DEVELOPMENT OF SPRINKLER IRRIGATION IN MOUNTAIN ENVIRONMENTS

experiences from Northern Peru

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Contents

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1. Introduction

In the history of irrigation development in Peru, there always existed a big gap between the coast, where large capital-intensive, fully controlled irrigation schemes have been constructed for export-oriented agriculture, and the Andean highlands, where indigenous people and colonial landowners had their small, low-cost canals which nowadays mainly serve for small-scale subsistence agriculture. Government policies emphasized on the importance of coastal irrigation schemes for the national economy, and private enterprises adopted modern irrigation technologies to keep up with developments in intensive cash crop farming in other parts of the world. In the mean time in the Sierra the aim of development institutions, governmental or NGO, remained oriented towards providing improvements, that generally maintained the existing technological level.

It is only in the last few decades that sprinkler irrigation as a technological innovation has started to penetrate into the Andes of Peru, Ecuador and Chile. Inspired by examples from the coast a process of technological change is taking place, gradually creating a growing demand for support and technical assistance.
Within development institutions, the vision that sprinkler irrigation would be too expensive and too complicated has changed, and a steadily growing number includes financial support and technical assistance in this field in its program of activities. SNV, supporting various institutions in Ecuador and Peru, has been actively involved in reinforcing institutional policies and technical capacities in order to adequately guide this process of technological innovation. This has led to a series of more or less documented experiences as well as a workshop to exchange these in November 1998 (SNV, 1998).

This paper focuses on experiences generated in the Northern Peruvian Andes between 1998 and 2000 in the context of a project for technical assistance between SNV and PRONAMACHCS (National Project for Catchment Management and Soil Conservation).
In combination with the development of methods to initiate and guide processes of integrated water resource management in micro-catchments, technological development of irrigation constituted a key opportunity to put into practice participatory planning, design, implementation and follow-up of interventions, which aimed at efficient and optimal use of irrigation water.
Here emphasis will be put on the way in which a process of technological change is being brought about, taking into account social acceptance and economic feasibility, and how it needs to be accompanied in the future.
First, in chapter 2, the role of irrigation in the production systems and the related socio-organizational issues will be discussed. Then, in chapter 3, the possibilities and limits of sprinkler irrigation will be analized in order to indicate the margins of its development potential. Next, design issues (chapter 4) and intervention strategies (chapter 5) related to development of sprinkler irrigation technology, applied in the context of the Northern Peruvian Andes, will be presented. Finally, results and final reflections are treated in chapter 6.
Chapter 3 and 5 are based on two documents written by J. Willet and myself, which are included in the bibliography (Anten and Willet, 2000a and d) and therefore no specific references are given in these two chapters to the mentioned documents.

The paper is written in English in order to contribute to the international debate on how to deal with the world's water resources. SNV-experts and their counterparts, working in countries in other parts of the world with similar agro-ecological and environmental conditions, as well as other professionals in watermanagement may take notice of experiences which otherwise would only be accessible to the Spanish-speaking public.

2. Irrigation in Andean peasant societies

2.1 Irrigation in the production system

Various authors have pointed out the multiple aspects of irrigation in mountain agriculture and in the farming systems of the Peruvian Andes in particular, stressing the extremely complex combination of variety in terrain (ecological zones, related to altitudes), micro-climates and other climate factors, hydrology, livelihood strategies and social patterns of organization, institutional arrangements, culture and cosmo-vision related to the management of water resources.

In an intent to limit myself to the most crucial aspects, and focussing on the situation in the Northern Peruvian Andes, the following points can be mentioned:

As Vincent puts it, irrigation water is vital in highland and high altitudes to complement the seasonal climates which bring heavy rains during certain periods of the year, supplying crop deficits during dry spells within the rainy season, while at the same time offering a protection against frost and increasing the flexibility of farmers to schedule rainfed crops either earlier or later in the season (Vincent, 1998). In the Sierra of Cajamarca, irrigation allows a second crop cycle on a limited scale in the short dry winter season (may - november), or maintains permanent crops like pasture, fruit trees, sugarcane etc. during this period.

Due to the development of dairy farming in the Cajamarca valley and surrounding mountains, at altitudes of approximately 2800 m. and above, irrigation is used almost exclusively to maintain pastures. In similar ecological zones at greater distances, out of the reach of dairy companies, potato is the most important crop grown under irrigation, usually in combination with a variety of crops like peas, garlic, alfalfa etc. Beneath 2800 m a variety of irrigated crops is found including fruit trees, potato, sweet potato, beans, cassava, sugarcane and pasture for fattening livestock for slaughter.

Boelens (1998) stresses the role of irrigation canals as axis in the management of agrarian production cycles in several altitudinal, ecological zones, provided they pass through both high and low zones making it possible for farmers to have irrigated plots in different agro-climatic areas.

Lynch (1988) emphasizes the importance of irrigation as a factor that increases flexibility in productive systems that incorporate different ecological zones and/or different employment sectors (agriculture, trade, paid work, etc.). The different productive activities compete with each other for the labour of the family, and since irrigated areas can be cultivated with fewer restrictions regarding the seasons of cultivating activities, it creates a certain convenience in the planning of all these activities.

Various authors point out that, in view of this appreciation, the crucial function of irrigation in production systems lies in a better use of the family labour throughout the year, including that of women and children (Lynch, 1988, Bennet and Tapia, 1998) The fact that water resources in the Sierra of Cajamarca usually consist of a great amount of extremely small springs, sources and small streams, all of which are used by relatively large numbers of families, for multiple purposes (domestic use, irrigation, energy), in many cases results in very small irrigated plots for each family[1]. The use of these plots is usually to diversify the family diet with vegetables or provide spices, to assure the energy component in the production system

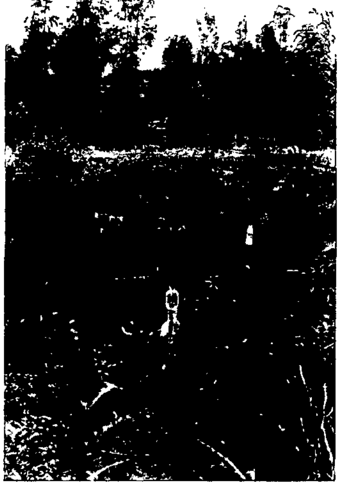
[1] As an example, the "Zorro" canal in the surrounding hills of Cajamarca has a flow of 6 litres/sec and a number of 64 water users, thus an average of less than 0,1 lit/sec per family. Thus, each can have an irrigated plot of some 1000 m^2 or less.

by providing fodder for draught animals, or to gain a small but constant income through diary farming.

