correct them. However, nonetheless, he recommended the project for approval[19]. This third evaluation also changed the volumes of cyclopean concrete calculated by the consultant and some unit prices. This new calculation was discussed and agreed with the designer and the Las Carreras municipality in March 1998. After this last evaluation, the project was approved by the FDC's Departmental Project Approval Committee (CDAP), without any involvement of National Irrigation Programme (PRONAR) staff.

In April 1998, the Financial Allocation Committee (CAF) approved project funding. Users promised to contribute their own cash input; agreeing that each should pay US$ 200 per *suyo.* (users complied with this promise). After these negotiations, a contract was signed between the FDC and the Municipality of Las Carreras, authorising the latter to put the project out to tender. The winning bidder offered to implement the project for a lower amount, approximately 84.5 % of the tender's base price.

Before beginning to implement the project approved by the FDC, Southern Chuquisaca funded part of the construction of an aqueduct designed by the users, by contributing cement for the project. At the end of that construction, users asked for its value to be taken into account as the

16 EE should have total responsibility during the project implementation

17 In 1997 FDC project evaluations were centralised, with evaluators headquartered in and visiting project zones from La Paz, generally evaluating several projects per trip. (Interview with PRONAR-Tarija staff march 2001).

18 Details are unknown. The hydrological study did not present results. There was no water balance, nor any calculation of the incremental area in the system with and without the project. There was no record of any calculation of the proposed facilities. There was no environmental impact file.

19 This person repeated these same observations during project implementation (October 1998).

community contribution for the project (June 1998)[20]. FDC did not accept this. For this reason, users had to deposit their entire counterpart contribution, as initially agreed. According to calculations based on the project's unit prices, the total cost of the aqueduct was US$ 3158.92.

In conclusion, this first phase was the longest part of the whole intervention process. Users estimate that it took four or five years from project identification until beginning construction. Unlike the other cases studied, because of the final design document's limitations, it is impossible to indicate the values for economic indicators on which this project was approved.

4.4.2 Project implementation

The *users' organisation* of the San Roque–Capellanía system organised a construction committee. This committee had two purposes: 1. To guarantee the community's contribution (US$ 200 per *suyo* of water) for the construction, and 2. To monitor and follow up on the building company's work.

Work began on 25 August 1998. Participating institutions' commitments (pursuant to contracts signed by the parties) are summarised below:

Table 4.11 Commitments assumed by the different institutions involved in the project

Institutions	Commitments undertaken
Rural Development Fund (FDC)	• To fund project implementation. • To approve the tender process. • To supervise the work up to final delivery.
Municipality of Las Carreras (EP)	• To deposit a counterpart contribution of US$ 20,709.56. • To tender the project and sign the contract. • To guarantee community input for the construction. • To monitor the project and help supervise it. • To participate in the implementation by officially inspecting the project, both directly and by organising a community committee.
Community of San Juan del Oro (Irrigation system users)	• To deposit a counterpart contribution of US$ 4141.91.(US$ 200 per suyo)
Building company	• To implement the work in 145 calendar days. • To comply with technical specifications, indices in metre distances and construction blueprints, as indicated in the tender package.

Source: Procedural manual for the San Juan del Oro project (1998-1999).

The real implementation time was 281 days, finally concluding on 6 June 1999. This total of 136 days' delay was justified by the company, alleging that the rainy season had interfered. The real project construction timetable is summarised in figure 4.4.

This timetable shows that work began with layout. The work order book and an interview with the builder (project director) told that this work faced difficulties because the designer left no

20 The application does not specify how they asked for this aqueduct to be recognised as a community contribution. In any event, I assume that the request was for the total cost of the aqueduct to be accepted instead of the cash contribution that they would have to pay for the project.

stakes after surveying and measuring. This meant that the canal had to be laid out "as they went along", according to the terrain.

Another difficulty encountered during construction was that the aqueduct was not inclined following the main canal layout (it was higher). This meant that the company initially considered demolishing it, but users opposed this. So, the slope of the canal was reduced from the intake and its cross-section was enlarged, so that the transition to the aqueduct would not be too sudden (the section of the aqueduct was bigger than the canal).

Figure 4.4 Project implementation timetable

Activities	1998					1999						Observations
	A	S	O	N	D	J	F	M	A	M	J	
1. Project layout	—	—	—	—								Construction began on 25 August 1998.
2. Intake construction	—	—	—									Work was often interrupted by river flooding (rainy season).
3. Main canal construction			—	—	—	—	—	—				Layout was done as they went along, because the topographer's stakes were lost or not found, so the project blueprint layout was not strictly followed
4. Ancillary and additional structure construction								—	—	—		More distribution points were built than specified by the design. The design did not indicate the exact location of the ancillary structures.

Note: This figure shows only the timetable for work actually done. The project document has no proposed implementation timetable. The contract specified only the 145-day deadline.

Source: San Juan del Oro project work order book.

The company set up work groups and began excavating to build the intake on the Las Carreras River in October. In this case users did not work in the work groups, because instead they paid US$200 per *suyo*. On 13 October 1998, flood waters filled in 15 m excavated at the intake site, ready to pour concrete, and awaiting only the supervisor's presence to authorise that work. However, the supervisor was unable to visit the site before this happened.

The project director reported (in the work order book) a loss of 80 m^3 of stone and 40 m^3 of sand that had been collected there, but which was all washed away by the river, plus 170 m^3 of excavation up to the intake site. As a result, users complained to the supervisor and project director. The supervisor agreed with the users and municipality about the losses caused by the river, stating that he was unable to reach the zone because no vehicle was available at the FDC Sucre office[21]. He also said it was unfortunate that no alternative supervisor from the municipality had ordered the pouring either, before the flooding happened. Finally, he ended by leaving

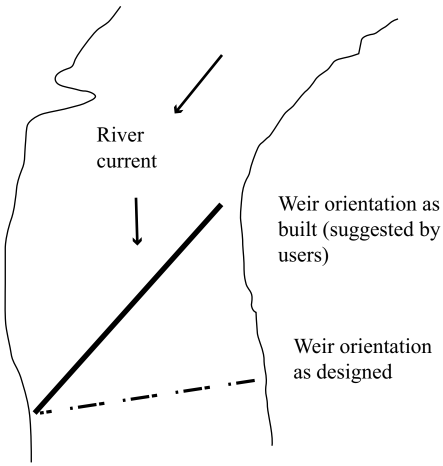
21 Capital city of the department of Chuquisaca

instructions that, from then on: "*Any supervision requirement shall be handled by telephone and later verified personally*" (work order book).

According to the project director, from then on many of the supervisor's instructions were given by telephone. Additionally, the Supervisor[22] (in order to reinforce the municipality's capacities) "*would delegate work to the Technical Head Officer[23], in the Work Order Book*", although, he felt that "*they needed a bit more authority, and the project director was an engineer of mature age and well-recognised prestige, so he had more authority than the delegated Supervisor*"(Interview with the Supervisor, 2001).

Taking advantage of the disaster, users suggested that the supervisor and project director change the orientation of the intake weir, because they felt that, with it perpendicular to the river's current, it would be more easily swept away. The users' suggestion was accepted by both of them, and the project director later told the supervisor to make this change in the blueprints. The supervisor replied that it was the building company's job (Field discussions with users, 2001).

Figure 4.5 Change in the orientation of the intake weir



Actually, it is not clear (in the work order book or interviews) who designed this change. Anyway, the weir orientation was changed, which also made it longer[24]. This change in the original design suspended construction until late October.

Work on the intake was suspended again on 21 November due to continual flooding, having built 45 m of the weir by then, with only 10 m left to conclude it. A meeting with users on that date agreed to suspend construction of the intake until after the rains subsided and concentrate wholly on lining the main canal.

The main canal began construction in early November. Since users were irrigating at the time, the building company, supervisor and irrigators agreed (at a meeting on 21 December 1998) to co-ordinate actions so the construction would not interfere with users' irrigation or the other way

22 The supervisor was a civil engineer hired by the FDC, but additionally supervised other works.

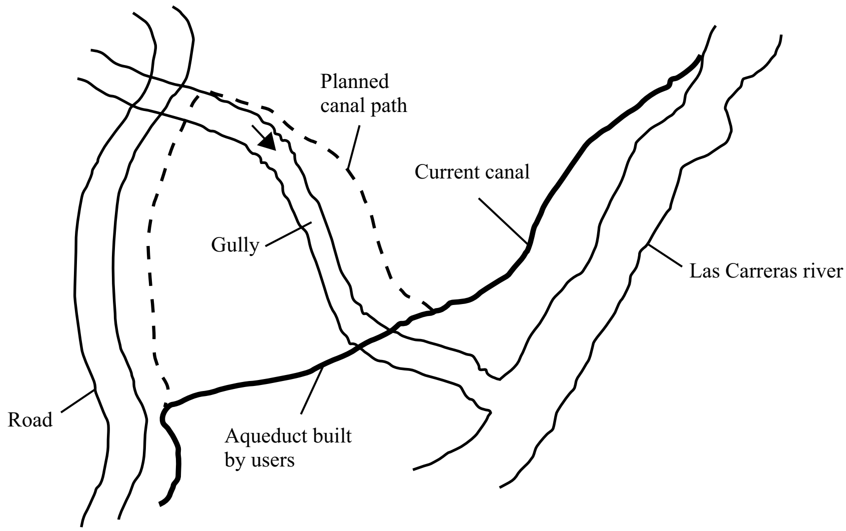
23 He was hired by the Municipality to oversee all the works construction, not only irrigation infrastructure.

24 The change cost US$ 8550 more than the original cost.

round. So, canal pouring days and irrigation days were to be co-ordinated every week by the project director and water judge. As might be expected, this lengthened main canal construction time and therefore total project implementation time. During construction, also the canal layout was changed from the original design. This was due to the aqueduct built by users, to cross a small gully with the canal. According to the design, this gully was to have been crossed by going around it, as shown in the figure 4.6 (dotted lines).

In December 1998, users wrote a letter to the building company and supervisor asking for the canal to be 0.4 m wide by 0.45 m high for 1000 m starting at the first user field gate, because they wanted more capacity. They also reiterated their request for the project they had built (the aqueduct) to be taken into account as their community contribution. This was not accepted by the building company, who did not feel that the request was in order (work order book). After project intervention, the lined canal is smaller than requested by users, which causes overflowing.

Figure 4.6 Change in main canal layout



The design plans do not specify the distribution point locations. Therefore, during building, the company placed the distribution points where the commissioner indicated. So, the users told the company to build 27 more distribution points than the 37 that had been calculated and budgeted for. So, spaces were left in the canal wall, and users promised to have their own gates made. Ten actually did so, but 17 distribution points remained open, and are plugged with sod and /or boards. The sod usually dirties the canal, adding to sediment build-up. The gates originally proposed in the project were metal but were changed to wooden ones. The second supervisor said that this change *"would guarantee the system's sustainability"* by avoiding any special technology, using a more locally available one costing about the same.

After the provisional delivery of the construction, users wrote a letter to the FDC indicating that only 32 gates had been installed, whereas the project stipulated 37. They also complained that 140 m of canal had not been lined, although the FDC supervisor (in September 1999) had said the budget would enable them to line another 200 m of canal.

Construction did not end when the building company left. Later, users continued working to improve the facilities. The builder had left the intake weir unfilled[25], so users had to do this, before flooding ruined it. They also raised the protection walls at the intake and lateral spillway, using cyclopean concrete. Valuing the volumes constructed, at the unit prices used in the project, their additions cost another US$ 434.02. The support entity gave the money for this work, as shown below.

4.4.3 Stakeholders and roles in the project

The Southern Chuquisaca Integrated Agricultural Project

This was a public institution, working with State funds. It was part of the Development Corporation Chuquisaca (CORDECH). The objective was to support the farmers in agriculture production in the south zone of the department of Chuquisaca. They had been working in the area for over two years, introducing new crops. This entity initially helped users identify the project, and promised its backing. Later, during the final design project preparation, they apparently only looked over the project document and approved it.

During implementation, they paid the amount promised to the municipality (US$ 12,000.00) as their counterpart contribution. At the time, the Project practically "disappeared" due to institutional changes in Bolivia (1996 -1997)[26]. They also granted funds to support aqueduct construction, and provided advisory support to users during its design and implementation.

The Sud Cinti Provincial Development Council.

The Council supported the users' proposal to carry out the project and took part in reviewing the final design document. A more visible player in this institution was a Councillor, who followed up on the project development during the implementation phase, by asking the FDC for reports on work status, obtaining a positive reply from that institution. The Provincial Council's role during the process did not influence its outcomes much, although their initial support for the project idea (identification) by system users was important to place the project before other agencies for consideration.

Users of the San Roque - Capellanía irrigation system

Irrigation system users belong to two important organisations in their community. One is the legally constituted community organisation, which is the Local Grassroots Organisation (OTB) that all community members belong to (85 members) and the other is the specific irrigation system organisation (37 users).

They participated concretely in the project in different ways, through organisations, which were of varying importance during the different stages of the intervention process, as outlined below.

The *community organisation (OTB)* played a major role in the early project phases. It obtained support from Southern Chuquisaca and the Provincial Council, which worked with the community as a whole and not specifically with users of the San Roque – Capellanía irrigation system.

25 The FDC and supervisors did not do an efficient checkup of the works before the building company delivered the works to the users.

26 In this phase a governmental structural change replaced the Development Corporations by the Departmental Prefectures.

During the project negotiation phase, the OTB presented the formal application to the FDC for funding. All the relations between system users and the Municipality of Las Carreras were through the OTB. This was very important to get the project included in the municipal Annual Operating Plans (POA 1996 and POA 1998), which even approved municipal project implementation counterpart contributions, which were deposited along with the amounts committed as the users' contribution. During the following stages (implementation and support) this community organisation did not participate noticeably. Therefore, the results of its actions were limited to guaranteeing project implementation, without directly influencing final outcomes.

The *construction committee* participated actively in the project starting when the implementation contract was awarded. This committee was specific for construction: the president was not the water judge, but a user who had worked for many years in a cement factory. The president then monitored and followed up on construction, including confrontations with the building company and supervisor. The committee made several demands during the construction (e.g. canal sizing, the initial intention to demolish the existing aqueduct, and the request to reorient the intake weir).

The Rural Development Fund (FDC)

The FDC began participating by evaluating the beneficiary community, the promoting entity and then the final design document. These evaluations were done under the FDC programme officer's responsibility. Another function performed by the FDC during the project intervention process was to supervise work. One problem with the supervision work was that it was done by remote control. Both supervisors responsible for the project, at different times, lived in Sucre. This meant that they were on site only occasionally, and many authorisations were given by telephone. Also they admitted that the building company delivered works with some deficiencies.

As experience shows, building companies aim to make a profit, which does not always mean that they will work properly. Therefore, only adequate, responsible supervision (frequent, close at hand) can guarantee quality work. That was not the case with this project.

National Irrigation Programme (PRONAR)

PRONAR participated in this project by funding it through the Programme's investment component and following up on the project by CAT-PRONAR technicians of Tarija. PRONAR technical staff members say that, despite the observations made by FDC - PRONAR and PRONAR evaluators, the project was unilaterally approved in the FDC[27]. Initially the project was passed on to another funding source and finally, after approving funding under the investment component, it was allocated funding from the IDB–PRONAR line. During project implementation, CAT-PRONAR technicians monitored progress, presenting reports after each visit. According to the contract, the investment was completely FDC's responsibility, so PRONAR technicians could only monitor and make suggestions, without any power to get involved in the building company's work.

An important contribution by PRONAR was to introduce "support" into the project cycle. According to PRONAR technicians, the intention was for the support to help the community during implementation and to consolidate an irrigation organisation. PRONAR proposed support:

27 Funding for the investment component of PRONAR was handled by the FDC, which would be responsible for technical and financial evaluation and final approval of project funding.

1. during final design to make the design more participatory, 2. during construction, to guarantee community input and provide users with technical assistance, and 3. to support operation and maintenance after the work was finished.

This proposal was not implemented in the San Roque – Capellanía project, because the tender for the support work went out when construction was almost done, due to bureaucratic administration. Although PRONAR promoted introduction of support into irrigation projects, it did not participate directly in the support phase for this project, either. The FDC hired and oversaw the work performed by the support entity. For this reason, without proper supervision, the support entity went along according to their own criteria and concepts, without necessarily considering the goals that PRONAR had in mind for this work.

The Municipality of Las Carreras

The Municipality participated in the project once the final design document was concluded. From then on, it was the users' intermediary in dealing with the FDC and PRONAR. This was fundamental during the project. The Municipality signed three contracts, which made it responsible for the entire implementation phase: 1. with the FDC, committing the FDC to fund construction; 2. with the building company, for the construction work; and 3. with the beneficiary community, to guarantee the community counterpart to construction (the cash contribution).

These contracts made the Municipality wholly responsible for construction, but this did not work out, for several reasons: 1. Although the FDC was to fund the work, the Municipality did not handle the money. The FDC disbursed to the building company (EC), although the latter's contract was not with the FDC, but with the Municipality. That is, the building company was actually accountable to the FDC and not the Municipality, although it was under contract to the latter; 2. The FDC supervised the work, taking responsibility for project outcomes. The Municipality appeared as the implementing entity only on paper, since the FDC played this role during implementation. The reasons for this are unclear, since the FDC could have assumed this role directly, cutting through all the red tape involved in implementing irrigation projects; 3. Rural municipalities (in this case a tiny one such as Las Carreras) have little technical capacity. This was an obstacle preventing them from directly administering and supervising relatively high-investment projects, such as irrigation projects. For instance, in this project users and supervisors all asked for the municipality to provide a technical supervisor to oversee the work more closely. Perhaps the most important contribution by the Municipality was to deposit the counterpart contribution for this work, which it got from the Southern Chuquisaca Project.

Building company

The building company won the contract by bidding a lower amount than the base bid for the tender. To implement the project, the company had different work groups[28], which were working in different sectors. Nevertheless, they took much longer to implement the work than initially planned. According to the project director, the main cause for the delay was the rainy season, which prevented them from advancing quickly in building the main canal and paralysed construction of the intake for quite a while because the river was in flood.

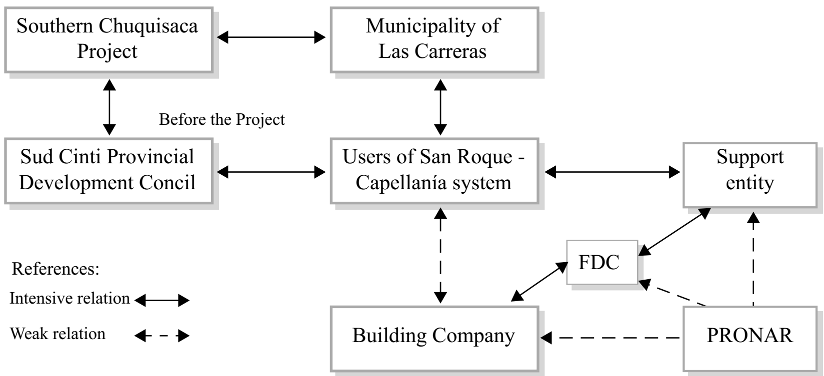
28 In this case there was no users' contribution in labour, because they paid US$ 200 per suyo. The work groups were hired by the building company.

Support entity

The support entity was hired by FDC through a public bid. The team was mainly made up of agronomists, although they had an economist and an attorney, part time. During their work, they emphasised irrigator organisation-building and training for leaders of the irrigation organisation, resulting in: 1. formation of an irrigation committee with a board of directors, 2. a document with irrigation system by-laws and regulations, 3. an operation and maintenance document, and 4. leader training manuals – however, all these products were low-impact.

An important action by the support entity was to help users expand the intake protection walls, although this work had nothing to do with the support work. The following figure presents the relationship among the different actors.

Figure 4.7 Relationship among actors



Now that the various stakeholders have been described, note that there was no close relationship among any of these different institutions. Ultimately, the FDC took charge of the entire construction process, leaving the other institutions with whom it had agreements out of the picture. This was because the FDC handled the funds and was not accountable to the institutional agreements.

Regarding relations between users and engineers, there was evidently almost no linkage between the designer and irrigators. Users were not even used as informants. During the construction stage, the building company dealt with users only when deciding where to locate gates. Since users paid their contribution in cash (US$200 per *suyo*) to keep their water rights during construction, they had no further involvement, and even less chance to have any influence.

During the support, there was quite a close relationship between users and the support entity. They co-ordinated many actions, including the arrangement for the support entity to use the resources allocated for support tasks to raise the intake protection walls, after the building company had left.

4.5 APPROPRIATENESS OF INFRASTRUCTURE TO MANAGEMENT CAPABILITY

The above descriptions and Tables 4.8, 4.9 and 4.10 are a major input to analyse the appropriateness of the infrastructure in terms of management capability. However, knowing that the characteristics of the design process mould the outcomes of the intervention process, it would be prudent to first consider some aspects of the design process, in the case at hand.

This case shows that the issue of interactive design has not truly been given a chance yet in Bolivia, but will need a lot of work if it is to become more than a mere slogan. There are still engineers who do not take users into account as co-designers. Proof is that users knew nothing about project characteristics in this case. This is a deficiency in agronomists' and civil engineers' professional training: when they have no socio-technical approach to respond to local realities, in most situations their interventions are deficient. Consequently, they have no choice but to use only technical know-how, which is not enough to guarantee irrigation system sustainability.

Administrative aspects also influence the results that a project can achieve. In this case, there was no clear contractual relationship among the designer, the municipality and the community. As a result, the project document features numerous gaps, which were never overcome, despite the observations made during the project approval phase.

Another problem related to the design process involves the lack of responsibility for monitoring and follow-up during the different stages. This led to improvisations during the implementation stage and additional work on infrastructure by users after the building company had left. Lack of monitoring and supervision of the support entity, which was responsible for designing "future management", meant that it pursued its activities according to its own criteria. In this case, they imitated the characteristics of another irrigation system (Punata), whose socio-economic and cultural context conditions are totally different.

4.5.1 Operational appropriateness of infrastructure to management capability

Although the final design project document did not mention anything at all about future water distribution, it would be deduced that they expected to deliver water through several field inlets at once. This is evident from the hydraulic design of the canal, because its "telescoping" cross-section implies that the canal flow volume is a function of the area served. These canal characteristics and the fact that water distribution has not been changed clearly shows how designers failed to match infrastructure characteristics with water management requirements of users For this reason, sometimes the canals do not have enough capacity to conduct the flow rate that users require, so there is overflowing that endangers the canal's stability.

Users have not attempted to change water distribution because they were more interested in reducing maintenance labour and improving conveyance efficiency: they were not interested in changing water distribution. This shows that water distribution is also subject to water availability and, at the same time, that local water demand is a function of water rights expression. It seems that water distribution reached a break-even point with water demand, since initially, when the zone had large areas covered with fruit orchards, watering every 22 days was "often enough" for these trees. With the gradual change in land use, this interval was shortened to twice as often, again according to crop requirements (in this case, vegetables). This shows the adaptations that can happen in water management (distribution) as agricultural production changes.

Regarding infrastructure operation, it is so simple that operating requirements are reduced to opening and closing gates, which members of the family with the water turn can do. Consequently, users have the capacity to operate the infrastructure as constructed. However, due to the canal's lack of capacity, users have to "guide" water by increasing its capacity by adding sod at the sides, which is extra work for users. If it had the required capacity, the canal would operate automatically and this "guiding" would be unnecessary.

Administrative positions and structure are an expression of the operational requirements to operate the irrigation system. In this case, the water judge and commissioner's positions are sufficient to cover these requirements. Implementing a structured organisation may not be functional and could, at some point, create confusion among users or duplication of functions. An example of this is that the positions proposed in this case are only nominal. An example of management needs during the process, from negotiations and tendering through project implementation, was the formation of the "construction committee", which played an important role in proposing changes in design, control and recognition of the community's contribution. Once the construction was over, this committee vanished and the organisation went back to operating as it had been before.

Finally, to analyse management capability, users' response to maintenance requirements should be considered. The new infrastructure has reduced their workload to clean canals and rebuild the intake from 200 days to 40 days a year, an 80% reduction. They achieved their objective, now they have less work. The only problem is that the requirements for economic inputs to maintain the irrigation infrastructure are not being covered by all users, although this is provided for in the organisation's by-laws and regulations.

This shows that just writing by-laws and regulations for an organisation does not guarantee compliance with local norms. The San Roque - Capellanía system shows that, on the contrary, what remains in effect and what users are willing to defend are local management principles based on collective consensus. In general, I may conclude that system operation (physical infrastructure and irrigation management) is *understandable* by all users, since it has the fundamental characteristics required, including *transparency*: 1. the system taps waters from a single water source, known to all users (the Las Carreras River), 2. during the time when the demand is highest, users water with a single flow, 3. each user knows that the water delivery order begins from the top and continues downward, and 4. each user knows their irrigation turn time and that this water right has been determined on the basis of their land area.

Also, water rights were allocated according to the principle that those who have more land should also receive more water. Under this principle of *equity* users have conserved their rights, also working proportionally to the water they receive (based on the land they have) for their water right.

Maintenance work involves the equity principle, expressed as the obligation to take part according to the amount of water owned (water *suyos*) but also the principle that those who use "more infrastructure" to get the water to their fields should also work more for maintenance. This equity principle has been altered now that the infrastructure is new, since the telescoping shape means that the canal does not provide the same service for users at the head as those located at the end, since the capacity of the canal is quite small in the last stretches.

4.5.2 Technical appropriateness of infrastructure to management capability

This case shows how the infrastructure design not only failed to take water management issues into account, but also has technical deficiencies. This is corroborated by users' dissatisfaction with the canal's size. It was designed and built without taking into account that it has to conduct water in the winter (dry season) and summer (rainy season). That is, designers and farmers have understood the infrastructure's function differently.

The capacity of the aqueduct built by users (100 l/s) could have guided canal design and construction. However, this was ignored in the design and designers assumed that the flow would be progressively divided, so the canal is smaller the further it goes. This was not known to users, because they never saw the project proposal. During construction, users could see before their eyes that the canal was being built too small for their irrigation and production practices in the zone. For this reason, they complained, asking for the canal's capacity to be enlarged, but engineers paid no attention. In summary, users were not taken into account in designing or building the system. Additionally, since there was no supervision close by, the canal has problems with changing slope, which makes the water overflow the canal's capacity.

Further, the failure to identify distribution point location during design meant that there was no budget for their total[29] cost, leaving the work incomplete, and preventing the system from functioning normally, while jeopardising the canal's usable lifetime.

Although users' request to change the intake weir angle for greater stability – quite justifiable in rustic intakes – was accepted, this was not justified in the case of such improved facilities. For greater stability in an improved intake, protection measures (e.g. a water buffer) are more important. The lack of such protection means that the intake is at risk of being destroyed, which demands greater investment in maintenance or eventual replacement.

4.5.3 Productive appropriateness of the infrastructure in relation to management capability

Conserving irrigation infrastructure in optimal conditions means that users must invest labour and money. They are not paying maintenance fees, so they are not doing routine and preventive maintenance. There are many reasons why they are not fulfilling this responsibility. Possibly the first cause is that they made a high economic investment (US$200 per *suyo*) during the construction of the infrastructure and they are hoping to have some return on this investment first.

Their capacity to make economic contributions is a function of the economic profits yielded by their irrigated agricultural production. Market-oriented production generates higher economic income, so in the San Roque – Capellanía system the greater availability of water led to increased area planted in vegetable crops. However, there is a factor that has prevented the San Juan del Oro zone from prospering as expected: the market. According to local farmers, potential markets are La Paz and Santa Cruz. However, transport conditions oblige them to sell at their farms to middlemen for low prices. A trip to these two markets can easily take two days, so the most profitable crops (e.g. tomatoes) cannot be marketed there, which discourages farmers from

29 There was money for 47 locations, but 17 have no gates. Remember that the building company presented a lower budget than was estimated for the project.

growing them. Under such growing conditions, in 2001 the income per family ranged from US$73/year to US$895/year (See Table 4.6).

To analyse their economic possibility of payment, revenues generated by irrigated agriculture have been compared to the annual infrastructure maintenance cost, estimated at US$1207/year (Table 4.12). This means that five families must pay about US$7.50/year, 11 families US$15/ year, nine families US$30/year, four families US$45/year, five families US$60/year and finally three families US$90/year. Considering only the cash inputs for maintenance they need US$ 163/year. This means that 5 families must pay US$1/year, 11 families US$2/year, nine families US$4.20/year, four families US$6.30/year, five families US$8.40/year and finally three families US$13/year.

Such calculations show that income generated by agriculture is higher than maintenance costs. However, in this case as in others, such payments are not being made. Consequently, there is no investment to meet collective demands or interests, as required for an irrigation system to be sustainable. Rather, the tendency is to satisfy individual interests and needs (e.g. education of children).

The income yielded by more water availability is still not enough to cover a family's basic requirements and currently young people are migrating to other cities and to Argentina. Even if income after the project doubled due to other activities that users do to make their livelihood, this is still not enough to satisfy a family's basic needs: US$ 1386/year, the budget estimated by the National Statistics Institute of Bolivia. (INE, 2002). Only three families would have enough income to satisfy their basic needs and pay the fees.

However, as it has seen in other cases above, even when it is economically feasible to cover maintenance fees, user families do not give a high priority to paying their fees. But, contrary to the other cases, it is more probable than users of this system will contribute their fees later on, because they already have the habit of paying commissioner quotas.

To conclude this chapter, this case shows that improving irrigation facilities in mountainous zones that are heavily exposed to destruction and sedimentation can considerably reduce labour requirements for maintenance. This is greatly appreciated by users. Nevertheless, the situation could have had even better impacts if the infrastructure also met water distribution requirements. Distribution modalities (in this case, single undivided flow and rotation) require the infrastructure to have a greater capacity than it does. Consequently, users have to do additional activity, controlling water flow. This flow control calls for temporary infrastructure adaptations (placing sod on canal walls) which wears facilities out and requires greater maintenance. This is the result of design lacking in effective interaction between users and engineers.

However, yet another restraining factor was the poor process with the leading role played by the FDC, as the entity handling funds, approving incomplete projects, allowing insufficient supervision, failing to require complete performance of contracts, signing contracts and failing to perform accordingly. This last point includes non-fulfilment of the contract with the Municipality, which was appointed as implementing body. According to the contract, the Municipality was responsible for implementing the work, but since the mechanisms for this to happen were not established, in practice the building company dealt directly with the FDC (which paid them) and did whatever they pleased. So, this and other cases show the social construction of infrastructure, combining knowledge, interests, skills, and strategies.

Table 4.12 Annual maintenance costs

Activity	Frequency	Cost of materials and inputs (us$)					Cost of labour			Total (US$)
		Item	Unit	Unit price	QTY	Total	Nº days	Unit price	Total	
INTAKE										
Intake inspection	2times/year	Notebook and pen		0.27	2.00	**0.54**	0.40	3.25	**1.30**	**1.84**
Intake repair and maintenance	Annual	Cement	Sack	4.73	9.00	42.57				
		Stone	m^3	4.00	2.64	10.56				
		Sand	m^3	4.00	1.68	6.72				
		Tools	PI	10.00	1.00	10.00				
						69.85	20.00	3.25	**65.00**	**134.85**
Operation inspection	Monthly			0.00	0.00	**0.00**	12.00	3.25	**39.00**	**39.00**
Intake cleaning	2times/year	Shovels/ pickaxes	PI	0.06	8.00	**0.48**	74.00	3.25	**240.50**	**240.98**
Subtotal 1						**70.87**	**106.40**		**345.80**	**416.67**
MAIN CANAL										
Canal review	2times/year					**0.00**	0.80	3.25	**2.60**	**2.60**
Weed and brush control	2times/year	Pickaxes	PI	0.03	5.00	0.15				
		Shovels	PI	0.03	20.00	0.60				
		*Machetes**	PI	0.03	37.00	1.11				
						1.86	37.00	3.25	**120.25**	**122.11**
Canal cleaning	3times/year	Shovels	PI	0.10	25.00	**2.50**	111.00	3.25	**360.75**	**363.25**
Canal repair and maintenance	Annual	Cement	Sack	4.73	10.00	47.30			0.00	
		Stone	m^3	4.00	2.93	11.72				
		Sand	m^3	4.00	1.87	7.48				
						66.50	20.00	3.25	**65.00**	**131.50**
Patching	1time/year	Cement	Sack	4.73	2.00	**9.46**				
		Tar	kg	1.00	5.00	**5.00**				
						14.46	10.00	3.25	**32.50**	**46.96**
Remarking station	Annual	Paint	PI	1.50	1.00	1.50				
		Brush 2.5”	PI	0.50	1.00	0.50				
		Wire brush	PI	2.00	1.00	2.00				
						4.00	3.00	3.25	**4.73**	**8.73**
Subtotal 2						**89.32**	**151.80**		**585.83**	**675.15**
DISTRIBUTION POINTS										
Gate maintenance	Annual	Antirust paint	l	2.00	0.50	1.00				
		Brush 2.5”	PI	0.50	1.00	0.50				
		Sandpaper	m^3	1.00	1.00	1.00				
						2.50	0.50	3.25	**1.63**	**4.13**
Handle cleaning valves	4times/year			0.00	0.00	**0.00**	0.20	3.25	**0.65**	**0.65**
Subtotal 3						**2.50**	**28.70**		**112.60**	**115.10**
TOTAL						**162.69**	**286.90**		**1044.23**	**1206.92**

*Big knives
PI: per item

Source: Field infrastructure inventory

5 TAMING THE WATER: THE NARANJOS MARGEN IZQUIERDA SYSTEM

INTRODUCTION

This irrigation system, Naranjos Margen Izquierda, has been selected because it belongs to another important agro-ecological zone of Bolivia, the meso thermal valleys. Naranjos community is located at 1200 metres above sea level, in the Municipality of Entre Ríos, O'Connor Province of Tarija Department. This community is unusual because there is sufficient water for irrigation, unlike most communities in Bolivia. But even though there is enough water, users need to have a good irrigation infrastructure to convey the water and use it.

In the area about 80% of the families are immigrants, coming from other communities of the department of Tarija, starting 50 years ago. This community has 297 ha. People from nearby Entre Ríos communities decided to produce in this area and they bought their land. People are organised in a syndicate, which works closely with the Sub Prefectura of Entre Ríos. There is diversity in holding size which has shaped how different households have tried to influence and extend the improved irrigation system layout. Naranjos is a special place, because of its climate and production. The average annual temperature is 19.7 ºC: in winter the average is 14.8ºC and in summer 23.3 ºC. The average precipitation in the year is 1031 mm. However, this is not enough, which is the reason why people irrigate in summer. Farmers produce peanuts for market. The city of Tarija is the principal market for this production. The distance from Naranjos to Tarija is 118 km by a dirt road.

People are sure that they can make more profit with peanuts than they used to get with maize. In 2001, they were experimenting with bean production, and this may be an innovation soon. Their interest in producing vegetables such as carrots dropped radically, because of the high demand for labour and excessive pesticide requirement. In addition to arable production, livestock is also important in this zone. Raising local breeds (cattle, goats, and sheep) extensively, they take advantage of adjacent mountain hillsides, with dense native bushy vegetation. These livelihood strategies are possible because they have plenty of irrigation water. This was not the case before the intervention, because they could not *"tame"* the water, because their facilities would be destroyed by the river's high-water flows. This was a constant concern and required investment of time and money.

Families living in this region are always trying to earn more. Unlike other communities, they reinvest their earnings in production. This is because they are exposed to a higher standard of living because there are trans-national oil companies nearby who have influenced their lifestyle. Other characteristics of the people in this zone are their capacities to negotiate with outsiders and obtain greater funding for local development. There is also full recognition by the government authority. For example, to enter Naranjos, authorisation from the Assistant Prefect (the authority representing the central government) is required. This authority's importance overrides other specific local organisations. Spanish is the only language that people use. Their clothing is clearly influenced by urban styles and is suited to the zone's climatic conditions (mesothermal valleys). As elsewhere throughout Bolivia, cheese and roasted meat are staples in their diet.

The community has several irrigation systems, called *Naranjos Margen Izquierda* [Left Bank], *Naranjos Margen Derecha* [Right Bank] and *Valle del Medio* [Valley in the Middle]. The three systems take the water of the same river, but each of them are independent. They do not mix their intakes of water. These names are the result of the intervention. For budget reasons, they were forced to set up separate projects. Only Naranjos Margen Izquierda is studied here to see how the intervention proceeded. ["Margen" is both masculine and feminine in gender, so the name can be "Izquierda" or "Izquierdo".]

This system dates back about 30 years, when farmers began using the water from the Salinas River. The human settlements from nearby Entre Ríos communities decided to build a rustic intake and a dirt canal to convey water to the irrigation area. However, continual high-water flows of the Salinas River[1] and landslides in the hills where the main canal ran would regularly block the water flow, repeatedly interrupting the Naranjos families' farming work. Therefore, in 1989 they decided to improve their irrigation system and looked for funding. Users wanted an intake facility and canal that could supply "safe" irrigation for their crops, since they never had any water availability limitations from the Salinas River. With IDB-PRONAR funding, the final design studies were done in 1997. Then, construction began in 1998, with funding from the same source, and they finished the facilities in 2000.

The rehabilitated infrastructure enables each user to take a significant flow rate, since the canal is designed to convey 120 l/s. They are utilising only 50% of the system's capacity in the dry season, which is enough to cover their crop requirements, because in winter they cultivate only 56 ha. With more availability of water it was possible to expand the irrigated area from about 100 hectares to 140 ha. This area includes the area irrigated in summer and winter. This means that in this irrigation system they can cultivate twice in a year in the same area. The land holdings range between 2.5 to 7.5 ha, but almost 35% of people have between four and seven ha total. Prior to the intervention, 26 families benefited, and now there are 33, who have improved their profits because water availability for their crops is more secure.

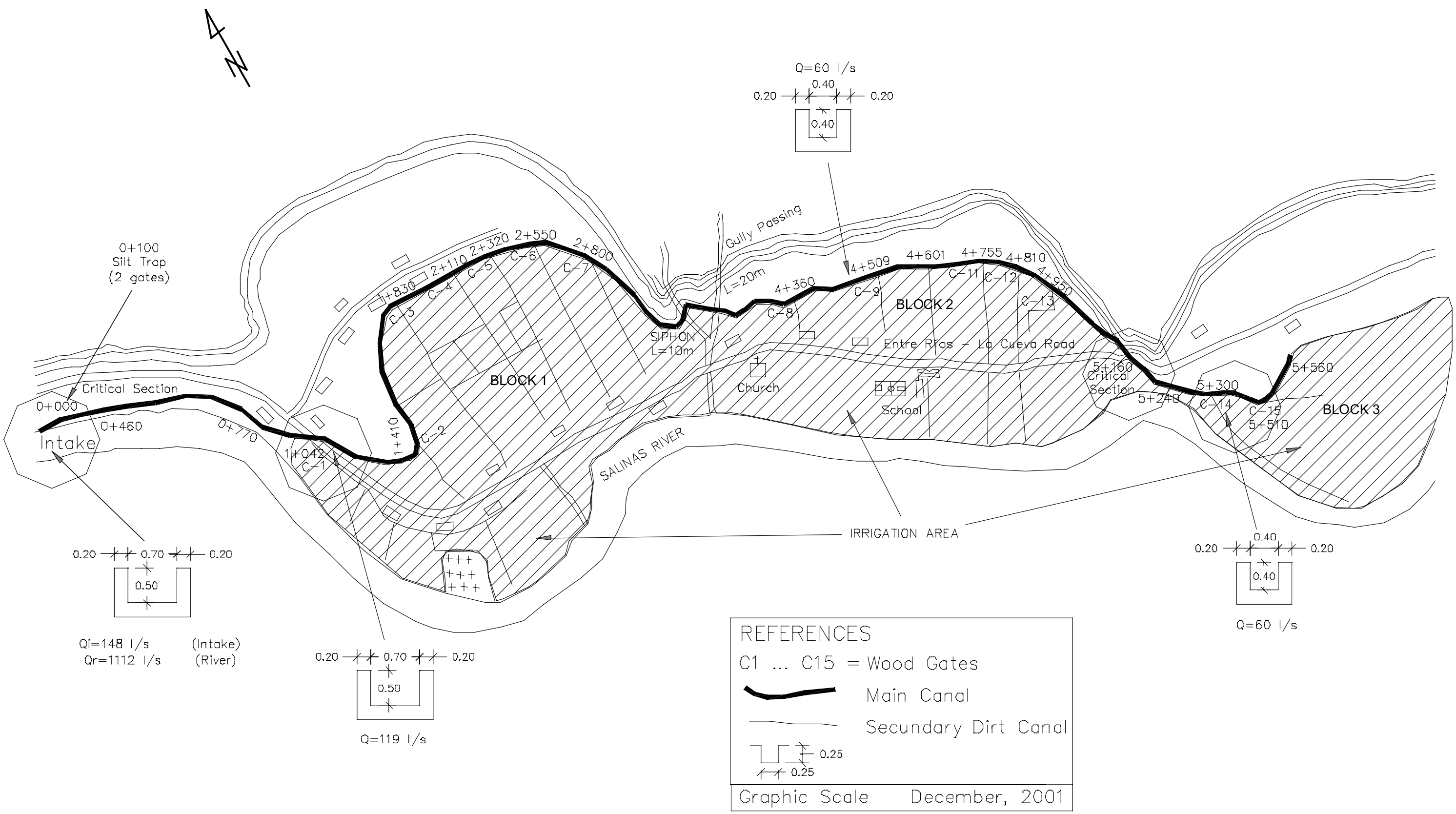
This chapter tells the story of this project's intervention. First the irrigation infrastructure of the irrigation system is described, followed by key aspects of the production system. Then aspects of system management prior to the project, and project proposals for future management are presented. Finally, the design process is described. All these elements make possible a quantitative analysis of the intervention in terms of how well the infrastructure fits management capability.

5.1 IRRIGATION INFRASTRUCTURE

Before the intervention, the irrigation system had a traditional intake (made of sticks, earth, and branches) for water from the Salinas River, which was conducted through earthen canals, which collapsed all the time. Since the intervention, the irrigation infrastructure has other characteristics, as shown below. The improved intake captures the water and users convey the water through the canals and different facilities. In order to deliver the water, users use gates in the distribution points. During the dry season water is distributed by turns, in rotation and with the full flow. During the rainy season the water delivery is by order, as shown below.

1 Measurements in 1994 and 1996 during the dry season determined a flow rate in the river of 1160 l/s, so plenty of water is available for each of these irrigation systems' requirements. (Project Naranjos Margen Izquierda

Figure 5.1 Map of the Naranjos Margen Izquierda Irrigation System



Intake

The irrigation system takes its water directly from the Salinas River through a "direct intake" that has a approach wall about 21.3 m long, 90º from the intake. The function of this approach wall is to conduct water to the intake opening. This opening is 0.70 m wide by 0.80 m high, and is protected by an inclined grate. Its gate can be operated from the top using a hoisting mechanism. All users can operate this gate. The crosswise wall is exposed to the river's flood flow. It is 5.50 m long, from the left bank of the river up to the approach wall, and ending with the skew wall, which is 2 m long, out into the river as a deflector.

The new intake is built on the riverbed, which is quite well consolidated. The river carries medium-diameter stones that could damage the facilities. During the dry season, there are problems to get water to the intake, because the water level where most of the river's flow will reach is slightly below the canal leading to the intake. This will get worse as time goes by, since the river level is tending to drop, so users have been obliged to build a rustic approach canal to be able to catch the water. This is a common problem in hill irrigation systems. After each rainy season, the intake requires maintenance and desilting. During the rainy season (2001), the main wall was slightly undermined. The marks left on the riverbanks are significant and may affect the intake structure.

One aspect that is having repercussions on the facility's durability and maintenance needs is the failure to take Salinas River high-water levels into account. There is a high-water level study in the final design document that was not used to redesign the intake.