Against this background, it has to be noted that there is limited potential in the Northern Andes to bring large areas under irrigation, due to the high level of disparity of existing water resources, and the high costs related to the implementation of highly technical solutions to store and convey important volumes of water. Most of the larger projects planned since more than a decade aim at transferring surplus water flowing off to the Amazon river to the other side of the "divortium aquarium" to provide coastal irrigation schemes on the Pacific side of the Andes with more water.

On the other hand, the great interest of highland farmers in the optimum use of the small quantities of water under their control in order to increase the flexibility of their production system and thus their ability to cope with the environmental and economic challenges they face, opens the way to a vast amount of small-scale improvements which can be and are undertaken, either by the farmers themselves or by development institutions.
The introduction of modernized irrigation techniques is one of the means by which farmers and external agents try to achieve this and explains the rapidly expanding interest of both parties during the last ten years.

Figure 1: A local solution to apply sprinkler irrigation



However, the great variety in results from numerous attempts to introduce pressurized irrigation, in the technical sphere as well as in the sphere of organization and social dynamics has given rise to discussion, reflection on intervention strategies, and exchange of experiences between farmers and professionals, and has demonstrated the delicacy of intervening in existing water use systems in order to transform them into pressurized systems.
Therefore, a closer look at socio-organizational issues related to Andean irrigation is called for before taking up the matter of strategies for intervention.

2.2 Organization and water rights

A vast quantity of literature exists on the description and the analysis of Andean irrigation systems and their social dimension, once again revealing an enormous diversity in complexity, organizational patterns and degrees of institutionalization.
Broeks & Calderón (1996), proposing a framework to analyse and classify water users organizations, reveal a set of important factors which determine the different organizational forms which can be found. Two basic parameters are used:

- The degree of institutionalization of organizations, determined by three factors: 1.water availability, ranging from very scarce to abundant; 2. the relative importance of irrigated agriculture for the household economy; and 3. the number of water users ranging from one family via several small groups to one big group of users.
- The basic structure of the organization, once again determined by three factors: 1. the number of water sources; 2. the irrigation methods applied (surface, pressurized or mixed); 3. the configuration of the irrigated area (concentrated or more dispersed).

In this way they distinguish eight different categories of organizational forms, varying from one single water user without any rules or regulations, to a highly centralized, highly institutionalized water users organization, and this shows how in each situation people have found a way, or need to find one, to organize themselves according to local conditions.

Boelens (1998) points out how, looking for local organizations within catchment areas, we can find that irrigation systems, connecting altitudinal zones, families and communities, can be considered as organizational fundaments, playing an important dynamic and bonding role in generating inter- and intra community organizations.
However, he adds that processes of colonization & agrarian reform have caused disintegration of irrigation practices, particularly in the inter-communal systems, while small communal systems have managed to maintain themselves or have been re-created.

The introduction of modernized irrigation methods, either as a spontaneous process or induced by development agencies, invariably has its effects on, and therefore needs to take into account this organizational context: in Cajamarca most of the successful adoptions of sprinkler technology by farmers themselves is found where every farmer has his own independent spring and therefore his individual system, while individuals or small groups of water users from a larger irrigation system, who take to sprinkler irrigation, usually create conflicts with the other users. Development agencies need to carefully accompany these processes if they want to avoid failing with their interventions.

One of the most crucial issues in Andean irrigation systems is the manner in which rights of access to water and distribution of water between users are established, as this constitutes the base of collaboration between a group of people who have to manage common water resources. The equity issue related to this has received extensive attention, as shown by the impressive compilation of contributions on justice and equity in peasant irrigation edited by Boelens and Dávila (1998).

Although thoroughly interwoven, I would like to treat the two issues *rights of access*[2] to water and *water distribution* in a separate manner in order to clarify the ways interventions have to deal with them.

<u>Rights of access</u>

Literature on the subject and experience in Cajamarca reveal that rights of access to water in the post hacienda era are determined by:

- location of the water sources: particularly in the case of small springs with one single family or a small group that uses them, the water is considered to "belong" to the owner of the land where the spring is located, and negotiations within a small group of households might determine conditions of each family to benefit from the spring. While the official water law stipulates that all water is State property, the use of these springs for the benefit of the community through construction of drinking water systems can only be achieved if the community manages to make a deal with the owner of the land, according to local criteria.

- type of use: it is frequently observed that the same water resources are used for various purposes (domestic consumption, watering of animals, energy and irrigation) and that for each type of use there is a different group of users, the use for domestic consumption and for animals usually involving the largest group.

- initiation of, and contribution to the process of constructing the water use system: the initiatives taken by (groups of) farmers and the participation in collective work to construct and/or rehabilitate water use systems are the most clearly visible criteria used to define rights of access to water. In existing systems, rehabilitation and/ or improvements undertaken with external support are often considered as an opportunity for new users to

[2] With the term 'rights of access' I am referring to the local arrangements and regulations, based on traditions and agreements between local people, determining who may or may not use water from a specific source. The Peruvian Water Law usually comes into scope only if external (governmental) agencies start to get involved in the local situation.

obtain access to the same water, leading to social struggles and negotiations which have to be settled before starting any project. In some cases, in exchange for doing the maintenance work of the system, the original group of water-users may grant rights of access to a new group.

Water distribution

One of the important issues in water distribution, emphasized on by Gutiérrez & Gerbrandy (1998) is the transparency of it: they cite Gandarillas et al (1992) saying that a distribution system is transparent when "the norms and rules of distribution are visible to all users and they can recognize any modification introduced in the system".

This is, as the authors say, achieved in most of Andean irrigation systems by rotating one water flow (in many cases the entire system flow) from one user to the next, until all users have received their share, and starting all over again with the first user. With the simple and low- cost technology used, this is the easiest and most visible way for everybody to understand how the water is distributed.

The water distribution between the users of an irrigation system can be based on various types of agreements, and mixes of these types. The most important criteria observed are:

- distribution based on social status or other existing rights and power relations in the community: some community members, usually leaders or other important persons, might have a fixed quantity of water assigned to them independently from the way in which the rest of the water users distribute their water. Sometimes the owner of the land where the source is located, or where a stream is tapped, exercises his power to bargain this kind of arrangements. In the same manner distribution between groups can be established, for example between the group who constructed the system and a new group of users, defining a fixed proportional distribution on the base of negotiation.

- distribution based on the area of plots to be irrigated: according to the area of each plot, volumes of water are designated. With the single flow rotating system described earlier, this is done by relating area with irrigation time, for example two hours per 0.5 hectare.

- distribution based on an equal amount of hours in which each "*chacra*" (plot) receives the flow of the canal, creating "*turnos*" (irrigation shifts) which, in different systems, may vary from 3 to 24 hours per plot.

From an equity point of view, particularly the last two points do not represent the "equality" they seem to, because:

- filtration losses in the (mostly earth lined) canals are rarely taken into account, creating great differences in volumes of water received between head- and tail-enders;
- water is distributed according to parcels of land rather than to individual users, thus differentiating between users with only one, and those with more than one plot.

Flexibility of these irrigation systems is often very limited in the sense that the distribution system does not vary throughout the irrigation season, thus making it difficult to adjust water delivery to the variation of crop water requirements of different crops and to growth stages in the crop cycle. Moreover, time intervals between two "turnos" can be very large, constituting a harass to crop development because of water stress. Therefore, Sierra farmers usually try to maximize the area to be irrigated rather than to apply optimum irrigation gifts to their crops.

3. Possibilities and limits of sprinkler irrigation

The rapid development of pressurized irrigation technology for capital-intensive, high yielding cash crop farming in countries like Israel, Spain, the United States, and in the coastal deserts of Peru and Chile, has started to offer possibilities for smallholders in the Andes to adopt those methods which suit them most. Considering the wide range of existing technologies in drip- irrigation, micro-sprinklers and sprayers, sprinklers and high-output water cannon, sprinkler irrigation appears to respond the most to the specific characteristics and requirements of Andean mountain irrigation. However, as we will see later on, other methods might very well be included as well in the near future.

In the next sections, a brief analysis will be made of the advantages of sprinkler irrigation for smallholders in the Sierra and of the technical and economic limitations encountered during the process of adoption of this technology.

3.1 Possibilities

Cost of systems pressurized by gravity:
In mountain areas it is, in general, easy to take advantage of the slopes of the land in order to pressurize the irrigation water without the use of expensive pumping installations. This means a considerable reduction in investment and operation costs for sprinkler irrigation systems, compared to the coastal irrigation schemes.
The cost per hectare of 23 sprinkler irrigation systems that have been constructed during the last two years by PRONAMACHCS Cajamarca fluctuates between US$ 900 an US$ 1800, with an average of approximately US$ 1200 (including costs of design, investment, labour and supervision)[3].
The factor that has most influence on the costs per hectare is the degree of fragmentation and spatial distribution of the land to be irrigated, that is, the more plots of land and users have to be served from a water source with a limited flow, the longer the connecting pipelines and thus the costs per irrigated hectare will be.

Once the choice for sprinkler irrigation has been made, there are some additional advantages related to the conduction of water in pipes, that are not specific to sprinkler irrigation, but that do make these investments more interesting: less filtration losses, elimination of open canals that interfere with farm work, conveying water through depressions using siphons, amongst others.

Water use efficiency:
For a lot of institutions that promote the sprinkler irrigation technology, an important argument is the saving of water. The figures that are generally used to estimate field application efficiency (30-50% in the case of surface irrigation, 60-75% in sprinkler irrigation) are derived from irrigation conditions in agriculture with high investment levels (especially on the coast). Recent evaluations of smallholder farms in the mountains, give us efficiencies of up to less than 10% for surface irrigation[4] and of 60% and more for sprinkler irrigation.

Evaluations in the Pedregal irrigation system (Celendín province) show that on slopes of 69%, sprinkler irrigation, if correctly installed, may show efficiencies of up to 78% (Horstman, 2000) However, this type of evaluations has to be done in more irrigation systems to obtain representative figures for the region.

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[3] For a detailed description of the costs of two "extreme" cases, see Anten and Willet, 2000a.
[4] These extremely low efficiencies apply particularly to the irrigation of pastures in the Cajamarca region, which is done with very little control or land preparation. Furrow and basin irrigation for other crops usually show more positive figures.

An important point to be considered with regard to efficiency is that in traditional irrigation canals inefficiencies of different types exist: important losses often take place at the distribution of water, due to lack of co-ordination between water users, the rotation system used, or the difficulties farmers have with distributing the water and irrigating during the night. Compared to this waste, losses at field level sometimes are of minor importance.
If the sprinkler irrigation systems are designed in a way that, apart from the losses at the field level, they also considerably reduce the loss in distribution, we may assume that sprinkler irrigation on mountainsides has the potential to increase the size of the area that can be irrigated with the available sources by a factor of three or more[5].