Conveyance Canal

At the outlet of the intake is the conveyance canal, which is 1042 m long. This canal conducts water from the intake to the head of the irrigation area. Most of the canal is on the left riverbank. It is not high enough above the high-water level to avoid exposure. It has been damaged by flood-level water flow during the 1999 and 2000 rainy seasons. The reinforced concrete canal covers cannot withstand the high-water flow and lift right off. Normally, each year during the rainy season, most of this canal has problems with silting up, since mountain slope runoff carries sediments that are deposited along the canal. Consequently, canal maintenance calls for high labour input to clean out the build-up. The sediments also impair the canal bottom.

Main canal

The main canal joins the conveyance canal at the 1+042 station. It is 4548 m long. Before the project this canal was 4800 m long. The main canal, like the conveyance canal, is mainly parallel to the Salinas River's left bank. This makes it vulnerable to high-water damage. This has already happened in one section, which has not yet been repaired by users. Most of the canal runs along slopes, so landslides are common, and the first stretches of the canal were covered with reinforced concrete slabs 10 cm thick to prevent blockage. However, the canal still gets clogged, so users must clean it continually to keep it working.

The last 660 m of canal were built at the users' insistence, because they wanted to irrigate more area that belongs to the users or users' relatives. They asked to use the funds earmarked for protecting the intake and conveyance canal to line that last stretch instead. They thought that in the future they would look for money from another institution to protect the works. Canal dimensions depend on the slope, as shown in the following table.

Table 5.1 Dimensions of the conduction and main canals

<table>
<tr><th colspan="2">Survey station</th><th>Width</th><th>Height</th><th>Slope %</th><th>Type of canal</th></tr>
<tr><td>0+000</td><td>0+850</td><td>0.70</td><td>0.50</td><td>0.7</td><td rowspan="2">Conveyance</td></tr>
<tr><td>0+850</td><td>1+250</td><td>0.70</td><td>0.50</td><td>0.7</td></tr>
<tr><td>1+250</td><td>1+700</td><td>0.70</td><td>0.45</td><td>1.5</td><td rowspan="10">Main ditch</td></tr>
<tr><td>1+700</td><td>2+311.6</td><td>0.70</td><td>0.45</td><td>1.5</td></tr>
<tr><td>2+311.6</td><td>3+550</td><td>0.45</td><td>0.40</td><td>1.5</td></tr>
<tr><td>3+350</td><td>3+650</td><td>0.40</td><td>0.30</td><td>1.5</td></tr>
<tr><td>3+650</td><td>3+900</td><td>0.30</td><td>0.50</td><td>1.5</td></tr>
<tr><td>3+900</td><td>4+100</td><td>0.30</td><td>0.20</td><td>3.0</td></tr>
<tr><td>4+100</td><td>4+650</td><td>0.30</td><td>0.35</td><td>3.0</td></tr>
<tr><td>4+650</td><td>5+000</td><td>0.30</td><td>0.45</td><td>1.0</td></tr>
<tr><td>5+000</td><td>5+225</td><td>0.30</td><td>0.45</td><td>2.0</td></tr>
<tr><td>5+225</td><td>5+700</td><td>0.30</td><td>0.45</td><td>1.5</td></tr>
</table>

Source: Information gathered in the field. (2001)

Along the main canal there are 15 distribution points, with wooden gates. These gates were introduced by the project and users operate them. The following chart outlines distribution points.

Table 5.2 Locations of distribution points

Dist. points	Survey station	Dist. points	Survey station	Dist.points	Survey station
1	1+042	6	2+550	11	4+755
2	1+410	7	2+800	12	4+810
3	1+880	8	4+360	13	4+850
4	2+110	9	4+509	14	5+300
5	2+320	10	4+601	15	5+510

Source: Information gathered in the field.(2001)

Each user has a different number of plots, distributed through the irrigated area. If one user has the water turn, he/she can open the gate that is best located in order to irrigate the plot that needs water. Each user can use different distribution points in order to irrigate his/her different plots.

Silt trap

Downstream from the conveyance canal (0+ 241 m) is the silt trap and spillway. There are some mudslides in the side spillway area. The structure is 6.02 m long with a transition 1.10 m long that changes from 0.70 m to 1.20 m wide, and the outlet structure is similar. The gates do not work well; they are out of order (broken shafts, no seal) because they were badly made.

Siphon

To get past one of the many gullies in the irrigation zone, there is a siphon 67 m long. The entry structure has an entry grating with spaces 0.10 x 0.10 m. The siphon is made of two 8" diameter PVC pipes parallel to each other. There is a purge chamber connected directly to the gully to clean out the siphon. The siphon does not have a surge chamber or silt trap[2], so it did not work well, since all sorts of sediments, debris, branches, and dead animals would plug the entrance. Some of these materials even get inside the siphon, causing serious plugging. The siphon outlet also has a grate like the other, but unlike the entrance there is also a silt trap and an excess spillway. Since the siphon inlet gets stopped up with sediments and debris, the canal fills and floods surrounding land. This requires someone to be present, continually cleaning the entry grate. This is a problem that users complain about a lot.

Aqueducts and gully passings

To transport water over the different gullies, there are four aqueducts. At station 2+340 there is an aqueduct 9.95 m long, with a central support 3 m high made of reinforced concrete, supported at both ends by pillars of cyclopean concrete. At station 3+220 there is another aqueduct of reinforced concrete 14.20 m long, with a central support 4.80 m long and supported at both ends by cyclopean concrete walls. At station 3+749 there is an aqueduct 32 m long with three central pillars, two 6 m high and one 4.60 m high, all of reinforced concrete, and supported at both ends on cyclopean concrete walls. Finally, at station 5+050 there is an aqueduct 7.20 m long supported at both ends by cyclopean concrete walls. The reinforced concrete aqueducts join the canal, which is cyclopean concrete with "water stop" additive. The aqueducts in general work well and have not had any problems.

To cope with the irregular terrain, four gully passes have been built, at stations 0+230, 0+815, 1+730, and 4+590. These structures worked and are working adequately, but they must be cleaned out regularly because they silt up quickly.

5.2 THE AGRICULTURAL PRODUCTION SYSTEM UNDER IRRIGATION

Agricultural activities begin in August, September and October, when land is prepared to plant peanuts, fresh maize, field maize and beans. After they are harvested, land is prepared for late potato, pea and fava bean crops in March, as shown in the following figure.

2 During the construction they did not build this protective device.

Figure 5.2 Current Cropping Calendar

Crop	J	A	S	O	N	D	J	F	M	A	M	J
Peanuts		■	■	■	■	■	■	■				
Fresh (sweet) maize				■	■	■	■	■				
Field maize					■	■	■	■	■	■		
Winter potatoes	■	■	■	■								
Late potatoes									■	■	■	■
Late peas									■	■	■	■
Citrus	■	■	■	■	■	■	■	■	■	■	■	■
Fava beans									■	■	■	■
Beans					■	■	■	■				

Source: Information gathered in the field (2001)

The zone's agro ecological conditions provide for different planting periods: peanuts are planted once a year in August and grow until harvest seven months later in February. Cropping is diversified in the irrigation zone, mainly peanuts, potatoes and peas for regional and departmental markets. However, crops such as field maize, beans and vegetables are planted in small areas for self-supply and local markets. There is increasing demand for peanuts, so farmers are planting more, even at the expense of vegetables such as tomatoes and carrots. Livestock complements crops to help rural families make ends meet. Cattle, sheep, goats, hogs and poultry are raised rudimentarily, feeding on the native vegetation, plus crop by-products (mainly maize).

Together, farming and livestock occupy all available community labour. More labour-intensive crops and more intensive cropping (mainly peanuts) have considerably reduced emigration (which was mainly to Argentina, Tarija and Entre Ríos). Labour in the community is mostly family members. When more manpower is required, hired hands from Entre Rios help prepare the land, plant and harvest, earning US$ 3.20 a day. The improved irrigation system provides more work for family members in productive activities, which generates demand for additional labour during planting and harvest times (Fieldwork, 2000).

If a landowner cannot plant, the land is rented to another person at a negotiated price (it depends on the size, the kind of soil, the crop that will be there), but just for one year's time. The community does not have such work arrangements as the ayni[3], or other forms of reciprocity to help with the planting and harvesting.

Changes in the farming production scenario due to the project

As already mentioned, the Salinas River has a considerable volume of flow, so there is no problem with water availability to cover irrigation system requirements. The intake facility and canals guarantee water availability, which was not the case in the past, when it was impossible to get the

3 The ayni is an arrangement in the reciprocity system whereby neighbours all work together on the plots of community or group members, rotating from one to the next, without cash or in-kind payment.

water and conduct it from the source to the fields. The intake has capacity to catch 120 l/s, which is plenty to cover crop irrigation requirements. As can be seen in table 5.3, in winter there are only 56 ha under cultivation. In summer, water supply security has made it possible to expand the area with irrigation and to introduce new crops. The area under irrigation is itemised in the following table.

Table 5.3 Area under Cultivation prior to the Project and at 2001 (hectares)

	Summer		Winter	
	Without project	In 2001	Without project	In 2001
Under irrigation	63.00	94.00	37.00	46.50
Area increased		31.00		9.50

Source: Evaluation of the Naranjos Margen Izquierda system. National Irrigation Program 2001

Improving the irrigation system increased the area under irrigation by 40.5 hectares. The most significant change has involved growing peanuts (see Table 5.4). Also as an effect of the assured water supply, yields have changed. In most crops yields are relatively higher than prior to the project. These yields before project used to be: peanuts 1.5 t/ha, winter potatoes 10t/ha, late peas 2.6 t/ha and citrus 13t/ha. Changes in production scenarios have enhanced economic income of irrigating families. The net average income from agricultural production under irrigation is presented in the following table.

Table 5.4 Costs, Volumes, Gross and Net Value of Production after intervention

Crop	ha	Yield t/ha	Vol.Prod. t	Price US$	Total Income	Cost/ha	Total cost	Net Value US$
Peanuts	83.00	1.90	157.70	818.00	128998.60	495.90	41159.49	87839.11
Fresh maize	3.00	3.00	9.00	114.00	1183.50	310.25	930.74	252.77
Field maize	3.00	2.50	7.50	132.00	1102.50	236.98	710.95	391.55
Winter potatoes	1.50	13.00	19.50	195.00	3802.50	1188.52	1782.78	2019.72
Late potatoes	5.00	12.00	60.00	180.00	10800.00	1259.04	6295.20	4504.80
Late peas	36.00	2.80	100.80	227.00	22881.60	435.97	15694.79	7186.82
Citrus	3.00	13.20	39.60	112.00	4435.20	609.53	1828.58	2606.63
Fava beans	1.00	3.20	3.20	126.00	403.20	345.99	345.99	57.21
Beans	2.00	2.80	5.60	130.00	728.00	290.04	580.07	147.93
TOTAL	**137.50**		**420.90**		**174335.10**		**69328.58**	**105006.52**

Source: Evaluation of the Naranjos Margen Izquierda system. National Irrigation Program 2001

Taking into account the net value of production and dividing it by the 33 irrigation system user families, the annual average income per household is US$ 3182 / year in 2001, higher than the situation before the project, with average household income of US$ 1191 / year. This is because users decided to grow peanuts, which is more profitable and has boosted their income. They make most of their profits with spring and summer crops, which receive irrigation to assure production. However, because they do not have the same water turns, not all users have the same irrigated area. Considering this aspect, it is clear that there are also different incomes. If this aspect is taken into account, there are 18 households with a dual turn averaging US$ 4200 / year income, 13 households with a single turn averaging US$ 2100 / year and the two households with half a turn obtain an average income of US$ 1050 / year.

5.3 WATER MANAGEMENT

Water rights

Users say that, years ago, only a few families lived along the river banks, and used water as they needed it. As more families came to the area, the number of water users also increased. They initially agreed that only those families would have water who took part in repairing the intake and the main canal. There was a high demand for labour because the facilities would be blocked off by landslides from the surrounding hills and damaged by high water flows. Eventually, they had the 26 user families in irrigation system, out of the 46 families belonging to the agrarian syndicate, about three decades ago.

Holding rights also entails obligations. After the intervention, in 2001 rights and obligations remain practically the same, but contributions are now in workdays and in cash. The following chart summarises the relationship between rights and obligations.

Table 5.5 Rights and obligations

Rights	Obligations
• To receive and use irrigation water • To elect and be elected to lead the users' organisation (rotating). To speak and vote in meetings.	• To participate in repairing the intake; • and the canal, from the intake to the plots. • To attend meetings that are called. To make contributions as agreed.

Source: Information gathered during field work 2000.

There is no special person monitoring infrastructure operation in this system. Representatives of the organisation monitor users' presence at meetings. To enforce these obligations, there are penalties, summarised in table 5.6.

Table 5.6 Obligations and penalties

Obligations	Penalties for non-compliance
• To participate in cleaning the canal and intake. • To make agreed contributions. • To attend regular and emergency meetings.	• To repay double workdays. • Temporary cut-off of water. Pay US$ 0.60 per absence.

Source: Information gathered during fieldwork. 2000

The by-laws and internal regulations are in force, so penalties can have impact. It was even agreed that, in the event of non-compliance, local legal authorities (sub prefecture authority or police) could be involved to enforce agreements.

Water distribution

This irrigation system had and still has two modes of water distribution: free on demand during the rainy season (November through June) and by turns during the dry season. In the first case, although the water is free on demand, users have agreed to continue organising water delivery. Irrigators let the water judge know that they need to use water, in order to prepare the list of water delivery. This avoids conflicts between users (for example, overlapping turns and/or days for distribution).

Before the project, during the period of delivery by turns, from July through October, the water judge received irrigation applications in the order that interested users apply. Once the distribution list was made up, it was presented to users at the monthly meeting for approval. Each user was entitled to use the single flow for 18 hours to irrigate one hectare, every week; people with 2 ha used to irrigate for 36 hours. This means that there was a relationship between the land size and the water turn. If users want, four or five of them could irrigate at the same time, with an average flow rate of 10 to 15 l/s, but more time. Since distribution was rather flexible under users' agreements, they could trade turns. A user could take the water to any plot, regardless of where it was located. They could also exchange turns with another user, as long as this did not change the scheduling decided on at the meetings. Users said that common conflicts regarding irrigation before the improvements included quarrels between neighbours, stealing water, and failing to abide by the agreed distribution schedule (which focused on "sequence or order" rather than "turns expressed in duration time"). Although there are norms and verbal agreements, they are generally not enforced (Interviews, 2001).

Maintenance

To obtain water, users had to build and rebuild the rustic intake, using stones, clods and branches, every week or two. High water and landslides would damage the main canal, which was often blocked. So, the most frequent problems for these structures included landslides, leakage and destruction, which called for ongoing maintenance to keep the system working. Sometimes they would use plastic bags to waterproof the main canal, which did not work very well.

Activity was greatest from July through October. People used shovels, picks and mattocks. The water judge was responsible for organising the maintenance work. Every time the high water damaged the rustic intake and canal, those responsible for the system would call users together to make repairs. Each would be given a stretch of canal called a "*suyo*" (about 2 meters). The number of *suyos* that each user had to clean was a function of the total length of canal to be cleaned. Rebuilding the rustic intake and canal maintenance required an annual investment of 78 workdays per user per year, including the cleaning of secondary canals. After improvements, criteria for maintenance remained the same, with the difference that the number of workdays required became about 44% less. However, users were also required to pay dues for maintenance, although most do not.

During the maintenance work the water judge was responsible to check the users list to know who were present and to organize the work. From the outset, they agreed that heavy work should be done by male heads of household, so children's participation was not taken into account, and women did not participate, either. Often, when the male head of household was not around, or the head of household was a woman, they could send a hired hand or the eldest son to do the assigned work. Failure to attend maintenance work was punished by a double workday, which would have to be repaid in work when required. Otherwise, the user would not have access to water until the penalty was paid. Secondary canal maintenance was normally done by the members of each family, when it was their turn to irrigate.

Organisation

Before the project, the water judge was the irrigation authority, and belonged to the syndicate organisation. This authority was appointed according to the membership list, rotating every June, at the first meeting called for intake and canal maintenance. Each member served as judge for a calendar year, although if they did not perform their duties efficiently for all users, they would be replaced immediately. The duties performed by the water judge were: To organise system maintenance, to distribute "*suyos*", to schedule turns and to oversee irrigated land area (Interviews October 2000)

The only benefit that the water judge would receive was not having to take part in infrastructure cleaning work. However, instead of this work, he would have to oversee the distribution of maintenance tasks and make sure they had been done. All the work was a community service, so the burden was shared as the position rotated. As a community member put it: *"We all have to put up with this burden at some point, for the community's benefit; in other words, it is something you give and then receive later".* In order to enforce the internal agreements, they decided on control mechanisms, as already presented in the preceding sections (see Table 5.6).

Table 5.7 summarises irrigation water management characteristics before the project intervention.

5.3.1 Project proposal regarding future management

As in the previous cases, the project's proposal for irrigation improvement is presented in two phases: pre-investment and investment. When the final design project document was prepared, there was a requirement for such final designs to propose activities for the support stage. Therefore, this pre-investment phase also included the proposal for support in the future. The appendix on investment (the "support" stage) presented concrete proposals made by the supporting entity. The project proposal regarding future management is presented in Table 5.8 and in the following paragraphs.

The project idea emerged in 1989 and 1990, when community members took the initiative to gather data. The idea was discarded because of the high cost of building irrigation infrastructure, and because users would have to contribute 50% of the project cost with labour and cash, which was beyond their capacity. Then, in 1994 the Tarija Development Corporation (CODETAR) undertook the Middle Valley Project to improve the irrigation systems of Valle del Medio, Naranjos Margen Izquierda and Naranjos Margen Derecha using water from the Salinas River. Engineering for this project proposed a single intake for the two different systems. Naranjos Margen Izquierda would be irrigated by building a siphon or aqueduct bridge.

Table 5.7 Naranjos Margen Izquierda irrigation management analysis I– Before project

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision at the general meeting of the syndicate to define obtaining water rights through workdays contributed to build the rustic irrigation infrastructure, regardless of the variety of rights.	Decision at the general meeting of the syndicate to: 1. Begin delivering water by roster of shifts in dry season and in order of demand when raining. 2. The roster of shifts is prepared monthly and approved by users monthly. 3- Elect the water judge, on a rotating basis, every June.	Decision at the meeting of the syndicate for each user to contribute the same workdays to reconstruct the intake and conduction canal and clean canals.	Decisions at the syndicate meeting to establish obligations and penalties regarding community organisation, operation, distribution and maintenance.	Decision at the syndicate meeting to organise activities for construction and permanent reconstruction of the intake and conduction canal.
	Activities involving keeping track of workdays during construction.	Activities involving preparing the roster of shifts and orderly delivery of water.	Activities involving organisation of permanent reconstruction of the intake, conduction canal and cleaning silt from ditches.	Activities involving fulfilling obligations.	Activities involving work organisation, normally organising work for emergencies.
Formal rules	Fulfilment of workdays. Rules establishing: 1 the implication of having water rights: obligations and rights. 2. Those belonging to the union and owning land in the area of influence of the canal can acquire rights.	Rules establishing that : 1. In the dry season, water is delivered by a single flow to each user 2. The water delivery interval is 14 days.. 3. Water is delivered in order of demand through the water judge during the rainy season.	Rules establishing users' obligation to participate in maintenance. Women and children are not allowed to participate in maintenance.	Rules punishing failure to honour agreements.	Rules establishing availability of labour always available. No women are allowed to contribute work. They must hire a labourer in their place.
Participants and roles	The syndicate oversees contribution of workdays and agreements. The group of users take part in the construction.	Water judge prepares the roster of shifts and monitors water delivery. The users group irrigate as entitled.	Water judge to organise work and group of users to work.	Water judge to oversee distribution and maintenance. President of the union to oversee attendance at meetings and delegated tasks. Users who fail to abide by established rules.	The water judge organises the work and users with water rights do the work.
Logic and informal rules	Logic of community self-control. Each user monitors his own number of workdays and those of others.	Logic of community self-control. Water is delivered by rotation and single flow. If users want they can irrigate simultaneously with others dividing the flow but more time.	Logic of community self-control. Each user comes to the intake with his tool and the necessary materials to rebuild the intake and conduction canal.	Conflicts are handled internally. If they cannot be solved by the committee, they turn to the outside authority (sub prefecture, police).	Logic of community self-control and collective action.

Table 5.8 Naranjos Margen Izquierda irrigation management analysis II – Project Proposal

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision by the irrigation committee to: 1.Contribute 23 workdays per hectare (based on the estimated cost of the project). 2. Granting water rights to another 7 new users.	Decision at the irrigation committee meeting to: 1. Establish 3 irrigation blocks and irrigate by dividing the flow. 2.Elect a president, secretary-treasurer and 3 water judges to organise water delivery.	Decision at the irrigation committee meeting to: 1. perform routine and preventive maintenance activities. 2. define maintenance fee contribution.	Decisions at the irrigation committee meeting to establish by-laws and regulations to handle conflicts.	Decision at the irrigation committee meeting to: 1. Define labour contribution by the community, equivalent to 20% of the total cost of the new infrastructure.
	Activities involving monitoring days worked.	Activities involving: water delivery by blocks, flow division, opening and closing gates to deliver water.	Activities involving routine and preventive maintenance.	Activities involving enforcement of by-laws and regulations.	Activities involving work organisation and supervision: groups, periods, tasks.
Formal rules	Rules involving fulfilment of obligations related to water rights.	Block 1 receives 50 l/s , subdivided into two subgroups, each with 25 l/s (10 hr/ha /user). Block 2 with 20 l/s (10hr/ha/user). Block 3 with 50 l/s subdivided into sub groups with each 25 l/s (10 hr/ha/user).	Rules establishing that each user must contribute US$5 per hectare irrigated and 5 workdays a year for maintenance.	Rules economically punishing non-observance of established norms and obligations. (Table 5.6)	Rules establishing planned work: schedule, periods, amounts.
Participants and roles	Engineers recording each user's contributions, irrigation committee recording days worked, and community members working.	3 water judges (1 per block) to oversee and users to irrigate and open / close gates.	President, treasurer and group of users with water rights.	President to enforce the penalty, treasurer to administer funds, and users to pay fines for failing to abide by established norms and rules.	Building committee organises work, engineers direct work and users do as planned.
Logic and informal rules	Open-system logic to incorporate new users with water rights.	Multiflow logic	Logic of monetary investment to guarantee facility sustainability.	Logic of economic supervision.	Logic of farmer investment to guarantee irrigation system sustainability.

In 1995 CODETAR applied to the National Irrigation Programme (PRONAR) for the funds to build this project. That year, the national government, through PRONAR, got Inter-American Development Bank (IDB) funding for irrigation projects. So, the IDG asked to see final design projects. PRONAR presented 52 projects, including the project for Naranjos Margen Izquierda.

In 1997, PRONAR undertook the final design under direct administration, deciding to divide the project into Naranjos Margen Izquierda (Left Bank), Naranjos Margen Derecha (Right Bank) and Valle del Medio (Mid Valley), because an eligibility criterion was for each project to cost no more than US$ 300,000.

Pre-investment phase

Water rights

The final design project document says the following about water rights: *"Water rights will be acquired on the basis of the amount of work that users will have to do and, at the same time, the work modality based on the amount of land area each family has under irrigation will be maintained".* Regarding future support for water rights decision-making, the project proposed: "*The supporting entity must collaborate in adopting system administration mechanisms such as a record of work days, to keep track of old and new users' rights. This will establish the modes of labour and cash contributions to construction, operation and maintenance*" (Naranjos Margen Izquierda Irrigation Project, 1996, p. 36).

Another issue that design engineers discussed with users during the project preparation period was to determine the workdays that each user should contribute in building the improved infrastructure. Since the new infrastructure would be superimposed on the current canal (4800 m), existing users agreed that new users, who had not participated previously in building the traditional canal, would have to work from the intake to the end of the main canal (5225 m) (including the expansion). Old users would work only from the main canal down to their fields. Finally, the result of this idea was that each new user should work 23 days/ha, in order to have water to irrigate 1 ha.

Water distribution

For water distribution, the project proposed "*that water be distributed by blocks and each block be subdivided in turn into sub-blocks, with continuous flow".* It also stated: "*that each 120 litres at the intake will be divided into 50 l/s for block 1(44ha), to be subdivided into two sub-groups, at 25 l/s each, for ten hours per hectare per user. Block 2 (18 ha) will irrigate with 20 l/s for ten hours per hectare. Block 3 (45 ha) will also be subdivided into two sub-groups, each with 25 l/s for ten hours per hectare".* The document also said: *"To ensure equity in distribution, the project proposes to install RBC direct-reading gauges at the head of each block*". (Ibid, p. 36). This meant that each user could know the flow with which they irrigate through the RBC, dividing the flow.

In summary, the project proposed water distribution on a multi-flow basis – dividing the water flow into parts – rather than the single-flow rotation used before the project. Finally, regarding water distribution organisation, the project document proposed for water delivery to be monitored by each water judge (for each group). They would oversee distribution, even at the sub-group level, and the land area irrigated, according to the season records.

In the project document, designers also proposed for the support entity to advise users on: 1. participatory preparation of the annual water distribution calendar (e.g. setting the date to begin irrigation), 2. overseeing water supply according to facility design and each user's rights, 3. monitoring proper, efficient use of water in the irrigation area. As we will see later, users agreed to organise the distribution in three blocks but on a rotating basis.

Maintenance

Designers proposed that, along with building the new infrastructure, the following maintenance work should be done, quoting verbatim from the document (Ibid., p. 37):

- *Collective maintenance of the intake by all system users in the same way as they have been accustomed to doing.*
- *In the main canal, from the intake to the end, maintenance by all users, since that canal is used as drainage when there is excess water.*
- *Work will be distributed according to the number of hectares under irrigation that each user has, maintaining the organisation of maintenance by "suyos".*
- *Secondary canals will be maintained by users who have their plots along that section, as people have been accustomed to doing.*

As for participation in maintenance, the project document indicates that users have agreed that, when the "man of the house" is not around, or the head of household is a woman, they must send a hired hand or the eldest son to perform the assigned tasks. Clearly, women's work in system maintenance has been less involved, or less valued by users and designers. Failure to attend maintenance work will be penalised by a double workday, which must be repaid in labour when required, or the user will lose rights to water.

Regarding the type of maintenance, it was proposed for maintenance to be routine and emergency, entailing the following activities:

At the **intake**: Inspection, reconstruction and maintenance. Examination of operation and cleaning the intake canal.

At the **main canal**: Review, reconstruction and maintenance of the canal. Clearing weeds and brush, and cleaning the canal.

The project also suggested "contributing five days' work per hectare irrigated, and US$5 per hectare irrigated for infrastructure maintenance and operation costs". Also, the final design document established that the support entity should provide advisory support for regular maintenance of the intake, canals and ancillary structures, and to protect the system from potential damage by outside factors, as well as for timely repair of emergency damage.

Organisation

The project suggested, for future system operation, to consolidate "*... an Irrigation Committee to establish responsibilities for operating and maintaining the new self-managed system, from the outset.* (Ibid, p. 37)

For this purpose, it proposed the following Irrigation Committee structure: *General assembly of users, board of directors and water judge.* The project document also stated that *"The Committee will determine the system's operating and maintenance modes, respecting existing rights and new rights acquired by users through their work. It is also suggested to innovate mechanisms to make the system viable and sustainable".* (Ibid, p. 37)

The project proposed that the support entity should work for two years on the irrigation system, supporting Irrigation Committee consolidation and operation, to manage the system. In this phase the project did not recommend a special person to operate the infrastructure

Investment or support stage

The support stage became a key phase, because this set the characteristics for water management regarding the infrastructure to be built during this stage. The responsibility for orienting this phase fell to the "support entity" (CDR s.r.l), hired through competitive public bidding by the FDC, on the basis of established terms of reference. But, as in all previous cases, the support entity began to work when the infrastructure was built. Their final output was an operating and maintenance manual, and by-laws and regulations to provide the norms for irrigation organisation processes. Although the supporting entity was present in this irrigation system, they could not do much about the plans, for several reasons. Users were unaware of the role that the support entity should play, so the latter had to spend a lot of time on information meetings, which took time away from their actual work.

With this background, the future irrigation system management can now be described.

Water distribution

The support entity's proposal for water distribution was the same as the designers had established in the project document. By the time the support was provided, the actual number of users[4] had already been established, and the hectares to be irrigated in each block were known, as an effect of the workdays contributed by each user family to construct the system. However, the support entity did not study the proposal prepared in the project document as to whether it was realistic. With the new number of users and hectares defined in each block, it would no longer be feasible to deliver water by a "multi-flow" (dividing the flow, point 5.5.1) system, because the time it would take to irrigate each block would be different.

Unfortunately, the support entity insisted on applying this distribution mode, and presented the proposal to the users. This caused confusion among users and they did not accept the idea of dividing the flow. However, they agreed with the idea to organise three blocks for irrigation, but on a rotating basis. Moreover, without flow gauges at the head of each block and sub-group, the situation was even more complicated. For this reason, users decided to keep the distribution system from prior to the intervention. However, they decided to introduce the blocks for organisational purposes.

In the current situation (2001), the reference turn is ten hours. That is, water is currently delivered on the basis of fixed turns, through the distribution points located in the main canal. The system has three irrigation zones or blocks and the total fixed turns for each block determines the irrigation time per each of the three blocks. The total of times for all three blocks determines how long it will be before each user gets water again. The Salinas River water's availability and infrastructure characteristics make it possible to convey flows of over 100 l/s, all the way to the last field in the system, so two or three users can irrigate at once, making the watering cycle about 14 days. The infrastructure also enables each user to take a significant flow rate, since the canal is designed to conduct 120 l/s. They are utilising only 50% of the system's capacity in the

4 The final project document established 46 beneficiary families.

dry season, which is enough to cover their crop requirements, because in winter they cultivate only 56 ha.

As already indicated, there are still two water distribution modes during the year. The period for using water freely on demand is longer (December through June). The second, in which water is delivered by turns, through a continuous flow and by the order of the blocks and applications received, is overseen by the judges for each block. Users decide where to use the water, respecting their assigned turns.

In conclusion, this experience shows that the support entity was responsible for defining future water delivery, along with users, because during construction it was evident who would have water rights, they agreed on the meaning of these rights, and their variations were determined. Unfortunately, the responsible entity did not analyse in detail whether the distribution system should be changed or not, although they had the information on water rights, which were the basis for defining future water delivery.

Maintenance

Maintenance activities proposed by the support entity were the same as proposed in the pre-investment stage:

Table 5.9 Maintenance work proposed by the support entity

Type of maintenance	Physical facilities	Description of tasks
Routine	Intake Main canal Chambers and siphon	Protect the intake Clean the canal Clean chambers and siphon, 4 times a year
Preventive	Gates Main canal	Paint and grease gates. Patch cracks and breakage

Source: Final project design document 1997.

Out of these tasks, only the routine canal cleaning was subsequently done. They also agreed with users that there would be two kinds of contributions: 1. US$ 2/ha/year for maintenance and operation, and 2. emergency contributions (no set amount, depending on the damage). Users did not accept to give US$5 ha/year as stipulated in the final project design document, and, no such contributions had been made up to 2002.

The support entity began to work late, so they could not work as was planned by PRONAR. It was not possible for them to have an interactive process. They were worried about trying to develop an operation and maintenance manual. In order to achieve this, the support institution did some workshops, in order to present what users should do in operation and maintenance (PRONAR engineers interviews, 2001).

Again, the support entity showed weak support for the local organisation, in determining maintenance activities. They did not discuss with the users about the risks that irrigation infrastructure in general was exposed to. Therefore, they did not propose complementary actions to protect facilities and decrease maintenance requirements, beyond simply protecting the intake. Nor did they observe the facility characteristics in terms of maintenance possibilities. For example, they did not tell users how to maintain a siphon, or train users how to maintain concrete constructions. The central point is that neither the support entity nor the FDC defined exactly the meaning of "support". The support entity wanted to produce the operation and maintenance manual as a list of things that users should do. Neither the support entity nor the users were really concerned about how to maintain the new works. Since the support entity did not do enough work regarding the system's "future maintenance" and users were not paying their fees for this activity in 2002, the facilities were poorly maintained, which jeopardised the system's sustainability.

Organisation

The support entity incorporated all the proposed aspects on organisation into the final design project document. The organisational chart proposed for the irrigators' organisation for the Naranjos Margen Izquierda system is in presented in the following figure.

Figure 5.3 Organisational chart for Naranjos Margen Izquierda Irrigation System

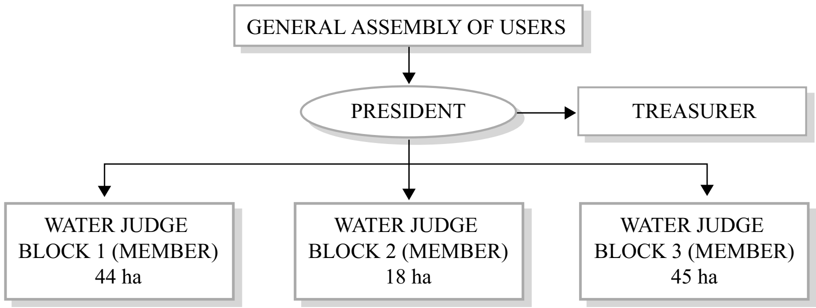


Table 5.10 Participants and functions

Role	Functions
President	Representative in dealing with other bodies Organises turn beginning Conflicts resolution Presides over meetings
Treasurer	Handles finances Support to the president
3 or judges of water (1 for each block)	Oversee the turn list Notify users Co-ordinate activities with the other water judges of blocks and with the president

Prepared on the basis of the By-laws and Internal Regulations of the Naranjos Margen Izquierda Irrigation System

Incorporating new positions on the irrigation organisation's board of directors looked like a good idea to system users, because this involves more participants. All users who have water rights may be elected to the board (president, treasurer, water judges). In many cases they may be ratified in their positions (to repeat a term) depending on their reputation, hard work and positive achievements in favour of users.

Further, pursuant to the support entity's contractual terms of reference, it prepared the by-laws and regulations for the irrigators' organisation. However, users did not follow them, especially in regard to quotas for maintenance. The agreements from prior to the intervention remained in force.

Water rights

There were 26 user families prior to the project, and in 2001 there were 33 user families, with differentiated rights. Eighteen users have rights to dual water turns, 13 with one turn and two with half a turn. Those with more land have worked more, to have more rights, and since water availability is not a limiting factor, there have been not squabbles among users. They determined that the workdays contributed in order to build the new infrastructure would be a function of the land area available in the irrigation area. They decided on 23 workdays per hectare of irrigated land. Users' rights and obligations, established in the by-laws and regulations, are summarised below:

Table 5.11 Summary of users' water access rights and obligations after the project

Rights	Obligations
• To speak and vote in scheduled meetings • To elect and be elected • To use irrigation water • To use and manage the system • To receive moral and material support from the organisation.	• To have worked all the days calculated for the project • To regularly attend meetings that are called. • To cover all economic contributions • To conserve the system infrastructure.

Prepared on the basis of the By-laws and Internal Regulations of Naranjos Margen Izquierda irrigation system.

One of the obligations introduced is subdivided into two: economic contributions and workdays to cover the community's counterpart input for the project. Obligations and penalties to keep water rights, current in effect in the system, are shown below:

Table 5.12 Obligations and penalties in effect in the irrigation system

Obligations	Penalties for non-compliance
• Work to maintain canals (one day a month) • Work for the intake • Fees for maintenance • Meeting attendance • Use of water only during each user's turn.	• Payment to the sub-prefecture • Loss of water turns until paid • Fine of US$ 0.60 • Loss of the turn • Fine of one workday

Prepared on the basis of the By-laws and Internal Regulations of Naranjos Margen Izquierda Irrigation System.

In both cases (Tables 5.11 and 5.12), all aspects were negotiated between the support entity and the community and the community assumed them. With the by-laws and internal regulations in effect after the project, penalties are normally monetary. They may turn to civil-society legal mechanisms to enforce agreements. In this system, one user failed to complete his community contribution. When he refused to make good on this payment, the board denounced him to the

Entre Ríos Sub-Prefecture. Under this body's pressure, he promised to pay his contributions, as long as they did not take his water rights away. Maintenance fees, however, are not paid, nor enforced by cutting off the water shift for non-payment, although this is set forth in the by-laws and regulations.

In spite of the work carried out by the support entity to change irrigation water management in the improved irrigation system, it has remained mainly just as it was before the project intervention, as can be seen in Table 5.13.

Table 5.13 Naranjos Margen Izquierda irrigation management analysis III– After project

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision at the committee's general meeting to define 2 workdays per hectare irrigated.	Decision at the committee's general meeting to: 1. Begin delivering water by shifts and free on demand. 2.In the dry season, the roster of shifts is followed, and in order when there is plenty of water. 3. The roster is prepared monthly and approved by users every month. 4. Elect the committee.	Decision at the irrigation committee meeting for each user to contribute the same number of workdays to clean the canals.	Decisions by committee meeting to establish obligations and penalties regarding community organisation, operation, distribution and maintenance.	Decision at the irrigation committee meeting to: organise a construction committee to supervise days worked and the quality of new infrastructure.
	Activities involving recording workdays.	Activities involving preparing the roster of shifts and listing for delivery on demand in order.	Activities involving cleaning sediments from the conduction canal and main canal.	Activities involving enforcement of obligations.	Activities involving organisation of construction.
Formal rules	Rules establishing the implications of having rights and obligations.	Rules establishing that : 1. In the dry season, water is delivered by rotation and single flow among blocks and divided flow within each block. 2. The water delivery interval is 14 days. 3. Deliver water by order in free-demand period, under water judge supervision.	Rules establishing users' obligation to take part in maintenance. Women and children are not allowed to participate in maintenance. Fees of US$1 /ha /year /user.	Rules fining those who fail to follow established norms and obligations. (Table 5.7)	Rules establishing the work schedule, non participation by women and children in construction. Female heads of household must hire a labourer.
Participants and roles	The committee monitors days worked and agreements fulfilled, and the users group fulfils the work and agreements.	Water judges prepare the roster of shifts and supervise water delivery. Users group irrigate as entitled and operate facilities.	Water judges to organise maintenance and users group to clean.	Committee authorities to enforce obligations and users who fail to follow established rules.	The building company directing the work, the construction committee overseeing quality, and users contributing labour.
Logics and informal rules	Logic of community control. Each user monitors his own days worked and those of others.	Logic of community control. Water is delivered by rotation and single flow.	Logic of community self-control. Partial routine maintenance but no preventive. Users do not pay maintenance fees.	Conflicts are handled internally. If the committee cannot solve them, they turn to the outside authority (sub prefecture, police).	Each user contributes different numbers of workdays according to their water rights.

5.4 THE DESIGN PROCESS

5.4. 1 Identifying and preparing the final design study

In 1997, PRONAR undertook the final design under direct administration. the Naranjos Margen Izquierda project was be funded by IDB – PRONAR finance, administered by the Rural Development Fund (FDC). Economic assessment indicators to approve the project and actual values once it had been implemented are shown below:

Table 5.14 Criteria for project eligibility

Indicators	Criteria for eligibility	Calculated project cost (US$)	Real cost (US$)
Cost per additional usable hectare	Less than or equal to US$2500	1869	4624
Cost per family	Less than or equal to US$4000	3414	5675

Evidently, costs far overran those estimated in the final design document, since the project cost much more than was estimated.

Economic indicators always were a bottleneck in irrigation system design. Internally, in PRONAR, everybody was worried about them, but as it was a rule defined between IDB and the State of Bolivia, it was impossible to change them. For this reason, the design engineers used to calculate first how much money would be available, taking into account the economic indicators, and finally propose the works. This it is the reason, for example, why engineers did not take into account the total length long of the main canal required by the users.

5.4.2 Project implementation

Project implementation took 375 days, although the company signed a contract with a 180-day deadline. Lack of decision-making and/or definition for different project adjustments (e.g. intake position, distribution point location) and the lack of continuous project supervision slowed the irrigation infrastructure construction considerably.

The actual implementation timetable is shown below:

Table 5.15 Project implementation timetable

Items	Date
Tender	10/08/1998
Award	15/09/1998
First disbursement	21/09/1998
Work began	5/10/1998
Conclusion	12/02/2000

Source: Naranjos Margen Izquierda project procedural manual.

During implementation, the important points were:

- During building, users contributed workdays, concretely “unskilled” labour, and local materials (stone, gravel and sand) as the beneficiary community counterpart. Users’ input increased by 6% over the project document calculation. This was due to delay in implementation, changes made during construction, and increased volumes in excavating for the siphon and the canal bridge.
- The users decided that the building company should invest the money earmarked for gabions (to protect the canal and intake) instead to extend 660 metres of main canal. This change has come to threaten the facilities’ security, especially in the two critical stretches, when the Salinas River overflows its banks. Users wanted to enlarge the irrigation area first, then attend to protection works.
- While building the facilities, users complained of delays. In July, the work was not finished, which prevented many users from watering to prepare their land for planting.
- When the community had worked all the days it had agreed to, the building company still required “unskilled” labour (according to the contract the building company should contract additional labour), so they hired some community youth who wanted to earn money, but failed to pay them completely, so the community was discontented with the company. In conformance with the contract, the building company should hire additional unskilled labour from local people who wanted to earn additional money.
- One problem with the company’s performance was the high turnover of contractor and subcontractor personnel, when people quit because they had not been paid for their work. Meanwhile, the community was continually put off, and uncertain as to whether the work would continue.

In October 1999, beneficiary community representatives, the Irrigation Committee President, the building company, the implementing entity (FDC) and the Rural Development Fund project supervisor met to discuss provisional delivery of the project. This meeting issued a provisional memorandum stating that the building company still had to fix the intake gate, clean the canal in sectors affected by rains, improve the ancillary structures, repair the plastering at the gate outlets, waterproof the canal where there were leaks, and place the reinforced concrete covers properly. The final completion agreement was done in February 2000. Having received the work to their satisfaction, the promoting entity, FDC project supervisor, departmental FDC supervision co-ordinator and FDC department head agreed, without involving the users in this procedure.

Due to flooding, on February 26 the canal was undermined, so project delivery to users was postponed until these problems could be repaired. In August 2000, supervisors reported to the regional FDC office that the work had concluded, and could be delivered to the users.

5.4.3 Stakeholders and roles in the project

System users

Users were important stakeholders when they negotiated for the project, through the Naranjos community organisation initially and then through the construction committee. The members of this committee indirectly co-ordinated with other project participants. The only proposal they made to change of the infrastructure during construction was to expand the length of the lined canal, using the budget earmarked for protection facilities, such as gabions.

As for management design, users agreed that water delivery could continue according to the distribution mode used prior to the project intervention, and refused to accept the support entity's proposal. They accepted the entity's proposed organisational structure and maintenance tasks. They played an active role in defining water rights, regarding the number of workdays that each family should invest in construction to acquire water rights as a function of their landholding in the irrigated area.

During construction, users provided workdays ("unskilled" labour) and gathered local materials (stone, gravel and sand), as the beneficiary community counterpart set forth in the project design.

Sub Prefecture of Entre Ríos

The Entre Ríos Sub-Prefecture, in the first stage of project implementation, made a major contribution by helping to organise the community to define contributions and enforce agreements established in the project. This was because the support entity had not yet been hired, and some institution was urgently required to co-ordinate activities with other social stakeholders. Subsequently, the Entre Ríos Sub-Prefecture technical team collaborated in overseeing resource use. They also provided dump-trucks to move local materials from the river to the worksite, as requisitioned by the contractor company. Therefore, they indirectly performed quality control for the material to be used to build the infrastructure.

Sub-Prefecture authorities also become the users' complaint desk, and channelled these complaints about work quality and delay by the building company. They also heard the users' demand that the building company be paid according to progress in the work, so that the company would stay on schedule. The Sub-Prefecture also helped the community enforce the contributions of those who refused to follow and obey local authorities. This work was done locally by the Naranjos Official (*Corregidor*). More than once, he enforced the law so that users who had failed to meet their obligations would make up for this by paying the corresponding fines.