The most extreme differences in efficiency are found in systems with very small flows: with surface irrigation, sources discharging less than 2 lit/sec in practice are often completely wasted, reason why farmers first of all demand the modernization of this type of sources. Traditionally, they construct small tanks, earth- or concrete lined, in which the water is collected during short periods (up to several days) and then emptied obtaining a flow appropriate for surface irrigation (10 to 20 lit/sec).

On the other hand care should be taken not to assume that we always gain when increasing efficiency as there are a lot of places in the Sierra where land is the most scarce production factor, and not water: in narrow valleys with steep and shallow soils the "command area" of an irrigation canal is often very limited.

A warning is called for as to the possibility that the water "lost" in an irrigation system because of infiltration- and percolation losses, is used further down the catchment in other systems: increasing water use efficiency in the higher parts might cause a reduction in water availability in lower parts. Therefore, an understanding of the hydraulic interdependencies between various parts of the catchment is essential to be able to evaluate the "external effects" of increasing irrigation efficiencies, especially in the middle and higher zones. This can be done by making an inventory of water recourses of the catchment, with a method described in Anten and Willet (2000c) and in Anten (2001).

Erosion:
Another argument often heard in favor of introduction of sprinkler irrigation in mountain areas (used both by professionals and by farmers), is erosion control. With a careful design of sprinkler irrigation, this advantage exists, especially in those places where surface irrigation is difficult, or carried out in an irresponsible manner.
On the other hand there is the impression that the advantages of sprinkler irrigation, regarding erosion, are sometimes exaggerated. Badly designed systems were seen in several places[6], as well as farmers who were unfamiliar with sprinkler irrigation, using sprinkler nozzles which were too large or taking them off entirely in order to irrigate with more water. They might also irrigate with too little pressure, trying to expand the irrigated area as much as possible. All these practices generate too high a precipitation with very big drops, thus causing surface runoff and eventually erosion.

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[5] In sprinkler irrigation systems built by PRONAMACHCS in Cajamarca a design flow of 0,35-0,4 lit/sec/ha is used, i.e. with a source of 1 lit/sec an area of 2,5 to 3 hectares can be irrigated. Normally, in irrigation projects based on surface irrigation, design flows of 0,65 to 1 lit/sec/hectare are used.
[6] It is not a common practice with professionals who design these irrigation systems, to do an infiltration test to adjust the precipitation intensity of the sprinklers to the infiltration capacity of the soil. Also there is a tendency to use sprinklers of 'home-made' manufacture (sprinklers of mud, of rejected syringes, etc.), whose characteristics are unknown, but that inevitably produce much higher precipitation intensities than brand sprinklers.

Frost protection:
A fourth advantage of sprinkler irrigation, which is often mentioned is the possibility to reduce damage to crops caused by night frost, because, if plants are sprayed during the night, the leaves are covered with a mix of ice and water which enables internal leaf temperatures to stay above the critical levels for maintaining biochemical processes (Vincent, 1995).

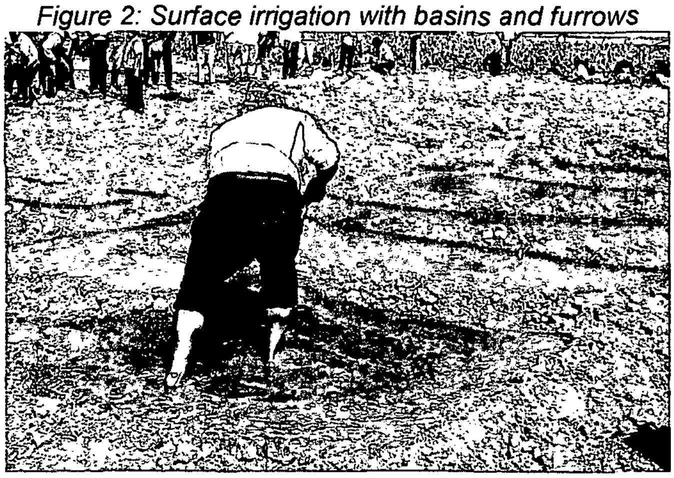
Control and Operation:
In many cases, the change from a traditional irrigation system to a pressurized system, involves changes in the distribution system of water that at the same time give the individual water user major flexibility of operation. This is the case when a permanent flow feeds (sectors of) the sprinkler irrigation system, or when a storage tank is built on a farmers' plot of land with the capacity to store his irrigation shift, which allows him to use the water exactly where and when he needs it (he can apply different intervals for different crops and different parts of the land, irrigation can be used as a protection from frost). Flexibility in water handling allows a diversification of crops: especially vegetables require shorter irrigation intervals than those between the shifts in irrigation systems with a traditional water distribution based on rotation of the entire system flow.
An additional advantage is that the organizational requirements for water distribution may be reduced.

Labour:
An important factor in evaluating the alternative of sprinkler irrigation, from the point of view of the farmer, is the required labour in irrigation.

Surface irrigation with very small amounts of water, occurring when the flow from the source is small or when the slopes are too steep to allow the use of larger flows, takes up a lot of the farmer's time. This is because of the careful and adequate land preparation which is needed, and in case of larger flows, because two or more persons might be necessary to handle the water.
In these cases sprinkler irrigation offers a significant reduction in labour requirements, considering different aspects:

- sprinkler irrigation does not require the extensive land preparation of furrows and basins necessary for most crops if surface irrigation is used (except for irrigated pastures for which hardly any soil preparation at all is done)
- the practice of sprinkler irrigation in itself is relatively light work: it mainly involves changing hoses, tubes and sprinklers, cleaning sprinklers and filters, and handling of valves, instead of the opening and closing of furrows, repairing of bunds etc. done when practising surface irrigation. Once put into position, the sprinklers can be left unattended for 6 –12 hours before changing their position.

Figure 2: Surface irrigation with basins and furrows



Time employment is thus quite different in the two cases: surface irrigation is intensive, hard work taking one day or two, every two or three weeks depending in the irrigation interval, and often requires contracted labour. Sprinkler irrigation, on the other hand, needs short but more frequent time investments (10 or 20 minutes, two or three times a day), and a more permanent presence of someone to achieve this. Therefore, in the case of smallholders households, particularly the women and children may be the ones taking up the tasks of sprinkler irrigation as they are usually at home, while men are more involved in all kinds of off-farm activities.

Apart from sprinkler irrigation being less labour intensive, erosion and irrigation efficiency are also related to the labour factor: insufficient effort in land preparation, in the case of surface irrigation, will cause erosion, and will decrease the efficiency. Therefore, the more difficult conditions are for surface irrigation (slopes, poor soil quality and texture, irregularities, etc.) the more advantage there is in sprinkler irrigation. And also, the more difficult it is to mobilize labour for irrigation (migration, women-headed households, lack of pastures for draught animals) the more attractive sprinkler irrigation may be.

From the above we can deduce that sprinkler irrigation in mountain areas is not only interesting in order to promote cash crops, but also to stimulate food security by means of small vegetable gardens, for example in sub-urban areas, or in combination with development of drinking water systems (combined systems, or of multiple use).

The impact of introduction of this technology on the quality of the life of rural women remains to be analyzed. From the above, it is clear that there are strong implications for gender relations, but there is still little information about the ways in which it affects the quality of life and the development opportunities of different groups within rural Andean communities.

3.2 Limits

Distribution:
In the preceding paragraph it has already been mentioned, that introduction of sprinkler irrigation in existing irrigation canals has an effect on the distribution of water.
The traditional water distribution, based on rotation of the entire system flow to each individual plot, results in irrigation with maximum flows (10 lit/sec on steep mountain slopes up to 100 lit/sec on gentle slopes with pastures) in order to reduce labour requirements and to take maximum profit of each irrigation shift (*turno*). Trying to implement sprinkler irrigation in the same intermittent way with the same flows would turn out to be very expensive: a large number of sprinklers and large dimensions of pipelines would be needed for a relatively small area.
Therefore, the only feasible way is to divide the total area to be irrigated into smaller sectors, each with a small constant flow.

This can be achieved in three ways:

1. Individual farmers or small groups of water users agree with all water users of the system to assign them a small, fixed proportion of the system flow instead of their *turno* in order to irrigate their plots with sprinklers. This solution is only feasible in the head-end stretches of canals where water runs almost constantly, and requires a very "visible", proportional water distribution and a high level of mutual confidence between water users, both of which are conditions difficult to fulfil.
2. Individual farmers or small groups build a storage tank to store their *turno*, and irrigate with pressurized equipment, leaving the traditional distribution system unchanged. The sprinkler systems can be relatively small and cheap since they operate constantly, but the storage tanks will be too large to be economically feasible: for

example, in the case of a plot of 1 hectare, which is irrigated with a *turno* of 8 hours every 10 days with a flow of 15 lit/sec, a tank of 430 m^3 is required, allowing sprinkler irrigation with a permanent flow of 0,5 lit/sec. This tank, however, has a cost of not less than US$ 1500.

3. The entire irrigation system is converted into pressurized irrigation, and is subdivided into a number if irrigation sectors. The water supply is distributed proportionally to the sectors, each of which receiving a permanent flow of 0,25 to 2 lit/sec according to the area to be irrigated. This means a radical change in the operation and maintenance of the system, and is generally difficult to realize in canals with well-established (and long existing) water distribution systems.

Introduction of sprinkler irrigation in existing canals is thus a difficult, delicate issue. Where this has taken place spontaneously, problems and dilemmas have come up gradually and may lead to a possible collapse of the distribution system[7]. The process can only be successful, if all the water users in an irrigation system are convinced of the benefits of sprinkler irrigation, and in the case of a total conversion, are willing to give up their traditional irrigation practices.

Investment and Maintenance Costs:
Though it was indicated that costs can be relatively low, the technology itself has financial strings attached to it (as opposed to the traditional irrigation canals that are often built and maintained without financial investment). This involves three problems for the farmer:

1. Production that has little connection with the market: often, production is destined for own consumption or for exchange. When production does not generate monetary income, funding of the investments and maintenance of the systems turns out to be difficult[8].
2. Limited access to credit: access to funding for investment in agriculture in the Sierra is very limited, and the cost of capital is high. In most cases it will turn out to be impossible to finance pressurized irrigation systems, if farmers themselves do not manage to make savings (through cattle for example).
3. Profitability of low-input agriculture: if investments in irrigation equipment are between US$ 700 and US$ 2300 per hectare, in most cases it will be necessary to increase production levels or change to other more profitable crops, to recover the investment[9]. This involves the necessity of innovation and intensification of agricultural and livestock practices (improving soil, quality of seeds, phytosanitary control, genetic quality, crop and livestock management, commercialization, etc.).

Against the multiple limits presented above, some general recommendations can be made that may mark the way to their solution.

In the first place, follow-up of each installed modernized irrigation project is needed, including the following components: 1) Technical and Economic Evaluation of the Project; 2) Training of the water users and their Organization to confront the changes in operation and management of the irrigation system; 3) Technical Assistance for Innovation and Intensification; and 4) Credit.

[7] Some undocumented cases from irrigation systems in Ecuador have show this process, in which gradually more and more farmers simply put a hose pipe in the canal to siphon the water to their sprinklers, violating the regulations for water distribution.
[8] Though there are some exceptions: In Ecuador there were examples of sprinkler irrigation use in agriculture for own consumption, funded by migration work.
[9] An evaluation made by Guerra (1999) in Shirac, San Marcos province, showed how sprinkler irrigation led to a second crop cycle in the dry season and a diversification of crops (potatoes, vegetables, peas and alfalfa) where previously only corn was grown. However, economic analysis of the potato production demonstrated that , without measures to improve soil fertility and pest control, it would be impossible to compensate for investments made in irrigation if these had to be paid at a monthly interest of 4 %.

In the second place, it is only through adequate inter-institutional co-ordination and collaboration that the necessary, diverse package of services required for successful technological innovation can be organized (organization of water users, appropriate designs, investments, credits, training, improvement of agricultural production).