The person responsible for the Entre Ríos Sub-Prefecture was interviewed (January 2001), and mentioned a number of problems. The building company agreed to implement three or four projects at once, with the same equipment and personnel, which made it difficult to stay on schedule. Another important issue he mentioned involved Supervisor's visits, which were irregular (because he had other projects to visit, preventing him from appearing more often). Also, the support entity's involvement was very brief, starting quite late and concluding when the new facilities were not yet in use. Therefore, for example, there was no practice of siphon management. When they began using this facility, the siphon began plugging, flooding homes near the siphon. Finally, he mentioned that it was difficult to elicit counterpart cash input (20%, equivalent to US$ 38,603) because people had limited resources, which prevented them from meeting their commitments.

Building Company

The building company was hired by FDC through a public bid. The building company ran 193 days late in delivering the work. Company spokespersons said that this was mainly because of deficiencies in project design and the time it took to correct and adapt to the terrain. For example, the intake position (especially the angle in regard to the river) was changed. They also reduced about 200 m of main canal because the soil conditions would not provide adequate stability. To implement these changes, the company had to wait for the supervisor's approval, and the supervisor could not authorise them without the approval of upper FDC management. Meanwhile, time ran on, and final delivery of the works to the community was further delayed past the deadline.

The building company applied for change orders to extend the canal rather than protect the facilities with gabions, at users' request. They also asked to relocate the canal in block 3, which increased the initial total cost, and applied for four extensions in the deadline, which were approved by the FDC, especially because users stopped participating because the building company did not pay its debts, arguing that the funding entity had not disbursed agreed payments to them. One conflict between some users and the building company was over non-payment for unskilled labour hired by the company. This situation created ill feeling and mistrust of the building company, dividing the organisation, because members of the Irrigation Committee signed the authorisation for final delivery without all users consensus. Users who were owed money did not want to receive the project until the company paid them for their work.

PRONAR Tarija

PRONAR negotiated the project package with the IDB, including the Naranjos Margen Izquierdo project. PRONAR was an external inspector and supported the Entre Ríos Sub-Prefecture. PRONAR mainly verified implementation and made suggestions to the company and users.

As in the other cases, an ongoing problem throughout activities was the lack of co-ordination between PRONAR technical staff and the FDC supervisor, because they belonged to different institutions. Consequently, for observations by PRONAR technicians to be considered by the FDC supervisor, they had to go through regular channels, including the FDC National Director. This process prevented direct co-ordination, took too long and often made observations too late.

Rural Development Fund (FDC)

The FDC took responsibility for hiring the building company, project supervisor and support entity, according to current norms and regulations for that type of activities. The FDC was responsible for the disbursement schedule, but failed to pay on time. This forced the building company to pay its own staff late, and they had to quit because they had not been paid.

Supervisor

The FDC supervisor authorised all changes in orders suggested by the community or building company. He authorised changes in intake location and extension of the main canal instead of building gabions to protect the critical sections. The supervisor also approved applications to extend the deadline, as requested by the building company.

Time between visits by the supervisor ranged from 7 to 21 days, more often at the beginning. This prevented the supervisor from requiring quality standard compliance in concrete work. So, test pieces were extracted to analyse the consistency of the concrete casting and breakage test certificates were done partly by the building company. The assigned supervisor had to oversee different projects, in different places, which prevented him from being present more continually at the work site. During an interview, the Supervisor stated: *"Theoretically, the "closed" supervision contract established two months intervention up to final delivery of the work. However, since the implementation schedule ran behind, it took eight months, during which the supervisor ought to stay on site, without any additional pay for this work".*

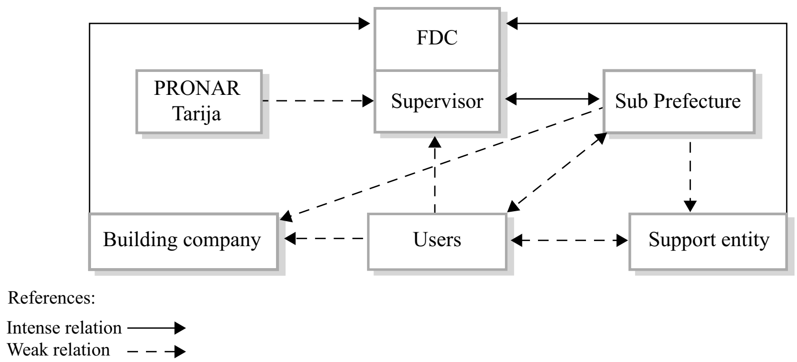
The supervisor suggested that the supervision contract should be prior to implementing the project to provide time to review the final project design on site, considering possible changes that might arise, before starting to build.

Support Entity

The support entity was hired by FDC through a public bid and started working on the system late, because the funding entity (FDC) was late signing the contract. The persons interviewed from the support entity stated that they could not accurately define the areas to irrigate, because families with greater land area tried to be authorities in the irrigators' organisation in order that the local norms would favour their interests (to irrigate more area) without working in the building of the infrastructure.

They also stated that their intervention was too brief, suggesting that the support entity should intervene at least two or three months prior to beginning the work. This would enable them to explain more clearly to users, well in advance, how the project would go and foresee possible technical problems and make any necessary adjustments in co-ordination with the supervisor. In this way, the building company would not "waste time" redesigning the project. This, by the way, is one of the excuses normally used to justify delay in implementation. PRONAR could not do anything about this problem because FDC was the institution that hired the services of the building company and the support entity. PRONAR was not an important actor during project implementation, although it helped supply funds.

Figure 5.4 Relationship among actors



So, in the inter-relationships among the various outside stakeholders, they acted unilaterally throughout the process, with very little co-ordination, thereby preventing users from learning or displaying any local skills, particularly for irrigation infrastructure maintenance. This was mainly because each external player acted mechanically in regard to their formal commitments, as service providers. There was no analysis or consideration of users as protagonists in the system, and they were taken into account only as labour, rather than as future system managers.

5.5 APPROPRIATENESS OF THE INFRASTRUCTURE TO MANAGEMENT CAPABILITY

Taking into account that the ultimate outcome of the intervention regarding appropriateness of infrastructure to management capability results from the conditions of how the intervention process has happened, it is necessary to analyse some aspects that have been decisive in this process, outlined below.

In this case, as in the previous ones, it is evident that the project concept for the intervention was in "fragmented stages". That is, improved irrigation was the result of combining different phases, each with a beginning and ending, and a particular way of understanding the *part* of the project that each outside player must perform. There was no linking between phases, no sequence or continuity in the project process, and this was decisive in the poor performance of the process, from its conception through final delivery of work. Consequently, design was arbitrarily changed during the building stage by other parties and by users, without involving those who did or supervised the final design study. This had repercussions, in this case, for the project's sustainability. For example, to make the lined canal longer as users wanted, the protection facilities were left out, leaving the project exposed to flood waters, with a high risk of being damaged or ruined.

Another aspect of the infrastructure's appropriateness to management capability was when the system was "delivered" to the farmers. The engineers' only concern was to verify the physical status of the work. There was never any question of operation or users' requirements for the project to work properly. Only one element of the system (the infrastructure) concerned them, without any reference to water management. For example, the infrastructure's adaptability to management capability was never analysed. The engineers' commitment should be to deliver an improved system that passes the "hydraulic test" and the "management test".

5.5.1 Operational appropriateness of infrastructure to management capability

The organisational appropriateness of infrastructure to management capability refers to the irrigator organisation's possibilities to meet the requirements of distributing, operating and maintaining the irrigation infrastructure. In this case, operating the infrastructure that has been constructed is simple, concentrated on opening and closing gates (although, since they are badly made, they are hard to operate).

With the new infrastructure, users do not need to do any activity regarding reconstruction of the intake, as they used to do when there was a rustic intake. But, the fact that the facilities are at high risk of damage by river flooding and mountainside landslides makes maintenance demands high. Users need to invest the same labour to clean sediments in the canal as they used to do. Also, since the support entity did not do its work properly, users were not trained in the requirements for the kind of facilities constructed. For example, users were not shown how to maintain the siphon valve, how to maintain the gates or how to fix problems occurring with the concrete. This situation is caused in part by the same users, but the consequence is that this reduces users' management capability and jeopardises system sustainability.

The siphon is one of the facilities that presented the greatest difficulty, because it did not have a surge chamber or a silt trap that would enable it to operate automatically. Siphons normally operate automatically, but as this facility is not complete, it requires someone's presence to continually clean out the entrance. This means that works that have problems in design or construction require complementary operating activities, which increases the work of the users unnecessarily. As the siphon is incompletely built, a new operating task has been created, "flow control". If this activity is not done, users downstream from the siphon could not receive their water, because the siphon would not let the water through properly, which would affect the irrigation system's equity criterion. This design deficiency prevents the system from optimally meeting the requirements of materialising rights, by interfering with water distribution.

This case shows, as in the previous ones, that the maintenance issue was not regarded fully by engineers, either in design or in implementation. It is not enough to discuss with users about fees or activities that users should do. The process was inadequate, not only from the standpoint of training in how maintenance "should be done", but also because there was no analysis of the economic demands to maintain the improved irrigation facility. The case shows that during the support phase, operating and maintenance manuals are not enough to cover these needs. In practice, the manual has not contributed to generating user management capability. This proves that, instead of spending effort to write a manual, activities should concentrate on meetings for joint analysis between users and engineers regarding the requirements for each facility, even before building them. In this way, if the requirements surpass users' capacities, other technical alternatives could be devised in time. This is not new. The debate on this issue in Bolivia was present in 1990, but, certainly, due to the lack of a methodological proposal specifying what the support entity should do concretely, the same problem continues.

Also, this case – like the others – shows that users do not make agreed economic contributions. This situation should lead engineers to reflect on this aspect and discuss with farmers when they make their technical proposals, to meet the goal of irrigation projects, which state that improved irrigation systems must be "user-managed".

5.5.2 Technical appropriateness of infrastructure to management capability

The case of Naranjos Margen Izquierda illustrates fundamental aspects reducing the infrastructure's technical appropriateness. It is evident that the physical risks decisively affected the requirements upon users, both to operate and to maintain the system. Such effort may be required that users will tend to abandon the facilities. In this case, although the intake is properly located, it lacks defence against flooding (because users preferred to have a longer lined canal), which has already undermined the river guide wall. Users have not yet repaired it.

Moreover, there are gullies in the Salinas River basin that become creeks during the rainy season, filling the river with a sediment mixture of mud, water and large stones. As well as affecting the intake structure, they also affect the canals built on the riverbanks. Normally, canals tend to fill with this sediment load, demanding heavy labour investments by users.

In addition to floodwaters endangering the system, landslides from mountain slopes tend to fill up the canals. This case shows that a genuine response is not being made from an engineering standpoint to meet users' needs. Some other alternative could have been chosen, such as piping, including inspection chambers to clean out obstructions. That would have increased the project's investment cost, but it would prevent the canal from being ruined and abandoned because cleaning sediments all the time makes it unsustainable. Another alternative to decrease landslide risks would be complementary work to manage the slopes, e.g. planting vegetation or digging crown ditches to reduce soil erosion. But these activities were not contemplated in the project. The problem was the criteria for project eligibility: the indicators limited the investments for protection works.

Finally, there is the issue of quality. This is closely related to a project's duration or lifetime. If built of good material, it will need less upkeep. Quality is a determining factor, with repercussions on maintenance costs. Moreover, poor quality construction can even lead to the destruction or abandonment of the facility. In this case, the gates are bad enough quality that they may be lost or abandoned. Users do not know how to maintain them, or to repair them by themselves or hire third parties. Nor do they have the money to be able to afford maintenance, when the gates are all such bad quality that they will be expensive to repair. Even if users had money, it is not acceptable to repair facilities that are relatively new.

The engineers involved in the project, especially supervisors, are responsible for the quality of work. Unfortunately, no matter how hard users try to oversee quality of work, their knowledge is not sufficient to inspect thoroughly. Users say that the best that they can verify is the quality of the concrete mix, because of their experience as brick-masons. This means that, during construction, the supervisor must assume responsibility with authority, to enforce the technical specifications, along with the building company. Users should also be trained to demand quality in all work. This knowledge would also help them take over maintenance tasks.

5.5.3 Productive appropriateness of infrastructure in relation to management capability

One of the main requirements to maintain the improved infrastructure is cash payment of dues by users. Consequently, with input from the support entity, users have agreed to pay a certain amount of money. However, this contribution is not being paid, so it will be useful to analyse users' income with the new infrastructure and economic demands for maintenance.

Annual maintenance costs of the Naranjos Margen Izquierdo system have been calculated at US$2783/year (see Table 5.16), but include inputs and labour. The differentiated rights give three cases: 18 families should contribute about US$ 111/year, 13 families should contribute US$ 56/year and two families should contribute US$ 28/year. Considering only the cash inputs, the annual maintenance cost is US$ 369; this means that 18 families should contribute about US$ 15/year, 13 families should contribute US$ 7.50/year and two families should contribute US$ 4/year.

Analysing families' income after the system improvement, the 18 with double turns have an annual income of US$4200, 13 with a single turn make US$2100 a year, and the two with half a turn make about US$1050/year (see Table 5.4). To learn more about this topic, a comparison was made between the income generated by irrigated agriculture in 2001 and the budget that a family needs to live in this area. According to the Bolivian Statistics Institute (INE 2002), average household spending in the valley was US$115.50 a month, making US$1386/year. In the first, subtracting the maintenance fee from annual earnings, the new income evidently can cover the average expenses for a family to make a living, plus the maintenance fee. In the second case, the same applies. Only in the third case are users' earnings too low to cover a family's average cost of living.

Knowing that families have more livelihood strategies in order to generate more income, it can be deduced that more of them are able to pay the fees. Although estimates would indicate that users can afford their maintenance fees, payment has been only partial. The first stretch of canal in this system is vulnerable to flooding damage. Even so, users have not contributed to build protective measures (The organisation is seeking outside funding for this work).

The fact that they do not pay maintenance fees, even though they could afford to do so, would lead one to think that users are unwilling to invest their income in communal projects, preferring to spend on personal or family efforts, such as children's schooling. Users say that they do not have money and they avoid talking about this issue. Apparently, users in this case have the idea that communal facilities such as an irrigation system must be built and maintained by the State or other institutions. It is also possible that the users of this system feel less responsibility for communal facilities because of past and present intervention style, in which they have been given no significant responsibility for design or construction, or any respect for their creative capacity. This situation undermines sustainability, since it is well known that the State will not undertake maintenance activities or irrigation system management.

To conclude this chapter, this case demonstrates the serious challenges to improve some irrigation systems. The lack of adequate infrastructure keeps villagers from using available water and thereby enhancing their economic income. However, new infrastructure entails new requirements for users to operate and maintain it sustainably. In this case, and in the others, operating requirements are generally not complicated and users can fulfil them. However, if the facility does not work right due to some design or construction problem, it will require additional work to keep it working. This is the case of the siphon. Although this is extra work, they do it.

The main problem now lies in covering maintenance requirements. Users, in order to obtain the facilities, agreed with everything that the support entity engineers said: to do routine and preventive maintenance and even to pay maintenance fees. Since users said that they were in agreement with these proposals, the support entity engineers devoted their time to preparing operating and maintenance manuals and by-laws and regulations. As the case study shows, these documents reflected only how the improved irrigation system "ought to be" managed, in terms of operation, maintenance, organisation and conflict resolution, but in practice were simply not followed.

This case shows that the support entity should ask whether users can comply with "what ought to be". To do so, requires a "management test", along with the hydraulic testing, before turning the system over to users. This will be the only way to be sure that there is relevant management capability.

Table 5.16 Annual maintenance costs

Activity	Frequency	Cost of materials and inputs (US$)					Cost of labour			Total (US$)
		Item	Unit	Unit price	QTY	Total	Nº days	Unit price	Total	
INTAKE										
Intake inspection	2times/year	Pen and notebook	PI	0.27	1.00	0.27	0.40	3.94	1.58	**1.85**
Intake repair and maintenance	Annual	Cement	Sack	4.73	7.00	33.11	15.00	3.94	59.10	
		Stones	m^3	4.00	2.20	8.80				
		Sand	m^3	4.00	1.40	5.60				
		Tools	PI	10.00	1.00	10.00				
						57.51			**59.10**	**116.61**
Operation monitoring	Monthly						24.00	3.94	**94.56**	**94.56**
Intake cleaning	4times/year	Shovels		0.06	24.00	**1.44**	132.00	3.94	**520.08**	**521.52**
Subtotal 1						**59.22**	**171.40**		**675.32**	**734.54**
MAIN AND CONVEYANCE CANAL										
Reviewing the canal	2times/year						1.60	3.94	**6.30**	**6.30**
Weed and brush control	2times/year	Pickaxes	PI	0.03	10.00	0.30				
		Shovels	PI	0.03	23.00	0.69				
		*Machetes**	PI	0.03	33.00	0.99				
						1.98	66.00	3.94	**260.04**	**262.02**
Canal cleaning	4times/year	Shovels	PI	0.10	33.00	**3.30**	264.00	3.94	**1,040.16**	**1,043.46**
Canal repair and maintenance	Annual	Cement	Sack	4.73	27.00	127.71	54.00	3.94	212.76	
		Stones	m^3	7.92	8.40	66.53				
		Sand	m^3	5.04	5.40	27.22				
						224.45			**212.76**	**434.21**
Remarking stations	Annual	Paint	PI	1.50	2.00	3.00				
		Brush 2.5”		0.50	1.00	0.50				
		Wire brush		2.00	1.00	2.00				
						5.50	3.00	3.94	**11.82**	**17.32**
Patching	1 time/year	Cement	Sack	4.73	4.00	18.92				
		Tar	Kg	1.00	10.00	10.00				
						28.92	20.00	3.94	**78.80**	**107.72**
Subtotal 2						**261.15**	**408.60**		**1,609.88**	**1,871.04**
CHAMBERS AND SIPHON										
Chamber and siphon review	3times/year						0.99	3.94	3.90	**3.90**
Chamber and siphon cleaning	3times/year	Shovels	PI	0.03	4.00	0.12				
		Mattocks	PI	0.03	4.00	0.12				
		Unplugger	PI	0.02	5.00	0.10				
						0.34	15.00	3.94	**59.10**	**59.44**
Gate maintenance	Annual	Anti-rust paint	l	2.00	2.00	4.00				
		Brush	PI	0.50	1.00	0.50				
		Sandpaper	m	1.00	2.00	2.00				
						6.50	1.00	3.94	**3.94**	**10.44**
Cleaning valve handling	4times/year						0.80	3.94	**3.15**	**3.15**
Subtotal 3						**6.84**	**17.79**	**3.94**	**70.09**	**76.93**
CANAL BRIDGE										
Patching	2times/year	Cement	Sack	4.73	8.00	37.84				
		Tar	Kg	1.00	4.00	4.00				
						41.84	15.00	3.94	**59.10**	**100.94**
Subtotal 4						**41.84**	**15.00**		**59.10**	**100.94**
TOTAL						**369.05**	**612.79**		**2,414.39**	**2,783.45**

*Big Knives PI: per item Source: Field infrastructure inventory

6 DESIGNING THE PRESENT AND BUILDING THE FUTURE: THE CAIGUA SYSTEM

INTRODUCTION

This case study was chosen because it is located in the Chaco, another important agro ecological zone of the country. Irrigated agriculture in the Chaco is new and with good results. Lately, there have been investments by the State to build and to improve irrigation systems in this area. Immigration from the West of Bolivia (Potosí and Chuquisaca) to the Chaco area of Tarija has influenced the production systems of Chaco population groups, who used to just raise cattle. One of these migratory experiences happened in Caigua, the last case study. This community is in the municipality of Villamontes, province of Gran Chaco, department of Tarija. Its average annual temperature is 23.8ºC, with a total annual precipitation of 1164 mm. This area features alluvial terraces, and piedmont geography with sloping hillsides and plains.

Agriculture and cattle-raising activities are the most important elements of the community's productive economy. Agriculture is diversified and intensive, mainly during summer. One of the main innovations was to introduce irrigated agriculture. Agricultural work is mainly done by immigrants from other regions. While this area receives temporary in-migration, there is also temporary outward migration, mainly by heads of household, who leave because water becomes so scarce during the winter.

The people living in and around Caigua feature an interesting mixture of cultural elements, related to the eastern part of Bolivia and to the Chaco region of Tarija. People in Caigua combine these lifestyles, and they practise specific dances and festivities as part of their traditions. They combine cultural practices from the valleys of Cochabamba, Chuquisaca and Potosí (e.g. cutting children's hair at a given age, with a special party) and from the Chaco (e.g. the chacarera dance from Tarija and Argentina). Someone who has not been to the Chaco would imagine that visitors to Caigua will find ranchers on horseback, wearing leather clothing, and a cowboy hat, but this is not the case, because of the great influence from western Bolivia. They have changed from ranching to farming, and are now irrigating their crops. As well as there are immigrants in this area, there are also native peoples, organised in the indigenous Assembly of the Guaraní people. The Tobas, another ethnic group in the region, and the Weenhayeks, all enrich this cultural mosaic, each with their own cultural expressions.

Until recently, this zone was mainly used for cattle ranching, with large areas for free grazing. The farmer immigrants introduced cultivated production into this area, as mentioned above. For this purpose, they have used the Caigua river to irrigate. At the beginning, some 25 years ago, the different families used their own rustic intakes and dirt canals, depending on their location. Therefore, many intakes are named after the owners of the fields at that time. Gradually, the number of families settling in the community grew, and water availability became an issue.

Caigua river flooding would permanently block family intakes and make them unusable. There were also disagreements among intake users, because there were no distribution agreements at that time. Accordingly, different user groups decided to join forces and form an Agrarian Syndicate[1]. Later, in this same organisational structure they decided to appoint a Water Judge, to co-ordinate irrigation water distribution with each intake group leader.

There were eight rustic intakes, located on the right and left bank of the Caigua river, namely: 1. Santa Rosa (40 users), 2. Montaño (19 users), 3. Delino – Colque (7 users), 4. Tórrez (4 users), 5. Del Bajo (36 users), 6. Grande (32 users), 7. Don Pepe (6 users) and 8. Tolay (3 users). Because of the difficulties in diverting and conducting water to their fields, with rustic infrastructure that was always being destroyed by floodwaters, users from the different intakes decided in 1992 to seek financing to improve their irrigation system. For three years, they applied to different institutions, until finally in 1995 they obtained IDB - PRONAR funding for pre-investment studies.

To improve the existing irrigation system infrastructure, engineers hired as consultants by PRONAR prepared two irrigation projects, from a single intake[2]. The first project, called “Caigua”, joined intakes 1 through 4. The second, “Acequia Grande”, joined intakes 5 through 8. This case study focuses on the former. Once the Caigua irrigation system had been renovated, water availability more than doubled, enabling them to expand irrigated area from 60 to 155 ha, making it possible to introduce new crops for market and self-supply.

The social, cultural, and economic peculiarities of Caigua influenced this intervention process, and will be described, followed by the project’s construction, and then the current agricultural production situation (post-intervention).Then follows a description of water management prior to the intervention, and the project’s water management proposal. To show results obtained by the project, the intervention process is described, identifying the parties, roles and their different proposals. All these elements are used as inputs to analyse the infrastructure’s appropriateness to management capability.

6.1 THE IRRIGATION INFRASTRUCTURE

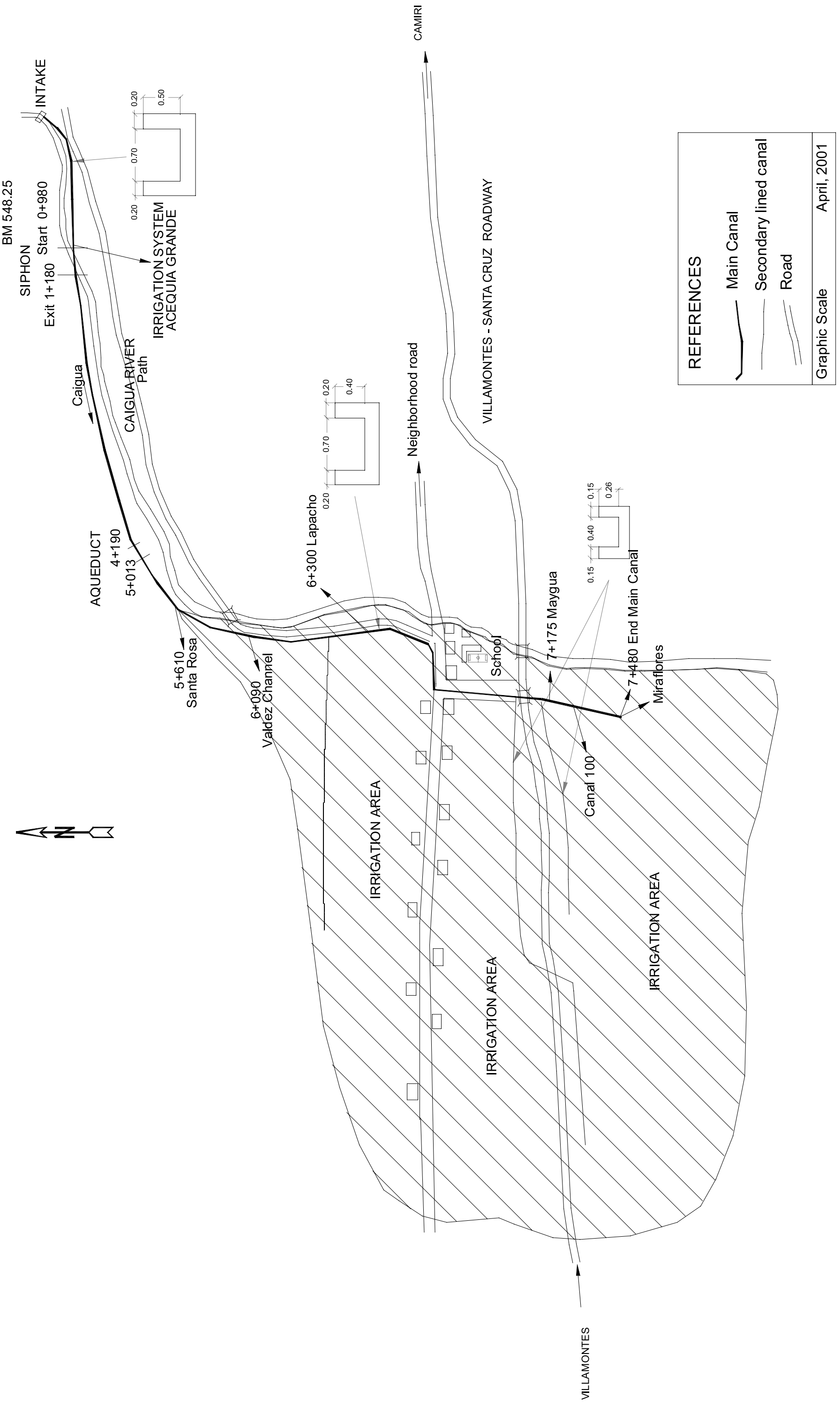
As indicated, prior to the intervention there were several rustic intakes to tap water from the Caigua river, which was conducted through dirt ditches. This section describes infrastructure inventoried in a field visit in 2001.

The new intake is common for two irrigation systems: Caigua located on the right riverbank and Acequia Grande located on the left riverbank. Both systems use the waters in a rotation with the whole flow: 3.5 days to Caigua and 3.5 days to Acequia Grande. Inside Caigua’s system the water is distributed in rotation with the whole flow through distribution points located in the canal. Each user receives the water by turn in dry season and by free demand in rainy season.

1 To establish and enforce water use agreements regarding the different intakes they formed the Caigua agrarian syndicate, which gave rise to the Caigua community.

8 For budgetary reasons, it was not possible to put all the intakes together in a single project, since the maximum investment per irrigation system, under project eligibility indicators, was set at a ceiling of US$350,000.

Figure 6.1 Map of the Caigua irrigation system



Intake

The new intake is located on the Caigua river, at a narrow stretch (22 m wide) over an alluvial deposit averaging 4 m thick. This structure is a derivation dam-type intake and is protected by a cut-off wall. The river wall on the left bank has a rectangular hole measuring 1.0 x 0.80 m, with a grating. The capacity of the intake is 200 l/s. The intake structure is located exactly after a curve. The entry orifice into the main canal is on the left bank and, since the orifice is located in the concave part of the curve, there is heavy deposition of waterborne material during the rainy season, removal of which is partly solved by the cleaning hole. The weir is 14.80 m long and has a cleaning hole 0.40 m wide, to remove these deposits from the intake.

Conveyance canal

The canal runs from the intake outlet, which is at survey station 0+000 to 0+980. Its cross-section is 0.70 m wide by 0.50 m high and 0.20 m thick. It is made of cyclopean concrete and has the capacity to convey 200 l/s. It is located on the left bank of the Caigua River. The first stretch of this canal (80 m long) is exposed to floodwaters. To solve this problem and prevent sediments eroded from the hillsides from entering the canal, it is covered with reinforced concrete lids. The covers are a solution to prevent landslides from filling the canal. They are not a solution for flooding, since they lift right off when the river rises: this is a common situation in Bolivia.

Main canal

This canal begins at station 0+980, where a siphon starts to cross the Caigua river from the left to the right bank, and continues to station 1+180, where the siphon ends. From there on, an open rectangular canal continues, with the same shape and size as the conveyance anal, down to station 7+480. Along this canal, there are the following distribution points. The distribution point gates are poor quality, mainly because of their fragile threads, which makes it difficult to deliver water.

Table 6.1 Location of distribution points

Distribution points	Survey Stations
Santa Rosa	5+610
Canal Valdez	6+090
Lapacho	6+300
Maygua	7+175
Canal 100	7+300
Miraflores	7+480

The gates are sliding type. The main canal runs mostly across a slope. During the rainy season, there is direct runoff from the steep hillsides, bearing eroded material, which clogs the canal. The canal is in good condition and well-built. Some stretches are no longer bermed, because users, each time they clean out the canal, deposit the sediments along the edge of the canal.

Silt trap

The silt trap is located at station 0+240, and its practical design works simply. Its transition is 4.0 m long and then there is a settling chamber 13 m long, ending with the outlet transition 4.0 m long. It has a cleaning gate and by-pass. The gate has operating problems, which affects this structure's operation overall.

Siphon

At station 0+980 is the siphon, which does not have a surge chamber, so it is quite readily clogged. On inspection (October 2001) a pile of leaves was found. Moreover, the sector is prone to landslides. Additionally, the purge chamber is poorly built, totally underwater, which corrodes the valves and other metal parts.

Aqueduct

The aqueduct is located at station 4+090, which overcomes a major topographical feature (gully). It is very good quality and works adequately. It has two middle columns for support and is 22.5 m long.

6.2 THE AGRICULTURAL PRODUCTION SYSTEM UNDER IRRIGATION

Agriculture in Caigua is diversified and intensive. Maize predominates in summer and different species of vegetables in autumn. There are also plenty of fruits, including citrus and grapes.

Water availability and families' irrigation turns are determining factors for crop diversification. The more water they have, the more they plant on much larger fields. Arable land is not really a limiting factor for this community (range of farm size is three to six ha). On the contrary, land is the most abundant resource. However, due to the scarcity of water, much land is unused, especially between July and October. During winter, 80% of arable land is left fallow because of the scarcity of irrigation water. When the rains begin, nearly 50% of this area is brought into production, mainly to grow maize. However, during the rainy season maize requires irrigation, because there are periods without precipitation (*veranillos*[3]). The rest of the land is prepared for autumn planting, especially vegetables grown with supplementary irrigation.

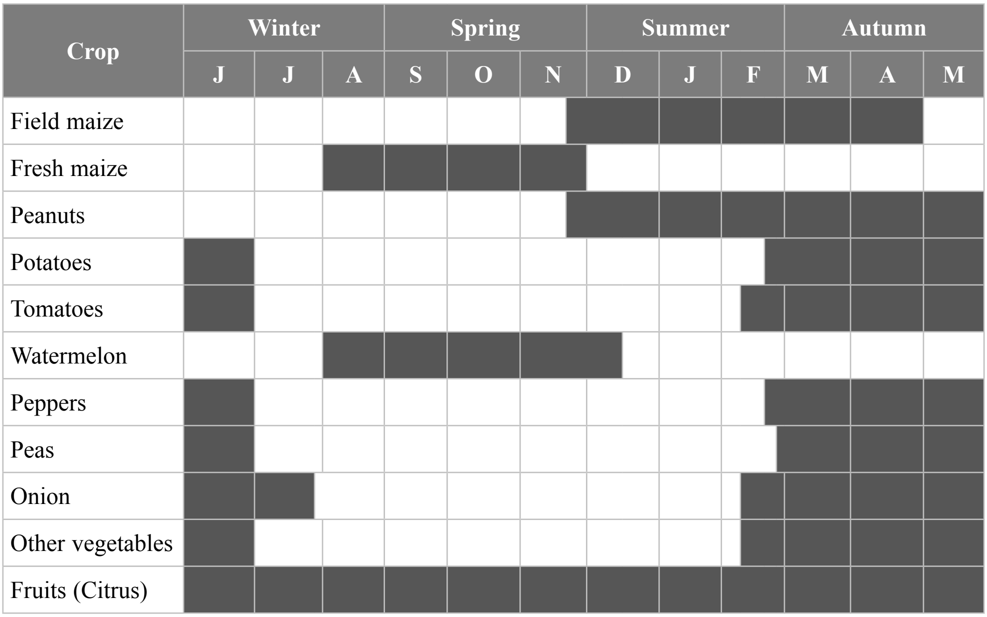
In Caigua, maize is considered the zone's most important traditional crop, and is planted right in the rainy season. Tomato and potato harvests coincide with the time when prices are most attractive in almost all markets, due to low production volumes in other regions, because of the adverse climatic effects of winter weather. The agricultural calendar for growing in the irrigation system is as shown in Figure 6.2. The figure shows that agricultural activities happen all year round, due to the very warm climate and agro-ecological characteristics of the Chaco plains. However, as already mentioned, the greatest limiting factor, especially during winter, is the marked water deficit, which leads to planting only relatively drought-tolerant crops, on only 20% of available area.

Vegetables are planted in autumn, and are economically the most important crops for farming families in Caigua. In this case, 80% are planted by immigrant families, mostly quite poor.

3 During the rainy season, there are dry spells, called veranillos.

Immigrant families come from the valleys of Tarija, Chuquisaca Chaco (Monteagudo) and Chuquisaca in general. Most of these families migrate temporarily between February and September to work as day labourers. After harvest, they return home untill the next year. Many immigrant families have plenty of experience in irrigated farming and have contributed greatly to the community's adoption of irrigation practices and introduction of new crops under irrigation. Other forms of work, such as the "*Ayni"* or "*Minka*", typical of the Andean region, are also common in this zone. Mainly the immigrant families co-operate in solidarity and reciprocity with each other.

Figure 6.2 Current agricultural calendar for crops.



Source: Information from fieldwork (2001)

Crops are mainly for self-supply and for local and departmental markets. Field corn is mainly for self-supply and animal feed (hogs, poultry). By contrast, fresh maize and vegetables in general are mainly for market. These products are commonly sold at the local market (Villamontes) and regional markets in the cities of Tarija, Camiri and Yacuiba. Other potential markets include the city of Santa Cruz and even some cities in northern Argentina, not only for vegetables, but also for citrus fruits, such as grapefruit, which is highly prized there.

Vegetable growing in Caigua during autumn offers comparative advantages and market opportunities compared to other farming regions in Bolivia. This is due to seasonal production and to climatic factors during winter. In fact, an opinion survey among businesspersons in Caigua shows that there is high demand for produce early in the winter and prices are high, especially in the cities of Tarija and Santa Cruz. Production volumes in Caigua are rather small, compared to the huge demand of these markets. However, the marketing system, with high prices, always yields better profits for businesspersons rather than for growers.

Within the irrigated zone, livestock raising complements farming, on a small scale, mainly with cattle, ranging from 5 to 20 head per family. They also have smaller stock (hogs, goats, sheep and poultry) of enormous socio-economic value. The basis for the cattle's fodder and to feed the other animals as well is the native brush on the hillsides. Leftover crop stubble after harvest, especially maize stalks is also used as forage. To feed the smaller stock (hogs, poultry) they mainly use by-products of crops, especially maize.

Net water availability in the irrigation system has increased from 87,150 m^3 to 323,700 m^3 [4] per year. The greater water supply made changes possible in the production scenario. There was less diversification in the pre-project situation, mainly maize, potatoes, peanuts and fruits. In 2001, the agricultural orientation remained, but a greater diversity of crops was evident, especially vegetables and others for market (see table 6.2). Also with the greater water availability, the area under irrigation has increased from 60 ha to 155 ha, as shown below:

Table 6.2 Area under irrigation with and without the project (ha)

Crops	Summer		Winter	
	Pre-project	November 2001	Pre-project	November 2001
Field maize	24,0	51,0	0,00	0,0
Fresh maize	0,0	0,0	4,00	10,0
Peanuts	8,0	6,0	0,00	0,0
Tomatoes	2,0	21,0	0,00	0,0
Watermelon	0,0	0,0	1,00	4,0
Peppers	1,0	6,0	0,00	0,0
Peas	2,0	5,5	0,00	0,0
Onion	0,0	9,0	0,00	0,0
Other vegetables	0,0	11,5	0,00	0,0
Fruits(Citrus)	8,0	8,0	(8,00)	(8,0)
Total under irrigation	55.0	141.0	5.0	14.0

Source: Evaluation of the Caigua system. National Irrigation Program 2001

Yields have increased slightly. This was foreseeable to some degree, since the production technology and inputs and seeds used remain traditional. Risk is the only factor that has reduced, enabling farmers to obtain guaranteed harvests rather than increased crop yields.

Net average income from agricultural production under irrigation

Income in the irrigation zone after project (in 2001) is calculated below:

4 These amounts were obtained by estimating the pre-project water balance and water use, 2001.

Table 6.3 Income from agricultural production

Crop	Net Value of Production (US$) Post project					Net Value US$
	ha	Cost/ha	Total cost	Income/ ha	Total Income	
Field maize	51.00	383.78	19,572.53	733.00	37,383.00	17,810.48
Fresh maize	10.00	392.38	3,923.75	771.00	7,710.00	3,786.25
Peanuts	6.00	495.58	2,973.45	720.00	4,320.00	1,346.55
Potatoes	23.00	1,090.05	25,071.15	1.820.00	41,860.00	16,788.85
Tomatoes	21.00	894.40	18,782.40	1.536.00	32,256.00	13,473.60
Watermelon	4.00	417.10	1,668.40	825.00	3,300.00	1,631.60
Peppers	6.00	539.65	3,237.90	986.00	5,916.00	2,678.10
Peas	5.50	535.35	2,944.43	924.00	5,082.00	2,137.58
Onion	9.00	687.57	6,188.13	1.380.00	12,420.00	6,231.87
Fruits (Citrus)	8.00	389.15	3,113.20	1.650.00	13,200.00	10,086.80
Other vegetables	11.50	703.70	8,092.49	1.416.00	16,284.00	8,191.51
Total	**155.00**		**87,475.33**		**163,447.00**	**75,971.67**

Source: Evaluation of the Caigua system. National Irrigation Program 2001

This information would indicate that average household income has increased from US$322/year/family[5] before the project to US$904/year/family[6] with the project. The current average income per irrigated hectare is US$490[7].

6.3 WATER MANAGEMENT

Water rights

People who were living in Caigua acquired water rights 25 years ago by contributing days worked and cash when they built the intakes and main canals. Scarcity of water at the source and the gradual addition of new users requesting access to the different intakes led them to establish water rights in terms of time even before the intervention.

Users of each intake were entitled to receive water for three hours when water was most available, and this time decreased as water became less available, down to only 1½ hours. The basic requirements to acquire water rights were: to belong to the community organisation, which granted

5 Information obtained from the final design project document.
6 Result of dividing the net amount among the 84 irrigation system user families.
7 Result of dividing the net amount among the 155 ha shown in chart 6-4.

the family water rights, to have land to plant within the irrigated area and to contribute workdays during infrastructure construction. Another common way to acquire water rights was by inheritance, passing land down from parents to children. Offspring who set up their own families would receive a fraction of their parents' land. To acquire water rights, they had to apply to the Agrarian Syndicate; the latter's acceptance gave them the same rights and obligations as any other users.

Having water rights entailed participation in decision-making within the organisation. In turn, this also entailed obligations and the respective penalties for non-observance, for all users, as summarised below:

Table 6.4 Obligations and penalties in force in the Caigua irrigation system before the project

Obligations	Penalties for non-compliance
• Participate in main canal and intake cleaning • Make agreed contributions • Attend regular and emergency meetings • Maintain lateral and sub-lateral canals	• Lose rights for a season • Temporary water cut-off • No penalties are evident • Suspension of water use until they comply

Water judges used to control the obligations and the penalties. Different penalties were generally just threats, and no cash fines were levied in any case. Moreover, a user was asked about penalty enforcement and replied *" ...as far as I can recall, thank God there have been no real problems with non-fulfilment of the obligations set forth. We all know that water, at that time, represented life or death for our existence". (Julio Mendoza ,2000, user)*

Before improving the irrigation system, there were 70 users. By 2001, 84 families had water rights, but the same principles underlying rights, obligations and penalties remain as above.

Water distribution

Before project implementation, there were two distribution modes, one during the rainy season and the other for the dry period. During the rains (December – May) distribution was free upon demand, but the amount at each intake was proportional to the number of users at each. During the rains, water judges oversaw water delivery anyway, especially when there were "*veranillo*" dry spells. At present, rainy-season delivery remains free on demand.

During the dry season, organisation for water distribution was more visible, beginning in May and lasting until November. Water was delivered during this period through 3-hour turns when water was most available, waning to 1½ hours when it was scarcest. Therefore, timing was not fixed, but flexible according to the river's flow, ranging from 10 to 20 l/s. For this purpose, water judges at each intake would receive applications from users interested in irrigating their fields. Each water judge was responsible for making up the distribution list and presenting it at the monthly meeting of all users for their approval.

Since the project, this water distribution mode remains in effect, but applications for different intakes are made to the respective sub-water judges (see Figure 6.3). Each user also receives water for two hours since the project, but with a greater flow rate. Three or four users can irrigate at once, because the flow rate used with the new canal is 80 l/s.

While taking turns, users have agreed that each bank should use the water for 3.5 days. Internally, each bank has decided how to distribute to each intake. After project intervention, this agreement remains in effect. The Caigua system receives water for 3.5 days and the Acequia Grande system for the 3.5 days to complete the week, so each user gets water every seven days. Construction of the shared intake has not changed this distribution arrangement, which remains the same as before, except that they receive more water after intervention project.

Organisation

The organisation grouping all users belonging to the different intake groups was the Agrarian Syndicate, now called a Local Grassroots Organisation (OTB). Before the project, water judge positions were part of the syndicate organisation board. These authorities were appointed for each intake from a three-person list suggested at meetings scheduled for canal cleaning. The election would be by consensus or direct vote. These positions could be held by women, who also had voting and speaking rights just as their husbands did. Duties lasted one calendar year, but depended on efficient performance for all users. Otherwise, they would immediately be replaced. Authorities who showed capacity and leadership in improving infrastructure would be re-elected for another term.

Other qualities that water judges had to demonstrate to be elected were honesty, fair decision-making, reliability and capacity to organise operation and maintain the system. Water judge activities especially involved equitable water distribution among the various intakes and avoiding infrastructure deterioration as far as possible. Asked about benefits for water judges, interviewees said that *“They would get an additional half to one complete irrigation turn, depending on the amount of water in the river”*. Moreover, occupying this position meant serving the community, and everyone was obliged to do so at some time in their lives.

In the organisation, users determined some control mechanisms to enforce internal agreements, through their internal regulations. For example, missing meetings would be penalised by one day’s work, to be paid in labour or the payment of one day’s wages. If a person did not clean the canal, they would also not be entitled to water during that season. There is currently an irrigation committee, as a result of the project intervention (see 6.3.1).

Maintenance

Before the intervention, intakes were built of stones, sod, clay and branches. Therefore, high water levels would usually damage intakes and main canals. They would often be blocked, forcing users to maintain them constantly to keep the system working.

The two periods of greatest activity were: 1. in December and January, when there was and still is a high risk of “*veranillo*” dry spells. For this reason, canals had to be well maintained to be used even during the rainy season; and 2. in May and June. Water judges were responsible for organising maintenance work. Some 70 users would take part (those with water rights at the time). Each would work independently in their corresponding group, intake and canals. Whenever flooding would affect the intakes and main canals, water judges would call their users for repair work. Each had to work on a given stretch, alternating until the canal was finished. The unit for distributing maintenance work was called a “*suyo*”, equivalent to 5 m of canal. Users said that each of them used to work 15 days/year to maintain the infrastructure.

Women were not allowed to take part in maintenance activities, since it was considered that women do not do heavy labour. For this reason, if the head of household was a woman, she would have to send a hired hand. Secondary canal maintenance was each family's responsibility and all family members would take part. In 2001, maintenance activities were limited to cleaning, but do not match the new infrastructure's requirements. Users had not made any economic contributions to cover the new infrastructure's maintenance needs.

Table 6.5 summarises irrigation water management characteristics before the project intervention.

6.3.1 Irrigation project proposal regarding future management

As in the preceding cases, there are two points when the project addressed water management issues: the pre-investment stage and the investment or support stage. In this case, like the others, different engineers prepared the pre-investment study from those providing support later. The engineers providing support were also different from those who built the irrigation infrastructure. The irrigation project proposal regarding future management is presented in Table 6.6 and in the following paragraphs.

Pre-investment stage

The pre-investment stage was done by consultants hired by PRONAR and unlike other cases (in community members' opinion) actively involved users[8]. They stated that: *There was ongoing dialogue with the engineers while they were preparing the project. They came to our meetings with their maps to explain how they were thinking of improving the canal. We would tell them whether we agreed or not and the project came together step by step. We have had to work hard to finish the work* (Felicindo Tolay, user, october 2001).

8 Although there was participation during project preparation, this does not mean that there was "participatory" construction as well during the project implementation stage, since the engineers who did the building and those who provided user support were different.

Table 6.5 Caigua irrigation management analysis I - Before project

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision at a union meeting to define water rights, obtained by contributing workdays to build the irrigation infrastructure.	Decision at a union meeting to: 1. Begin delivering water by turns and freely upon demand. 2. During the dry season, delivery by rotation with main canal single flow, which is subdivided to 3 or 4 users; and during the rainy season, a flow proportional to the number of users at each intake. Elect the water judge and sub-judges annually.	Decision at a union meeting to contribute workdays to rebuild the intake and clean canals, regardless of the variety of rights.	Decisions at a union meeting to establish penalties for failure to comply with norms and obligations.	Decision at community meeting to organise activities involving construction and permanent reconstruction of the intake and conveyancen canal.
	Activities involving keeping track of days actually worked.	Activities involving preparing the roster of shifts for each intake and delivering water proportionally to each intake during free use period.	Activities involving organising, rebuilding the intake and cleaning silt out of canals.	Activities involving establishing and overseeing compliance with norms and obligations.	Activities involving organisation of construction and reconstruction: work groups, who normally organise emergency work.
Formal rules	Rules involving the implications of having water rights: rights and obligations.	Each judge organizes irrigation shifts at each intake. The roster is prepared monthly and approved at a meeting.	Rules establishing users' obligation to take part in maintenance. Women and children are not allowed to take part in maintenance.	Rules punishing non-fulfilment of norms and agreements.	Rules establishing labour availability. Women are not allowed to work, but must send a male labourer in their place.
Participants and roles	The union oversees days worked and users who contribute workdays.	Water judges who prepare the shift roster during dry season and oversee flow distribution to each intake during free use period. Users, who irrigate.	Water judge to oversee and users' group to reconstruct and clean.	President and water judges to oversee fulfilment and users who do not comply with established rules.	Water judges who organise the work and users with water rights who do the work.
Logi and informal rules	Community supervision approach. Each user keeps track of his/her own and other users' workdays.	Logic of community self-control (equitable and flexible). Delivery by rotation and single flow.	Logic of community self-supervision, contributing work to keep rights.	Different penalties established are generally just threats, without any monetary fines.	Logic of community self-control. Users reconstruct intakes on a routine basis.

Table 6.6 Caigua irrigation management analysis II - Project Proposal

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions and tasks	Decision by the system committee: 1. Contribute 30 workdays to maintain water rights. 2. Keep the same number of users with rights (70).	Decision at irrigation committee to: 1. Begin delivering water by turns and free upon demand. 2. In the dry season, delivery by rotation and in the rainy season, proportional to the number of users in each group. 3. Elect the irrigation committee.	Decision at an irrigation committee meeting to: 1. Perform routine and preventive maintenance activities. 2. Define maintenance fee payment.	Decisions in irrigation committee meeting to establish by-laws and regulations to govern system operation.	Decision at irrigation committee meeting to: 1. Define a community labour contribution equivalent to 20% of the total new infrastructure cost.
	Activities involving oversight of days worked.	Activities related to delivering water in dry and rainy seasons.	Activities involving preventive and routine maintenance	Activities involving oversight of compliance with norms and obligations.	Activities involving organisation and supervision of work.
Formal rules	Rules involving fulfilment of obligations entailed by water rights: obligations and benefits.	Each sub-judge organises users-shifts in each group or branch.	Rules establishing that each user must contribute US$ 6.50 per year for maintenance, and contribute workdays.	Rules penalising failure to fulfil established norms and obligations.	Rules establishing planned work: work schedule, periods, amounts.
Participants and roles	Engineers noting each user's contribution, irrigation committee recording days worked and community members fulfilling their workdays.	President: organises beginning of shifts, water judge co-ordinates distribution, sub-judges oversee each branch's roster of shifts, users irrigate.	President, treasurer and group of users with water rights.	Committee fails to enforce established norms and rules. Users comply with norms.	The construction committee organising the work, engineers directing the work and users working as planned.
Logic and informal rules	Rights are acquired by investing.	Logic of delivering water by rotation and undivided flow.	Logic of monetary investment to guarantee facility sustainability.	Internal conflict resolution, before turning to legal measures.	Logic of community investment to guarantee irrigation system sustainability.

In general, the final design project document shows designers' interest in involving users in decision-making especially in user management of the irrigation system. It states verbatim:" *...this will have to be jointly ratified by users and Implementing Entity technical staff, since system operation is the outgrowth of a social process, based on negotiations among the parties involved". (*Final design document, Caigua project, 1997, page 42). It also mentions that "*due to changes in infrastructure and the management process, it is recommended that any new criterion to be introduced in operation and maintenance be compatible with the participating community's uses, customs and practices, so the system can be readily managed by users".* (Ibid, page 43)

Designers in the pre-investment stage especially considered aspects to be taken into account to design future water management. They emphasised that the time to fine-tune future water management would be the "support stage", with user participation. For this purpose, they recommended that the support entity to hold workshops to define water rights, user contributions, operating and maintenance manuals along with users. Another job for the support entity was to help users maintain and operate the improved system, so they recommended that *"The support entity should train beneficiary farmers in complementary techniques that fit in with their own thinking about irrigation. The process should include practices and skills for using gauges, siphons and distribution points".* (Ibid, page 43). Possible changes in the four elements of user management for the Caigua irrigation system are described below in greater detail.

Distribution

The project document states: "*that water distribution will be substantially changed by introducing new elements, such as construction of a single intake, thereby merging the systems and incorporating new users".* (Ibid., page 44)

"The water taken in by the main intake (200 l/s) will be conveyed along the main canal to the different intake users' delivery points. The flow rate will be distributed according to the users' rights at each intake." (Ibid, page44)

"Caigua micro-irrigation users will respect the 3.5 day irrigation turns. The last person to irrigate will have to open the gate so the water will go over to the other bank of the creek (Acequia Grande system)". (Ibid, page 44)

Finally, the project recommended to set up a Water Committee. For distribution in particular, they stated: "*There will be a water judge to oversee operation and distribution for the entire system".* They also proposed to "*have sub-judges for each branch to oversee water distribution in their respective sectors".* (Ibid, page 45)

Maintenance

Since the new intake and conveyance canal is shared by two systems (Caigua and Acequia Grande), designers recommended for them to do maintenance together. They also proposed for all users to take part in maintenance work.

The main canal was to be maintained by sectors. The users from the first intake would maintain the first stretch of the canal, down to their delivery point, and so on. The project document also stated: *"In the future, eight workdays per hectare irrigated will be required for maintenance. The mode of fees for system maintenance must also be introduced, to purchase construction material. The suggested fee is US$ 4.94 per hectare irrigated, since the operation and maintenance cost is estimated at 1.5% of project investment".* (Ibid, page 46)

They recommended two kinds of maintenance, routine and emergency, involving the following activities: at the **intake,** inspection, repair, review of operation and cleaning the intake canal. At the **main canal**, activities involved review, repair, week and brush removal and canal cleaning.

Organisation

The project proposed the following organisation: *"Because several different intakes are being incorporated into a single system, the users' organisation will change in structure. We propose to organise an institution comprising a System Committee, with representatives from each intake, focusing on operation and maintenance. As of each distribution point, each intake will maintain its own organisation".* (Ibid, page 46)

The final design project document for the improved system also states: *"In all cases, we recommend to maintain traditional organisational characteristics. The position of water judge must be maintained, with all its features".* (Ibid, page 46)

Water rights

The project document says, about water rights: *"Because of changes that will arise in water rights, traditional uses and customs must remain in force, compatibly with norms established".* (Ibid., page 47). Another section of the document says: "*Water rights shall be acquired on the basis of the amount of work that users have to do (new and old users), maintaining their modes of work by land area under irrigation that each owns. They must take into account that the new infrastructure will be superimposed over the existing one, so users will have to reach an agreement to compensate for those who did the work to build the current canals".* (Ibid, page 47)

Support stage

The support entity ONG MTCB, was hired through a public bid: FDC hired them. They began working in the zone during the last stages of implementation, focusing on preparing by-laws and regulations, the operation and maintenance manual, and helping agricultural production. With good climate conditions and water availability users could have more production, so they began to sell their production in markets in other countries like Paraguay and Argentina. At the beginning they used to transport their products in an individual way. However, in 2000 they formed a group in order to have more information about the market prices and the availability of inputs for production. They also asked the Municipality for support for agriculture production in order to introduce new crops and new varieties

The support entity's work is described in greater detail below:

Water rights

The number of users before the project was 70, so the infrastructure was designed, tested and built for that number. After finishing the project, another 14 new users applied to join, and were accepted once they met the following requirements: belonging to the syndicate organisation, writing a letter applying to the irrigation committee, having land within the irrigation area, and paying US$50.

The support entity helped update user rosters to determine each user's actual workday contribution. Water rights were set by community members at continual meetings. They established that each user should contribute a total of 30 workdays to have water rights.

Being a system user involved rights and obligations. Project intervention increased some rights and obligations, pursuant to the by-laws and regulations, as summarised below:

Table 6.7 Summary of users' water access rights and obligations after the project

Rights	Obligations
• To speak and vote at scheduled meetings • To elect and be elected • To use irrigation water • To use and maintain the irrigation system. • To take part in community organisations for marketing products.	• To have fulfilled all workdays calculated for the project • To attend meetings regularly • To pay maintenance fees • To take part in infrastructure maintenance • To take part in community work as decided at meetings

Along with obligations, penalties were decided for each obligation to conserve water rights, as summarised below:

Table 6.8 Obligations and penalties in force at present in the irrigation system

Obligations	Penalties for non-compliance
• To have fulfilled all workdays calculated for the project • To attend meetings regularly • To pay maintenance fees • To take part in infrastructure maintenance • To take part in community work as decided at meetings	• Lose water rights for the season • Admonishments and fines for delay and/or non-fulfilment. Amounts were not set. • Admonishments and loss of rights for the season • Admonishments, notices, and loss of rights for the season • Loss of rights for the season

With the by-laws and internal regulations in effect after the project, penalties are not necessarily monetary, but rather coercive measures to find solutions internally rather than turning to legal authorities. The water judge is responsible for monitoring the fulfilment of the agreements established on rights, obligations and penalties. However, there is flexibility in enforcement.

Water distribution

The support entity respected pre-project thinking and water distribution norms. The water distribution agreement between Caigua and Acequia Grande was maintained, i.e. 3.5 days for one and 3.5 days for the other. On this basis, all that the support entity did was to document and systematise existing local norms regarding distribution that users had already arranged. After intervention in 2001, each user receives water for two hours, without counting the trickling remainder, which is minimal. Water used to take at least five hours to get to the end of the system, but this is now only one hour. Moreover, the flow rate (10 to 20 l/s) reaching each intake would enable no more than two users to water at once, for 3 to 1½ hours. Now, they get two hours, with a flow rate of 20 to 30 l/s per user, and three or four can irrigate at once, since the new canal's flow rate is 80 l/s.

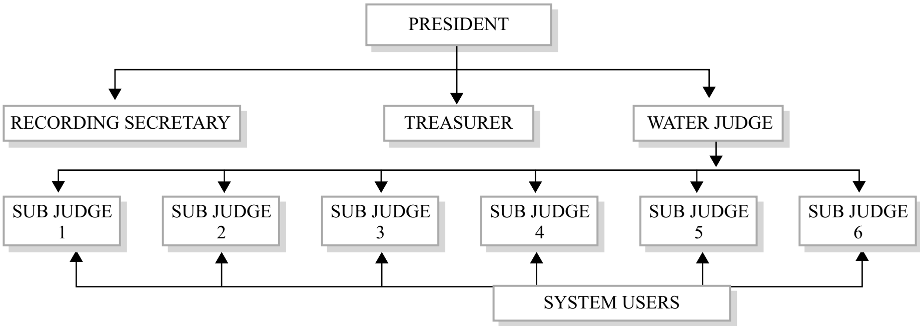
The two water distribution modes also remain in force: free on demand and by turns. Criteria governing water distribution during the two modes remain as before project intervention.

Organisation

The support entity supported the formation of a board of directors that also served as the construction committee. This body had the function of overseeing users' work input during infrastructure construction, co-ordinating with the building company, the Municipality of Villamontes and the project supervisor, and to oversee fulfilment of the activities schedule and the use of contributed materials.

The construction committee was to become the Caigua irrigation committee. It comprises the President, Recording Secretary, Treasurer, Water Judge and Sub-Judges, inter-relating as shown below:

Figure 6.3 Organisational chart of the Caigua irrigation system



The duties of each irrigation committee position are shown below

Table 6.9 Positions and duties on the Irrigation Committee board

Position	Functions
President	• Representative in dealing with other bodies • Organises turn beginning • Conflict resolution • Presides over meetings
Recording Secretary	• Supports President's activities • Keeps minutes of meetings
Treasurer	• Handles finances • Collects contributions and fines
Water Judge	• Co-ordinates infrastructure maintenance activities and water distribution • Co-ordinates with sub-judges
Sub-judges	• Oversee the list of turns for each branch • Notify users in their branch Co-ordinate activities with the Water Judge

The new positions on the users' organisation board were seen as useful by system users. They say that this involves more people and more share system concerns. The Caigua irrigation system currently features solid organisation, expressed by the community's capability to negotiate for new projects (e.g. funding being arranged for the Acequia Grande project). They have regular meetings since they began to implement the project. Users attend meetings with regularity. At the beginning of the meeting, the president calls the users roll in order to verify attendance. Then the authorities and users establish the issues that should be analysed in the meeting. The recording secretary registers all the treated points in the minutes book. The authorities of the organisation are responsible for ensuring compliance with the rights and obligations that users have.

The organisation has by-laws and regulations. The support entity helped users prepare these documents. It also helped prepare the internal regulations and system operation manual, giving copies to the Irrigation Committee president to apply to keep the system working. However, users interviewed (October 2001) reveal that these documents are not used. They say that, when a problem comes up, it is resolved at collective meetings, involving all users. They do say that such documents might be useful at some point to apply for legal recognition, but that process has not begun yet.

Maintenance

Prior to the project, maintenance centred on cleaning and rebuilding intakes. The support entity proposed new activities, as outlined below:

Table 6.10 Maintenance work

Type of maintenance	Facilities	Description of tasks
Routine	Intake Main canal Chambers and siphons Secondary canals	Protect the intake Clean the canal Clean chambers and siphon twice a year Clean and clear out weeds
Preventive	Gates Main canal Siphon	Paint and grease gates Patch cracks and leaks Clean and re-seal

Of all the tasks shown in this chart, only routine maintenance has been done so far. Another decision at users meetings was for a yearly maintenance fee of US$ 6.50 per user, to cover both routine and emergency maintenance. To 2003 no fees have yet been collected for maintenance and operation.

Table 6.11 summarises irrigation management characteristics after project intervention.

6.4 THE DESIGN PROCESS

6.4.1 Identifying and preparing the final design study

Users from the community of Caigua began taking action to undertake the project in 1992. At the request of local community members and the municipality of Villamontes, using Inter-American Development Bank (IDB) funds, PRONAR prepared the final design for the Caigua irrigation system and Acequia Grande system project in 1995. Once the final design project document was finished, in May 1995 the Regional Head of the Tarija Development Corporation (CODETAR), as implementing entity, signed a commitment with the Caigua OTB President for project implementation. Users promised to solve all problems involving easements, water rights and labour contributions. Users also promised to take responsibility for system operation and maintenance once work was completed.

Table 6.11 Caigua irrigation management analysis III - After project

Scheme of activities / Organisation	Water allocation	System operation and water distribution	System maintenance	Conflict management	Construction and rehabilitation
Decisions & tasks	Decision by the system committee: 1. Contribute 30 workdays to maintain water rights. 2. Incorporate 14 new users belonging to the community, each paying US$ 50.	Decision in irrigation committee to: 1. Begin delivering water by turns and free on demand. 2. In dry season, by rotation, with main canal single flow, which is subdivided to 3 or 4 users and in rainy season, proportional to each group's number of users. 3. Elect the irrigation committee.	Decision at irrigation committee meeting for each user to contribute the same number of workdays for maintenance.	Decisions at irrigation committee meeting to establish penalties for those who fail to comply with norms and obligations.	Decision at irrigation committee meeting to define community labour contribution as the equivalent of 20% of the total cost of the new infrastructure.
	Activities involving supervision of days worked.	Activities involving making up the roster of shifts for each group in the dry season and proportional distribution during the rainy season.	Activities involving el mantenimiento rutinario (limpieza de canales)	Activities involving monitoring fulfilment of norms and obligations.	Activities involving organisation and supervision of work.
Formal rules	Rules related to implications of water rights: rights and obligations.	Each sub-judge organises users' shifts in each group or branch. The roster is prepared monthly and approved at a meeting.	Rules establishing the users' obligation to take part in maintenance, and to contribute US$ 6.50 / user / year.	Rules punishing non-fulfilment of established norms and obligations.	Rules establishing planned work: work schedules, periods, amounts.
Participants	Construction committee, recording days worked, and users working.	President: organises beginning of shifts. Water judge co-ordinates distribution activities. Sub-judges oversee roster of shifts for each branch. Users irrigate.	Water judge to organise maintenance work and users group cleaning facilities.	President to enforce penalties and handle conflicts, and users who fail to fulfil agreements.	The construction committee organising the work, engineers directing the work and users working as planned.
Logics and informal rules	Open-system logic, incorporating new users.	Logic of delivering water by rotation and single flow.	Logic based on contributing labour (not money, no maintenance fees).	They do not use the regulations and by-laws prepared for them by the project support body.	Logic of community investment to guarantee irrigation system sustainability.

Eligibility indicators under which the project was approved fell within established ranges, but this changed as infrastructure was built:

Table 6.12 Indicators of project eligibility

Indicators	Eligibility criteria	Calculated in the project (us$)	Real amount (us$)
Cost per incremental hectare	Less than or equal to US$ 2500	2207	3411
Cost per family	Less than or equal to US$ 4000	4098	3858

Source: Final design Document, Caigua Irrigation Project and Caigua project procedural manual

6.4.2 Project implementation

This project was first put out to tender in August 1998. Envelopes were opened that September and the project was awarded to a building company during that month. The contract deadline was 246 calendar days. However, time overrun was significant, as shown below:

Table 6.13 Real implementation timetable

Items	Date	Time (days)
Tender	26/08/1998	240
Award	3/09/1998	246
Work began	1/10/1998	
Conclusion	20/12/1999	446

Interviews (October 2001) highlighted the following points about the project implementation process

- Users were dissatisfied with project implementation delays, since they could not use water while facilities were unfinished.
- The first excavations were interrupted by Caigua river flooding. Users had to repeat their work, because the building company was still waiting for the supervisor to authorise a change in the course of the main canal.
- In the absence of the supervisor and the technician from the Municipality of Villamontes, community authorities oversaw implementation according to technical specifications. Concretely, they sent correspondence to the FDC or PRONAR specifying the stretches in which the building company was not doing its work adequately. They observed particularly especially the quality of the mixture. Normally the answer was that they will obligate the building company to repair the mistakes, taking into account the contract conditions.
- When the work was finished, they saw that the wooden gates were not suitable, and rejected 45 of them. The high atmospheric humidity, and intense solar radiation made the wood swell and warp, leading to water leakage at gate joints.

It took 446 days to complete the work, which was delivered on December 20, 1999. The provisional reception memorandum had the following activities that users wanted the building company to do:

- Fix the rubber on the silt trap gate
- Seal the front of the silt trap with concrete
- Improve sealing of canal cover slabs
- Fix the thread of the gate at survey station 0+540
- Fix leaks, cracks, breakage and holes throughout the canal
- Reinforce the frame of siphon gates
- Remake the siphon outlet chamber concrete cover
- Change the hand-wheel for the gate at station 1+965.
- Fix the thread on the gate at station 2+015.

However, these problems were not solved by the building company, because the municipality did not make the corresponding disbursement as its project counterpart contribution.

6.4.3 Project stakeholders and roles

The role played by each stakeholder in the project is summarised briefly below:

Caigua Users

Irrigation system users participated actively during the project design stage, making decisions about facility characteristics. During construction, users contributed their "unskilled" labour (33 days work for each user), and gathered local materials (stone, gravel and sand), as the beneficiary counterpart contribution determined in the final design project document. To define workday contributions, users discussed at a number of meetings how best to acquire water rights. They finally settled on a contribution of 30 workdays per user for construction. When the work was finished, they had accrued a total of 24 workdays per user.

During construction, they oversaw quality and completion of facilities according to their own experience. During implementation they were also in close contact with the Rural Development Fund (FDC) and PRONAR, which obliged the building company to work as properly as possible.

Municipality of Villamontes

The Municipality of Villamontes was involved from the project's outset. It collaborated in applying for funding and also committed its own counterpart funding. The municipality never came through with its counterpart funding as committed, and for this reason the building company never received full payment. This led to a series of difficulties in the final delivery of the work. When this study was conducted in 2001, this situation had not yet been resolved, so the project was never officially turned over to the community.

The Municipality collaborated in monitoring resources. It also delegated a technician to collaborate directly in supervising the work. It thereby took part actively in overseeing work quality. The results were a good-quality facility, which operates as expected. That supervisor also helped assure that the building company would be paid according to progress in the work. He also heard users' complaints and channelled them to the building company and funding entities. Users usually complained about the building company's failure to keep up to schedule.

The Municipality of Villamontes also co-ordinated with the FDC supervisor and the support entity. It participated in activities organised by the latter, helping with community workshops and preparation of legal documents (e.g. by-laws, regulations, and operation and maintenance manual).

Building company

The company that won the bid took 446 days to finish, a delay of 206 days. This was due to delay in disbursement by the funding entity and non-payment by the Municipality of Villamontes' contribution, interference by rains, continual turnover of staff on the worksite, and sporadic presence of the project supervisor.

The building company applied for a deadline extension twice, and the FDC granted these postponements. The building company's representative was interviewed and stated that: *"One problem we faced was poor project design quality. The building company technical people had to redesign the intake and main canal"*[9]. He pointed out that changes had to be approved by the supervisor; who unfortunately was slow in doing so, preventing work from beginning on schedule.

He added that *"Timeframes should be more flexible, especially with climatic conditions (frequent rain, intense sunshine) and soil conditions in the Bolivian Chaco, concretely in Villamontes, set us back in fulfilling the original timetable"*.

Company representatives stated that community members did fulfil their promised labour input, so the company had no complaints about beneficiary community compliance. During construction there were unforeseen occurrences, such as during the common excavation when there were landslides at the main canal's first sections. Also, sediments borne by the Caigua river during heavy rains made it necessary to clean out the intake excavations again. To overcome these problems, users had to work all over again to clean out these sections.

PRONAR Tarija

PRONAR, through their Training and Technical Assistance component for Tarija (CAT – PRONAR) collaborated in final design, and in pursuing approval of funding for the Caigua irrigation project. They later co-ordinated with the FDC in supporting the tender process, hiring of the building company and the support entity.

The PRONAR team in Tarija responsible for the project provided outside inspection. They supported the Municipality of Villamontes in its supervisory role. They collaborated with community members by clearing up their doubts during implementation. PRONAR's work consisted in verifying whether implementation was on schedule. They also gave users suggestions to improve users' own supervisory role in regard to community contributions to the project.

9 The project document shows that the actual intake and main canal have the same characteristics as in the project.

Rural Development Fund (FDC)

The Rural Development Fund's departments performed the selection, evaluation, approval and tendering of the Caigua irrigation project, according to agreed terms and regulations. Subsequently, the project was funded by FDC, whose main function was to disburse according to the agreed timetable. To maintain continual presence at the worksite, FDC engaged an outside supervisor.

Supervisor

For unknown reasons, the first supervisor initially hired by FDC rescinded the contract, and had to be replaced. This disconcerted the building company and beneficiary community, because they had to review activities that had already been approved by the previous supervisor.

The second supervisor was in contact with the community to be able to incorporate their demands. He also considered changes suggested by the building company. The supervisor approved the deadline extensions requested by the building company. He required them to meet technical specifications, to ensure quality of work. He verified the taking of test samples to analyse the consistency of concrete pouring and the certificates of breakage testing done by the building company.

In general both supervisors during their work period did their job adequately, by participating in the work and co-ordinating with local organisations (the Municipality, farmer organisations and regional / departmental authorities). Insofar as possible, they reviewed and commented on payrolls, thereby helping get them approved and get the building company paid.

FDC's supervisor co-ordinated continually with the supervisor assigned by the Municipality of Villamontes, who contributed to the information flow, so the FDC supervisor would remain abreast of developments, to be able to make the most advisable decisions for each situation.

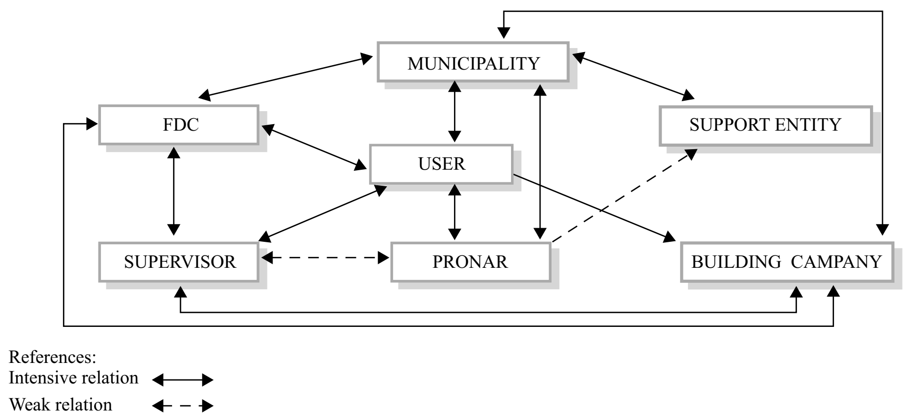
Support entity

The support entity was hired by FDC through a public bid. Inter-relations among the building company, support entity, municipal supervisor and users were adequate, co-ordinating among the various institutions. This enabled each to do its work better. Support technicians have stated that they made the efforts required to co-ordinate meetings and invited the various institutions to take part in scheduled training workshops. They also collaborated with users in preparing minutes of meetings and requests or complaints for other project players.

The support entity assisted users in preparing their by-laws, regulations and operation and maintenance manuals. Users were asked about the support entity's work, and have replied that no practical demonstrations were given to show them how to operate and manage some new facilities, such as the siphon, cleaning out chambers, etc. The lack of training was evident in users, because they could not operate the facilities and did not know how to maintain the infrastructure.

Clearly, there were many project stakeholders, but it is important in this case that the users' organisation was a key player. Users made decisions about key project features, both during the pre-investment stage and during implementation. The outside stakeholders enabled users to play a protagonist's role, by establishing mechanisms so users could become co-designers. It is important to emphasize the good work carried out by the supervisors, due to which users could become co-designers. Moreover, inter-institutional relations were good, especially because the municipality did not abandon users, becoming an intermediary to channel users' complaints and suggestions to funders. The support entity also worked to involve the different players when it was time for them to participate.

Figure 6.4 Interaction of actors in Caigua Project



As a consequence of stakeholders' actions and the inter-relationships established among them, outcomes in this irrigation system intervention are more encouraging, despite the fact that the Municipality's non-payment left the final delivery of work dangling.

6.5 APPROPRIATENESS OF THE INFRASTRUCTURE TO MANAGEMENT CAPABILITY

As this and other cases have shown, the results of intervention in an irrigation project largely depend on the characteristics of the design process. This process includes engineers' approaches and different stakeholders' roles. This means that participation, responsibilities undertaken and local criteria taken into account by various players shape the new irrigation system's sustainability. In this case study, the interaction among engineers and users in setting infrastructure characteristics and irrigation system management has resulted in the system's appropriateness to management capability.

This irrigation system involved users more during design. As a consequence, there were fewer user complaints about the intervention's outcomes.

6.5.1 Operational appropriateness of the infrastructure to management capability

Although the project joined several "irrigation systems" by building a single intake, the principles of water distribution have not been changed. The system is still viewed by users as equitable, because each user family is sure that they will receive the amount of water that they are entitled to. New organisational arrangements for water distribution help maintain equity in the system among and within groups.

Since the facilities constructed are not complex, users understand how the system works; know what activities they have to perform to operate them, according to the turns system set up by users, which delivers water on a single-flow basis. Similarly, the organisation suits water delivery characteristics, with three sub-water judges to cover water distribution needs within each group.

However, from the standpoint of users' capability to handle maintenance, this case once again shows weaknesses here. The facilities themselves (i.e. siphon and gates) cause problems. This is because the support entity never specified or practised maintenance activities with users for each facility, according to the users themselves.

This and the other cases show that the issue of "user-managed" irrigation systems, specifically in regard to the infrastructure's suitability or adaptability to management capability, is left to chance. Engineers are not working under plans to "design water management". Although such management is not "plan-able" in a linear, predictable manner, it is crucial to facilitate orderly structuring of management in support projects. Although there has been progress in considering water rights as a starting point to improve irrigation systems, failing to plan for analysis of operation and maintenance requirements leaves design of future irrigation system management pending. This will require the development of a conceptual and methodological framework. Proof of this is that, in this case the support entity had plenty of good intentions, but did not know how to "operationalise" what designers (in the pre-investment phase) recommended for them to do (during support for implementation).

6.5.2 Technical appropriateness of infrastructure to management capability

This case shows that, since users did take part in defining the infrastructure there were no major problems with user dissatisfaction, specifically in regard to location or sizing of facilities. The part that causes the most problems is the siphon, because it has no surge chamber, and the purge chamber floods, exposing metal parts to corrosion. This case, along with the Naranjos Margen Izquierdo system, show weakness in designing and building siphons, since maintenance possibilities or the siphon's safety or functionality are not analysed. Therefore, it can be concluded that design and construction criteria must be established for this work, specifically in mountainous areas, and clear training sources

Another lesson learned from this case and the others studied, is that building companies select inappropriate gates or install poor quality gates. Failure to provide proper quality gates is one of their most profitable gambits. Unfortunately, absence or lack of good supervision lets them get away with it, and users must eventually make up for this, or be forced to abandon the facility.

It would be logical for the work delivered to users to have expected quality and functional capacity. The company was obliged to deliver users a facility in proper condition. It is not right to turn over facilities that must first be fixed in order to operate properly, and expect them to correct construction flaws through their maintenance work. It is necessary to realise that users cannot afford to remedy such deficiencies, because they do not even earn enough to be able to afford maintenance. If these factors are ignored, a facility is destined to fail and be abandoned eventually.

6.5.3 Productive appropriateness of infrastructure in relation to management capability

To meet the improved infrastructure's requirements, money is required to purchase such construction materials as cement, paint and so on. This money must be chipped in by users. In this case study, annual maintenance costs for the improved infrastructure totals US$2609, as shown in

Table 6.14, which amounts to US$31/year per system user household. Without considering the labour the maintenance costs are US$407/year, this means almost US$ 4.84/year/user.

Analysing users' possibilities of making this payment, it should be seen first whether their household income increased enough for them to afford it. In this case, average Caigua irrigation system household income increased by US$582. The fees required to maintain the infrastructure (per user family, including labour) amount to 5.5 % of their additional income.

Calculations show that users could afford to pay maintenance fees, but in practice they do not. For this reason, actual irrigated agriculture income (US$904/family/year) was compared with the average living requirement. According to the Bolivian Institute of Statistics (INE 2002), average living requirement in the Chaco is US$1786/year. Comparing this amount with their new income (US$ 904/year) irrigated agriculture covers 51% of living requirements. There is a shortfall of US$ 868 / year.

Analysing the situation of the Caigua users, taking into account an economic logic of cost – benefit, all users should contribute maintenance costs, because they know that they can have more money due to new infrastructure, and they need to have the infrastructure in good condition. However, labour is needed and put into production rather than maintenance.

This means that there are more reasons than only the economic aspects, for users' agreement to pay the fees or not. But these other reasons are beyond the project's control. This situation would recommend designing and building functional, long-lasting facilities that require less economic contribution and improve agricultural production conditions in the area, so productivity will result in greater availability to cover more of their living requirement. Marketing conditions (security) are also important, often causing a bottleneck preventing farmers from reaching the expected goal "for irrigation systems to be user-managed and sustainable".

In conclusion, this case study shows that it is possible to make users the co-designers of their irrigation systems, rather than just using "co-design" as an empty catch-phrase. This all depends on the attitude of engineers, to listen and be listened to. In this case, being co-designers has enabled users to get to know the changes that should be made in irrigation infrastructure, which has granted them greater power to oversee progress in the work and also to be able to complain when the building company makes mistakes. As a consequence of co-designing facilities, infrastructure complaints are also reduced compared to the other cases studied. Nevertheless, there are still mistakes in this case, especially involving the type and quality of gates.

Quality of work is a central issue, since poor-quality works will require repairs almost immediately and will not last for their full life expectancy. In response to these deficiencies regarding quality and, in general, problems with the facilities as built, Bolivia uses the term "*adecuación*" (adaptation, i.e. fixing). But adaptation requires additional money to repair facilities. This gives rise to the question: in this case, who should pay the price of "adapting" the gates? Users cannot be expected to take this responsibility.

This case also shows, once again, that usage requirements for the new infrastructure have not been suitably addressed. The supporting entity placed great emphasis on manuals, by-laws and regulations to guide irrigation system management. Producing these documents has become an end in itself (though users never put them in practice), rather than as a means or instrument to analyze precisely the requirements for usage and possibilities for users to meet these requirements. The greatest problem is that both the FDC (contracting party) and the supporting entity (contractor) have failed to operationalise what might be called the management design, by analysing net usage requirements.

Table 6.14 Annual maintenance costs - Caigua

Activity	Frequency	Cost of materials and inputs (US$)					Cost of labour			Total (US$)
		Item	Unit	Unit price	QTY	Total	Nº days	Unit price	Total	
INTAKE										
Inspect intake	2times/year	Notebook and pen	PI	0.27	1.00	**0.27**	0.40	3.94	**1.58**	**1.85**
Repair and maintain	Annual	Cement	Sack	4.73	9.00	42.57				
		Stone	m^3	4.00	2.64	10.56				
		Sand	m^3	4.00	1.68	6.72				
		Tools	PI	10.00	1.00	10.00				
						69.85	10.00	3.94	**39.40**	**109.25**
Review operation	Monthly				0.00	0.00	1.00	3.94	**3.94**	**3.94**
Clean intake	4times/year	Shovels	PI	0.06	8.00	**0.48**	84.00	3.94	**330.96**	**331.44**
Subtotal 1						**70.60**	**95.40**		**375.88**	**446.48**
CONVEYANCE AND MAIN CANAL										
Review canal	2times/year					0.00	2.00	3.94	**7.88**	**7.88**
Remove weeds and brush	2times/year	Picks	PI	0.03	20.00	0.60				
		Shovels	PI	0.03	20.00	0.60				
		*Machetes**	PI	0.03	84.00	2.52				
						3.72	21.00	3.94	**82.74**	**86.46**
Clean canal	3times/year	Shovels	PI	0.10	42.00	**4.20**	252.00	3.94	**992.88**	**997.08**
Repair -maintenance	Annual	Cement	Sack	4.73	38.00	179.74				
		Stone	m^3	4.00	11.82	47.28				
		Sand	m^3	4.00	7.60	30.40				
						257.42	76.00	3.94	**299.44**	**556.86**
Patch canal	1time/year	Cement	Sack	4.73	6.00	28.38				
		Tar	kg	1.00	14.00	14.00				
						42.38	20.00	3.94	**23.94**	**66.32**
Remarking stations	Annual	Paint	l	1.50	1.00	1.50				
		Brush 2.5”	PI	0.50	1.00	0.50				
		Wire brush	PI	2.00	1.00	2.00				
						4.00	3.00	3.94	**11.82**	**15.82**
Subtotal 2						**311.72**	**278.00**		**1095.32**	**1730.42**
CHAMBERS AND SIPHON										
Review	3times/year					0.00	0.50	3.94	1.97	**1.97**
Clean	3times/year	Shovels	PI	0.03	4.00	0.12				
		Mattocks	PI	0.03	4.00	0.12				
		Unplugger	PI	0.02	5.00	0.10				
						0.34	15.00	3.94	**59.10**	**59.44**
Maintain gates	Annual	Anti-rust paint.(l)	l	2.00	3.00	6.00				
		Brush	PI	0.50	2.00	1.00				
		Sandpaper	m	1.00	3.00	3.00				
						10.00	3.00	3.94	**11.82**	**21.82**
Operate cleaning valves	4times/year			0.00	0.00	**0.00**	0.80	3.94	**3.15**	**3.15**
						10.34	**19.30**	**3.94**	**76.04**	**86.38**
SECONDARY CANAL										
Review secondary canal	2times/year						0.12	3.94	**0.47**	**0.47**
Patch and Clean	2 imes/year	Cement		4.73	3.00	14.19				
		Tar	kg	1.00	0.50	0.50				
						14.69	84.00	3.94	**330.96**	**345.65**
						14.69	**84.12**		**331.43**	**346.12**
TOTAL						**407.35**	**476.82**	**3.94**	**1878.67**	**2609.40**

*Big knives PI: per item Source: Field infrastructure inventory

7 IRRIGATION INFRASTRUCTURE DEVELOPMENT AND USERS' MANAGEMENT CAPABILITY

INTRODUCTION

This chapter makes a comparative analysis of the irrigation infrastructure and users' management capability on the basis of findings from the four case studies (chapter 3-6). For this purpose, the concepts set forth in the conceptual framework for this research effort will be used: 1. Operational appropriateness of infrastructure to management capability, 2. Technical appropriateness of the infrastructure to management capability 3. Productive appropriateness of the infrastructure in relation to management capability. In addition, because of the importance and influence of the design process regarding these issues, it is indispensable to refer to the process as well.

7.1 OPERATIONAL APPROPRIATENESS OF INFRASTRUCTURE TO MANAGEMENT CAPABILITY

This section builds analysis of the following aspects: 1. The irrigation management before and after the intervention and the project proposal about irrigation management in the four case studies, 2. The relationship between project proposal for improved irrigation management and users practice of irrigation management, 3. Operation and maintenance capability and 4- requirements of the new infrastructure versus small farmers' management criteria.

7.1.1 Water management models in irrigation projects

To analyze the irrigation water management before and after project interventions, three charts have been prepared (7.1, 7.2, and 7.3). At the top go activities involving irrigation management: water allocation, system operation & water distribution and system maintenance. To analyze each of these aspects, three items have been established regarding how activities are organised: decisions & tasks, formal rules and participants and roles enforcing activities. These tables will make it possible to analyze water management features as proposed by projects, compared to users' practice before and after the intervention in each of the case studies. The analysis of each of them is concise to avoid repetition.

Condorchinoka

Analysis for Condorchinoka shows that the decisions in relation to water allocation were important, with the fact that the conception of water rights for users changed in the situation before and after the project. For users, the project was an opportunity to establish a firmer relationship between manpower investment and water rights in cost-benefit terms, but expressed in wages. It changed their concept of equity. Before the project, all users worked the same number of days although they had different water rights. During the project phase, they felt that it was more equitable that those users with more water rights should work more. Other aspects, such as formal rules, participants and roles enforcing activities, did not change. The project also did not propose big changes on these aspects (see Table 7.1).