Technical Assistance:
Farmers, as well as professionals, are involved in the process of sprinkler development, in which most of the experiences are still mainly obtained through some sort of "trail and error" strategy. In front of a growing demand of farmers for advise and support in designing sprinkler systems, there is a lack of quantitatively and qualitatively sound technical assistance: those engineers who do have knowledge about the matter usually apply concepts for large scale, capital-intensive sprinkler systems on the coast. Development agencies and irrigation professionals are only beginning to find answers to the reality of mountain agriculture in this respect.

Some basic mistakes that are frequently observed are:

- Insufficient pressure, resulting in poor performance of sprinklers, low efficiencies and possibly erosion: the topography of the irrigated areas does not always allow sufficient pressure to be generated to irrigate in all parts of a farmers plot. In this case, the area to be irrigated has to be located further down the slope, or else the feasibility of sprinkler irrigation should be reconsidered[10].
- As already mentioned, designers do not have the habit to determine soil infiltration rates nor to consult tables of hydraulic characteristics of sprinklers. Especially on heavy soils surface runoff may occur when the sprinkler precipitation exceeds the infiltration capacity of the soil.
- Some agencies expect far too much of the "miracles" that sprinkler irrigation may bring; over-estimating the area to be irrigated with a given flow of water. This results in under-irrigation of crops and superficial irrigation depths.

Adapted technology and availability on the market:
Although primarily developed for capital intensive agriculture, the current sprinkler technology available in Peru can be used in the more marginal mountain agriculture albeit with necessary adaptations to local circumstances and needs: cheap family labour and limited financing capacity make it necessary to design systems with a minimum of necessary equipment (sprinklers, tubes, hoses, filters, etc.) and a maximum use of the locally available labour. Moreover, optimum use of the rough topography to generate pressure requires creative design, taking into account the wide variation of terrain conditions in each specific case. An adapted technology for sprinkler irrigation in mountain areas thus needs quite some technical ingenuity to cope with harsh local conditions.
However there is still a gap between successful experiences with adapted sprinkler technology developed so far and availability of adequate products and equipment on the local market: in Cajamarca, over the last few years, retail shops were selling sprinkler irrigation products, but not yet those which really are most required, and it has often been necessary to order equipment from wholesalers in Lima, which is not easily done by the farmers themselves.

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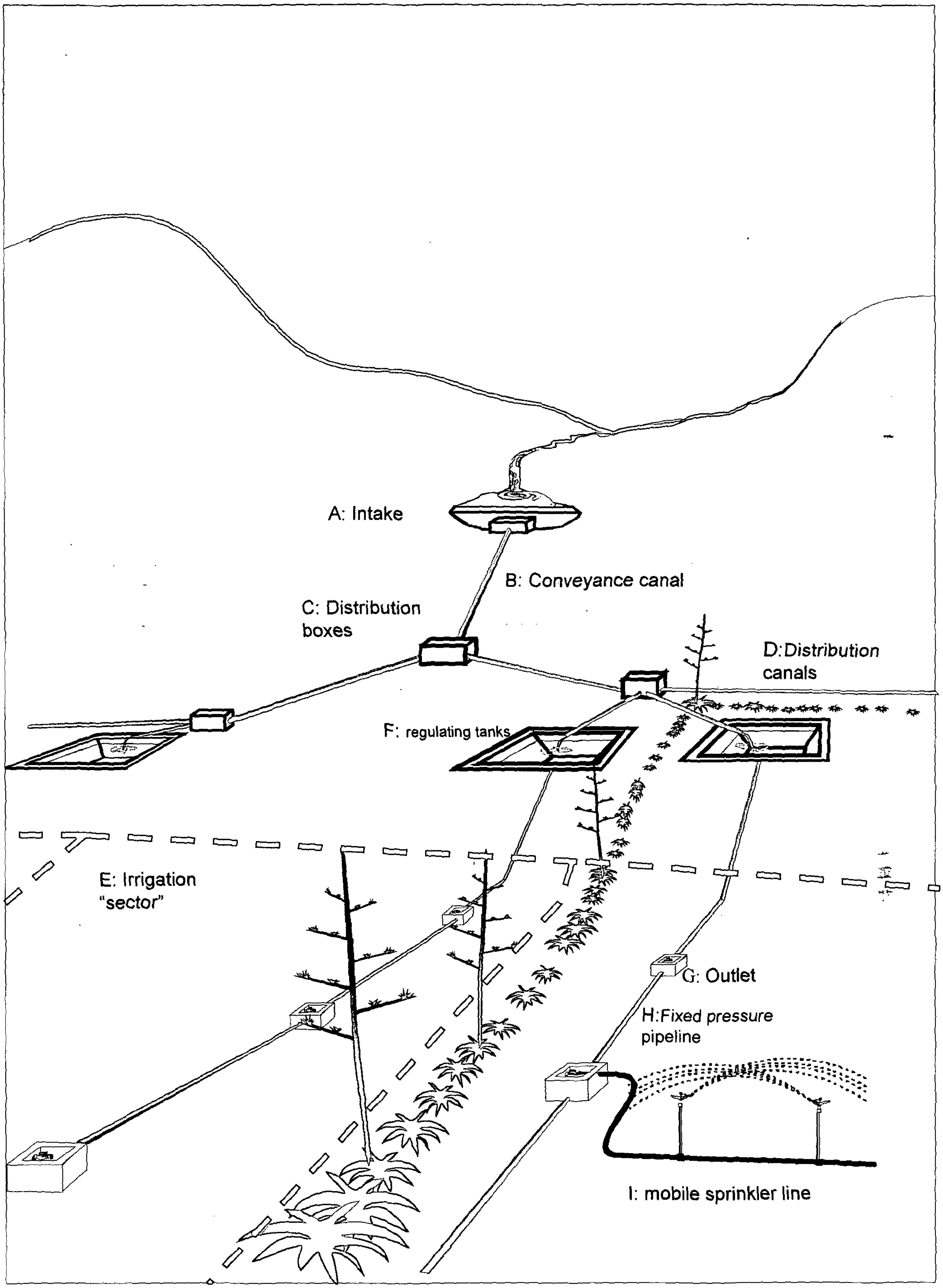
[10] As this problem occurs quite frequently, the technological possibilities of drip- or micro sprinkler-irrigation might offer solutions the near future, because these require less operating pressure. However, costs of these systems are still a major limiting factor for its adoption by Andean smallholders.