Table 7.1 Comparative approaches – water allocation

Organisation		Condorchinoka	San Roque - Capellania	Naranjos Margen Izquierda	Caigua
Decisions and tasks	Before	By the syndicate	By the irrigators' organisation	By the syndicate	By the syndicate
	Project plan	By an irrigation committee	By an irrigation association	By an irrigation committee	By an irrigation committee
	After	By an irrigation committee (with their own norms)	By the irrigators' organisation	By an irrigation committee (with their own norms)	By an irrigation committee (with their own norms)
Formal rules (Roles establishing the relations between rights and obligations)	Before	Attending meetings, serving in position on a rotation basis	Fulfilment of workday commitment and obligation regarding water rights	Fulfilment of workday commitment and obligation regarding water rights	Fulfilment of workday commitment and obligation regarding water rights
	Project plan	Maintaining infrastructure, attending meetings, using only water to which one is entitled	Contributing US$ 200/suyo	Fulfilment of workday commitment and obligation regarding water rights	Fulfilment of workday commitment and obligation regarding water rights
	After	Attending meetings, holding positions on rotational basis, paying some maintenance dues	Contributing US$ 200/ suyo. Compliance with obligations involving water rights	Fulfilment of workday commitment and obligation regarding water rights	Fulfilment of workday commitment and obligation regarding water rights
Participants and roles	Before	The syndicate	The irrigators' organisation	The syndicate	The syndicate
	Project plan	Engineers and construction committee noting each users work input	The irrigation association	Engineers and construction committee noting each users work input	Engineers and construction committee noting each users work input
	After	Irrigation committee who monitored workdays	Irrigation association who monitored the money contribution	Irrigation committee who monitored workdays	Irrigation committee who monitored workdays

Table 7.2 Comparative approaches – system operation and water distribution

Organisation		Condorchinoka	San Roque - Capellania	Naranjos Margen Izquierda	Caigua
Decisions and tasks	Before	General meeting of the syndicate for elections of water judge and setting shifts in irrigation	General meeting of the irrigation organisation for election of the commissioner and setting shifts in irrigation	General meeting of the syndicate for elections of water judge and setting shifts in irrigation	General meeting of the syndicate for elections of water judge and setting shifts in irrigation
	Project plan	Irrigation committee to decide order of water delivery and operation of gates	Irrigation association to control water delivery as before	Irrigation committee to water delivery by blocks, flow division and operation of gates	Irrigation committee, each sub-water judge control water delivery in each group of branch
	After	Irrigation committee, tasks as with syndicate, name of “judge” still used.	Irrigation organisation, tasks as with irrigation organisation	Irrigation committee, tasks as with the syndicate	Irrigation committee, each sub-judge control water delivery in each group of branch
Formal rules	Before	Rights in dry season irrigation, irrigation with full flow, flow mixing, maximum irrigation interval 7 days	Rights in dry season irrigation, irrigation with full flow, irrigation interval 11 days. Water delivery in order during the free on demand period.	Rights in dry season irrigation, irrigation with full flow, irrigation interval 14 days. Water delivery in order during the free on demand period	Rights in dry season irrigation. Delivery of water proportionally to each intake.
	Project plan	Water delivered in order, plot by plot.	Water delivery as before, but recorded in a operating manual	Water delivered dividing flow in 3 blocks	Water delivery by rotation and with full flow among branches.
	After	As before project	As before project.	As before project	Water delivery by rotation and with full flow among branches
Participants and roles enforcing activities	Before	Water Judge	Commissioner	Water judge	Water judges
	Project plan	Group of users with water rights and a supervisor	Secretary of O&M	Water judge and sub-judges	Water judge and sub-judges
	After	Water judge	Commissioner	Water judge and sub-judges	Water judge and sub-judges

Table 7.3 Comparative approaches – system maintenance

Organisation		Condorchinoka	San Roque - Capellania	Naranjos Margen Izquierda	Caigua
Decisions and tasks	Before	General meeting of the syndicate to organize activities involving cleaning	General meeting of the irrigation organisation to organize activities involving cleaning canals and rehabilitating the intake	General meeting of the syndicate to organize activities involving cleaning canals and rehabilitating the intake and conveyance canal	General meeting of the syndicate organisation to organize activities involving cleaning canals and rehabilitating the intake
	Project plan	Irrigation committee to organize activities involving preventive and routine maintenance	Project did not specify maintenance tasks	Irrigation committee to organize activities involving preventive and routine maintenance	Irrigation committee to organize activities involving preventive and routine maintenance
	After	Irrigation committee, activities involving cleaning sediments	Irrigation organisation activities involving cleaning sediments	Irrigation committee, activities involving cleaning sediments	Irrigation committee, activities involving cleaning sediments
Formal rules	Before	Each user contributes one workday/month to clean.	Each user contributes with workdays proportional to their water rights	Each user contributes the same workdays. Women and children are not allowed	Users' obligation to take part in maintenance. Women and children are not allowed
	Project plan	Each user contributes US$ 2.40 for 6 hr shift and necessary workdays each year	Each user contribute US$ 4/suyo/year	Each user contributes US$ 5 per hectare irrigated and 5 workdays each year.	Each user contributes US$ 6.5/year
	After	As before project	As before project.	As before project	As before
Participants and roles enforcing activities	Before	Water Judge	Commissioner	Water judge	Water judges
	Project plan	President, treasurer and group of users	Secretary of O&M treasurer and group of users	President, treasurer and group of users	Water judge and sub-judges
	After	Water judge	Commissioner	Water judge and sub-judges	Water judge and sub-judges

In relation with system operation and distribution, the situation is the same before and after the project; the logic is to distribute the water in rotation and with one flow. This means that each user can irrigate with his or her water turn the plots that he or she wants without regard to plot location. The project position was to deliver water in an orderly way to avoid “jumps of water” and to increase efficiency. However, this proposal was not accepted by users, because it reduced transparency. They preferred transparency over efficiency. To implement the proposal meant that the water judge should be continually monitoring the time that each user irrigated in each of his or her plot until completing his or her water turn. (see Table 7.2)

System maintenance has not changed in essence, being the same before and after the project. The contribution for maintenance is grounded in manpower, and in carrying out activities related with cleaning. The project proposal was based on manpower and money contribution. It also incorporated new tasks in routine and preventive maintenance (see Table 7.3). The proposal was incorporated partially by users. In relation with conflict management, the agreements, norms and sanctions remain the same before and after the project. The project has implemented an irrigation committee with by-laws and regulations to operate and maintenance the irrigation system. But users did not use the regulation and by-laws.

Regarding construction and rehabilitation, before and after the project users contribute manpower to construct and rehabilitate the infrastructure. The project position was not different; it requested users’ manpower.

San Roque – Capellanía

In relation to water allocation, users took advantage of the project to introduce a change in the decisions and tasks for water rights acquisition and water rights maintenance; users decided to contribute money and not manpower to infrastructure construction (see Table 7.1).

Regarding system operation and water distribution, users decided not to change tasks, rules or participants. Before and after the project the logic of water delivery was: rotation and one flow. The project took no concrete position on this topic, only elaborating a manual that incorporated the existing distribution practice (see Table 7.2). It did, however make it severely difficult to follow users distribution wishes since it designed a main canal that was not adequate to carry the full flow at the tail-end.

As in Condorchinoka, for system maintenance users decided to contribute manpower, based fundamentally on cleaning. The project position was to incorporate the contribution of maintenance fees besides the manpower, and propose activities for routine and preventive maintenance (see Table 7.3). Conflict management before and after the project remained the same: users make decisions at “water organisation” meetings about agreements and sanctions, based on a logic of communal control. The project position was the same as in Condorchinoka, to incorporate an irrigation committee with by-laws and regulations for irrigation system management.

For construction and rehabilitation, the fact that users decided to contribute money and not workdays has a consequence. During construction, users did not participate in organising the work; all tasks were done by the building company and hired workers

Naranjos Margen Izquierda

Issues involving water allocation are similar to Condorchinoka: the concept of water rights for users changed in the situation before and after the project. For users the project was an opportunity to establish a firmer relationship between manpower investment and water rights. It changed their concept of equity. Before the project all users worked the same number of days although they had different water rights. After the project they felt that it was more equitable for those users with more water rights to work more. Other aspects, such as formal rules, participants and roles, did not change. Nor did the project propose big changes in these aspects (see Table 7.1).

Regarding system operation and water distribution, the water delivery logic for rotation and with one flow remained the same before and after the project. The project proposed to deliver water by dividing the flow into three blocks, and irrigate the three blocks at the same time. Users preferred to install the three blocks as organizational bases for water delivery, but maintaining the logic of rotation and one flow. Consequently each block has its sub-judge; users adopted the organisational structure proposed by the project with regard to the incorporation of 3 sub-judges (see Table 7.2).

Again, in this case about system maintenance, users decided to contribute manpower for maintenance tasks, based fundamentally on cleaning. The project position was to incorporate maintenance fees in addition to manpower, and introduce new activities in routine and preventive maintenance (see Table 7.3).

In this case, as in Condorchinoka and San Roque Capellanía, for conflict management after the project, users decided to make decisions in meetings to establish obligations and sanctions, as before. Again, in this case as in the other ones, the project elaborated by-laws and regulations to regulate irrigation system operation, but this formalisation was not implemented in practice. Users decided during the project to contribute manpower as they always have done for construction and reconstruction. The project proposal was the same.

Caigua

For water allocation, users' concept of water rights did not change in the situation before, during and after the project. Aspects such as formal rules, participants and roles did not change. The project proposal was the same as users had developed earlier (see Table 7.1).

As for system operation and water distribution, before the project, each branch had its own traditional intake, and irrigated independently, rotating and with a single flow. The project position was to unite these small systems (branches) through a single intake and distribute the water in rotation and one flow. The project proposal was incorporated by users in their distribution practice (see Table 7.2).

Once again, in this case users decided to contribute for maintenance through manpower. Also, they decided to clean the infrastructure as they used to do. The project proposal was to incorporate the payment of maintenance fees and to contribute with manpower. Also, the project proposed to introduce routine and preventive maintenance activities (see Table 7.3).

In Caigua, users decided to incorporate the organisational structure proposed by the project. However they maintained the modality of conflict management through meetings. In committee meetings they established obligations and sanctions. The project proposed incorporation of by-laws and regulations to regularise irrigation system operation, but users did not incorporate them. Regarding construction and rehabilitation, users decided to maintain their way of participating in these activities, providing manpower and organising works. The project supported this initiative and made no other proposal

An analysis of projects across all the cases suggests the conclusion that proposals about "future irrigation management" in improved irrigation systems all followed a "model", pursuing the same objectives. All support entities put their efforts into two points: 1. Preparing by-laws and regulations and 2. Writing an operation and maintenance manual. To enforce regulations, an authority is required, so projects have proposed an organisation to enforce obligations, for both maintenance and operation. Consequently, all cases proposed an "irrigation committee".

Because engineers know that economic contributions are important, projects have included them in by-laws and regulations. Comparing this approach by projects to management capability with users' practice before and after the intervention, it is found that compliance with obligations is flexible and that the "authority" does not act coercively. Therefore, a failure to collect maintenance fee dues does not mean that the authority, or the organisation, is weak. Further, all cases studied show total disregard for new by-laws and regulations to enforce obligations and penalties. The cases studied show that neither the practical part of management (i.e. operation and maintenance) nor the normative part underwent any changes, despite support agency efforts.

7.1.2 Operations facilitate while maintenance challenges management capability

Lessons learned from the cases studied show that, to analyse operational appropriateness to management capability, operation and maintenance must necessarily be addressed separately. So, this section begins by analysing the requirements for facilities to be operated and maintained. Then I will assess whether users have the capacity to meet these requirements or not.

Users' capability to perform operations

The operation requirements of the infrastructure are closely bound to the distribution practices in the irrigation system. When the distribution is for rotation and in one flow as in the case studies, these requirements reduce to a simple task: regulation.

Regulation consists mainly of handling gates at all levels of delivery. Because of distribution characteristics, this is normally circumscribed to opening and closing gates. Another job done occasionally is to close the intake or drain when the river rises suddenly. This happens in all cases, except in the Condorchinoka irrigation system, where users do not close or regulate the intake because it is a filtration gallery. Another characteristic of operation, reflected in water delivery and distribution, is operational flexibility[1]. Existing distribution infrastructure (regulation gates and side outlets) are of the adjustable infrastructure type. This flexibility makes it possible to regulate and occasionally divide the flow according to users' requirements.

Also, the case studies show that facility usage requirements involve their own operational possibilities. In general, facilities built in the different case studies operate automatically, except that some of them had problems in design or construction. Consequently, they require additional tasks of operation in order to work correctly, as can be seen in the following table.

1 According to Horst (1998), there are fundamentally two types of distribution infrastructure: fixed and adjustable. The latter enable greater flexibility in distribution.

Table 7.4 Operating requirements of the improved infrastructure

Type of infrastructure	Observation	Operating requirements
Intake	Sediments tend to build up, upstream from the weir	Continually rebuild a rustic approach canal to keep it working (e.g. Caigua)
	Intakes without spillways	Intake gate regulation tasks
Canals	Canal capacity	Add sod along the edges of canals to attempt to increase their capacity
Siphons	Siphon plug	Controlling the flow entering
Filtration gallery	Loopholes clog	Cleaning the loopholes

These additional tasks involve flow control. Other facilities, such as aqueducts and gully passes do not present additional operating requirements.

Flow control is yet another operating chore, because facilities work poorly. If they worked properly, this additional task would be avoided. As shown in the cases studied, users must monitor facilities while distributing water, to prevent plugging, especially at intakes and siphons. Similarly, abundant vegetation in some zones (Naranjos Margen Izquierda, Caigua) makes flow control work more intensive, to keep the system operating normally and provide a stable flow. Insufficient canal capacity makes flow control a necessary chore for members of the families whose turn it is to water.

In turn, work involving drainage is very similar in the cases studied, centring on controlling the flow entering the system at the catchment area and where it drains into natural watercourses (the river and creeks).

To conclude, users in the cases studied have shown capability to meet the operating requirements of the improved infrastructure (regulation and flow control), despite its design and construction problems. This is because the facilities are simple and the users have decided that water should be delivered on a rotational basis with undivided flow.

Users' capabilities to perform maintenance

The cases showed that improved irrigation system maintenance required many new activities and resources, varying in implementation. New requirements (labour and money) in the improved irrigation system are shown in the next table.

Table 7.5 Labour days and cost for infrastructure maintenance

Irrigation system	Labour days /year	Inputs US$/year
Condorchinoka	236.50	297.95
San Roque- Capellanía	286.90	162.69
Naranjos Margen Izquierda	612.79	369.05
Caigua	476.82	407.35

The new maintenance requirements in purchased inputs average: US$7/family/year in Condorchinoka, US$4/family/year in San Roque Capellanía, US$11/family/year in Naranjos Margen Izquierda and US$5/family/year in Caigua. Maintenance depends on whether users can respond to these requirements, and on the priority that users grant to the activity, as shown in the following table.

Table 7.6 Maintenance requirements of the improved infrastructure

Activity	Requirement	Implementation level
Removing sediments	Labour and knowledge	High, with some difficulties in galleries and siphons
Repairing concrete	Money. No special expertise	Users do not perform this
Replacing joints	Money and knowledge	Users do not perform this
Repairing side walls	Money. Not special expertise	Users do not perform this
Forming berms	Labour	No high priority for users
Repairing gates	Money and knowledge	Users repair only if indispensable
Protecting valves and pipes	Money. No special expertise	Users rarely do this activity
Protection facilities	Money and knowledge	No high priorities for users

Out of all the activities required to maintain the improved infrastructure, sediment removal is one that users can readily handle. However, in the systems studied, cleaning is done on set dates (once or twice a year), just like when the infrastructure was rustic. This situation limits facilities from working properly. In some cases (e.g. Naranjos Margen Izquierda) silt build-up requires significant work investment for cleaning. This demand is often so great that it exceeds users' capability.

Additionally, silted-up facilities create silt flow that wears away the floor and walls of canals and the concrete must consequently be repaired. Although cleaning is a practice that users can handle, it does not have the expected effects, because they do not understand how the facility works. This is the case with the filtration galleries. With this kind of facility, users contribute their workdays to clean out the vault, without realising that what they have to do is reconstruct the filter to prevent the loopholes from silting right back up. This is the case in Condorchinoka, due to the badly-built filter.

In conclusion, the case studies show that users do little maintenance on improved systems beyond "cleaning", since they have their own concept of maintenance, resulting from a number of factors, including the type of technology and conditions, and/or their local expertise. Most other user maintenance proposal is simply ignored, so the facilities cannot be guaranteed to last. The infrastructure's maintainability is a bottleneck for the system's sustainability.

Users do not contribute to cover the demands for maintenance. Moreover, maintenance necessarily calls for local fund-raising, materials and expertise to meet the ongoing requirements to keep the improved irrigation system working. Knowledge and money are the weakest links among the requirements to preserve the improved system. Users do not feel that it is a high priority to invest money in maintenance, nor do they know how to cope with the new technology, since they received no training from the engineers, so the system's sustainability is jeopardised.

Maintenance requires well-planned work and local resources (labour and continual fee payment) in order to purchase materials and pay for hired-in services. It also calls for capacity and skills. Capacity involves knowledge, and skills to maintain the facilities should be analysed during the design process (and during construction), to prepare users for the needs they will face. This analysis would also enable technical players to verify whether the facilities' technical features will actually be easy or possible to maintain.

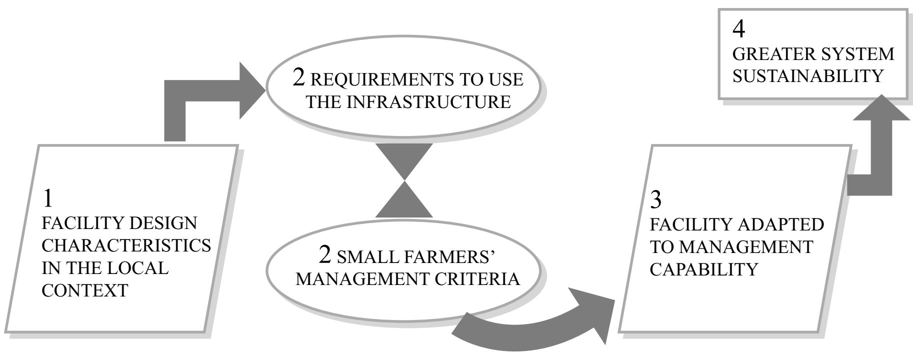
None of this happened in the cases studied, as will be discussed below. This seriously hampers users' capability to meet the maintenance requirements of the improved infrastructure

7.1.3 Requirements of the new infrastructure versus small farmers' management criteria

Finally, this section will analyse whether the infrastructure's new requirements fit in with small farmers' criteria regarding water management or not. The case studies show that each project, as designed and built, has certain requirements for use. These requirements have to do mainly with the demands to operate and maintain the facilities. If these new requirements, expressed as water management practices, fit in with small-farmer water management criteria, then the facility is adapted to their management capability. Management criteria are understood to be the foundation, the principles underlying agreements and activities shaping water management, and manifested in the different specific rules for each irrigation system.

When institutions intervene in traditional irrigation systems, improving the infrastructure, these management criteria are affected in some cases, which jeopardises the system's sustainability. This is shown schematically below:

Figure 7.1 Flowchart to analyse the infrastructure's adaptability to management capability



According to this flowchart, each management criterion will now be analyzed– transparency, conflict minimisation, equity, and usage capability – in regard to operating and maintenance requirements.

Transparency

Transparency regarding operation of the improved infrastructure is evident because water distribution is also transparent, for several reasons: water delivery is by undivided flow and by rotation, avoiding any mixing of water from different irrigation systems and with minimal hierarchical levels.

As all the case studies show, when main water is delivered by *single flow and rotation*, this contributes to the fact that users feel that they get their fair share of watering time, because the “whole” flow waters their fields. Users often *avoid mixing water* from different irrigation systems, as it has been seen in the San Roque - Capellanía system, which operates alongside others in the community of San Juan del Oro. The cases researched also show that *minimal hierarchical levels* in water distribution organisation favour social control and forestall potential social conflicts. Consequently, activities are transparent and visible to family members. Users can oversee compliance with agreed management and avoid misinterpretation in water delivery.

The characteristics of distribution (single-flow and rotation) that users chose after the improved irrigation infrastructure was built, along with facilities simplicity, limits operation in all cases to “regulation” and “flow control”. These activities are simple enough that they require no specialists to perform them. So, family members, even children, can operate the facilities and distribute water. This is especially applicable to distribution facilities.

Also, since water is delivered by single flow and rotation when water is most scarce, the type of infrastructure (fixed or adjustable) does not make much difference in operating requirements. If distribution had been by multi-flow in these cases, they would have to be more careful in the type of structure, since a fixed structure has lower operating requirements, but can be less flexible in water distribution. However, if the adjustable structure is chosen, design must provide for transparent flow division. Division gauges are not always a suitable solution. Anyway, in the cases studied no gauges were used.

In summary, operation in the irrigation systems studied is transparent because:

- They are simple and not intensive.
- They are clear about who is responsible to do distribution work at each level.
- They require only unskilled personnel, generally only one person.
- Requirements can be met by male and female users, and in some cases even children.
- Operating tasks are less intensive in systems without regulation at the source.

When the principle of **transparency in relation to maintenance** is analysed, it is easy to conclude that sediment removal and berming can be done by users, because they need no expertise that they do not already have, as in all the case studies. The situation changes with other activities, such as concrete repair, joint replacement, gate repair, valve and pipe repair and protective structure construction. These activities do require additional knowledge (in some cases low in others high), not only to do them, but even to hire someone to do them. Unfortunately, the engineers in all the case studies simply listed the activities (in operation and maintenance manuals) that users should do for routine, preventive and emergency maintenance, but they never practised them with users so the users could acquire practice and experience.

Lack of knowledge is a key element preventing transparency in maintenance. For example, in the case of the filtration gallery in Condorchinoka, technical players during construction and support work never discussed maintenance requirements with users. So, users never learned to place or maintain filters, which are key maintenance functions, and therefore waste their time cleaning out sediments. This reduces water catchment capacity and consequently available water overall.

Another facility with maintenance problems is the siphon. It was badly designed to begin with, and users were never told how to maintain it, because of a flawed design process. So, users make pointless efforts to maintain the siphons, and end up having to use pumps to clean them out. There is a similar problem with sliding gates. Users hire welders to repair them, but since they require such force to open and close them they break down again. Users do not realise that the rod and bushings must also be changed.

Along with the economic constraints, the lack of available time and impossibility of understanding how to maintain the facilities make the irrigation system less sustainable. Users quit using facilities when they can no longer be maintained.

Conflict minimisation

Most facilities do fit in with the overall principle of minimising conflicts involving operation. There is no hierarchy of canals, and users settled on rotating, single-flow distribution, so conflicts are minimised. Had the multi-flow distribution recommended by the technicians in the case Naranjos Margen Izquierda been implemented, this would have generated water distribution conflicts, especially since no gauges were built to help divide flows.

There is one conflict involving catchment facilities design. The facility was located on a site that lends itself to territorial squabbling between neighbouring communities. In Condorchinoqa, they have problems with the community of Pisaqueri, who claim that the filtration gallery is located in their territory. This often happens in the altiplano. Since land slopes so steeply, to obtain water and irrigate a greater area, they have to raise the level where the intake is located. This site is often outside a community's territory. Consequently, the conveyance canal must also pass through other territory. So, the terrain forces neighbouring communities to settle these arrangements beforehand, but conflicts always resurface in the long run.

At the system level, in some cases (Condorchinoka, San Roque – Capellanía, Naranjos Margen Izquierda), poorly conceived infrastructure has caused conflicts. For example, when canals do not have sufficient capacity, users downstream do not get all the water they are entitled to.

Regarding maintenance, in general the new infrastructure increases conflicts, because maintenance requirements cannot be met. Failure to make contributions prevents users from solving problems involving the new infrastructure.

Equity

In systems without problems in the irrigation system's conveyance infrastructure, users perceive greater equity (e.g. Caigua). They are happy with the improved or built infrastructure that serves users at both the head and tail of the system. This is because the lined canal, even if not fully lined, shortens the time it takes for water to arrive from the intake to the land at the tail of the system, so all users can enjoy their water rights under equal conditions[2] (e.g. Condorchinoka).

However, when the conveyance infrastructure features bottlenecks (e.g. San Roque-Capellanía, Naranjos Margen Izquierda), such as siphons that do not work properly because they do not have

2 Obviously, equitable distribution does not depend solely on the infrastructure's characteristics.

cleaning mechanisms, canals with insufficient capacity, or canals that silt up or break down, this prevents normal water distribution. So, users downstream from the facilities that work badly cannot receive the water they are entitled to.

Usage capability

Capability to use the infrastructure involves the facilities' functionality, expressed as the possibility of adjusting them according to distribution rules. In the cases studied, most facilities studied are simple enough that both men and women users are able to use them.

However, design and construction problems also prevent efficient use of some facilities, e.g. canals that silt up, canals exposed to floodwater damage, canals subject to erosion, siphons that overflow, intakes clogged by sediments, or intakes left hanging (as often happens with direct intakes). Silt traps that do not work, and poorly designed spillways, will be discussed in greater detail in section 7.2. The same happens when the infrastructure's capacity cannot conduct changing volumes of water (for summer and winter irrigation).

Ease of managing the infrastructure for both daytime and night irrigation is an important aspect for the operation – maintenance relationship. In all the case studies, facilities deteriorate because they are hard to handle, which increases their maintenance requirements. This is the case with gates, which work poorly and must be hammered into place, and consequently are not used. Therefore, it is essential to analyse the relationship between facility operating requirements and maintenance, in order to choose the right type of infrastructure. High maintenance requirements can cause difficulties in operating the infrastructure, as it breaks down progressively. Finally, operation is closely related to maintenance. A properly maintained structure will be easier to operate, and functional facilities will be regularly maintained, which is not common in the cases studied.

In summary, the management of the improved infrastructure involves:

- Users' possibility of controlling all aspects regarding operation and maintenance of the new infrastructure*: transparency and usage capability.*
- Users' knowledge that the facilities favour all system users fairly and enable each to receive the water they are entitled to. Also, new maintenance requirements for the infrastructure must be based on acquired or assigned water rights: *equity.*
- The possibility to use the infrastructure to irrigate each time, the year round, under different water availability conditions, in order to meet production and water use requirements. The facilities must also work properly and meet the objectives for which they were designed and built: *usage capability.*
- Mobilising community resources to maintain and operate the system over time according to distribution criteria for obligations that are deemed fair by users: *usage capability and equity.*
- The way water is distributed (single flow - rotation) and non-hierarchisation of canals: *conflict minimisation*.

An analysis of the different criteria on maintenance in the cases studied shows that some imporved facilities are not well adapted to management capability. When an irrigation system is not readily maintainable, management capability is decreased and it becomes a very fragile aspect, making it difficult to guarantee the system's sustainability.

7.2 TECHNICAL APPROPRIATENESS OF THE INFRASTRUCTURE TO MANAGEMENT CAPABILITY

To determine the infrastructure's technical appropriateness it is useful to examine the facilities' hydraulic suitability and quality of construction, in regard to users' capability to operate and maintain them. As it has been seen in the different cases, there are no great problems for users to operate the infrastructure, because the facilities are simple. However, some infrastructure problems must be mentioned that do make their normal operation more difficult and consequently lead to deterioration. Therefore, under this heading, I will first analyse the most important aspects influencing infrastructure operation. Then, I will consider the hydraulic aspects influencing the possibility of maintaining the facilities. To conclude, I will refer to technical aspects of design and construction contributing to management capability.

7.2.1 Main problems resulting in the infrastructure's poor operation

Of course, if the water flows freely, the infrastructure will have no operating problems and consequently there will be no additional operating and maintenance requirements due to improper operation. The cases studied show that design and construction problems that subsequently affect maintenance involve deficient use of such criteria as: *design flow rate, reaction of the flow at bifurcation points,* and *operation of the system as a network.* These issues are explained below.

Design flow rate

In classical engineering practice, design flow rate becomes a key data point to size irrigation infrastructure. Design flow rate is calculated on the basis of crop irrigation requirements. This figure is obtained by taking the crop's evapotranspiration, the crop coefficient and irrigation efficiency. This was the approach used to design the San Roque – Capellanía irrigation system. As a consequence, there is a capacity problem with the irrigation infrastructure.

An analysis of the cases studied shows that, on the contrary, the design flow rate should be determined by inter-relating various factors, such as: watering fields to prepare them, irrigation schedules (summer and winter irrigation), water uses, interconnection of water sources and water distribution mode.

Preparatory irrigation is a deep-rooted practice in small-farmer agriculture in the irrigation systems studied. For this type of irrigation, farmers use muddy water, taking advantage of the occasional high-water levels of the river during rainy season. They feel that this is one of the best ways to enhance their land's fertility and reduce the need to use chemical fertilisers. Similarly, in irrigation systems with salt problems, farmers like to apply high flow rates to their plots to wash the salt out. These practices entail direct requirements regarding irrigation infrastructure characteristics, specifically the design flow rate, which will determine facilities' physical capacity.

In the systems studied, there are two kinds of **irrigation schedules** - fully supply and supplemental- due to Bolivia's climatic conditions. During the dry season ("winter") system needs to deliver full requirements, and during the rainy season ("summer") it is supplemental to cover dry spells or increase yields. During the two seasons, different flow rates are used and this should be reflected in the infrastructure's design flow rate, which needs to satisfy both conditions. Ignoring these different seasons, which require infrastructure with the capacity to conduct both high and low flow rates, makes the design inadequate. This happened in the San Roque – Capellanía system, whose canals were made "telescoping" in size, in response to the design criterion of service area. For this reason, some canals overflow. This destabilises the facility, entailing greater maintenance requirements.

Another aspect determining the design flow rate involves different **uses of water.** In almost all irrigation systems researched, water has multiple uses. It is used for livestock, to wash produce and for irrigation. All these aspects together define the irrigation infrastructure requirements, in this case specifically the infrastructure's design flow rate, to enable the community to continue to use water all these ways, which are needs for their daily life.

Similarly, **interconnecting** water sources are another factor influencing design flow rate, since many irrigation systems use a main water source, plus other sources to increase the flow. For example, in Condorchinoka the water taken in through the infiltration galleries (underground water) is increased by surface water the users get by an intake in the river, plus water from wells. In this case, since the design did not consider the system's different water sources, the canals were built with limited capacity. During construction, users asked to increase the canal's capacity, making the walls less thick to compensate for the additional expense of expanding canal capacity.

Finally, the **water distribution mode** also determines the design flow rate. In the irrigation systems studied, water is distributed by a single, undivided flow, rotated at different levels, so the design flow rate must meet this requirement. Also, the minimum amounts for delivery flow rate are conditioned by the water's running from the head down to the most distant irrigated plot (the "tail"), and by the time that the flow takes to arrive (arrival time) to the tail of the system. These aspects are directly related to the infrastructure's network design characteristics.

Reactions at bifurcation points

The cases studied show that an important aspect to avoid reactions at bifurcation points is to properly locate distribution points. When they are located at a super-critical point in the water regime, flow fluctuations prevent them from operating properly. This is because, when the gate in the canal is closed to direct water to the field or to another canal, there is splashing of the water, which undermines the facility. This increases the demand for maintenance.

Flow fluctuations at distribution points, as well as wearing out the facility itself, interfere with equitable, transparent distribution. In the cases studied, since water is delivered by a rotated single flow, there have been no problems among users. These single-flow, rotation water distribution characteristics, as in these cases, make flow fluctuation analysis unimportant for distribution. This is different in large systems and those delivering water by multiple flows.

Operation of the infrastructure as a network

In the cases studied, due to flaws in facility design and construction, there are problems with the infrastructure's operation as a network. For example, siphons – which are catalogued as passive facilities – do not operate automatically, but require "flow control" activities to operate them and deliver water as desired. Users, through flow control, also keep the infrastructure from being damaged by overflowing, which would also increase maintenance requirements. When canals do not have the capacity to transport the flow desired by users, they become obstacles for the system to operate as a network, delivering water equitably.

Water delivery characteristics in the systems studied (single flow, rotation) mean that distribution points are no longer active nodes, so they do not require regulation. They operate “open or closed” and no operator is required where a distribution point is located to make sure flow is not disturbed.

In the cases studied, the presence or absence of overflow spillways also affects the system’s operation. When there are none, users have to control water entry using the intake gate but it is not always possible to do this, especially when the intake is at a distance. The lack of overflow spillways exposes the infrastructure and irrigated area to flooding risks.

Additionally, the situation of facilities and infrastructure maintenance conditions (silting, erosion, breakage, cracking and so on) affect the system’s operation as a network. Consequently, there are users who cannot exercise their water rights.

To conclude, although the *infrastructure as a network* is a very good concept to analyse hydraulic suitability, the cases studied show that the water distribution characteristics (single flow, rotation) the design and construction of active facilities, such as distribution points, are not so important in enabling the desired flow rate.

7.2.2 Between common sense and the obvious: Main design and construction limitations restricting manageability

The case studies reveal that building infrastructure in mountainous areas requires a lot of technical ability. Many works of the irrigation systems studied work perfectly and don’t have design problems and construction. However, in some cases, analysing the usage requirements for the facilities constructed reveal that in some works there are poor sizing, a tendency to silt up, non-completion, wrong siting, irrelevance, exposure to risks and bad quality, all of which decreases their hydraulic suitability. Consequently, users have less possibility (management capability) to satisfy maintenance requirements.

Sizing of facilities

Sizing analyses mainly width, height and weight of facilities, in regard to maintenance possibilities. Deep canals and other facilities make it hard to shovel out sediments, making this work hard for users. For example, in the Caigua system, conditions are not appropriate for cleaning out the siphon chambers, because they are so deep. Consequently, the possibility of proper maintenance is closely related to sizing.

First reflection

> Proper sizing of facilities, taking into account the possibilities of different family members to perform maintenance conveniently, will increase their likelihood of being maintained.

Sedimentation

A common problem in irrigation systems is sedimentation, especially in mountain rivers, which makes facilities require continual cleaning if they are to work properly. In the cases studied, the catchment facilities silt up (e.g. Naranjos Margen Izquierda and Caigua). This situation obliges users to clean out sediments continually for the intake to work. Otherwise, they have to build a rustic approach canal to lead water to the intake.

There is also silting in facilities located on river banks, when the river floods, as in the conveyance canals of the Naranjos Margen Izquierda and Caigua systems, which have this problem all the time. In the San Roque - Capellanía system, users have increased the height of the protection wall to prevent flooding from harming their facilities and irrigated area.

Projects located at the foot of mountain slopes are also exposed to sedimentation, as shown in the case studies of Naranjos Margen Izquierda and Caigua. Another cause for sedimentation of facilities is insufficient gradient, as happened with the gallery and conduction canal in Condorchinoka and the Naranjos Margen Izquierda system, where to gain head and irrigate a larger area they built the conveyance canal and main canal with very low inclination slopes.

Second reflection

> Minimising sedimentation by facility design and construction will enhance their hydraulic suitability, making them more functional and reducing maintenance requirements.

Non-completion of construction

The cases studied show that complete construction reduces maintenance demands. Although this would seem obvious, many facilities are not completely designed or constructed, as it has been seen in the case studies. For instance, lacking or badly constructed filters (without graduation) in infiltration galleries let the openings clog with sediments and interfere with operation, is the case of Condorchinoka irrigation sytem. There are also intakes without any buffering structure downstream from the weir, which is undermined, as is the case of San Roque - Capellanía.

The lack of siphon sand traps and surge chambers leads to plugging is the case of Naranjos Margen Izquierda irrigation system. Moreover, silt traps without any bottom gate or which do not work properly require manual cleaning, which is hard work for users (e.g. Caigua and Naranjos Margen Izquierda). Finally, protection structures (gabions, crown ditches) are an aspect that is often overlooked in designing and building irrigation infrastructure (e.g. Condorchinoka, Caigua, Naranjos Margen Izquierda).

Third reflection

> Complete design and construction favours facilities' hydraulic suitability, making them more functional and reducing operating and especially maintenance requirements.

Irrelevance of facilities

A facility is irrelevant when it is not functional (effective) and fails to cope with the adverse conditions posed by the natural environment, such as landslides, sedimentation, or erosion. The cases studied show many irrelevant situations. For example, in Condorchinoka a creek empties directly into the canal, breaking down the canal's concrete surfaces by sediment impact. In San Roque - Capellanía the canal is tapered telescopically, so users have to increase its carrying capacity by raising the edges with stones and sod, but even so the water overflows, jeopardising the canal's stability. In Caigua the flooded purge chamber in the siphon corrodes the valves and other metal fittings.

Moreover, wooden gates in zones with changing climates swell and cannot be operated (e.g. Caigua and Naranjos Margen izquierda). Another mistake is to locate open canals next to river banks and at the foot of hillsides (e.g. Naranjos Margen Izquierda and Caigua), which makes them prone to clogging, calling for heavy labour investments to remove sediments, and in danger of destruction.

In the case of direct intakes that do not operate or operate only partially, river flow is highly fluctuating (from powerful flooding down to minimal trickles). The flow also tends to take changing directions according to the river's characteristics. Therefore, in rivers over 50 m wide, direct intakes are normally not advisable. This is because, during the dry season, they require heavy maintenance work and, during the rainy season, they can be operated only when the water level reaches the facility (e.g. San Roque - Capellanía). Direct intakes can be constructed only when there are exceptional conditions, such as when the river flows continually at the intake site and the riverbed is stable, preferably bedrock. Under these conditions, it is best to place an intake with a spillway or orifice along the flow direction, since this placement will not alter the river course geomorphology. However, this will all depend on topographical conditions.

Fifth reflection

> The relevance of a facility to adverse operating and environmental conditions increases users' maintenance capacity.

Exposure to physical risks

In mountainous areas, irrigation facilities are very vulnerable to physical risks. This is because watersheds expose them to conditions in which heavy erosion and sediment transport prevail. In the cases studied, rivers run at steep slopes, with major differences between high and low flow rates. During the rainy season, rivers are overflowing and during the dry season runoff volumes are slight. In some cases, the rivers dry up, except for Naranjos Margen Izquierda in this study.

In the watersheds studied, erosion is heavy due to flow velocity, generating strong shear stresses on the riverbed's surface and granting the flowing water great transport capacity. Erosion of the bottom excavates it ever-deeper, increasing the height of the sides, which destabilises banks. Catchment facilities are affected because they are generally located in areas where most of the river basin's eroded material is deposited. Moreover, the watercourse changes continually, in the barely sloping alluvial plain. The lower capacity to transport sediments deposits them in a disorderly fashion, leading to continual changes in flow direction and affecting facilities' operation.

Another risk to which facilities are subject in the cases studied is that they are exposed to frequent landslides. This sloughing not only affects surface facilities but also underground canals. Therefore, studies must always be made of the soil's substrates and grain size. It is also wise to locate water tables.

Through this all, it is possible to adopt preventive measures, such as organising drainage, establishing anchors and biophysical slope protection (above and below facilities). Such aspects are hardly considered when building. For instance, in the case of Naranjos Margen Izquierda and Caigua excavation at the foot of slopes has significantly decreased the lateral support for the materials comprising them, with the consequent risk of sloughing. The case studies show how high risks can be for these facilities. However, although engineers may give this aspect some consideration, it is not done in any great depth, which has serious consequences as protective structures are required, or extra maintenance requirements. Unfortunately, building protection structures entails additional investment, which cannot always be justified, because there are national parameters for irrigation projects. In the cases studied, the limitations on investments (indicators such as US$ 2500 per additional hectare of land irrigated and US$ 4000 per family benefited) condition costs of designing and constructing infrastructure in mountainous conditions. So, the risks of landslides caused by building irrigation canals and other facilities, lost investments of money and labour due to natural landslides, and costs per hectare to control erosion / landslides, including costs of protecting the irrigation infrastructure's area of influence, are not considered in designing and building irrigation systems, as has been seen in the cases studied.

Sixth reflection

> For facilities to operate optimally, with minimal damage, it is important to consider physical risks to which they are subject, designing and building protective structures to reduce maintenance requirements.

Quality of workmanship

Facility quality is one of the aspects that users have complained about the most while building them. Although building companies' contracts clearly stipulated technical quality specifications, these were not met, for different reasons, as it will be examined in a subsequent section.

Among the main problems that have hampered quality have been: 1. Inadequate curing of cement, mainly in the *altiplano*, since the concrete has been poured at low temperatures. 2. Non-compliance by building companies regarding the concrete mixture established in the terms of reference. 3. Installation of poor quality gates, which do not work properly, are therefore misused and destroyed. 4. Failure to use formwork on the outside of the canal, which gets dirt into the mix and consequently leads to cracking and leakage.

Seventh reflection

> The quality of the work, expressed in its durability, will decrease maintenance requirements and enhance management capability.

All the reflections derived from the analysis of the different case studies may be considered basic and obvious, from an engineering standpoint. However, they are overlooked, institutionalising a type of design that ignores elementary factors and common sense, such as taking local physical features and users' socio-economic and cultural conditions into account.

7.2.3 Main infrastructure design and construction criteria to contributing to maintainability

The case studies have shown that infrastructure has been turned over to users with design and construction constraints from a technical and practical standpoint, with well-founded complaints by users. Deficiencies in design and construction require adaptation of facilities through interactive design but, since this does not happen, facilities have operating problems and especially maintenance issues continually. The continual need for adaptation can even be confused with maintenance, mistakenly accusing users of being unwilling to perform maintenance. In the cases studied, many limitations regarding maintenance are due precisely to the fact that the facilities are not suitable. Before commissioning them, they should have been adjusted to local conditions.

The case studies show that facilities have better hydraulic and constructive suitability and consequently greater capacity for user maintenance when the following design criteria have been taken into account: requiring a lower number of ancillary structures, less earth movement, inducing canal stability, and designing width and height of facilities to enable convenient cleaning and repair work. Also, while building, it is important to use stone masonry when materials and labour are available in the area, avoiding the use of concrete in areas with extreme temperature fluctuations.

The analysis of the research cases has also identified the following technical criteria for design and construction, to contribute to users' maintenance capacity: 1. Durability (good-quality work), 2. Functionality and flexibility (facilities that operate properly) and 3. Safety (infrastructure that is not subject to the risk of being destroyed).

To make these criteria evident, a series of technical guidelines have been identified to be considered in designing and building these types of improvement project (see appendix 4). A summary is presented in table 7.7.

All these criteria together, resulting from lessons learned in the different cases, are so simple that they should go without saying, but since they are repeated mistakes in the different systems and are also determining factors in their sustainability, they call for serious, sincere consideration so that engineering will not only prioritise technical and mechanical design aspects, but at least propose sustainable scenarios: *Does the infrastructure as built fit in with the natural physical environment and meet users' local needs and capabilities?*

Table 7.7 Technical criteria for designs and construction to contribute to management capability

Durability		Functionality and flexibility		Safety	
Design criteria	Construction criteria	Design criteria	Construction criteria	Design criteria	Construction criteria
Use gradients that will not erode the canal floor and walls	Use concrete in high-velocity sections	Define the design flow rate as a function of: farmers' demand for water, availability of source water and system distribution mode, avoiding overflowing, which endangers project stability.	Place rubber along the canal groove so gates can seal tight.	Leave an edge free to prevent overflowing that damages facilities	Construct protective structures to shield infrastructure from flooding and sloughing
Use slopes that will not encourage settling out of suspended solids	Pour canal bottoms and sides together, if it is not possible pour the bottom and then the walls	Additional other uses of the canal		Design gradual transition stretches, especially in the transition from lined to dirt canals	Bury pipes to protect from the impact of landslides, and the passing of vehicles, people and animals
Respect the hydrodynamic flow of the water	Place cracking joints at adequate intervals (3-6 m)	Avoid design of ancillary structures on curved stretches of the canal			Build on slopes following the original profile, avoiding construction on fill.
Consider other uses that people make of infrastructure	Place expansion joints (waterstop) when two different construction materials are joined	Before a pipe or siphon, design the entry chamber			
Avoid splashing that, in the long run, will compromise infrastructure stability	Construct berms to keep coarse material from entering the facilities and assure side wall stability	Design rod or flap type gates no larger than half a metre square. For larger gate sizes, design sliding gates no larger than one metre square.			
Design firm gates that will stand up to people's use and misuse.	In cold areas, consider the concrete pouring time.				

Recommendations from fieldwork

7.3 PRODUCTIVE APPROPRIATENESS OF THE INFRASTRUCTURE IN RELATION TO MANAGEMENT CAPABILITY

The appropriateness of the infrastructure economically and for agricultural production will be analysed in three ways. First of all, the influence of small-farmer production approaches on production scenarios will be compared. Subsequently the effects of the improvement of the infrastructure in relation to users' new income. Lastly, demands of the maintenance of the irrigation systems will be compared them with new user income

7.3.1 Production scenarios are moulded by the small farmer's approach to production

In preparing the irrigation projects studied, engineers took agricultural production into account only for the economic assessment, to justify the investment. The case studies show that professionals forecast a production scenario expressed in areas to irrigate, crops, yields and planting calendar, which has not been followed once the irrigation project was implemented.

This is because they did not take into account that local knowledge is expressed concretely in more than just the growing calendars, crop assortments, technical inventories[3] and small farmer practices. Designers did not consider the behaviour of farmers who have to respond to a heterogeneous, diverse environment, and for this purpose establish a production strategy to minimise their farming risks, based on their own approach, to mould production scenarios. This means that "designing" future agricultural production under the irrigation system requires incorporating other elements. To address the issue of agricultural production in irrigation projects with an eye to making them socially, technically and economically sustainable, requires considering aspects related to rural livelihoods, involving production goals and environmental conditions. The cases studied show that farmers set two goals for agricultural production: food security and marketing their produce.

The production goal for self-supply (e.g. San Roque - Capellanía) aims to assure agricultural production to cover family consumption and then market any surplus. This aims primarily to meet basic nutritional needs and then to access certain goods and services not produced on the farm, which must be purchased (clothing, school supplies, candles, etc.). From this perspective, water is used to irrigate self-supply crops.

In Naranjos Margen Izquierda and Condorchinoka, the goal of production is for market produce. Therefore, they produce and diversify into cash crops, and users carry out a set of productive activities to enable them to take advantage of higher prices and better times to sell, in order to get the highest possible income. This goal entails the use of improved technologies and inputs. It calls for more available water, due to improved infrastructure, to generate a scenario of growing driven by market demand.

However, irrigators' livelihoods also have intermediate aims, such as in Caigua, where they combine the two approaches of food security and growing for market. This approach, with greater water availability, will generate a production scenario with a combined assortment of crops, a growing calendar in accordance with these goals, and areas planted with both types of crops.

3 Technical inventories are all the activities that farmers do to produce a crop on their plots.

Production objectives are also conditioned by the resources available to the family, their resource usage strategy and environmental conditions. The family's resources include irrigation water, land, labour, and capital, for agricultural production. The case studies have shown that the usage strategy and magnitude (quantity and quality) of resources mould a given production scenario as a function of the production goal.

The research cases reveal that **water** provides greater production security and that users pursue a series of strategies to obtain greater productivity from their water use. Productivity is expressed in many ways, as the concrete outcome of applying diverse production strategies. Some of the strategies applied singly or jointly include diversifying crops, staggered planting dates, increased irrigated area, reducing irrigation to a productive optimal dose, companion cropping, adapting growing areas to water availability and adapting species and/or varieties to water availability. Farmers' vision of the irrigation systems studied and most irrigation systems in Bolivia, is to expand available water to a greater growing area, which reduces yield per land unit, but generates greater production per unit of water, i.e. achieving greater productivity from the water.

Another central element in the case studies for changing production scenarios is the availability of **land** suited for irrigation. For example, in the Caigua system, there is a lot of land, for which irrigated area could expand with more available water. On the contrary, in San Roque – Capellanía they have no more land available in order to expand the area under irrigation. So, on the basis of arable land available in the system's area of influence, farmers turn to different strategies for access to and usage of land, expressed in different ways such as share-cropping, renting and taking land under antichresis (land in exchange for an interest-free loan) arrangements.

Moreover, more available water normally requires more **labour** for farm production. Normally, family members' labour input is not sufficient (in most cases studied except San Roque – Capellanía) and farmers have to involve more or even hire labourers during certain stages of the growing cycle. If there is not sufficient labour available in the irrigation system, diversification and intensification of agricultural production is not possible. Labour usage strategies depend on production goals and available resources, with different forms of access, quantity, type and work modes. According to the size of areas under cultivation, two types of labour are used: family members when the growing area is small and hired hands when it is large. When family labour becomes scarce and there is no money to hire workers, they use labour trading (*ayni*), sharecropping and "tithing" (*diezmo*), as seen in most case studies.

Access to **technology** is quite important to mould a given production scenario, especially improved "irrigation infrastructure" that makes more water available. First of all, farmers have more production security and consequently this decreases the risks representing agricultural production. In the cases studied, all improved irrigation systems have enabled greater production and consequently greater economic income.

Another important factor influencing how production goals are met is **capital,** to purchase inputs, tools, pay for hired hands, access technology, expand and diversify their crop assortments. For example, in Condorchinoka and Naranjos Margen Izquierda, users invest large amounts of money in agricultural production, mainly for market. On the contrary, if users do not have enough capital, it will be difficult for them to diversity and intensify their irrigated cropping, as is the case in San Roque Capellanía.

Achieving objectives also depends on the environment, including the **economic environment,** one of the most influential in the production scenario. The cases studied have shown how expanding areas under irrigation is directly related with greater market demand for certain types of crops. This means that market demand is yet another factor determining the increase in irrigated areas, with certain required crops. At the same time, introducing another assortment of crops entails a new agricultural schedule. For example, in Caigua the introduction of vegetables in response to growing market demand, promotes in turn changes in traditional production objectives.

Increased irrigated area and changes in crops planted is closely related to greater demand for capital to invest in production. The capacity to invest capital determines the power to purchase inputs and labour to plant new crops. Thus farmers in the irrigation systems of Condorchinoka, Naranjos Margen Izquierda and Caigua are willing to invest more capital in their crops, but not in irrigation, although irrigation makes greater production possible, which generates greater income. Selling merchandise well provides one's own capital, especially when they sell produce from "winter" planting, as in Caigua.

Moreover, access to, distance from and size of market fairs determines market insertion, and in turn the degree of market insertion directly influences changes in production scenarios. For example, the presence of road infrastructure and short distance from larger markets makes it possible to quickly and effectively transport produce. It also provides access to information about price fluctuation in different fairs, which makes it possible to make quick decisions about selling merchandise, as in Condorchinoka. On the contrary, irrigation systems that are far from important markets, such as San Roque - Capellanía, have difficulties selling their products.

Increased irrigated area is not automatic, either, but is conditioned by the **socio-cultural environment,** which provides the context for social relations and cultural perceptions regarding the use of water. For example, in some irrigation systems studied, they let new users join, because they have a more collective vision of resource usage, whereas in other systems there is more restriction on membership, either because there is a tendency to apply more individualistic strategies, which makes inequities worse regarding access to and use of productive resources, or because users perceive that water available can not satisfy the needs of a larger users' group.

Another important aspect in the cultural setting is migration. The irrigation systems studied feature different types of migration. In San Roque - Capellanía most migration is temporary, to work in department capital cities, other provinces and other countries. This enables migrants to acquire new knowledge about irrigated agriculture, which they introduce in their home villages. However, systems may also receive migrants, as in Caigua which introduces not only new crops, but also irrigated agriculture practices because there was no irrigation in the area before.

As for the **natural physical environment,** elements have been identified to characterise it, in terms of topography and climate. The *topography* of each irrigation system defines the location of the infrastructure and crops, enabling or limiting expansion of the agricultural frontier or area under irrigation. Irrigation systems with rugged terrain such as Caigua and Naranjos Margen Izquierda require engineering to expand the area under irrigation. To expand the irrigation zone requires building siphons or aqueducts to cross rivers and gullies.

The *climate and natural phenomena* are an element conditioning crop development. Under good climatic and irrigation conditions, such as in Caigua, agricultural calendars change, and as many as three crops a year can be produced. The climate also determines crop adaptability and consequently the range of crops selected. In this way, crop yields are affected by the climate. In most cases, farmers try to plant "winter" crops as soon as possible in order to harvest when prices are high, but these crops may be harmed by frost or snow during the winter. Most farmers also plan to plant during the summer, to avoid crops rotting from the rains.

To conclude, there are several factors involved in defining production scenarios. Water is one factor among the many analysed above. Overlooking the analysis of these different factors, as unfortunately has been done in the cases studied, makes production scenario forecasts unattainable.

Production scenarios in the different case studies are the result of individual decisions by each irrigating family (although often embedded in collective decision making and shared management opportunities and practices), on the basis of their available resources, which could improve if they receive "support" for the production process, once the irrigation systems are renovated, so users can improve their family well-being and have the money they need to cover renovated infrastructure requirements.

7.3.2 Effects of irrigation infrastructure improvement on agricultural production

The different case studies show that with improvement of infrastructure and all the strategies explained above, users of the irrigation systems improve the agricultural production conditions and consequently their economic income. In all cases the immediate effect of the improved infrastructure is the increment of the irrigated area and consequently more production and more income. Also users improved their income because they changed their crops, they produced more crops for market, and in almost all the cases users decided to cultivate vegetables. In Naranjos Margen Izquierda users opted for peanuts, that brings them better economic revenues.

Users following their own production strategy have been able to improve their economic revenues as it is shown in Table 7.8. The table shows that increased average economic income per family is more than 100%. This demonstrates that users were able to achieve their production objective and improve their living conditions. That is why users showed satisfaction in spite all the problems that there have been in the process of project implementation. Nevertheless, although incomes doubled, they are still low, especially in Condorchinoka and San Roque Capellanía. The problem is that the prices of agricultural products are very low, and peasants subsidise the economy of the rest of Bolivia[4]. Especially vegetables[5] and fruits bring a very low price, but users prefer these crops because they generate continual economic income.

4 80% of national consumption is from peasants' production.

5 Usually, during the year tomatoes bring a higher price than other vegetables; for a reference 1 kg of tomato costs US$0.20, and 25 oranges costs US$0.36.

Table7.8 Net Value of production before and after project

Irrigation System	Phase	Area (ha)	Net Value (US$)	Income / family (US$)	% Increased income
Condorchinoka	Before project	29.0	9288	258	
	After project	54.0	22,365.34	533	106
San Roque Capellanía	Before Project*	-	-	-	
	After Project	31.0	12204.35	516	-
Naranjos Margen Izquieda	Before Project	100.0	30922	1191	
	After Project	140.5	105006.52	3182	167
Caigua	Before Project	60,0	27.076,80	322	
	After Project	155,0	75.971,67	904	181

* The San Juan del Oro Final Design project document does not have this information

7.3.3 Household net income and labour availability

In almost all the case studies, the manpower requirement for maintenance has diminished especially with permanent reconstruction of intakes. This situation is very gratifying for users and they show a good degree of satisfaction. Still, people are also reluctant to respond to maintenance activities

Table 7.9 Requirement of family labour for maintenance before and after projects

Irrigation System	Before workdays/ family/year	After workdays/ family/year	% Decrease
Condorchinoka*	1	1	-
San Roque Capellanía	30	8	73
Naranjos Margen Izquierda	78	19	76
Caigua	15	5	67

*In this irrigation system there was a gallery before the project, so the new channel continues demanding in total a day of maintenance per family per year

The table shows that the manpower requirement for maintenance decreased by 2/3 and even 3/4 (67 to 76%). If manpower is valued economically, one can deduce that these costs decreased for users, and one of their main objectives has been achieved: to reduce manpower requirements and to have greater water security.

Now it is important to analyse the other aspect involving maintenance, the economic costs. In strictly economic terms, a user can afford the maintenance fee as long as the fee is smaller than his or her additional net income (prior to paying the fee) that is attributable to irrigation infrastructure. In other words, as long as the maintenance fee does not leave the user with less net income than they would have received in the absence of the new infrastructure, the fee is economically affordable. Taking into account this premise in the cases studies, users can afford maintenance fees, as shown in the table 7.10. The maintenance fee, considering labour and inputs, is only 2.4 to 6.7 % of irrigated agriculture income. These costs are substantially lower considering only inputs (0.11 to 1.69%) and not labour.

Looking at Table 7.10, is it realistic to expect that low – income farmers can afford to pay the costs of maintenance? Comparing irrigated agriculture income with the income that each family needs to live (INE 2002), in one case earnings are higher, but in the other cases, the income covers barely 20 to 50% of necessary family income. In order to cover these needs, families develop other strategies to survive, one being migration. This explains why migration from San Roque - Capellanía is high.

Table 7.10 Ratios of income, maintenance cost and minimum for basic needs

Irrigation system	Family income US$ irrigated agricul-ture	Additional family income US$ irrigated agriculture after project	Required mainte-nance input with labour / family US$	Required mainte-nance input without labour / family US$	Relation income / input with labour %	Relation income / input without labour %	Necessary family income / year	Ratio, Family income/ Necessary family income
Condorchi-noka	414	156	25	7	6	1.69	924	45
San Roque-Capellanía	329	Without information	22	2.8	6.7	0.85	1386	24
Naranjos Margen Izquierda	3182	1991	75	3.7	2.4	0.11	1386	-
Caigua	904	582	32	1.1	3.5	0.12	1786	51

The case studies have demonstrated that the possibility of collecting fees was low. Allowing for this situation, support entities established an organization with by-laws and regulations to enforce this requirement. However, as these had no validity, non-payment went un-punished. In none of the cases was the topic of fees discussed in a users' meeting. When they discussed maintenance, they talked about organising maintenance activities regarding manpower only.

7.4 DESIGN PROCESS

The design process covers all activities done in each irrigation system researched, from project identification through the final delivery of facilities to system users. Analysis of the design process has made it possible to identify key points in the intervention that have strongly influenced whether users will have the capability or not to manage the improved infrastructure. These issues are discussed below.

7.4.1 Constraints in project intervention approaches that prevent them from developing management capability

To analyse management capability, it is necessary to consider how institutions implement irrigation projects in practice, from the water management standpoint. The case studies show two approaches: 1. The classical approach, in which “design and construction” are grounded in only technical parameters. 2. The approach based on recognising management, but which fails to combine hydraulic expertise with the way the facility will operate within the economic-productive and socio-organisational context. In other words, to turn knowledge about irrigation management into concrete infrastructure design.

To see how irrigation projects approach management capability, which will be reflected in the way the improved system is commissioned, the way that these two approaches address the issue of distribution-operation and maintenance will be analysed below.

Regarding design or planning of future distribution and maintenance of systems studied, it is possible to see that little importance is granted, in general, to such planning during the project formulation stage. For example, the Capellanía-San Roque system was designed under the classical approach, leaving issues regarding distribution design for the post-project situation. The irrigation system’s water management characteristics were not even considered. In the remaining cases (Condorchinoka, Caigua and Naranjos Margen Izquierda) designed on the basis of management recognition, future distribution was proposed, at least superficially. No analysis was made of the projected infrastructure’s requirements for distribution-maintenance or users’ capabilities to meet them.

In San Roque - Capellanía the technical approach was emphasised, so design centred on infrastructure, disregarding the other aspects. The design elements – climate and water – were the main drivers of design, because this information determines water supply and demand, through a balance to cover crop water requirements, and finally to determine design flow rate to size irrigation infrastructure. This approach considers other design elements such as terrain, soils and socio-economic aspects influencing possible crops.

In other cases (approach 2), although engineers considered water management as the starting point, future water management was proposed as part of technical assistance, after the project has been finished. Evidently, planned training or technical assistance aims to adapt users to the infrastructure as built. This mistaken approach to management, taken out of the local context, prevents users from appropriating of the projected management system. Moreover, the cases show that infrastructure design did not analyse the possibilities for users to maintain the facilities, either. Whether the project would be maintainable was ignored. Aspects regarding physical risks for facilities, and their implications for maintenance, were also ignored.

Finally, there is little or no relationship between the proposal (design document) and current practice, in both distribution-operation and maintenance, for one of the following reasons: 1. No design. 2. General recommendations were made, to be focused after work was done. 3. The proposal was made on the basis of conventional technical assumptions or concepts, without taking into account existing farmers’ practices or requirements.

7.4.2 Users and engineers: failures to communicate during design phases

The irrigation project concepts analysed in the case studies show the approach of working by phases, as shown schematically in the following figure:

Figure 7.2 Phases in project intervention

In the cases studied, each stage evidently has its own objective, which does not mean that the summation of these goals has been coherent with the overall project aims. This way of conceiving of a project tends to prevent any sharing of responsibility for project outcomes, aside from partial responsibility for each stage. So, the goal of the first phase (pre-investment) is to bring out the final design document, with the future irrigation system's characteristics. The goal of the implementation (investment) phase is to build the facility, and the support phase is to get the constructed irrigation system going, by setting up an operation and maintenance manual and by-laws and regulations to orient the irrigators' organisation.

On the contrary, from the users' standpoint, irrigation system improvement is an ongoing process, involving engineers at one point to help them meet their goals, which vary from one project to another. (In some cases, the aim was to enhance water availability, in others to make water available). This process is "ongoing" because, as shown in the cases studied, when designing the infrastructure, users are already thinking about how to distribute water in the system. This is proven because they complain about canal capacity while canals are being built.

These two approaches by users and engineers coincide in some parts of the design process and in others do not, as analysed below:

First phase: engineers want the final design document while users want to obtain financing

In the first phase, while preparing the final design document, engineers and users had different aims. Engineers wanted a final project document, to show how the improved irrigation system will be. Paradoxically, the users' goal was to get financing to improve their irrigation system. During the first phase, the economic constraints that prevent a thorough assessment or establishing the conditions to involve users in decision-making (which would take longer and cost more), led engineers (in most case studies) to work with a few individuals and/or groups. Indeed, in San Roque – Capellanía the designer went practically un-noticed during the study up to the final project design phase.

In view of users' limited participation in defining such important aspects as future infrastructure, future water management and subsequent production scenarios, this collective viability analysis and planning period has not had the expected scope in most cases researched. However, users have not called for greater influence during this period, either, or found out anything about project contents, because their interest has focused on getting a project document to negotiate funding, regardless of the document's quality. Interviews with users also emphasise an important aspect regarding (non-) "ownership" of the project by users during the design phase. It would seem that users are not interested in taking part actively in the project design phase, despite their strong demand for the project. However, another aspect that may be more important than a lack of interest, is that the farmers internalise the image that *"a project must be made by an engineer"* and that users do not feel able to provide technical criteria in response to engineers' proposals. It would also seem that engineers overestimate their own importance, having plenty of technical expertise and "modern tools" to show the villagers, but very little field experience or an attitude with little openness to listen to farmers' criteria regarding projects.

This impossibility of interaction among engineers and users in preparing the final design keeps users' expectations for the new or renovated system out of the design, so the contents are not "theirs". However, the final design document is the basis for financing and building the infrastructure. Nevertheless this budget, supposedly for a consensus-based infrastructure, does not provide for subsequent design changes, as it will be seen below.

Second phase: engineers want to construct / users want to design and construct

From the standpoint of engineers and funders, implementation is the phase that materialises the final design document. Case studies show that users see this as the phase for *discussion and construction*, since the implementation process is when users can see facilities' layout, sizing, location, exposure to risks, and quality. During this period, users begin to feel ownership of the project. Unfortunately, from a project phase standpoint, this is no time for design. This mismatch between engineers' *"construction phase"* and farmers' *"design and construction"* aspirations denies farmers the flexibility they would need to influence decision-making, because the building company that won the contract based their winning bid's economic calculations on the blueprints and technical specifications in the final design document.

This situation creates uncertainty regarding projects' characteristics, depending on the building company's flexibility, the supervisor's skill in adapting the project and irrigators' negotiating power. In the cases studied, building companies have evidently failed to pay due attention to farmers' complaints, so facilities have failed to meet users' needs. However, in other systems where users had greater negotiating power, the outcomes have been better. For example, in the Caigua irrigation system, when the supervisor failed to respond to users' complaints, they turned to the funding entity (FDC) to make their demands heard.

Clearly, failure to involve users in preparing the final design document results in infrastructure that meets engineers' expectations, but not users'. In the cases studied, facilities have many problems affecting quality and maintainability. All these aspects could have been mitigated if users had actually taken part in the pre-investment phase, when the irrigation project was drawn up.

7.4.3 Failures in the period of construction are source of delay an additional work

The case studies show that one of the greatest problems in the construction period has been that building companies' work schedules have not matched those of users. As usual, the companies were under pressure from funders, demanding contractual compliance. This made things tense with users, who had their own pace and priorities. In general, in all cases studied, users have responded and complied with established workday input requirements, in some cases more than agreed, when they were un-apprised of the actual contribution agreed to[6]. Although some systems

6 In most cases, support service was provided after the facilities were built. This prevented users from being fully informed about the work input they were expected to contribute.

have had problems with work input compliance, none of the companies allowed users to skimp on this responsibility.

Another problem during construction, since building companies were hired late, was that they started working at a bad time of year, in some cases preventing users from planting for an entire season or more. In different irrigation systems, users continually asked to be able to use the canal and water their crops. Priorities clashed: companies wanted to finish as soon as possible to meet their deadline, whereas farmers wanted to grow crops and feed their families. The untimeliness of construction periods and excessive time overrun meant that building ran into the rainy season, causing multiple problems and forcing users to work more than calculated. In many cases (e.g. Caigua, San Roque-Capellanía and Condorchinoka) material such as sand and stone had been gathered and was washed away by the river's floodwaters.

Although users were part of the construction process, they have had objections to accepting finished projects. It has even happened that users have refused, and the supervisor and company have had to prepare for delivery repeatedly (e.g.Naranjos Margen Izquierda, Caigua, San Roque Capellanía). Users have objected to final reception because of the company's failure to meet users' demands regarding infrastructure.

Workmanship, understood as lasting quality, suited to users' needs, has largely depended on the company's quality. One continual complaint by users has been unavailability of equipment and machinery to meet construction needs. Companies awarded the contract have not provided the equipment they listed in their bid. It has also been common in the cases studied that building companies tend to fall short of technical specifications, especially in regard to material mixes. Users always complain about contents, which they know something about, having worked as masons. Another failure has been the quality of gates, many of which were substandard. This keeps them from working properly, requiring additional activities to make them work, including piling up sod, knocking them open and/or closed, etc.

Moreover, to reduce costs they hired very young professionals and in some cases master brickmasons as the "resident engineers" (e.g. Condorchinoka). This meant that there was no one qualified to actually interact with the project supervisor, or discuss users' complaints with them and make decisions.

Another aspect that has affected infrastructure quality is that change orders have been issued without thinking about how they affected the rest of the infrastructure. In Naranjos Margen Izquierda, accepting the prolongation of the lined canal in the irrigation zone using the money that was for intake and conveyance canal protection, jeopardised the stability of these facilities. This is one example of the many reasons making the construction period quite tense. Although users were concerned with providing their established workdays (to reaffirm or earn water rights), constant annoyances did limit compliance as time wore on. In this situation of constant tension about the way users had to deal with the company, interference with growing produce and food, and the prolonged construction and reconstruction period, users settled for many flawed construction details just to get it over with. These flaws have surfaced as the facilities are used.

7.4.4 A rope around the neck: project eligibility criteria

As for designers or consultants, it is readily apparent and, to some degree, pre-established institutionally or even politically at the national or external funding level, that projects are justified premeditatedly. This almost directly affects infrastructure proposals for irrigation projects. The way to justify irrigation investment through increased areas and financial-economic profitability has been seen to encourage designers to have to balance facility design and the future production scenario, to make the project “eligible”. This has been obvious in the cases studied, because increased farming area, number of users, and estimated investment amounts, are not well substantiated. Final design documents have little to do with real project implementation, as it is presented in the following table.

Table 7.11 Comparisons between the values of projected and actual eligibility indicators

Project*	Indicators	Eligibility criteria	Project estimate (Us$)	Real amount (Us$)	Difference %
Condorchinoka	Cost per additional hectare	Under US$ 2500.	2,386.64	3,021.12	27
	Cost per family	Under US$ 4000.	1,345.20	2,229.87	66
Naranjos Margen Izquierda	Cost per additional hectare	Under US$ 2500.	1869	4624	147
	Cost per family	Under US$ 4000.	3414	5675	66
Caigua	Cost per additional hectare	Under US$ 2500.	2207	3411	55
	Cost per family	Under US$ 4000.	4098	3858	-6

* As already indicated in chapter 4 the Final Design document of San Roque Capellanía is without this information

In all the cases the real cost has been higher than estimated, exceeding by 27 to 147%. Nevertheless, the real amount was not enough to build all the necessary works, for example the protection works. The fact that projects are justified on the basis of estimates as to how many hectares will be brought under cultivation by making more water available, establishing US$ 2500 per additional hectare as the ceiling for eligibility, is one of the tightest bottlenecks, because projects are planned in terms of a predetermined budget. That is, first they calculate how much water will be added, then how many additional hectares can be watered, according to the water balance study. Limited resource availability forces designers to skip many complementary facilities, such as protective structures, or skimp on capacity. All this then influences maintenance requirements, which as has been seen challenges low users’ management capability and consequently the improved system’s sustainability.

8 CONCLUSIONS

INTRODUCTION

Irrigation systems in Bolivia characteristically have less water supply than demand, even after improvements. This situation means that water management is an intense activity, forcing users to establish agreements and norms to make each irrigation system work. The case of Naranjos Margen Izquierda, which obtained adequate water, is rare. Irrigation systems in general and the cases researched in particular are user-managed. The Bolivian government invests very little, and has almost never spent any resources on water management, having relative influence only by regulating and creating norms for water management at the local level. The concrete management of each irrigation system is based on a series of user criteria that facilitate their operation, as outlined in Chapter 2. Water management is moulded by the larger environment, and economic, ecological and socio-cultural forces also mould irrigation management criteria. Users' recognition of these criteria and materialisation of them in operational terms enables them to manage their own irrigation systems in particular ways and consequently contribute to the sustainability of these local systems.

However, city dwellers' demand for food, and the need to ensure families' own self-supply, means that the economic environment plays a major role in local modes of organising and materialising water management. Expansion of the agricultural frontier and intensification of agricultural production for market have recently increased both water requirements and competition for more water rights to cover this need. This has promoted increasing commoditisation of water in some community systems, by different arrangements: purchase-and-sale, rental and lending of water. But generally there is no sale of water rights, only water turns (except for cases in which both land and water rights are sold), as in all the case studies. Often, this commoditisation process acts to the detriment of an un-monetarised reciprocity system, based on *ayni* and *minka* forms. At the same time, since commoditisation gives water and land an added value, it gives an economic boost to families with greater economic resources, creating potential social differentiation among families, that many communities struggle against in order to maintain equity in water access.

When irrigation projects introduce improved or new technology, this also affects water management criteria. Infrastructure is not neutral to such social aspects as water management. Therefore, intervention approaches that consider only technical aspects fail to meet the requirements for user-managed irrigation systems, as this research has shown.

Although there is currently an inclination by several institutions in Bolivia to introduce the socio-technical approach into irrigation project implementation, they have not yet found how to link social aspects with technical aspects, as demonstrated in the cases of Condorchinoka, Caigua, and Naranjos Margen Izquierda. That is, projects have been unable to combine the preparation of technical designs with the generation of normative, operational and organisational proposals that will grant users appropriate but sufficient capability to manage their irrigation system after the construction is finished. One way to achieve this aim is through management design. *Management design* is the array of normative, operational and organisational proposals involving: water rights, distribution and operation modes, maintenance and user organisation. The importance of water management design for infrastructure sustainability becomes evident when the *requirements* demanded by the water management infrastructure are analysed, as this study has shown.

The analysis of requirements sets the conditions for choosing a given structure and its characteristics. For facilities to be sustainable they have to be within limits compatible with users' capabilities[1], especially from the distribution-operation and maintenance standpoint, as proven by this research.

In most cases studied, although the final design documents have described future management characteristics, they are not related to the infrastructure's design per se. They are mentioned or described and often used as an argument for assuming that possible changes generated by project implementation can be assimilated by users. It has been disregarded that designing a system's management calls for even greater attention in cases of improvement or rehabilitation, as in the case studies. Engineers failed to take into account that introducing changes into the infrastructure entails a certain breaking of existing rules and norms, so this will call for users' willingness and capability. Therefore, irrigation management components must be analysed, to use this information as a basis for designing future water management and irrigation infrastructure.

No case studied featured any analysis of the *inter-relationship between facilities' design and management components* or the consequences of proposed improved facilities for management and vice versa. The project documents that did address future system operation made only superficial statements about operation and maintenance, leaving this responsibility for the support phase. In the case studies, irrigation infrastructure was designed in isolation from water management design. It was not considered that any change made in irrigation infrastructure would influence water management, affecting water rights, water distribution, irrigation system maintenance and organisation.

Reviewing the activities done by support entities in the case studies, the purpose of support was for user organisations to be able to assume new operation and maintenance responsibilities. To meet this aim, operation and maintenance manuals were prepared, which were of no practical use for users. The effects or results of the intervention would have been more effective if the proposed facilities' requirements had been analysed regarding water management components. If these new requirements had been matched with each irrigation system's management criteria, this would have strengthened management capability and would consequently have promoted the sustainability of the new infrastructure and the system in general.

The cases studied show that an initial error was made by skipping the analysis of "*distribution and maintenance requirements*" more explicitly in each case. This omission not only failed to create a platform for discussion with users, but forestalled any analysis of distribution-operation and maintenance capability as central design elements.

In this context, the purpose of this research has been to develop concepts contributing to irrigation system design, starting with the question *What characteristics of irrigation infrastructure make it appropriate given the management capability and social and productive settings of farmers in the Bolivian Andes, and how and why have the designs developed by irrigation improvement projects been reshaped by farmers?*

1 Current capabilities or those that can be realistically expected or generated in the near future.

Although the central issue here involves irrigation infrastructure, the findings of this research show that irrigation system design is a socio-technical phenomenon covering two dimensions: contents and process. The research illustrates that users' management capability for the renovated infrastructure depends on the elements of the design contents dimension (management design, technical infrastructure design and agricultural production proposals). But the study also reveals that users' capability to manage infrastructure results from the particular features of the design process used to define infrastructure, water management and agricultural production characteristics.

To analyse design characteristics in terms of contents, these concepts have been developed:

- Operational appropriateness of infrastructure to management capability
- Technical appropriateness of infrastructure to management capability
- Productive appropriateness of infrastructure in relation to management capability.

These concepts are closely inter-related and have the same degree of importance in designing irrigation system infrastructure under small-farmer management in the Andean zone in general and in Bolivia in particular. Applying these concepts in irrigation infrastructure design combines knowledge about hydraulic design with the facilities' function within the economic production and social organisational context. That is, knowledge of irrigation management and agricultural production issues results in concrete facility designs adapted to conditions prevailing in the Andean environment.

Moreover, to analyse the process dimension, I have studied stakeholders, their roles and inter-relationships among them.

8.1 OPERATIONAL APPROPRIATENESS OF INFRASTRUCTURE TO MANAGEMENT CAPABILITY

The infrastructure's organisational – operational management capability becomes manifest when:

- Water rights and rules of work are clear and socially accepted.
- There is organisational suitability to assume distribution and maintenance.
- There is adequate competency or capability to distribute the water.
- There is the ability to maintain the irrigation infrastructure.

These elements of water management will enable the assessment of management capability in the irrigation systems researched, and will be discussed below:

Establishing clear, socially accepted rights and working rules

In all cases studied except Capellanía – San Roque, irrigation development entities did consider water rights inclusion and exclusion to some degree in designing the irrigation systems. It is commonplace to include in the design the relationship between the days of work or money that each user must contribute and the allocation of water rights that they will receive for this investment.

The inclusion and exclusion of water rights in the design process regarding acquiring water rights may be one of the social aspects that is most often included by engineers, although quite "instrumentally". This is because calculating the infrastructure cost in workdays and money is quite well known to designers, as shown in the case studies. This makes it easy to relate the project cost to the number of users and define the contribution that each user must make versus the benefit that each will receive. The balance between the size of the project, the availability of water and the contribution that the project will demand from users for construction and maintenance will directly influence water rights allocation.

Although it is praiseworthy for engineers to include the issue of water rights design as part of their standard design practice, project designers have evidently been unwilling or unable to understand the rights existing before the project intervention. For this reason, they have not been able to contribute optimally to match infrastructure design to the previously prevailing contents and distribution of rights. Nevertheless, as has been evident in the case studies, this is not a problem, since these systems are small enough that users have been able to solve this problem among themselves.

However, it is evident that engineers established the ratio of labour to water rights because the institutional approach has demanded that the community contribute a certain percentage (5%). Through this indirect way property rights were being created, thereby defining the hydraulic property. The concept of hydraulic property is applicable in all four case studies, because users created water rights during the construction process of their traditional infrastructure (creating objects of ownership). However, there are some irrigation systems where the idea of ownership is not perceptible (see Chapter 2). In some contexts, water access conditions are not always related to labour or capital invested to create ownership. In the case of *ayllus* and *capitanías*, in these systems the water rights creation phenomenon is unknown. Irrigation was a natural activity, organised on a consensus basis. It must be recognised that the priority regarding rights lies in understanding the logic of how people "acquire" water rights, so that projects can orient their work without the fixed idea of either "granting"("conceding") or "creating rights" in systems where that is not the logic of how water use is allowed.

One issue that arises during the water rights allocation process is that this is a time when water ownership is legitimised. Therefore, it is also the point at which certain users are excluded who are not in a position to contribute what the project demands. This can happen in irrigation systems that decide not to let women take part in infrastructure construction and maintenance work. This way, families without a male adult member (if the males have emigrated or because the head of household is a woman) may be excluded, especially if the family does not have the resources to hire a labourer to provide the workdays required for the water rights during system construction.

When irrigation projects are designed, users are also called beneficiaries, and assumed to be a homogenous group. However, when results of benefits brought by irrigation are analysed, some are seen to benefit more than others. Irrigation projects sometimes legitimise differentiation among users (e.g. the cases of Condorchinoka, San Roque Capellanía, and Naranjos Margen Izquierda). These experiences expressly show that those with more resources can more readily inter-relate more with design engineers, in order to achieve their own purposes and influence system design.

Organisational suitability to assume management

The case studies are all small[2], within a single community[3], with a simple system infrastructure and an organisation to go along with such conditions. They have specific conditions to make

2 Systems with an area from 10 to 100 hectares
3 Two communities at most

it possible for irrigation systems to operate, such as water judges or stewards[4]. The irrigation system is also managed on the basis of agreements that are periodically changed according to circumstances and eventualities, such as water availability or other environmental aspects.

However, irrigation project design and implementation tends mechanically to set up "irrigation committees" or "irrigation associations" with classic irrigation committee organisational structures. Consequently, two organisations exist side by side, such as the syndicate and the irrigation committee, when the system is in a community, or the original native organisation and the irrigation committee in the case of ayllus. The results teach us that efforts made by support entities to achieve this purpose in small irrigation systems are not justified, since this structure is not functional in any of the cases studied. Rather, the previously existing positions (water judge, commissioner or steward) remain the top authorities in irrigation system management issues, even after the project intervention.

Linked with this proposed irrigation organisation structure, there are by-laws and regulations. In all cases studied, the by-laws and regulations have been prepared to comply with the terms of reference under which the support entities were engaged. Although the support entities have made a considerable effort, in some cases, to recover and "complement" local norms in a document that could be used as a basic document to formalise or legalise the organisation's operations, they are apparently useful only for that, since many of the stipulations in these by-laws and regulations go unenforced, starting from the proposed organisational form itself. *Wouldn't it then be more advisable to understand the local organisational arrangements, and analyse the relevance of setting up a specific organisation, taking into account the irrigation system's characteristics?*

Here it is important to take into account the thinking according to which irrigation systems are organised, which is largely in response to the requirements of water distribution – operation and infrastructure maintenance. In irrigation systems with plenty of water available, in which water is free on demand, irrigation organisation is devoted to maintenance tasks. By contrast, in irrigation systems with pressure on water, calling for accurate distribution under greater control, then the irrigation organisation is involved in distribution and maintenance required by the system.

Because of the usual simplicity of operating tasks, it is not complex to define the respective responsibilities, entailing changes in the existing organisational structure, as might happen with requirements resulting from changes in water distribution. Consequently, operating tasks will generally be an additional responsibility for water distribution authorities, or for the users themselves. Research findings show that the users define who will be the authority/ies or person(s)/user(s) authorised to distribute and operate the infrastructure, activities in which the project support entity could assist. This could vary according to the level of distribution in the irrigation system.

Finally, a new aspect that arises as a result of the research is that, in improved irrigation systems, there is a need for the organisation to meet new maintenance requirements for the new infrastructure, which entails having the knowledge, labour force and capital. If the organisation does not have these factors, this lack of organisational capability jeopardises the system's sustainability, as the case studies have shown. Therefore, infrastructure proposals must be evaluated jointly so that choices will not surpass the management capability of the organisation and the users as a whole. A simple maintenance budget as calculated for each of the case studies can indicate these problems, especially when compared with net increases in income.

4 The name of this position varies according to the region where the irrigation system is located.

Competency or adequate capability to operate and distribute the water

Operating requirements of the projects constructed in the different irrigation systems researched are closely related to the water distribution mode. In these cases and many other irrigation systems in Bolivia, water is delivered during the critical season by turns, rotating a single flow, in order to keep the system transparent in view of little available water. Under these characteristics, the only operating requirements are**: regulation and flow control.** In the cases researched, regulation activities are limited to opening and closing gates at different structures, which family members can do.

Flow control is necessary in traditional systems, guiding the water from the source to the field, to avoid overflowing, damming and detours. This activity ought to be minimal in improved systems. However, in the case studies, since some systems do not operate adequately, due to various design and construction flaws, users continue doing flow control. This especially happens with siphons, intakes and canals with limited capacity. However, although users are bothered about having to do this additional activity, they have sufficient expertise to deal with the situation.

This reality gets more complicated when the system introduces distribution of water by dividing the flow, since this calls for “controlled regulation” and for users to be able to handle this requirement. In the case studies, users have opposed this management design approach. If this practice were introduced, there would surely not have been operating capability. This is the case because the engineers did not analyse “distribution and operation requirements” during the preinvestment or investment stage.

This research shows that water distribution practice never changed in any case studies, although projects mistakenly proposed changes in some cases. It should be remembered that local water management and use practices are adapted to a series of local principles and conditions, which have not been changed by the project. From this standpoint, one cannot only say that design need not entail “transcendental” changes in existing water distribution principles, but also suggest the alternative of “no change” in certain major features.

The case studies show the importance of considering users’ proposals regarding future operation – distribution and the respective infrastructure, grounded in community management criteria seeking to materialise sufficient degrees of equity, transparency, autonomy and flexibility. This is evidently different in different systems, according to the zone or region where they are located. The important thing is to interpret them in context and integrate them into design proposals.

Obviously, to begin discussing alternatives for water distribution, users’ demands must be clearly identified, with detailed knowledge of the irrigation system involved. When proposals are made, efforts will have to concentrate on analysing the relationship between distributing water and other irrigation system elements: analysing requirements and implications.

More specifically, the cases recommend focusing on analysis of water distribution alternatives (delivery mode and flow) in relation to the irrigation infrastructure. The fundamental aim is to make sure that the project, as designed and built, will not be an obstacle to distribution practices. This means that the water delivery mode (continuous / discontinuous, single / multi-flow) must be decided clearly beforehand. This is a key element due to its implications regarding delivery flow and therefore the capacity required for irrigation infrastructure. Additionally, the delivery mode generates requirements regarding the type and some characteristics of the infrastructure (e.g. need for regulation structures – fixed or mobile, intermediate ponds, gauging points, etc.).

It is indispensable to determine the water delivery mode at the different existing distribution levels in the irrigation system. Also, to avoid the most common project errors, described in Chapters 3, 4, 5 and 6, it is important for the delivery flow rate to be estimated to determine the infrastructure's capacity. In this regard, the estimate must be done considering: supply dynamics and water availability, irrigation practices at the field level, water uses, and overlapping with other water utilisation systems. This should not be simply the calculation of crop water requirements at the most critical time of year (peak month), which is the usual way of designing canal sizing (e.g. San Roque – Capellanía).

Finally, although the other elements of water distribution (duration, interval and scheduling of delivery) are closely related to delivery mode and flow, they do not directly affect the infrastructure, once the mode and type of flow are defined. Therefore, these aspects do not necessarily have to be discussed when establishing the infrastructure characteristics, but later, whenever necessary.

To conclude, study results teach that support after the construction will not be an indispensable step in the water distribution design process, as long as substantial design changes are not made. If there are major changes, the analysis and support must focus more on implementing, evaluating and adjusting distribution alternatives, according to such details as: programming water delivery, adjusting intervals and duration of water delivery at different distribution levels. However, farmers must be consulted before such major changes are made. Engineers need to realise that what they may see as "simple" changes are often significant to farmers if they redesign delivery or management options.

Maintenance capability

The case studies lead to the conclusion that maintaining improved infrastructure is one of the main bottlenecks limiting management capability of improved irrigation systems. In general, the requirements identified to maintain the new infrastructure are not performed satisfactorily by users. Even activities requiring only labour, such as cleaning out sediments and berming, are not done correctly or on a timely basis by users. They have the idea that maintenance consists solely of cleaning out silt once or twice a year, as they used to do when the system was rustic.

Many maintenance activities are not known or understood by users. This lack of transparency makes it difficult for them to manage their improved irrigation system. One thing weakening their maintenance capability and consequently their usage capability is that the facilities are not functional. The non-functionality is due to various flaws in design and construction, as will be analysed below. Many users who are affected by non-functional facilities see that these have generated lack of equity in water distribution, and such facilities that prevent equitable distribution may be destroyed.

Another aspect with repercussions for users' capability to handle maintenance is that, during project design and construction, there is insufficient assessment of the risks that it will be exposed to. Therefore, engineers do not prepare users to plan and schedule actions and resources for the short and medium term, or to define levels of responsibility for each case. Planning and scheduling resources requires programming activities and becomes a new element within traditional maintenance practices, which is not taken into account with the necessary depth by engineers during the design process. The cases studied show that it is not enough to establish by-law and regulation obligations for each user to pay dues for maintenance, because users will not pay their dues, even if these rules are made.

The case studies show that in on–farm irrigation systems in Bolivia, the classic concept of preventive maintenance is not useful. This is because users are not accustomed to saving. According to their way of thinking, as it has been seen in the case studies, users only begin collecting dues when facilities have been destroyed, to rebuild and address the emergency. The problem is that the resources required may be too great to meet at the time, much less if the damage happens at a time when people are out of money, such as any time of year except harvest time. Also there are problems related with inflation and security of holding or transporting collected funds. It would be more useful to establish a fixed date to do preventive maintenance, after users harvest their products (once a year). Knowing users' logic, it would be better not to pre –establish maintenance fees. Instead of this they should give an amount of money that is necessary at that moment in order to do preventive maintenance.

In summary, maintaining improved infrastructure evidently presents "new" requirements, which users must meet to appropriately use the new technology. Lack of capability to meet these requirements, because they are beyond their possibilities, because of lack of knowledge, lack of resources, or deficiencies in the facilities, jeopardises irrigation systems' sustainability and consequently weakens community management of them. This situation proposes new conceptual and methodological challenges and a change in attitude by professionals who intervene in small-farmer irrigation systems. The conceptual framework on management in this study can be a tool to open understanding of existing practices in the future.

Farmers reshape and re-appropriate improvements

As has been seen in the case studies, users have a great capacity to reshape the "new". Users adopt what they need, adapt it and apply it. For example, in Caigua before the project, different irrigation systems were independent, but when users had the possibility to have an irrigation infrastructure that gives them water security, they formed one single organisation, but maintained their autonomy inside each branch. The same thing happened with organisational proposals. Some discarded the project proposal completely, as was the case of San Roque - Capellanía. Others, such as Condorchinoka and Naranjos Margen Izquierda, incorporated the new organisational structure, but they maintained their organisational principles, discarding the institutional principles based on by-laws and regulations. Also, in Naranjos Margen Izquierda users took the idea of forming blocks for water distribution and incorporated the idea, because it allowed them to form groups to facilitate control and reduce the work of a single water judge, but they maintained the distribution criteria: rotation and a single, undivided flow.

It is also important to indicate that, in spite of all the problems that the improved infrastructure could present, users had the capability to re-apropriate their irrigation system, to incorporate small farmers' criteria of management, and be self-managed again. This also indicates that farmers with irrigation systems are practical and patient, and are always looking for new alternatives to improve their living conditions.

8.2 TECHICAL APPROPRIATENESS OF INFRASTRUCTURE TO MANAGEMENT CAPABILITY

Case studies show that one of the important reasons that infrastructure has limited hydraulic and constructive suitability, which affects management capability, has to do with deficient criteria for designing and building irrigation infrastructure, which are consequently unsuitable for the Andean region. These deficiencies may be grouped into two main aspects: 1. Design and construction criteria that interfere with infrastructure's operation. 2. Design and construction criteria that restrict the infrastructure's hydraulic and construction suitability and replacement.

Design and construction criteria that interfere with the infrastructure's operation

Research findings indicate that each irrigation system has improved facilities that do not work properly, and are therefore not used adequately. Using them wrongly entails the need for constant repairs, as with the gates. When facility repair requirements surpass users' possibilities, the facilities are abandoned or destroyed.

The cases studied show how deficient many improved operating facilities are, mainly due to simple errors by engineers in designing and building irrigation facilities that are not suited to the Andean region's characteristics. One first aspect influencing functionality is when facilities do not match the adverse terrain where they are built. For example, intakes in rivers with steep inclinations and heavy silt entrainment require special treatment in the basin, which is not done. Problems are also caused by building facilities at the foot of hillside slopes, which run a high risk of being filled in. In general, building under adverse conditions requires greater investments, especially for protective structures, as well as parallel tasks such as afforesting hills, and building crown ditches. One possible reason that engineers do not provide adequate responses to enable facilities to operate properly under such conditions is because investment indicators are established (US$ 2500 per incremental hectare under irrigation and US$ 4500 per family) for irrigation projects that make additional construction unaffordable. For this reason, projects often propose only partial improvement of facilities, generally building an intake and a stretch of main canal with its ancillary structures for that stretch.