Figure 3: Typical layout and components of an irrigation system pressurized by gravity.



Source: Anten and Willet, 2000a

4. Design issues: challenges for engineers *and* farmers

In the previous chapter it has been made clear that sprinkler technology development in the Sierra is a delicate process in which ample attention needs to be given to the local circumstances and to the process water users and external agencies need to go through. As we have seen, there are only a few technological options which are feasible from an economic point of view, which also appear to offer satisfactory results in the socio-organizational sphere, once the process of introduction and acceptance has been completed. In this chapter, some more insight is given into these technical options before going into detail about the approach to introduce them.

One of the key design principles applied in the experiences in Cajamarca is to distribute the water supply for an irrigation system proportionally and with continuous flow down to the lowest level possible, thus providing this level wit a permanent source of water which is pressurized in order to apply sprinkler irrigation. In this way, the costs of conveyance and distribution lines are reduced, because water flows decrease and pipe diameters get smaller throughout the system. At field level, volumes of water are small and can be used with simple irrigation equipment. Thus, as illustrated in figure 3, water is tapped from a spring or diverted from a stream through the intake (fig. 3-A), passes through the conveyance canal/pipeline (fig. 3-B), is proportionally distributed to different parts of the system (fig. 3-C and fig. 3-D), until it reaches the appropriate level where small regulating tanks (fig. 3-F) give entrance to the pressurized part of the system (fig. 3-E).
Ideally, every irrigated plot in a system should be able to have its small, permanent flow, but this would turn out to be too complicated to design, as in many cases farmers in an irrigation system may only have one or several plots of 0,1 – 0,25 ha each, requiring individual flows of 0,1 liter/sec or less.
In these cases, "sectores" of 2 to 4 irrigators are formed (fig. 3-E) which receive a flow of 0,25 – 0,5 lit./sec. which is rotated among them by shifting a mobile set of sprinklers (fig. 3-I) from outlet to outlet (fig. 3-G) from one irrigator's plot to the other[11], all the plots being connected to each other through fixed pressure pipelines (fig. 3-H). In some cases where each farmer has an irrigated area of 1 ha or more, each one constitutes a sector and receives an individual flow.

This design principle implies a shift in system operation and water distribution from the traditional, centralized way in which water was rotated from the main canal to each individual farmer, to a more decentralized manner, where, according to the design, either individuals handle their own flow or groups of three or four farmers organize water distribution within their sector. As a consequence, flexibility at the individual level is increased as farmers no longer depend on the fixed "turnos" and long time intervals between them, but can organize water allocation and distribution according to their needs. Conflicts are reduced because irrigators only have to deal with their direct neighbours (with whom they often have family ties) and much less with water users at the other end of the system. At the same time, operation and distribution activities at the central level are reduced to a minimum and usually only include the control of volumes of water at the intake of the system.

Equity and equality in water distribution are also strongly influenced by this way of changing from traditional to sprinkler irrigation: In the first place, because all water is conveyed through PVC and polyethylene tubes and concrete- lined boxes and tanks, from the intake down to

[11] Irrigation simultaneously within one sector, each farmer with his sprinkler, does not work because differences in pressure between the plots would cause unequal water distribution, and therefore easily leads to conflicts. This problem could also be solved by using a sprinkler type which is combined with a pressure-regulator, as shown by experiences in Lluishi, Ecuador (SNV, 1998). However, this would increase the complexity and costs of the irrigation system.

the field, it was already mentioned in chapter 3 that filtration, conveyance and distribution losses are reduced to a minimum. This makes it feasible to equally distribute the water to various parts of the system, eliminating great differences between head- and tail-enders usually found in the traditional situation (see chapter 2).

In the second place, water distribution among the users of the system can be established according to their own criteria: one option frequently chosen for is to divide the entire system flow by the number of water users, thus providing each one wit the same small quantity of water. This is usually done in cases where the area of the land owned by each farmer largely exceeds the area which can be irrigated, so that an irrigated plot of the same area can be assigned to everyone. In cases where water is more abundant, and where the total irrigable area approaches the total area of land in the command area of the system, the water distribution may be proportional to the area of land owned by each farmer, sometimes determining a maximum to avoid extreme differences. For example, see figure 4.

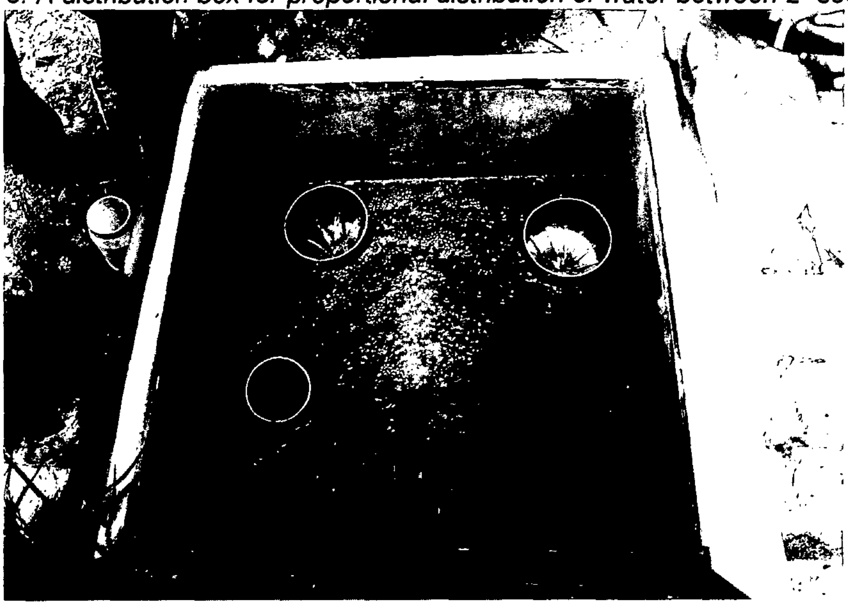
Figure 4: Example of three ways to distribute the area to be irrigated