Although this could be a reason explaining poor functionality in some projects, there are some that do not work adequately because of simple, obvious technical errors. For example, facilities without adequate capacity, because different water uses in small-farmer irrigation systems were not taken into consideration. Nor do they take into account the different types of irrigation at different times of the year (winter and summer), so that infrastructure capacity will not become a bottleneck limiting water distribution. Design also often ignores different water sources that farmers use. That is, the infrastructure must have sufficient capacity to carry water from different sources (e.g. Condorchinoka) that small farmers irrigate with.

Functionality is also affected by technical aspects that are apparently elementary and should go without mentioning – for instance, when construction is incomplete (e.g. siphons, which sometimes have no surge chamber, sand trap, or purge chamber). Finally, functionality also involves the quality of materials with which facilities are built. For example, in most cases studied the gates have problems with poor quality.

Poor functionality is also due to improper location of facilities, mainly catchment structures. In most cases, improved catchment facilities require additional tasks to operate, building approach canals as with traditional intakes. Since this approach canal is made with local materials (stones, clay, branches), it must be continually rebuilt to keep it taking in water. What, then, is the usefulness of an improved intake?

The case studies also show that, when engineers design, they normally forget that facilities are part of a network, which must operate in a connected, smooth manner. One of the main deficiencies in this regard, is that there is the tendency to design and build them in isolation, without considering their implications for the remaining structures, and the other components comprising the irrigation system in its local environment.

Altogether, these aspects affect functionality, so facilities must be "improved", i.e. changed and rebuilt. This means that, within the current characteristics followed by irrigation projects, the project cycle should add a "repair" stage. However, repairs call for additional funding, and the country is obviously not in a position to afford this. The situation is even worse if it is assumed that users will be responsible, as shown in this research. So, the only solution remaining is to prevent the need of such repairs. The cases show that this requires: 1. During the design stage, interaction between users and engineers, so they can share responsibility for the project. 2. Serious, modest engineers, who will not only emphasise technical and mechanical aspects of design but also take into account users' possibilities of responding to the usage requirements of the proposed infrastructure to make the system sustainable, and 3. The hiring of supervisors who will enforce technical specifications, as well as helping users oversee construction.

Design and construction criteria that restrict the infrastructure's hydraulic and construction appropriateness

The analysis of social requirements to use the irrigation technology in the cases researched shows that hydraulic and constructive suitability is limited from the standpoint of maintenance more than by operation. The core issue in the case studies is that engineers, while designing and building, never asked whether the facilities met conditions for users to maintain them. If usage requirements had been taken into account, particularly maintenance requirements, engineers would have responded to these needs, by considering criteria that are obvious and simple, as outlined below.

One first aspect is sizing. Facilities that are not the right dimensions for users to conveniently perform maintenance tasks run the risk of not being attended to, and even cleaning is neglected. Another issue appearing repeatedly in all cases is that design and construction failed to take the danger of sedimentation into account. The tendency to silt up is high, since there is plenty of erosion in the Andean region. Hillsides slopes are changed when building the irrigation infrastructure, leaving them unstable. In some cases, the sedimentation is even worse than when systems were traditional. So, the question arises: *Why invest in facilities that take such effort to be maintained, and may eventually even be abandoned because it is impossible to keep up with the high maintenance demands?*

The rugged terrain of the Andean region entails a physical risk that is important, but is often not taken into account in design or construction. This research reveals that it is not a common practice for engineers to think carefully about risks. This shortcoming makes designs unresponsive to this need, so plans fail to budget, for example, for protective structures.

This indicates that management capability and specifically the capability to maintain finished facilities are heavily undermined by the facilities' intrinsic characteristics. This shows that engineers are designing and building facilities without taking into account the proposal for interactive design, local management conditions and our region's environmental features, which call for new concepts, such as: Maintainability, Durability, Functionality, Operability and Safety. As shown in Chapter 7 and Appendix 4, these criteria can be introduced into design and construction by taking basic, obvious technical considerations into account. That is, purely technical aspects can help facilities be maintainable, durable, functional, operable and safe. If facilities meet these conditions, they will be technically adaptable to users' management capability.

The lack of these criteria in design forces us to review, question and change the current conceptual framework with which civil engineers and agronomists are being trained for irrigation and to question irrigation project implementation processes in Bolivia. This study has proven that, because of the way irrigation projects are implemented, no one is found liable for poor outcomes: building companies are allowed to ignore technical specifications, support entities are allowed to perform unreliably, and supervisors are allowed to act negligently.

8.3 PRODUCTIVE APPROPRIATENESS OF INFRASTRUCTURE TO MANAGEMENT CAPABILITY

The cases studied show that the improvement of irrigation systems has increased available water. With more water available, users have changed their production scenarios (more area under irrigation, new assortments of crops, better yields and new planting calendar) and consequently have improved their economic income. The changes that have happened in each irrigation system are the result of just the farming activities pursued by each villager, based on his or her own goals and resources. In no case has there been any institutional approach for agricultural production so that users will make better use of more available water, in order to optimise farmers' strategies and yields.

Although income has increased to higher levels, only in Naranjos Margen Izquierda average household go above basic income needs after improvement.The cases studied reveal that irrigation system users do not have enough economic possibilities to afford a "special" requirement, such as maintenance of the rehabilitated infrastructure. Farmers still need to invest available resources in production for better income. In general, economic capacity (even in the new situation) does not go along with the economic requirements of the new infrastructure. No infrastructure is going to be sustainable if not maintained, for which labour and cash are required.

The appropriateness of the irrigation infrastructure to the rural economy depends on how irrigated agricultural issues are faced during irrigation projects' pre-investment, investment and post-project stages. The outcomes found show significant weakness in how this situation is addressed. This topic must be analysed through more research work, which can yield broader findings on how irrigation investments can have an impact on local economies and go beyond, up to the national level. Infrastructure demanding less farmer investment in operation and maintenance, plus infrastructure that can make a greater impact on local economies, would enable irrigation system users to satisfy their families' living needs and meet the economic requirements of maintaining irrigation systems.

This shows the need to define institutional policies that will accompany not only irrigation project implementation, but also agricultural production planning by users, to enable the country's different eco-regions to design their own local development proposals. These proposals will contribute, in turn, to designing regional and national proposals. Further, they would make it possible to rethink a more sustainable type of agriculture, in environmental and socio-economic terms. The simple assessment methods used in this study have provided examples of how such studies can be done.

8.4 THE OTHER DIMENSION: THE INFRASTRUCTURE DESIGN PROCESS

The project process

The cases presented show that project process is highly important, because inter-relationships among stakeholders shape the infrastructure and the irrigation management in the improved irrigation system. That is the reason why all stakeholders should participate under equal conditions. In the case studies, although many social stakeholders were involved in the project process, none acted responsibly enough in meeting their assumed commitments.

This study shows clearly that construction stage is very important, as each user is better positioned to understand the implications of plans. The case studies show how users began making observations, but they were not always taken into account. Users were not central players in defining facility characteristics, although they would be responsible for managing the improved irrigation system. The construction stage was a key phase for inter-relating, when it was important to keep procedures, responsibilities and tasks of each player quite clear. However, the cases studied had no one responsible for conveying different stakeholders' ideas or perceptions, or for establishing procedures, responsibilities or tasks. Although the support entity was supposed to do this work, in practice the support entities' activities came along too late. The people responsible for providing user support never guided communities to analyse whether any facility suited their interests, from the standpoint of their ability to meet new operating or maintenance requirements. This would have been crucial to define infrastructure characteristics to meet users' actual capabilities and make sure systems would be sustainable. Taking users into account would have averted current problems of deficient maintenance.

The results of this study show how institutions with economic power (FDC) are central actors; they can decide about all critical aspects concerning project implementation. In the case studies, promoting entities (e.g. municipalities and prefectures) did not properly assess the results of their contractors' work, since these promoting entities depended almost entirely on the FDC to finance projects. Therefore, they had to accept the conditions imposed by the funder, who financed the project, leaving the promoting entity to play the contract management role (tenders, signing contracts) without handling the funds. Therefore, building companies engaged by the promoting entity were accountable to the FDC and not to the promoting entity, from whom they required only a few authorisations.

Moreover, the tenuous relationship between the FDC and the building company (supervisors and project director) resulted mainly from the type of supervision provided for the projects researched. First of all, supervisors operated out of their capital-city headquarters, which made their site visits infrequent, and secondly there was high supervisor turnover. This also weakened relations with user organisations.

The power of the FDC became evident also in the inter-relationship with PRONAR, in spite of the fact that funding was supposedly for PRONAR. Nevertheless, PRONAR had to accept FDC organisational structure. The weak relations of PRONAR with other stakeholders during the intervention process were also informal. This was due to the monitoring role played by PRONAR in project implementation, which prevented them from being very involved in the processes.

These findings show that inter-relationship analysis is not just a theory describing overall relations and cause-and-effect mechanisms, but enables us to understand how technical phenomena and processes are moulded by people's actions, as in the cases studied. So, stakeholders' actions and interactions have determined or shaped the concrete, current characteristics of these irrigation systems, in regard to infrastructure, management and agricultural production. These findings show that the project is not simply the implementation of a specified action plan with expected outcomes. Therefore, this aspect – which is not being taken into account in the process of designing irrigation systems – must be granted special attention.

The findings that facilitate or constrain infrastructure management are the outcome of positions taken and decisions and attitudes that different stakeholders have assumed during the intervention process. However, the different players' actions have been moulded by the different socio-economic, political and cultural settings, and by the capacity of each of them to enlist other players in their own "projects". Under such conditions, the stakeholders, through their own strategies and actions, have influenced the flow of the different events in which each case has arisen. In Caigua, more interactive support processes built management capability and new capacity to undertake collective actions. The results of these aspects, in terms of infrastructure, are positive compared to the other case studies.

Further, each project has followed its own process and has been moulded by features of its economic, social, political and cultural setting. The different processes have revealed many weaknesses, the most important of which include both lack of knowledge about integrated irrigation system design, and lack of interactive design.

Lack of interactive design

The main infrastructure problems in the case studies are due largely to the lack of interaction between engineers and users in the design process. Intervention has characteristically lacked interactive design. Because of the professional training of design teams, they have tended not to pay any attention to users' opinions, to different degrees in the case studies. Usually, farmers have been seen just as "manpower" and not as a source of knowledge. This premise has impeded any real inter-relations among engineers and users, to design interactively.

Interactive design is grounded in the recognition that all stakeholders are important for design, and all contribute their knowledge, a premise that was not present in most cases (except Caigua). The lack of in-depth knowledge about system characteristics (infrastructure, management and agricultural production) or any improvement in engineers' attitudes made interactive design impossible. It would have been necessary to understand proposals, value local farmers' expertise and propose different design alternatives that could suit each system's reality better.

Also, when the design team comprises professionals from different disciplines, the team itself must interact, rather than dividing up responsibilities, which is current practice, as shown by the case studies.

Interactive design means designers must spend longer in the field and the design team must work more creatively. Each design must meet the objectives identified, unique to each group of users. That is, each design must be custom-made, not cookie-cut from pre-established patterns, as seen in some of the cases studied.

This sceptical disregard of interactive design may also be due to professional training and the way they learned the different concepts. This refers to the fact that, when one studies at the university, one receives certain "professional" information, commonly without reflecting much about it. When one graduates and attempts to put this learning into practice, one finds that reality is "somewhat different", and many feel uncertain about how best to proceed in the field. Many cling to the formulas they were taught, to established procedures, pre-determined guidelines, etc. This results in an ideal profile – from the engineer's vantage point – and undermines the creativity and skill that could address each case as a new situation.

Research in the context of our reality, such as the present effort, represents one of the main ways to help generate new concepts and methodologies that will support such design processes, and break out of slavishly following pre-determined recipes, protocols or models. It should be remembered that the users are the ones who will have to manage their systems, so they must make the decisions about changes in their local economy through irrigation.

Obviously, this change is not so simple, since it involves larger environments, such as institutional settings, or structural problems with professional education, which experience has shown can hardly be changed until there is awareness, the capacity for self-criticism and recognition by higher political and education authorities that there must be changes. Definitely, it is time to challenge the prevailing power relationship between the different levels (users – engineers, users – funding agencies, students – professors) that prevent a more interactive development of irrigation systems; indeed, the intervention itself often replicates these relationships of power inequality.

Based on shortfalls seen in design in the case studies, these conclusions end with some proposals to help drive more interactive design in the future. The design of irrigation system should include the design of hydraulic infrastructure and future management. So, it is necessary to use very different kinds of data (topographical, hydrological, agronomic, hydraulic, social, economic, cultural), which all together provide the foundation for proposing improvements. This research proved that there is an inter-dependence between the technical and social dimensions, so it is indispensable in the design to include an analysis of social requirements for use regarding technical proposals, in order to assess their "social compatibility". It has been demonstrated that designing an irrigation system is a social process, in which various stakeholders influence decision-making about changes in the irrigation system, each according to their own interests, goals and possibilities. For this reason, the design should be organised as a co-operative activity among all stakeholders involved, in which each one contributes specific knowledge and skills to the different design process phases.

This study shows that design an irrigation system is an ongoing process throughout an irrigation project cycle. Its activities concentrate on the "design phase", in which the main elements of the design are sketched out, but continue in subsequent phases of implementation (construction) and operation, during which specific elements are changed or adjusted. Then, designin an irrigation system is an iterative process, in which the consequences of previous decisions for later decisions must be continually reviewed, and vice versa (see Gutierrez & Hoogendam 1998).

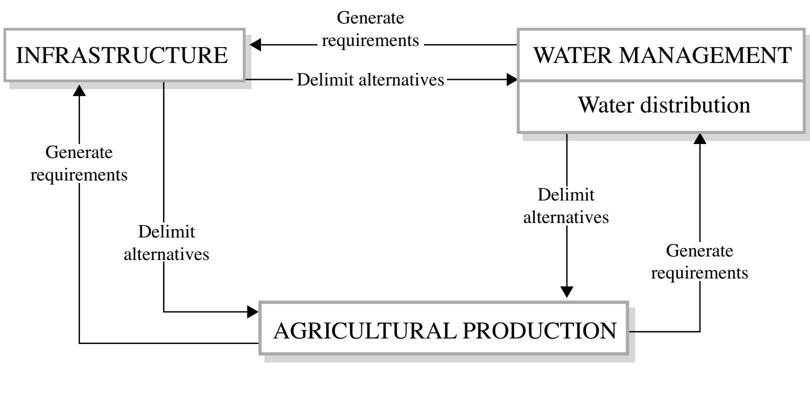
Lack of knowledge about integrated design

The cases enable us to conclude that the design concept was based on fragmentation of the different areas comprising an irrigation system. The infrastructure design was done considering only technical aspects. Matters involving water management were addressed in isolation from irrigation infrastructure and agricultural production. Similarly, future production was forecast without considering the future characteristics of management or the infrastructure. This means that there is lack of knowledge about the integrated design approach that would have contemplated aspects of infrastructure, management and agricultural production inter-relatedly. It is known that any change in irrigation infrastructure will influence water management. That is, there may be effects on water rights, water distribution, irrigation system maintenance and organisation. When analysing the social requirements for use of infrastructure during the infrastructure design, the future[5] irrigation system management is also designed on the basis of knowledge of the existing management system and understanding of how farmers think about their production. Management capability is closely related to the degree of analysis about infrastructure requirements for use and translating this information into adequate infrastructure design.

A coherent, integrated, interactive design process could be viewed cyclically:

- First, define water rights.
- Then, the main aspects are the future way of operating / distributing water and maintaining the system, on the basis of an analysis of the infrastructure's social requirements for use.
- When making an analysis of management versus infrastructure characteristics, also consider agricultural production requirements regarding both facets. Distribution, then, is the point where these three aspects of the irrigation system (management, infrastructure and production) converge. Agricultural production generates water distribution requirements, because a given production scenario will demand, for example, a certain irrigation frequency (water delivery intervals), and a certain volume (duration of the turn, and flow rate). If the water distribution characteristics (water delivery interval, turn duration and flow rate) do not fit crop requirements, then this limits production alternatives. For example, if water is delivered at very infrequent intervals, crops demanding more frequent irrigation (vegetables, flowers, etc.) cannot be grown.
- Finally, the irrigation system will be organised as a result of analysing the requirements of distribution and irrigation system maintenance, as shown in the figure below:

Figure 8.1 Inter-relationships among infrastructure, management and production, generating requirements and delimiting alternatives



5 "Future" does not necessarily mean different than at present.

The influence of role of the local government

In every case studied, in order to meet FDC's institutional requirements, each project had to have a Promoting Entity to be responsible for project implementation. This involved as project stakeholders the municipalities in Caigua and San Roque - Capellanía, the Prefecture in Condorchinoka and the Sub Prefecture in Naranjos Margen Izquierda. Each responded differently. The Oruro Prefecture's involvement made no difference, and therefore did not influence the results obtained in terms of infrastructure or water management. The Sub Prefecture of Entre Rios got more involved, but had only one technical staff member trying to cover all the projects that the sub prefecture was involved in, so their influence was also negligible. The case of Caigua was unique, because the Municipality of Villamontes had several technicians, with various specialties. Their role in supervision was fundamental, making sure that the building company and support entity met the technical specifications of their contracts.

In saying that entities' actions affected outcomes or not, specific reference is made to the practical part of infrastructure and water management characteristics. These promoting entities' actions did greatly influence users' negotiation capability during project arrangements, because they felt abandoned in most cases studied. The promoting entity's presence, with their technical people in the irrigation zone, was very important, to achieve the objectives of the "users' project". For instance, in Caigua, the presence of municipal technicians enabled users to interact smoothly with them and be part of the design and construction process.

In conclusion, in all cases, the promoting entities had no further relationship with users' organisations, after the project finished. With the project over, users resumed their responsibilities of keeping the system working, as they used to do prior to the intervention.

Influence of agroecological zones

As indicated in Chapter 1, the case studies were located in four different agroecological zones of Bolivia. The particular conditions of each strongly influence livelihood strategies and thus water control rules, rights and practices as well as technology development and thus they have influenced the results obtained. So, in the Altiplano, problems involved for example socio-territoriality, as in Condorchinoka. The Altiplano's steep slopes mean that many intakes and canals in irrigation systems have to be located outside users' territory. This forces them to seek agreements with other communities or irrigation systems.

The cases studied show that agroecological conditions have an especially direct influence in purely technical aspects, such as the difficulty for cement to set in the Altiplano and the Chaco, transport of sediments to valleys and mesothermal valleys due to river characteristics, landslides in valleys, mesothermal valleys and the Chaco due to the terrain and characteristics of soils, as well as many other aspects. So, the ability to respond to these different, highly complicated agroecological conditions from a topographical, geological and hydrological standpoint in designing and building the facilities, has affected management capability in the systems researched, especially in terms of operation and maintenance. This has influenced these irrigation systems' greater or lesser management capability. Engineers must continue developing design and construction criteria that will respond to the country's diverse agroecological conditions and equally diverse management characteristics.

8.5 THE CONCEPTUAL FRAMEWORK TO ANALYSE THE ADAPTABILITY OF INFRASTRUCTURE TO MANAGEMENT CAPABILITY

The conceptual framework for this research has been explained in Chapter 1. There are three fundamental concepts grounding this study: 1.- Operational appropriateness of infrastructure to management capability, 2.- Technical appropriateness of infrastructure to management capability, 3.- Productive appropriateness of infrastructure in relation to management capability.

Operational appropriateness of infrastructure to management capability

An extremely important aspect, for improved irrigation systems to continue being community-manageable and sustainable over time, is for users to be able to operate and use the improved infrastructure. Elements of water management analysed under the first fundamental concept of this research effort (including water rights: linkage between infrastructure and water access, water management roles and organization, management practices for water distribution: water division and operation, maintenance of infrastructure) are quite useful for this purpose. These elements first reveal the water management situation prior to the intervention. Then, analysing these same elements in comparison with requirements to use the new infrastructure, it is possible to "design future water management". Logically, this analysis must be done jointly by users and engineers. In other words, the point is to analyse the implications of each water management element of each proposed project, so that new usage requirements will remain within users' management capability.

This research has proven that, although there is a change, a willingness to incorporate water management elements in irrigation project preparation and implementation (as seen in the introduction of a new stage, user support) the expected improvements have not yet been achieved. The study framework can be a very useful tool to "design future water management".

Technical appropriateness of infrastructure to management capability

This research has shown that infrastructure characteristics affect irrigation system users' management possibilities. In other words, technology is not neutral. Normally, this concept is not taken into account by designers. One contribution by this study is to develop the conceptual framework on technical appropriateness of the infrastructure to management capability. This makes it possible for this aspect, neglected by engineers, to be taken into account when designing irrigation systems under small-farmer management. The elements developed under this second fundamental concept are: hydraulic suitability in relation to management capability and constructive suitability in regard to management capability and maintenance capability.

Under each, specific aspects have been seen to be necessary for facilities to work properly and fit water management characteristics. In this case, facility compatibility is analysed through "structural design requirements" (e.g. sizing of facilities, quality of workmanship and the many other aspects examined under this study). So, just as irrigation facilities have social requirements for usage, they must also meet certain technical requirements. In the absence of this analysis, the study has shown that projects continue to be designed without inter-relating the facility with its management. Consequently, civil engineers design without any regard for management, and irrigation engineers address management without giving a thought to the physical structure.

Therefore, the elements under this second fundamental concept make up a useful tool that can readily be operationalised in practice by engineers, who are always looking for practical methodologies to design irrigation systems.

Productive appropriateness of infrastructure in relation to management capability

This research has shown that irrigation infrastructure can limit or enable the desired production, under new production scenarios. It has also shown that these production scenarios and resulting earnings also either enable users to meet specific maintenance requirements or not, in the cases studied.

Management capability is specifically expressed in the possibility of actually maintaining the new improved infrastructure. For this reason, the third fundamental concept of this research was developed, including the following elements: Productive scenario promoted and local community economy, achievement of farmers' production goals, household net income and labour availability increment.

Users' economic situation heavily affects irrigation system performance, specifically in this case the possibility of maintaining the improved infrastructure. Hence it is necessary to analyse future production scenarios in greater depth, considering farmers' production strategies. It is also important to analyse whether new earnings from improved infrastructure will enable users to be able to cover the costs of operating and maintaining an improved irrigation system. And finally, it is important to analyse the possibility of paying operation and maintenance fees, comparing new earnings from irrigated farming and economic requirements to cover household requirements.

As this research has shown, the economic analysis should not only be used for irrigation project implementation feasibility analysis, but also to analyse maintenance costs and users' economic ability to contribute funds for maintenance. This aspect is not usually analysed in depth; normally, maintenance cost is estimated with projects as 1% of the total investment. But this study showed that it was straightforward to calculate new maintenance costs, for each system in detail, as shown in the case studies, and discuss these costs with the irrigation system users.

In conclusion, these three fundamental concepts are inter-related. It is crucial to take them into account in designing improved irrigation systems under small-farmer management, so that systems can once again be community-managed and sustainable.

APPENDIX 1

The socio-technical approach

There are two predominant positions (Frawley 1997, Ginsburg 1997, Hees 1997). One is the social science theory called "technological determinism", which confidently predicts that technology will remain the social change agent *par excellence*, driving the development of future societies. The other position is taken by the constructivists, who remind us that we construct our technology, to some degree, socially.

Technological determinism

Technological determinism may be considered the more classical position, because studies and interpretations have been made from this perspective for longer. As Ronderos & Valderrama (2002) point out, technological determinism as such has existed since the 20th century. There are very clear examples of such concepts since the 17th "Century of Light", with emphasis during the 19th century by French thinkers such as Condorcet or Turgot. Within the deterministic concept, the idea of progress stands out. It is no accident that this view of history and society was in vogue during the age of industrialisation, mass production and economic booms, in which humanity was triumphing over Nature (Agazzi 1996, Alonso et al. 1996, Echevarria 1996, Chalmers 1998). This school of thought favoured by theoreticians, social and natural scientists, engineers and ordinary people's concepts, "technology" acts as the driver of social change. This means that implementing a specific technology causes social transformations, moulds and conditions behaviours, customs and the overall working of the society in which this occurs.

US historian Bruce 1996, promoting determinism (*Three faces of technological determinism)* shows us three interpretations: nomological, normative and unintended consequences. The nomological interpretation (naturalistic approach) sees technological development happening according to a natural, logical process, unaffected by social or cultural changes, because society is the consequence of technology, which always acts as a cause. The normative interpretation (autonomous approach) grants technology a leading role, but leaves society the capacity to lend political and cultural significance to devices, within society's own conceptual system – cultural norms and underlying power, domination and control influence any technology. Finally, a third approach focuses on the unintended consequences of technical enterprise. Outcomes of actions are uncertain and uncontrollable. Even wilful, ethical social actors can't anticipate the effects of technological development. Thus technology is partly autonomous. Technological developments have a role in determining social outcomes that is beyond human control. No underlying logic drives development.

The social construction of technology

In response to paradigmatic Technological Determinism, a group of American and European intellectuals have worked since the late 1960s to consolidate a new theoretical toolkit, in order to rethink technological history. One of the main works from this group of intellectuals is *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, edited by Bijker, Pinch & Hughes 1987. The three most significant proposals in this group are: social construction of technology, by Bijker &Pinch, the actor-network theory proposed by French thinker Callon, and Hughes' technological systems.

Bijker & Pinch analyse how the very design of a device is the result of processes of negotiating interpretations among societal groups, which they call "social construction of technology". Accordingly, they adapt the achievements of a sociological programme analysing the development of science. This *Empirical Programme of Relativism,* developed by English and American intellectuals to open the black box of scientific communities, their processes and products, relates the contents of science with the contexts in which they are produced and transferred.

These authors revisit the history of bicycles, by applying new methodological tools, and conclude that devices and technological knowledge are designed and evolve according to no "natural" route, but depend strongly on the contexts in which they develop, depending on many more people than the single inventor, depending on whole social groups in ongoing interaction, over long periods of time. These analyses also reveal the tensions and power relationships in those societies in which these developments arise, a critical aspect ignored or taken for granted in analyses under the theoretical current of "technological determinism".

The Actor Network theory (Callon 1995, Latour 1992, Latour & Woolgar 1996) understands processes of innovation as a struggle among different stakeholders who attempt to impose their definition of the problem to be solved. The concept of "actor" includes both human and non-human agents (tools, machines, designs, institutions, etc.). The dichotomy between social actors and objects, humans and non-humans, can no longer be sustained; rather, one must speak of networks of close relationships among all these collective players.

Studies of socio-technical systems have attempted to apply systems theory to the history of technology. There is great interest in unveiling mutual interactions between technology and society, beyond discussions of alleged determinisms of some sort or another. Hughes (1987) says that these interactions give rise to new technologies that change social relationships, but also bring out new social factors, by which certain stakeholders can, in turn, configure technologies to defend their own interests.

Some critiques of social constructivism of technology

The constructivist view of technology has been criticised by those pragmatic traditions concerned with the sequences of technological development, who have accused it of almost totally neglecting the social consequences of technical choice (Durbín 1992, Mitchan 1989, Pacey 1990, Winner 1991). The concept of relevant social groups or actors has also been criticised, because it is not clear who decides which groups or interests are relevant. There is concern for those *with no voice,* who are however effected by the results of technical change. They indicate that it is important to examine decisions that are made, how they are made, and also the "hidden agenda" influencing such decisions, which is never seen explicitly. The idea is to reveal deeper social processes and interests that could lie at the base of social choices regarding technology. Finally, the apparent scorn for anything sounding like evaluation, either moral or political, is criticised, because such evaluation could be useful to judge the possibilities offered by technologies, from the standpoint of human wellbeing and development. (Winner 1991)

The American "school" of cultural critics, traditionally concerned with the values of technology, possible impacts and educational renewal, has especially influenced the possibility of evaluating and controlling technical and scientific development. Such authors as Winner (1991) stress that technology changes our self-image as individuals and the role of society in many subtle, often unnoticed ways. Winner feels that, if we uncritically accept a technology, we are implicitly signing a social contract, with consequences that will be seen only long after signing. This "technological sleep-walking" leads to remodelling human living conditions in undesired ways, with negative consequences for large sectors of the population and for the future of this planet. Pacey (1990) says that Technology should be defined, not only in material terms (technology, devices) but also organisationally (economic and industrial activity, professional activity, users and consumers) and culturally (goals and values affected by the technology and which should be respected by it). Another influential American cultural critic is Mitchan (1989), who calls for the primacy of philosophy and the humanities to recover human and social values in the face of technology's steam-roller.

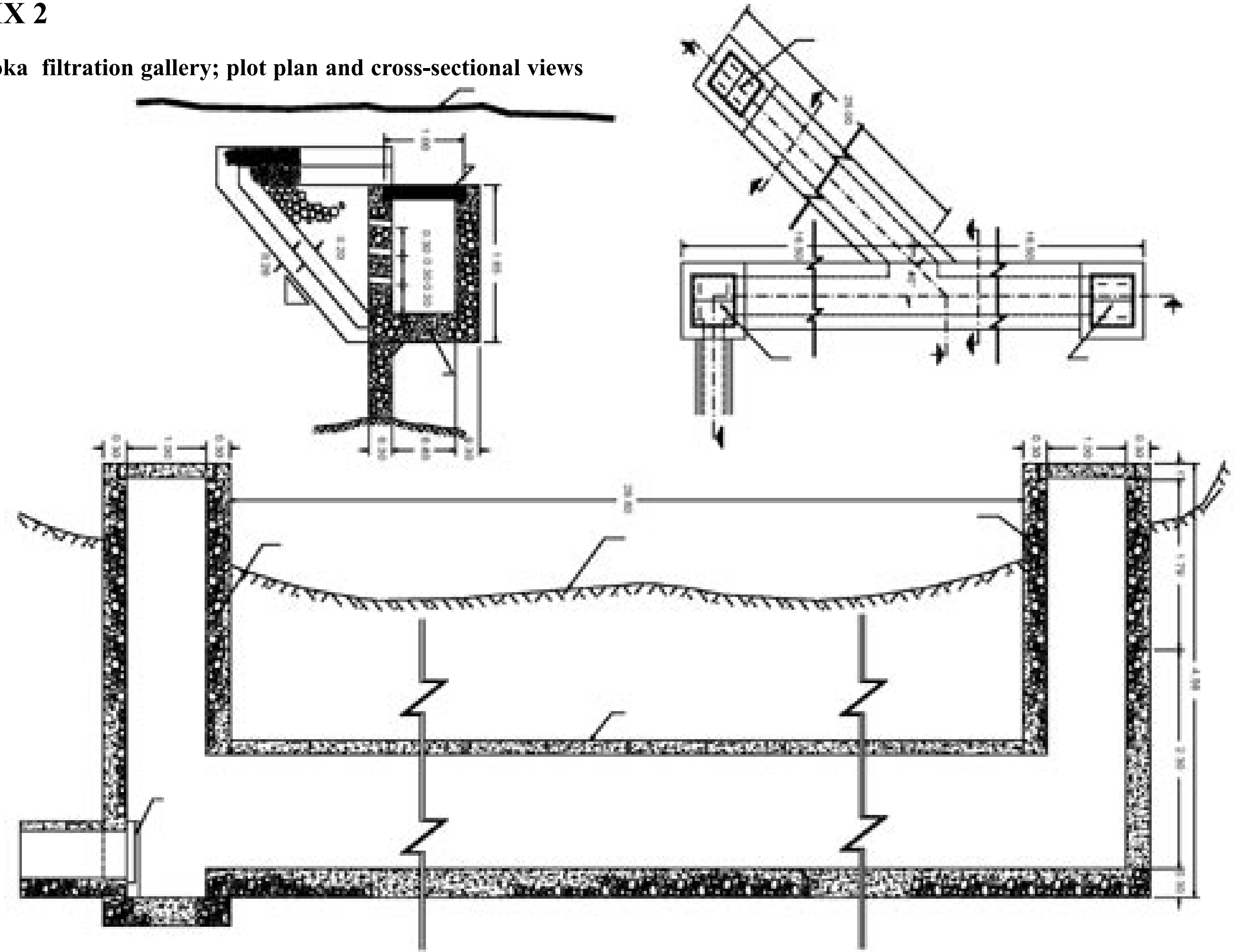
According to a new paradigm, called "constructive technology assessment" (Wynne 1995), science and technology have become strategic political and economic resources, for States and for industries. However, although citizens are aware of the advantages for their wellbeing that a techno-scientific development could contribute, there is also profound awareness that technological change is the basis for many environmental and social problems. Irremediably, science and technology have become more politicised and complex, and their beneficent image can no longer be taken for granted, nor can their practitioners expect to maintain their status in society.

There is also criticism of the traditional evaluation model's failure to work. Along with increasingly intense social pressure, this calls for greater citizen involvement in technological decisions. In response, the paradigm of constructive technology assessment has arisen, to definitively banish the pretension to objective, neutral evaluation based solely on expert opinions; rather, social and cultural opinions associated with certain technologies and socialisation of decision-making become more important. One of the main goals of constructive assessment of technologies should be the need for social experimentation and learning as an integral part of managing technology (Nelkin 1995, Webster 1991, Wynne 1995).

Wynne 1995 has been one of the most active authors in the new evaluative paradigm, having undertaken to study risks in the context of social learning. His approach is reflexive, studying what technology reflects and reproduces through prior cultural and social values and forms. In reply to the technocratic opinion that the public perception of risks is often irrational, Wynne maintains that this perception brings together symbols, values and essential knowledge to contextualise technologies and integrate them socially.

APPENDIX 2

Condorchinoka filtration gallery; plot plan and cross-sectional views



APPENDIX 3

Assessing water management

1. Overall system data

- System name and location: system's geographical boundaries, political and geographic location, and altitude.
- Physiographic characteristics: landscapes, ruggedness, topography, soil origin, vegetation.
- Climatic aspects: temperature, precipitation, wind, frost.
- Physical characteristics of the soil: texture, structure, depth.
- Chemical characteristics of the soil: salinity.
- Water resources: water sources, water availability by seasons (flow rate).
- Water quality: quality of water for irrigation, pH, degree of pollution.
- Type of system: river intake (infiltration gallery, breakwater), dam, pond, spring, well or combinations.
- Type of agricultural production: family self-supply, sale, combined.
- Distribution of land according to use: grazing area, arable area, area under the system's influence, net irrigated area.
- Soil management and conservation practices: levelling, terracing.
- Economic aspects: produce sale, existence of markets, non-agricultural activities, importance of migration.
- Historical facts: origin of the community, origin of the system, institutions involved in irrigation activities.

2. Cycles of irrigated agriculture

- Agricultural cycle: ordering crop, other crops, planting and harvesting seasons, cultivation, labour-intensity, participants and their activities.
- Water cycle: water sources, behaviour of sources (flow rates according to season), types of irrigation depending on crops, irrigation scheduling according to crops, maintenance and reconstruction periods.
- Festive cycle: main festivity, invitation to celebrations (youth, adults, men, women, all), relationship between festivals and the agricultural calendar.
- Migratory cycle: who migrates, causes of migration, types of migration: occasional, permanent, intermittent.

3. Infrastructure

- Catchment type and area.
- Distance between the source and the irrigation area.
- Description of canals: length of canals, type of canals, name of canals and their area of influence.
- Exchange point locations (distribution points).
- Arrangement of the irrigation area and irrigation units.

4. Water management

4.1. Water rights

- System users.
- Origin of rights.
- Variety of rights.
- Rules and agreements about acquiring rights.
- Rights regarding community organisation.
- Rights and obligations.
- Obligations and penalties.
- Water rights and access.
- Outside influences on water rights.

4.2. Water distribution

Water distribution at the inter-community (watershed) level

- Distribution mode.
- Irrigation calendar or inter-community role.
- Positions for inter-community distribution.

Community-level water distribution

- Ordering of water delivery according to types of rights.
- Methods of water delivery.
- Ways of operating the source.
- Small-farmer practices for water delivery.
- Rotation, and rotation of rotation.
- Types of flow (single and divided).
- Compensations in water distribution.
- Presence of groups in water distribution.
- Different water uses and distribution.

Family-level water distribution

- Household organisation for irrigation.
  - Family members' participation in irrigation.
  - Ways of accessing water.
- Water use.
- Water use for each crop.
- Irrigation methods.
- Flow rates applied.
- Frequency of irrigation.

4.3. Organisational aspects

- Organisation for distribution.
  - Positions for water distribution, functions and election procedures.

4.4. Maintenance.

- Types of maintenance
- Periods for maintenance
- Organisation for maintenance
- Ways to take part in maintenance, workdays used for maintenance, type of maintenance, agreements, penalties and status of infrastructure.

5. Rituals involving water

APPENDIX 4

Technical design and construction criteria according to the type of structure

1.- Design criteria to improve management capability

Design criteria for canals
Maintainability
• Design the layout of the system's area of influence to cover users' demand, to ensure the criterion of equity. • Design the main canals' layout to cover the greatest area of influence, require the least number of ancillary structures, entail the least earth movement and induce canal stability. • Design canal layout to coincide with community or group boundaries to minimise conflicts. • Design canal width and height to enable convenient cleaning and repair work.
Durability
• Use slopes that will not erode the canal's side walls and floor, in order to reduce maintenance requirements. • Use slopes that will not increase sedimentation of suspended solids, to prevent algae growth, especially in the *altiplano*. • Design respecting the water's hydrodynamic flow to avoid sudden changes in direction that could cause overflowing, especially canals with right-angle bends.
Safety and security
• Leave one edge free to prevent overflowing that will wear down the canal. • Design sections with gradual transition, especially in the transition from lined canal to earthen canal, in order to prevent erosion and reduce maintenance requirements. • Locate canals in stable sections. • Protect canals with slab covers when they are on steep slopes where there is landslide risk. • In curved canals, adjust the free edge of the canal or cover the curved section to prevent overflowing.
Functionality
• The design flow rate must be decided as a function of farmers' water demand (preparation water, crop watering, *lameo* silt flooding to fertilise), availability at the source (summer / winter season), system distribution mode (single or multiple flow), avoiding overflowing, which can jeopardise stability. • Adapt the design to other additional uses of the canal (washing laundry, watering cattle). • Avoid designing ancillary structures along curved stretches of canal, because if they are difficult to operate they may be damaged.

Design criteria for weirs
Functionality
• Locate the overflow spillway in places not prone to erosion.

Design criteria for aqueducts
Durability
• Design floor width to perform complementary functions of the structure, especially if it is used as a footbridge. • Design a free edge equal to or greater than the free edge of the canal (by at least 10 cm) to avoid overflowing. In curved aqueducts, increase the edge height on curves.
Safety and security
• Design pillar height taking the maximum level of creeks and rivers into account. Design structures to contain and protect (gabions) buttresses and pillars.

Design criteria for siphons
Maintainability
• Design a purge valve at the bottom of the pipeline. • Design the grill with bars in the direction of flow and devices that make it possible to remove the grill to facilitate cleaning.
Safety and security
• Design a silt / gravel trap as close as possible to the siphon to keep heavy and suspended material out of the siphon, so outside materials cannot get it. • Design an overflow spillway suited to extraordinary events, so that the spillway crest design flow is at the level of the water-free surface.
Functionality
• Design the pipeline with a safety flow rate to ensure the system's flexibility. • Design the entrance transition so the top of the siphon is normally underwater. • Design an inclined entrance grill so water flow will push floating material away, leaving as much area free as possible for water to get in.

Design criteria for distribution points
Functionality
• Design distribution points considering the different water delivery modes and proportions during the year (proportional division. Fixed flow rates, variable flow rates). • Design gates the same size to guarantee transparency by distributing similar flow rates. • Design rod or flap gates no larger than 0.5 x 0.5 m. For larger leaf size, design worm gates up to no more than 1 m. For larger gates, divide the canal area into several parts. • Design gates that seal well so users will not need to stop leaks by wedging in stones and mud. • Do not design sunken distribution boxes in areas with a high solids load because otherwise sediments will clog the structure. • In areas with a high solid load, design distribution points with inlet and outlet canal floor al the same level, to divide the solid load.
Durability
• Design distribution points with easy-to-handle components. • Design sturdy gates to withstand users' usage and misuse.

Design criteria for drops
Maintainability
• Design the structure to overcome a height difference of no more than one meter.
Durability
• Design the structure to prevent the splashing that, over time, jeopardise its stability.
Safety and security
• Design drains or weep holes in the vertical wall acting as an earth retaining wall to relieve hydrostatic pressure of water contained in the earth, to prevent cracking or breakage of the wall. • Design the structure on existing land rather than on fill, to prevent the structure from settling and collapsing.

Design criteria for ponds
Durability
• Design an energy disperser at the pond inlet to prevent wall erosion. • Design an overflow spillway to prevent spilling over walls, which would cause erosion and structural collapse. • Design an energy disperser at the pond outlet to prevent canal erosion.
Functionality
• Design a filter to keep out materials that could plug the relief duct.
Maintainability
• Design a silt trap at the inlet (see sand traps) to keep sediments out of the pond.

Design criteria for filtration galleries
Maintainability
• Design the catchment chamber and inspection chamber large enough for a person to be able to get in and freely use a tool for maintenance.

Design criteria for derivation-dam type intakes
Functionality
• Design the intake lintel at the same level or slightly lower than the weir crest so water will come in even when flow rates are low, so users do not have to construct a canal to get water to the intake. • Design complete facilities, including a silt and/or gravel trap, according to the river's material entrainment conditions, and overflow spillways (this is an aspect to be considered for all types of intakes).
Maintainability
• Design a cleaning gate on the weir that is large enough to allow sediment removal, to reduce users' maintenance work.
Safety and security
• Locate the intake along straight stretches of the river's course. • Design the intake taking the foundation land characteristics into account and on the basis of a risk analysis for the watershed.
Design criteria for direct intakes
Direct intakes are not recommended for our country, due to rivers' characteristics. Exceptionally, they could be designed in rocky, narrow rivers with a continual flow of water.

2.- Construction criteria to improve management capability

Construction criteria for canals
Maintainability .
• Use stonework when materials and labour are available locally
Durability
• Avoid using concrete in areas with extreme temperature fluctuations. • Use concrete in high-speed sections to reduce maintenance requirements. • Cast the floor and side walls at the same time. If this is not possible, first cast the floor and then the walls. • Place cracking grooves at suitable intervals (3 - 6 m). • Place expansion joints (waterstop) when two different construction materials are joined. • Construct berms to keep coarse material out of the canal and ensure side wall stability when the canal rises above ground level. • In cold areas, consider the concrete casting time, taking setting times into account so it will not freeze first and be ruined.
Safety and security
• Construct canals on hillsides following the original slope profile, not on fill.

Construction criteria for aqueducts
Durability
• Place waterproof tape at places where the structure changes from canal to aqueduct, to withstand water pressure. Fasten the tape to the reinforcing the formwork to prevent it from budging during pouring.

Construction criteria for siphons
Safety and security
• Bury the pipeline to protect it and guarantee its durability.

Construction criteria for drops
Durability
• In stepwise drops, when pouring the stilling pool, leave notches so water will not form a stagnant pool when the structure is not in use. • The control section is where the drop begins. It must end in a curve, not a right angle, so the flow will hit the vertical wall and reach the stilling pond with less of an impact.

Construction criteria for distribution points
Durability
• To construct gates, use sheets thick enough to withstand users' usage and mistreatment and the pressures to which they will be subjected. • The bushing of a worm-type distribution point must be made of iron and bronze.
Functionality
• Place a rubber seal in the canal groove so the gate will seal tight.

Construction criteria for silt traps
Functionality
• Construct the bottom gate right in the relief canal, with this canal sloping steeply so solids retained in the trap will be cleaned out automatically, but being careful not to erode the canal outlet location.

Construction criteria for ponds
Durability
• Include expansion joints to prevent the concrete from cracking.

Construction criteria for filtration galleries
Functionality
• While making the filter, rigorously observe grain size (material selection) in layering.
Safety and security
• The chamber must be above the maximum water level of the gallery and under the river bed erosion level.

Construction criteria for derivation-dam type intakes
Durability
• Ground the weir on stable material to prevent it siphoning and collapsing around its base. • Construct the stilling pond and weir with strong enough material to withstand impact by stones, gravel, etc. • Determine the undermining depth to define the type of foundation that will ensure facility stability.
Safety and security
• Do a careful treat of the lengthwise profile of the river by the compensation slope (flow control facilities) to keep structures from collapsing (valid for all types of intake).

Source (Gutiérrez, Alarcón & Saldías 2003, Bottega & Hoogendam 2004, Sanchez et al. 2002a,b, Monroy et al.2002, Muñoz et al. 2002).

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SUMMARY

Because of Bolivia's agro-climatic conditions, irrigation has become a priority issue for our country's agricultural production. Therefore, rural people press for improvements for their existing irrigation systems or construction of new systems. Accordingly, irrigation system construction and upgrades figure prominently in municipal, prefecture and sub-prefecture operating plans. In this context, Bolivia is investing funds from various sources to implement numerous irrigation projects.

One key aspect of Bolivian irrigation systems is that they are user-managed. The Bolivian government invests very little and has almost never invested any resources in water management; its role in regulating and creating norms for local water management has been relatively minor. This implies that any improvements introduced in them must ensure that user-management can continue, based on users' current or potential irrigation management capacity.

Although most irrigation systems in Bolivia are community-managed[1], there are many "threats", partly involving irrigation projects themselves. So far, the results are discouraging. Much of the infrastructure built by intervention projects is not being used or is in bad condition, which calls for in-depth research into the causes. In response, this book sets out to explore these unforeseen threats from interventions expected to improve irrigated agriculture and farmers' responses to them, and to help learning for the future, through detailed case studies of four intervention projects to improve irrigation infrastructure and management. Its objectives are to explore and demonstrate the 'divorce' that is taking place between how critical actors think about irrigation infrastructure design and management, and how designers often impose their own narrow preferences in infrastructure composition and performance, without reflecting on users' preferences and needs. It also sets out to debate the conditions that will help new irrigation infrastructure fit better in with management characteristics and production potential of irrigation systems, in order to guarantee sustainability.

This research has devoted special attention to analyses of infrastructure, in relation to their management and support organisation. However, this study is not a detailed study of infrastructure hydraulics, nor a study of knowledge and biases in design, nor an ethnographic study of social practices. Rather it provides an integrated analysis of infrastructure, management principles to obtain water using that infrastructure, and intervention support to build both. This is done to show how farmers (re)create systems that are functional and sustainable according to their current needs, and can still enable new future possibilities for production and labour deployment by farmers. While infrastructure diagnosis and its relation to design is the critical empirical material, the entry and closing debate always relates it back to farmers' production systems.

This thesis comprises 8 chapters. In general, the first chapter contains background on the research, the conceptual framework and the methodology. Also this chapter introduces the characteristics of the research sites regarding their agroecological zones, and an overview of agrarian & economic reforms, irrigation development in and intervention policies in Bolivia.

1 There is great diversity in the form of this local management (system size, economic aspects, development history, etc.) but users always have control over water management.

Chapter 2 presents the characteristics of traditional irrigation infrastructure and water management found in Bolivian irrigation systems, to provide an introductory context for the case studies. Chapters 3 through 6 show empirical data from four case studies. Chapter 7 analyses the findings, focusing on the infrastructure's adaptability to management capacity. Finally, Chapter 8 presents this study's conclusions.

The first chapter reviews the different conceptual approaches used to address irrigation system design. The conceptual framework for the research is grounded in the conviction that irrigation technology is a social and technical phenomenon, with social requirements of use. The research framework is based on the fact that irrigation system design has two main dimensions: 1. The contents dimension, regarding outcomes, and involving the following main elements: infrastructure design, future water management design, and design of the agricultural production system under irrigation. 2. The process dimension, which studies the ways that decisions are made. This includes attention to the stakeholders involved in the process, their positions, roles and activities leading to design outcomes. Whether planning interventions that create new ones or transforming existing systems, these two dimensions are inseparable. However, for programmatic and methodological reasons, the overall focus of analysis in this research is on the content dimension and, within this dimension, specifically on infrastructure design and how its change is related with accepted changes in production and social organisation. It builds around the concept of 'appropriateness' of technology, in both how a system is appropriate and suitable to current needs, but also how (and whether) farmers can transform a system themselves, or re-appropriate their system after its transformation, to run it themselves as relevant to local principles and practices.

For this purpose, the following main research areas are developed to focus on the operational, material and productive dimensions between infrastructure and management:

1. Operational appropriateness of infrastructure to management capability (related to operations and functionality of a system). These are the institutional characteristics of requirements for use of the improved irrigation system overall and at local level, as related to management capacity, especially in rights, rules and roles and work needed to ensure water delivery and self-administration.
2. Technical appropriateness of infrastructure to management capability. These are the technical characteristics of improved physical settings in relation to management capability, especially in their hydraulic and constructive suitability and potential to ensure environmental stability, and their maintenance requirements.
3. Productive appropriateness of infrastructure in relation to management capability. This involves the possibilities for inter-related transformations of production options and management institutions with improved infrastructure.

The second chapter will discuss two major aspects as a framework for this study: traditional infrastructure and small-farmer irrigation management. The issues addressed under each heading characterise irrigation systems in Bolivia in general and the wider experiences which the case studies document in more detail. In this context, irrigation projects have intervened to improve existing irrigation systems.

Chapters 3 through 6 present the case studies for improved irrigation systems in Condorchinoka, San Roque - Capellanía, Naranjos Margen Izquierda and Caigua, in that order. Each describes and analyses the characteristics of the improved infrastructure and of water management, contrasting farmers practice and projects' water management proposals. Agricultural production characteristics are also presented, emphasising changes in production scenarios as a result of irrigation system improvement. Then the design process is analysed, to understand the findings. This has served as a basis for analysing the infrastructure's adaptability to management capacity in each case, in terms of the three concepts presented in the conceptual framework.

These four case studies are then compared in Chapter 7, which analyses the improved irrigation infrastructure and users' management capacity, again in terms of the three key concepts. The first concept (the infrastructure's operational adaptability to water management capacity) analyses three key aspects: a. Project proposals for future water management, and users' response. b. Management capacity to operate and maintain improved infrastructure. c. Requirements to operate and maintain new facilities, under farmers' management criteria.

The analysis of infrastructure's technical adaptability to management capacity examines: a. the problems in the main infrastructure and their repercussions in system operation, examining the hydraulic adaptability of facilities and quality of construction in relation to users' operation and maintenance capacity. b. the main constraints on design and construction restricting management capacity. c. the main design and construction criteria contributing to management capacity, principally involving technical issues.

Finally, to analyse adaptability of infrastructure to production in terms of management capacity, the following aspects are considered: a. production scenarios in relation to farmers' production strategy. b. the effects of improved irrigation systems on agricultural production. c. household economic income and labour availability.

Chapter 7 also analyses the design process in order to understand findings, taking into account the following aspects: a. ways that project intervention approaches limit development of management capacity. b. non-interaction between users and engineers during design phases. c. implications of irrigation project eligibility indicators.

An analysis of *infrastructure's operational adaptability to management capacity* leads to the conclusion that the inclusion or exclusion of water rights from the design process (in terms of people acquiring water rights) is one of the social aspects that engineers most often take into account, although quite "instrumentally". In designing and implementing irrigation projects, there is a mechanical tendency to set up "irrigation committees / associations" with classic irrigation committee organisational structures. This type of parallel organisations does not work and is discarded by users, along with the related by-laws and regulations. Here it is important to recognise that irrigation systems are organised largely in response to water distribution (operation and division) requirements and infrastructure maintenance. Because operating tasks are usually simple, their respective responsibilities are not defined as complex activities entailing changes in the existing organisational structure, as could be the case in requirements resulting from changes in water distribution. Consequently, operational tasks are generally kept as an additional responsibility for authorities in charge of water distribution, or are handled by users themselves.

Finally, a new issue arising out of the research is that, in improved irrigation systems, the organisation must cope with new maintenance requirements demands, which entails having knowledge, labour and capital. If the organisation does not have these factors, this jeopardises the system's sustainability, due to lack of organisational capacity. Therefore, it is necessary for infrastructure proposals to be evaluated jointly so that the options chosen do not surpass the organisation's management capacity and that of users overall.

Regarding the competency to distribute water in improved irrigation systems, operating requirements for facilities constructed in the different irrigation systems studied are closely related to the water distribution mode. In the cases studied, water is delivered during the critical season by turns, rotating a single flow of water, in order to maintain the system's transparency and because little water is available. Accordingly, the only operating requirements are regulation and flow control. Regulation activities are limited to opening and closing gates on the different facilities, which family members can handle. Flow control must be minimal in improved systems. However, since some improved facilities in the case studies do not work adequately, due to a number of flaws in design and construction, users have to continue flow control or do extra tasks. This especially happens with siphons, intakes and canals with limited capacity. So, users have to take the trouble to carry out this additional activity, but they have sufficient knowledge to handle the situation.

Findings indicate that it is vital to analyse water distribution alternatives (delivery mode and flow) in relation to the irrigation infrastructure. The fundamental issue is to ensure that the facilities designed and constructed will not constrain distribution practices. This means that the water delivery mode (continuous-discontinuous, single/multi-flow) must be defined clearly beforehand. This is a key element with implications for delivery flow, and therefore for the irrigation infrastructure's required capacity. Further, the delivery mode generates requirements regarding the type and characteristics of infrastructure, such as the need for regulation structures: fixed or mobile, intermediate ponds, measurement points, etc.

The case studies show that new infrastructure maintenance is one of the main bottlenecks limiting improved irrigation systems' management capacity. In general, the requirements to maintain new infrastructure are not satisfactorily met by users. Evidently, renewed infrastructure upkeep entails "new" requirements, which users must perform to use improved technology appropriately. If they are unable to fulfil these new requirements (due to lack of knowledge, lack of resources, deficient facilities, or their being beyond their capacities) this jeopardises the irrigation system's sustainability and consequently its user-management capacity. This situation poses new conceptual and methodological challenges and calls for an attitude shift among professionals who intervene in small-farmer irrigation systems.

An analysis of the *infrastructure's technical adaptability to management capacity* shows that one major cause for limited hydraulic and constructive suitability, affecting management capacity, involves deficient criteria for designing and building irrigation infrastructure to operate in the Andean environment. These deficiencies may be grouped into two main categories: 1. Design and construction criteria that interfere with infrastructure's operation, and 2. Design and construction criteria that restrict its hydraulic and constructive suitability.

Regarding the first point, findings indicate that each irrigation system had improved facilities that did not work properly and were consequently misused. Improper use of facilities required continual repairs. When repair requirements surpassed user' possibilities, the facilities were abandoned or destroyed.

Facilities worked badly most often due to engineers' simple mistakes, designing and constructing them without taking Andean region characteristics into account. One first functionality problem is when facilities are unsuited to their adverse physiographic location. Technical issues affecting functionality are often apparently too elementary to even discuss with farmers. Functionality of facilities is also impaired by from the poor quality of materials used to build them. In most cases studied, functionality problems stem from poor quality construction.

Infrastructure functionality is also impaired by poor location of facilities, especially catchment abstraction facilities. The case studies also show that when engineers design, they normally ignore that these facilities are part of a network, which must operated connectedly and smoothly. One of the greatest deficiencies in this regard is the tendency to design and construct infrastructure components in isolation, ad hoc, without considering the implications for the remaining facilities and other components that comprise the irrigation system in its local setting.

All the above issues, taken together, make facilities less functional, and some must be adjusted or changed, or even rebuilt. The current irrigation project cycle would have to add a stage called "adjustment". However, such repairs call for additional funds, which Bolivia obviously cannot afford. The situation is even worse if we assume that users will be saddled with this responsibility (as shown in this research). So, this additional stage must be avoided. Case studies have shown the importance of: 1. user-engineer interaction during the design phase, so both groups share responsibility for the project, 2. serious, humble engineering stressing not only technical and mechanical design considerations but also users' possibilities to use the proposed infrastructure sustainably and 3. hiring supervisors who will enforce technical specifications, and help users monitor construction.

Under the second point, the cases researched show that social requirements to use technology, to achieve hydraulic and constructive suitability, are limited more in terms of irrigation infrastructure maintenance than operation. The central issue is that engineers never posed the question, while designing and building, whether the case study facilities could be maintained by users. If usage requirements had been taken into account, particularly regarding maintenance, engineers would have met this need by considering simple, obvious criteria. This all shows that facilities' management capacity – specifically maintenance capacity – is strongly affected by their intrinsic characteristics. Engineers are designing and building without taking interactive design requirements into account. Local management conditions and environmental features of our region demand new concepts, including: Maintainability, Durability, Functionality, Operability and Safety. Since these criteria are left out of design, the current conceptual framework and design context within which civil engineers and agronomists work must be reviewed, questioned and changed. Also, irrigation project implementation processes in Bolivia must be questioned. The way irrigation projects are implemented does not make designers accountable for outcomes and allows builders to shirk on technical specifications, support entities to act irresponsibly, and supervisors to be negligent.

An analysis of *infrastructure's productive adaptability to management capacity* leads us to conclude that renewing irrigation systems has indeed increased available water. With greater availability, users have changed their production scenarios (more land under irrigation, a new assortment of crops, better yields and a new planting schedule) which has improved their economic income. Changes in each irrigation system have been the result of farming activities by each user, based on their own aims and resources. In the case study projects researched, there has never been any institutional support for agricultural production to enable users to make better use of greater availability of water and optimise their farming strategies and yields.

Even when they have increased their income, the case studies show that irrigation users still cannot afford the indispensable requirement -maintenance of the rehabilitated infrastructure. In general, their economic capacity – even under the new situation – falls short of the requirements to maintain the new infrastructure. No infrastructure will ever be sustainable if not maintained, which requires labour and money.

So, irrigation infrastructure's adaptability or suitability for rural economies depends on how irrigated agriculture is addressed during irrigation projects' pre-investment, investment and post-project phases. Findings show that this situation is not being faced adequately. This will require further research, to set guidelines for irrigation investments, so they can better transform local economies and their impacts up to the national level. Infrastructure requiring less farmer investment in operation and maintenance, while making a greater impact on local livelihoods, will enable irrigation system users to meet their families' needs, while also fulfilling the economic requirements to maintain their irrigation systems.

This shows the need to set institutional policies not only for irrigation project implementation, but also to help users plan their agricultural production, so the country's various eco-regions can design their own local development proposals. This will contribute, in turn, to designing regional and national proposals, and to rethinking agriculture, to be more sustainable in environmental and socio-economic terms.

In conclusion, these three fundamental concepts are inter-related. It is crucial to take them into account in designing improved irrigation systems under small-farmer management, so that systems can once again be community-managed and sustainable.

Finally, analysing the *design process* has shown how results found to facilitate or limit infrastructure's management capacity are the outgrowth of positions taken, decisions made and attitudes shown by the different stakeholders involved in the intervention process. However, these intervention behaviours have been moulded by their different socio-economic, political and cultural contexts, and their capacity to involve other players in their "own" projects. Under these conditions, stakeholders' strategies and actions have influenced the flow of different events in each case.

Moreover, each project has followed its own process, shaped by the economic, social, political and cultural setting. Different processes have revealed numerous weaknesses, including insufficient knowledge of the overall design of irrigation systems, and the lack of any interactive design.

Research in the context of our reality, as in this case, can provide a foundation to generate new concepts and methodologies to support these design processes, in order to break out of slavish application of pre-established recipes, protocols or patterns. We must remember that users have to manage their systems, so they must be involved in decisions regarding changes in their local economy under irrigation.

Obviously, this is not such a simple change, involving large-scale institutional environments, and structural problems with professional education – which experience shows can hardly be changed at all until higher education authorities are aware, with the self-critical capacity to acknowledge the need for a change. It is definitely time to challenge the power relationships among different levels (users-agencies-funders, students-professors, designs-operators) that stand in the way of developing irrigation systems more interactively. Without this the intervention practice itself can continue to reproduce this imbalanced power relationship.

SAMENVATTING IN HET NEDERLANDS

In Bolivia is irrigatie van groot belang voor de landbouwproductie. Dit heeft te maken met de agro-klimatologische omstandigheden in het land. De plattelandsbevolking heeft daarom belang bij verbetering van bestaande irrigatiesystemen, of op de bouw van nieuwe systemen. Irrigatieverbeteringen en bouwprojecten staan daarom vaak boven aan op de ontwikkelingsagenda's van dorpen en (sub-)prefecturen. Het is in deze context dat de Boliviaanse overheid, gebruik makend van diverse fondsen, veel irrigatieprojecten financiert en uitvoert.

Een belangrijk aspect van Boliviaanse irrigatiesystemen is dat ze beheerd worden door gebruikers. De Boliviaanse regering heeft bijna nooit geld gestoken in het beheer van water en de overheid speelt maar een relatief kleine rol in het opstellen van regels voor en reguleren van lokaal waterbeheer. Verbeteringen in het irrigatiesysteem zouden daarom het huidige systeem van gebruikersbeheer in tact moeten laten. Het is belangrijk dat de verbeteringen gebaseerd worden op het (potentiële) vermogen van de gebruikers het irrigatiesysteem te beheren.

Dat de meeste irrigatiesystemen in Bolivia worden beheerd door de gebruikers betekent niet dat er niet van alles mis gaat. Sommige dreigingen ontstaan zelfs door nieuwe projecten, waarvan de resultaten vaak ontmoedigend zijn. Van de ontwikkelingsprojecten werd gedacht dat ze de geïrrigeerde landbouw zouden verbeteren en de betrokkenheid van de boeren zouden vergroten. De ervaring leert echter dat nieuwe stelsels soms helemaal niet in gebruik worden genomen, terwijl andere nieuwe of verbeterde stelsels in een zeer slechte staat van onderhoud verkeren. In dit boek wordt onderzocht wat er misgaat. Aan de hand van vier gedetailleerde casestudies wordt bekeken hoe, in de toekomst, de irrigatie-infrastructuur en het beheer ervan verbeterd kunnen worden. De bedoeling van dit boek is de kloof te laten zien, die ontstaan is tussen aan de ene kant de critici, met hun ideeën over ontwerp en beheer, en aan de andere kant de ingenieurs, die vaak hun eigen – beperkte- visie op het ontwerpen en functioneren van een infrastructuur aan anderen willen opleggen, zonder zich daarbij te bekommeren om de behoeften en voorkeuren van de gebruikers. In dit boek worden ook de voorwaarden besproken waaronder nieuwe of verbeterde irrigatiestelsels beter kunnen passen bij de bestaande waterbeheerstradities om zodoende de duurzaamheid van investeringen te vergroten.

In dit onderzoek wordt in het bijzonder aandacht geschonken aan het analyseren van de verhouding van de infrastructuur tot de organisatie van het onderhoud en beheer van die infrastructuur. Toch is dit boek geen gedetailleerde technische studie naar de hydraulische kenmerken van irrigatiestelsels. Ook is het geen studie naar bestaande ontwerptradities of vooronderstellingen, noch een etnografische studie naar sociale irrigatiepraktijken en tradities. In plaats daarvan is deze studie opgezet als een beschrijving van infrastructuur, de beheersprincipes die ten grondslag liggen aan het gebruik ervan, en de benodigde ondersteunende diensten voor beiden. Ook wordt er in uitgelegd hoe boeren goed werkende en duurzame irrigatiestelsels kunnen (her)ontwerpen die aansluiten bij hun behoeften en toch nieuwe mogelijkheden bieden tot aanwending van arbeid en productieverhoging. Hoewel het grootste deel van het empirisch materiaal in dit boek zal bestaan uit de beschrijving van de infrastructuur en het ontwerp ervan, zal er steeds verwezen worden naar het productiesysteem van de boeren.

Het proefschrift bestaat uit 8 hoofdstukken. In het eerste hoofdstuk worden de achtergrond van het onderzoek, het conceptuele kader en de methodologie beschreven. Ook wordt in dit hoofdstuk aandacht besteed aan een karakterisering van de agro-ecologie, agrarische en economische hervormingen, de ontwikkeling van irrigatie in Bolivia en ontwikkelingsbeleid ten aanzien van irrigatie.

In hoofdstuk 2 worden de oorspronkelijke irrigatie-infrastructuur en het waterbeheer van Boliviaanse irrigatiesystemen beschreven. Deze beschrijving is bedoeld om de casestudies beter te begrijpen. De hoofdstukken 3 tot 6 bevatten de empirische gegevens van de 4 casestudies. In hoofdstuk 7 worden de bevindingen geanalyseerd, waarbij de nadruk ligt op de geschiktheid van de infrastructuur voor waterbeheer. Tenslotte worden in hoofdstuk 8 de conclusies van het onderzoek gepresenteerd.

In het eerste hoofdstuk worden verschillende conceptuele benaderingen besproken, die gebruikt zijn om het ontwerpen van irrigatiestelsels te begrijpen. Het conceptuele kader van dit onderzoek is gebaseerd op de overtuiging dat irrigatietechnologie zowel een sociale als een technische aangelegenheid is, en dat irrigatie sociale voorschriften voor gebruik in zich draagt. Er wordt uitgegaan van de gedachte dat het ontwerp van irrigatiesystemen twee kanten heeft.

- de inhoudelijke kant, betreffende de volgende elementen: ontwerp van de infrastructuur, ontwerp van waterbeheer in de toekomst en ontwerp van een systeem voor de landbouwproductie binnen een irrigatie-infrastructuur.
- de procesmatige kant, waarin onderzocht wordt hoe beslissingen genomen worden. Er wordt aandacht geschonken aan de partijen die bij het proces betrokken zijn: wat is hun positie, welke rol spelen ze in de uitvoering van het ontwerp?

Of het nou gaat over het ontwerpen en aanleggen van een geheel nieuw systeem neerzet, of om het verbeteren van een bestaand systeem, deze twee kanten zijn onlosmakelijk met elkaar verbonden. Om programmatische en methodologische redenen zal in dit onderzoek toch de nadruk komen te liggen op de inhoudelijke kant. Specifieker zal het gaan over het ontwerp van stelsels en over voorgestelde veranderingen zich verhouden tot de organisatie van de landbouw productie en de bredere sociale organisatie. Het onderzoek concentreert zich op de ´geschiktheid´ van de technologie. De vraag is niet alleen of een systeem geschikt is en aansluit bij de vraag van dat moment, maar ook hoe (en of) boeren zelf een systeem kunnen (her)ontwerpen, om het zelf te beheren in overeenstemming met hun lokale praktijken en tradities.

Om de operationele, materiële en productieve dimensies te belichten, zijn de volgende onderzoeksgebieden tussen infrastructuur en beheer te onderscheiden:

1. Operationele geschiktheid (of bedieningsgemak) van de infrastructuur voor het beheer (gerelateerd aan de werking en de bediening van een stelsel). Het gaat hier om de institutionele kenmerken van de gebruiksvoorschriften die besloten liggen in ontwerpen ter verbetering van (onderdelen van) het systeem in relatie tot het aanwezige vermogen het systeem te beheren. Hierbij ligt de nadruk op de rechten, regels en het werk dat nodig is voor de aanvoer en de verdeling van water en zelfbestuur.
2. De geschiktheid van de infrastructuur voor het beheer op het niveau van de techniek. Het betreft hier de technische kenmerken van het de vernieuwde fysieke infrastruktuur in relatie tot het beheer ervan. En dan in het bijzonder waar het de hydraulische en contructie-technische geschiktheid betreft in relatie tot de specifieke kenmerken van de omgeving waarin het stelsel gebruikt wordt en in relatie tot de onderhoudsvereisten.

3. De productie-technische geschiktheid van het stelsel in relatie tot het beheer ervan. Het gaat hier over de manier waarop verbeteringen in de gewasproductie samenhangen met verschillende beheersmogelijkheden en onderhoudsvereisten.

In het tweede hoofdstuk worden twee belangrijke aspecten van het onderzoekskader besproken: de traditionele infrastructuur en de aanwezige irrigatiebeheersvormen van kleine boeren. De onderwerpen die aan bod komen zijn: de bestaande irrigatiesystemen in Bolivia in het algemeen en meer in het bijzonder de uitgebreide ervaringen uit de casestudies. De irrigatieprojecten werden in deze casestudies allemaal ontwikkeld om bestaande systemen te verbeteren.

In hoofdstuk 3 t/m 6 worden de casestudies van externe pogingen irrigatiesystemen te verbeteren besproken in respectievelijk Condorchinoka, San Roque Capellanía, Naranjos Margen Izquierda en Caigua. In elk afzonderlijk hoofdstuk worden de voorgestelde verbeteringen van de infrastructuur en het waterbeheer beschreven en geanalyseerd en gecontrasteerd met de bestaande praktijken en tradities van de boeren zelf en hun eigen ideeën met betrekking tot waterbeheer. De kenmerken van de landbouwproductie worden benoemd, waarbij de nadruk ligt op hoe verbeteringen in irrigatie het productiesysteem zullen veranderen. Vervolgens wordt het irrigatieontwerpproces geanalyseerd. De casestudies liggen ten grondslag aan een analyse waarin gekeken wordt of de betreffende infrastructuur geschikt is om in aanmerking te komen voor beheer door de gebruikers. Deze analyse geschiedt op basis van de drie eerder genoemde concepten.

In hoofdstuk 7 komen de 4 casestudies samen. Er wordt hierin een analyse gemaakt, wederom op basis van de eerder genoemde concepten, van verbeterde infrastructuren in relatie tot gebruikersbeheer. Het eerste concept (de operationele geschiktheid (of het bedieningsgemak)) van de infrastructuur) bevat de volgende drie punten:

a. Projectvoorstellen voor toekomstig waterbeheer en de reactie van de gebruikers daarop.

b. Het aanwezige vermogen om de verbeterde infrastructuur te bedienen en onderhouden, en deze taken goed te organiseren.

c. Vereisten voor het bedienen en onderhouden van het nieuwe stelsel, uitgaande van beheer door gebruikers.

Het onderzoek naar de technische geschiktheid van het stelsel ten opzichte van het aanwezige beheersvermogen omvat de volgende onderdelen:

a. De grootste infrastructurele problemen van het stelsel. Hierbij zal gelet worden op zowel de hydraulische geschiktheid van (de onderdelen van het) irrigatiestelsel als op de kwaliteit van de constructie met betrekking tot de geschiktheid voor gebruikersbeheer en –onderhoud.

b. De grootste ontwerp- en contructie-technische belemmeringen voor wat betreft gebruikersbeheer.

c. De belangrijkste technische ontwerp en constructie-technische criteria die van invloed zijn voor het beheer.

Tot slot worden de gevolgen voor het beheer van de verbeterde infrastructuur met betrekking tot de gewasproductie onderzocht. De volgende aspecten komen aan bod:

a. Productiescenario’s met betrekking tot boeren productiestrategieën.

b. De effecten van verbeterde infrastructuren op de landbouwproductie.

c. Inkomensgevolgen op het niveau van het huishouden en de beschikbaarheid van arbeid.

In hoofdstuk 7 wordt ook het hele ontwerpproces geanalyseerd. De volgende aspecten spelen hierbij een rol:

a. Hoe ontwikkelingelingsprojecten door hun aanpak de ontwikkeling van gebruikersbeheer belemmeren.

b. Het gebrek aan communicatie tussen gebruikers en ingenieurs tijdens het ontwerpproces.

c. Gevolgen van het gebruik van criteria op basis waarvan projecten worden goed (of af-) gekeurd.

De analyse van de operationele geschiktheid (het bedieningsgemak) van het ontwerp voor het beheer leidt tot de conclusie dat waterrechten eén van de sociale kwesties is die ingenieurs wel degelijk betrekken in hun ontwerpen, zij het meestal op een vrij instrumentele manier. Ook behoort het opzetten van gebruikersorganisaties vaak tot de standaard ingrediënten van het ontwerp en de uitvoering van irrigatieprojecten. Dit gebeurt echter vaak volgens standaard procedures en richtlijnen, uitgaande van een model organisatie met een voorgeschreven interne structuur. Deze nieuwe organisaties worden vaak opgezet en bestaan naast de reeds aanwezige waterbeheersorganisaties, hetgeen de reden is dat ze niet functioneren en door de gebruikers zelf genegeerd worden. Hierdoor komen ook de nieuw verordonneerde wetten en regels niet bij de gebruikers terecht. Hierbij dient vermeld dat irrigatiesystemen veelal georganiseerd worden in overeenstemming met de voorschriften voor waterverdeling en met de voorschriften voor het onderhoud van de infrastructuur. Het bedienen van het systeem is meestal vrij eenvoudig. De bijbehorende verantwoordelijkheden worden niet omschreven als ingewikkelde activiteiten, en zijn niet vastgelegd, dus hebben ze geen gevolgen voor de organisatiestructuur. De wijze van waterverdeling heeft meer invloed op de gekozen beheersvorm. Dit is de reden dat de aanwezige waterverdelingsautoriteiten doorgaans de bedieningstaken er ook bij nemen. Vaak wordt de bediening van het stelsel ook door gebruikers zelf gedaan.

Een nieuw aspect dat uit het onderzoek naar voren komt is, dat de organisatie van een verbeterd irrigatiesysteem te maken krijgt met nieuwe voorschriften en eisen ten aanzien van onderhoud, waar dan weer nieuwe kennis, arbeid en kapitaal voor nodig zijn. Indien kapitaal, kennis en arbeid niet in voldoende mate voorhanden zijn, dreigt het systeem uit elkaar te vallen. Bij het opstellen van de plannen ter verbetering moet hier rekening mee gehouden worden. De organisaties, maar ook de gebruikers, moeten steeds bij het overleg betrokken worden.

De bedieningsvoorschriften voor de verbeterde irrigatiesystemen in kwestie, hangen samen met de manier waarop de verdeling van het water plaatsvindt. Bij de onderzochte systemen wordt het water in het droge seizoen bij toerbeurt geleverd, waarbij de verschillende irrigeerders om de beurt gebruik maken van één en dezelfde waterstroom. Dit is gedaan om ten bate van de inzichtelijkheid van het systeem, maar ook omdat er maar weinig water is. Voorschriften voor de bediening betreffen dus alleen regulering en waterbeheersing. De regulering houdt het openen en sluiten van sluizen, verdeelwerken en inlaten in, op de verschillende plekken – relatief eenvoudig werk dat door bijna iedereen gedaan kan worden. De nieuwe verbeterde systemen zijn vaak ontworpen om de benodigde waterbeheersingsmaatregelen tot een minimum te bepreken. Dat de meeste gebruikers toch veel aan waterbeheersing moeten doen, heeft te maken met het feit dat ontwerp en constructie nogal eens zwakke plekken vertonen. Het gaat hier in het bijzonder om de sifons, de inlaten en het feit dat kanalen ondergedimensioneerd zijn. Alhoewel de gebruikers over voldoende kennis beschikken, betekent het wel extra werk voor hen.

Een grondige analyse van alternatieve methoden voor de distributie van water, in relatie tot de irrigatie-infrastructuur, is onontbeerlijk, zo blijkt uit de bevindingen. Het is vooral van belang dat de nieuw ontworpen kunstwerken en het stelsel als geheel aansluiten bij bestaande waterver delingspraktijken. De waterverdelingsmethode (continu of niet; één of meerdere stromen) moet daarom duidelijk van tevoren omschreven moet zijn. De gekozen verdelingsmethode heeft weer gevolgen voor manieren van waterbeheersing en daarmee ook voor de benodigde capaciteit van de irrigatie-infrastructuur. De wijze van verdelen bepaalt ook mede de keuze voor de verdeel- en meetwerken: permanent of tijdelijk, wel of in het stelsel opgenomen reservoirs, soort en hoeveelheid meetpunten…enz.

De studies laten zien dat het onderhoud van de vernieuwde stelsels het grootste knelpunt vormt voor het beheer van de stelsels. De gebruikers ontbreekt het in het algemeen aan de kennis die noodzakelijk is voor het onderhoud van de verbeterde infrastructuur. Vanzelfsprekend vraagt een verbeterd systeem om een gewijzigde aanpak van de gebruikers, om de nieuwe technologie goed te kunnen toepassen. Als de gebruikers niet in staat zijn aan de nieuwe eisen te voldoen (dit staat nog los van hun mogelijkheden, gebrek aan kennis, middelen of niet werkende apparatuur), dan vormt dat een bedreiging voor de duurzaamheid van het systeem en, daarmee samenhangend, het vermogen om de infrastructuur door de gebruikers te laten beheren. Dit roept nieuwe conceptuele en methodologische uitdagingen op, en vraagt aan om een verandering in de houding van degenen die zich beroepsmatig met boeren-irrigatie bezig houden.

Wat levert een analyse op van de technische geschiktheid van de nieuwe stelsels voor beheer door gebruikers? De belangrijkste oorzaak van de beperkte hydraulische en constructie-technische geschiktheid van de nieuwe stelsels heeft te maken het feit dat de gebruikte ontwerp– en constructiecriteria niet zijn toegesneden op de specifieke kenmerken van de Andes. De redenen voor ongeschiktheid kunnen in twee groepen verdeeld worden:

1. Ontwerp- en constructiecriteria die de bediening van het stelsel belemmeren.
2. Ontwerp- en constructiecriteria die de hydraulische en constructieve geschiktheid van het stelsel beperken.

Uit het onderzoek blijkt dat, wat het eerste punt betreft, alle irrigatiesystemen onderdelen hebben die weliswaar vernieuwd zijn, maar die niet naar behoren functioneren. Dit leidt tot verkeerd gebruik van deze onderdelen. Bij onjuist gebruik zijn voortdurend reparaties nodig. Wanneer de vereiste kennis om een onderdeel te repareren bij de gebruikers ontbreekt, worden de betreffende delen van het systeem verlaten of vernietigd.

De onderdelen werken meestal slecht door relatief simpele ontwerp en contructie fouten die voortkomen uit het feit dat ingenieurs geen rekening houden met de specifieke karakteristieken van het Andesgebied. Klaarblijkelijk zijn technische zaken die het goede functioneren kunnen belemmeren vaak niet belangrijk genoeg om te (her)overwegen of te overdenken. De werking van onderdelen van het systeem hangt ook af van de kwaliteit van de materialen die gebruikt zijn. In de meeste cases die in dit boek beschreven zijn, komen problemen met de werking van stelsels voort uit de slechte kwaliteit van de gebruikte bouwmaterialen.

De slechte werking van de apparatuur ligt soms ook aan de slecht gekozen locatie, vooral waar het betreft de inlaat. De casestudies laten zien dat ontwerpers vaak geen rekening houden met het feit dat de verschillende onderdelen van een stelsel deel uitmaken van een netwerk. Dat netwerk moet een samenhangend en soepel geheel zijn. Een van de grootste gebreken is de neiging geïsoleerd en tamelijk ad hoc te ontwerpen en bouwen, zonder rekening te houden met de andere onderdelen die deel uitmaken van het irrigatiesysteem in de lokale setting.

Alle bovengenoemde punten zorgen ervoor dat de onderdelen minder goed werken, en dat er soms aanpassingen, veranderingen en verbouwingen nodig zijn. Het lijkt er daardoor op of er aan het huidige traject van (het bouwen van) irrigatieprojecten een fase toegevoegd zou moeten worden., die van de afstemming. Zulke ‘afstemmingsreparaties’ kosten echter geld dat meestal niet voorhanden is, waardoor de gebruikers de facto worden opgezadeld met de verantwoordelijkheid het stelsel te her-ontwerpen zodat het wel functioneert. Dit is waarom het beter is de noodzaak tot afstemming na afronding van het project te voorkomen. De casestudies hebben het belang laten zien van

1. De interactie tussen gebruiker en ontwerper tijdens de ontwerpfase, ertoe leidend dat beide partijen verantwoordelijkheid dragen voor het eindresultaat.
2. Serieuze, bescheiden ontwerpen waarbij de nadruk niet alleen ligt op technische en mechanische ontwerpcriteria, maar waarbij, dan al, afstemming plaatsvindt met de gebruikers die de voorgestelde infrastructuur langdurig moeten kunnen gebruiken.
3. Het in dienst nemen van opzichters die oog hebben voor de technische specificaties en die de gebruikers helpen het constructie proces in de gaten te houden.

De analyse van de sociale gebruiksvoorwaarden nodig om een stelsel op een hydraulisch en constructie-technisch geschikte manier te laten functioneren laten zien dat de grootste belemmeringen liggen op het gebied van het onderhoud, en niet op het gebied van de bediening. Het probleem is dat de ingenieurs zich tijdens het ontwerpproces nooit hebben afgevraagd of (de onderdelen van) het irrigatiesysteem onderhouden kunnen worden door de gebruikers. Als er rekening was gehouden met de gebruikers, dan zouden de ontwerpers heldere en eenvoudige criteria opgesteld hebben. Dit betekent dat het vermogen het systeem te beheren, en vooral te onderhouden, sterk beïnvloed wordt door zijn intrinsieke eigenschappen. Ingenieurs ontwerpen en bouwen zonder rekening te houden met de eisen die door de gebruikers gesteld worden. De lokale voorwaarden voor beheer en de specifieke eigenschappen van het gebied vragen om een nieuwe benadering. Belangrijke ingrediënten van zo een nieuwe benadering zijn: onderhoudsgemak, duurzaamheid, functionaliteit, bedieningsgemak, en veiligheid. Op dit moment worden deze punten niet bij het ontwerp betrokken. Daarom zouden de benadering en het ontwerp waarmee civiele ingenieurs en agronomen werken, heroverwogen, bevraagd, en veranderd moeten worden. Ook zou de totstandkoming van irrigatieprojecten in Bolivia aan een onderzoek onderworpen moeten worden. Door de wijze waarop dat nu gebeurt zijn ingenieurs niet aansprakelijk voor de behaalde resultaten. Bovendien kunnen aannemers de technische specificaties omzeilen, worden dienstverlenende instellingen aangemoedigd om onverantwoord te werk te gaan, en worden de opzichters aangespoord tot slordigheid.

Analyse van de geschiktheid van de nieuwe stelsels voor de gewasproductie in relatie tot het beheer ervan leidt tot de conclusie, dat vernieuwde irrigatiesystemen daadwerkelijk meer water opleveren. De boeren hebben hun productieplannen hierdoor kunnen aanpassen (meer geïrrigeerd land, nieuwe gewassen, betere oogst) en hebben meer inkomsten. Zulke verbeteringen zijn veelal op het conto te schrijven van van de afzonderlijke gebruikers, die resultaten behaalden door de inzet van hun eigen doelen en middelen. Er is nooit enige institutionele steun geweest (uit de beschreven casestudies) ter bevordering van die de landbouwproductie, waardoor de gebruikers de grotere beschikbaarheid van water zouden kunnen benutten voor het optimaliseren van de gewasproductie strategieën en het verhogen van hun oogsten.

De casestudies laten zien dat zelfs als het inkomen groter is geworden, de gebruikers zich nog steeds niet de investeringen die nodig zijn voor het onderhoud van de vernieuwde stelsels kunnen veroorloven. De gebruikers komen dus, zelfs in de nieuwe situatie, nog steeds geld tekort voor het onderhoud. Geen enkele infrastructuur overleeft zonder onderhoud, en daar zijn geld en arbeid voor nodig.

De geschiktheid van irrigatiestelsels op het platteland hangt af van hoe de geïrrigeerde landbouw benaderd wordt tijdens de verschillende fasen van een interventie project. In het verleden is dit vaak niet adequaat omgegaan. Voor het opstellen van richtlijnen voor investering in irrigatieprojecten, is verder onderzoek noodzakelijk. Dan zouden de projecten op lokaal niveau invloed kunnen uitoefenen in de besluitvorming, en zelfs een stem kunnen krijgen in besluiten en plannen die op nationaal niveau genomen worden. Betere stelsels die dus minder geld voor onderhoud van de gebruikers zelf vragen en met meer positief effect op de lokale leefomstandigheden zullen ervoor zorgen dat de gebruikers beter in hun levensonderhoud kunnen voorzien, terwijl ook aan de onderhoudseisen voldaan wordt.

Dit alles geeft de noodzaak aan tot het opstellen van institutioneel beleid, niet alleen voor de uitvoering van irrigatieprojecten, maar ook om gebruikers te helpen hun landbouwproductie te plannen, zodat de verscheidene ecologische gebieden van het land hun eigen ontwikkelingsplannen kunnen opstellen. Dat zou weer kunnen bijdragen aan regionale en nationale plannen en aan een herziening van de landbouw, zodat die ecologisch, sociaal en economisch duurzamer wordt.

Bij wijze van conclusie kan gesteld worden dat de drie basisconcepten met elkaar verweven zijn. Het is van het grootste belang ze alledrie te betrekken bij het ontwerpen van verbeterde irrigatiesystemen die onder het beheer van kleine boeren vallen, waardoor ze langer meegaan.

Analyse van het ontwerpproces laat zien dat het vermogen de infrastructuur te beheren, deels het resultaat zijn van ingenomen stellingen, bepaalde besluiten, en van de opstelling van de partijen betrokken bij het ontwikkelingsproces. Hoe de verschillende partijen zich opstellen en gedragen hangt weer af van hun sociaal-economische, politieke en culturele context, alsmede van hun vermogen andere spelers bij het ‘eigen project’ te betrekken. In elk van de case-studies hebben de besluiten en het gedrag van de verschillende belanghebbenden de richting en aard van het ontwikkelingsproces beïnvloed. Bovendien heeft elk project een eigen proces gevolgd, gevormd door de economische, sociale, politieke en culturele setting. De verschillende processen laten vele zwakke plekken zien, bijvoorbeeld onvoldoende kennis van het ontwerp in zijn geheel of gebrek aan communicatie over en weer met gebruikers.

Dit soort onderzoek kan een startpunt zijn voor het ontwikkelen van nieuwe concepten en methoden die een bijdrage kunnen leveren aan de ontwerpprocessen. Zo komt er een eind aan het slaafs uitvoeren van standaard protocollen en blauwdrukken.. We zouden moeten onthouden dat de gebruikers hun eigen systeem moeten kunnen beheren. Daarom moeten ze betrokken worden bij de beslissingen die van invloed zijn op hun lokale irrigatie-economie.

De beoogde veranderingen zijn niet eenvodig, en behelzen niet alleen de bredere institutionele context, maar ook de structurele problemen in het irrigatie-onderwijs. De ervaring leert dat veranderingen bijna onmogelijk zijn tot op het moment dat de onderwijsautoriteiten ervan doordrongen raken, met de zelfkritiek die nodig is om in te zien dat veranderingen noodzakelijk zijn. Het wordt hoog tijd de machtsverhoudingen eens flink op te schudden (tussen ontwerpers en gebruikers, tussen studenten en docenten). Irrigatiesystemen zouden dan meer interactief tot stand komen. Als dit niet gebeurt, is er en risico dat ongelijke machtsverhoudingen door de aard het het proces van de interventie zélf gereproduceerd worden.

CURRICULUM VITAE

Zulema Gutiérrez- Pérez studied at the School of Agronomy of the Universidad Mayor de San Simón in Cochabamba, Bolivia. Upon completing her studies, she worked with the Inter-Valleys Irrigation Project (PRIV) for seven years. She was responsible for the on farm irrigation system component and was on the irrigation management team.

She was later engaged as professor and researcher with the Andean and Valley Irrigation Research and Teaching Programme (PEIRAV), an agreement between the University of Wageningen, Netherlands and the Universidad Mayor de San Simón. She spent another seven years with this institution, as Research Co-ordinator, and teacher of the subjects of "Irrigation Management", "Irrigation Systems Design" and the Thesis Workshop of the Engineering Department of the School of Agronomy. She was also responsible for conducting various consultancies nationally and internationally. During her time with PEIRAV, she pursued specialised studies with the University of Wageningen, Netherlands, earning an MSc degree in Soils and Irrigation. Upon her return to Bolivia, she remained with PEIRAV until 1998.

In 1998, she was engaged as Applied Research Officer for the National Irrigation Programme (PRONAR), which got her more involved with research into irrigation issues in Bolivia. This work enabled her to publish a series of research papers, and gave her the opportunity to research for her PhD. She remained with that institution through August 2004, when the funding ran out for the PRONAR Applied Research sub-component. Since then, she has been working on her PhD dissertation and a broad array of consulting missions.