Equal distribution Available flow: 1,4 lit/sec			Proportional distribution Available flow: 4,3 lit/sec			Proportional distribution with a maximum Available flow: 4,3 lit/sec		
Plot	Total Area (ha)	Area to be irrigated	Plot	Total Area (ha)	Area to be irrigated	Plot	Total Area (ha)	Area to be irrigated
1	4,2	0,3	1	4,2	2,80	1	4,2	1,41
2	1,5	0,3	2	1,5	1,00	2	1,5	1,41
3	0,5	0,3	3	0,5	0,33	3	0,5	0,50
4	0,8	0,3	4	0,8	0,53	4	0,8	0,80
5	0,4	0,3	5	0,4	0,27	5	0,4	0,40
6	1,1	0,3	6	1,1	0,73	6	1,1	1,10
7	2,8	0,3	7	2,8	1,87	7	2,8	1,41
8	1,8	0,3	8	1,8	1,20	8	1,8	1,41
9	0,6	0,3	9	0,6	0,40	9	0,6	0,60
10	0,3	0,3	10	0,3	0,20	10	0,3	0,30
Total	14	3	Total	14	9,33	Total	14	9,34

Source: Anten and Willet, 2000a

Whatever the option chosen, water distribution can be made perfectly transparent and visible using distribution boxes initially developed by SNV Ecuador as shown in fig. 5. In these boxes, the flow assigned to each water- user or to each sector may be represented by one or more "unit flows". Each orifice in the shown funnel-shaped vertical PVC tubes with its jet of water represents one of these "unit flows", and the distribution is determined by the number of orifices in each PVC tube. If necessary, farmers can adjust the distribution by closing or adding orifices. However, care should be taken as to assure correct installation with all orifices at the required level.

Figure 5: A distribution box for proportional distribution of water between 2 "sectores"



It may be clear that all these issues require a lot of consultation between engineers and water users, in order to understand the implications of sprinkler irrigation on irrigation practices and system management, and to take decisions about which options to choose in each individual case. A thorough explanation of pros and contras of each option is indispensable, but even then, experience in Cajamarca has shown that during the construction changes and adaptations were made to the design because it was only then that farmers really started to understand the implications of the sprinkler system.

Another important design issue is the flexibility of the entire irrigation system: as discharges of water resources vary considerably throughout the year, this fluctuation has to be taken into account in the dimensions. However, an optimum has to be found between cost reduction and capacity of the system, and in Cajamarca the flow rates at the end of the first month of the dry season are taken as a reference for design.

At field level, as pointed out in chapter 3, irrigation practices using sprinklers gives good results only if the right type of sprinkler is chosen within the right pressure range, and if the farmers are correctly trained in how to use them. On mountain slopes, pressures between different parts of one and the same irrigated plot may vary considerably and sprinkler performance in terms of discharge and range varies with it.
Therefore, in order to obtain acceptable efficiencies, spacing between sprinklers and irrigation times have to be different in each position, without making it too complicated for the farmers. An example of a simple set of recommendations for a specific sprinkler model, NAAN 427, in which only the spacing has to vary for positions with different pressures, is shown in fig. 6. These recommendations are based on tests done with NAAN sprinklers by Horstman (2000), and should be developed for each sprinkler model used.

Figure 6: Recommended spacing for the NAAN 427 sprinkler (4 mm nozzle) for different operating pressures.

Pressure (Bar)	Sprinkler discharge (lit/sec)	Irrigation time / Irrigation interval	Spacing between sprinklers
< 1,15	< 0,18	12 hours / 14 days	11 x 11 m
1,15 – 1,75	0,18 – 0,22	12 hours / 14 days	11 x 13 m
1,75 – 2,5	0,22 – 0,26	12 hours / 14 days	13 x 15 m
> 2,5	> 0,26	12 hours / 14 days	15 x 15 m

Source: Anten and Willet, 2000a.

Figure 7: Mobile sprinkler equipment on steep slopes

Photo: J. Willet

5. Intervention strategies: how to guide technological change

Based on the analysis of possibilities and limits of sprinkler irrigation and the design issues mentioned in the previous chapters, the following strategic options are presented that have been put into practice in the Northern Peruvian Sierra.

From small, individual springs to larger systems

As stated earlier, spontaneous sprinkler technology adoption has occurred almost invariably at the level of individual farmers or in small groups within the communities. An interesting example is the Mapacho valley in the Paucartambo province of Southern Peru where Solís (1997) describes how a "hacendado" started to experiment with sprinkler irrigation on his hacienda. After the "Reforma Agraria", some farmers went on using sprinklers, and over a period of some 20 years groups of families in 13 communities had developed their own sprinkler irrigation technology adapted to their local realities. In any event, introduction of sprinkler irrigation in a context where it is unknown to the local people is preferably initiated through small-scale pilot experiments with individuals or small groups[12]. Small springs can be used (0,1 – 2 lit./sec.) which because of their high losses and under-exploitation, easily offer "spectacular" results, while at the same time avoiding the complexity of having to change well-established distribution procedures, should larger existing canals be concerned. Investments are relatively low and quickly recovered, and it is possible to have experiments in different communities and ecological zones rather than concentrating all efforts on a large project in one single irrigation system.

It is indispensable to have information about the existence and location of all water resources, their discharges in the dry season, actual and potential water use patterns, and existing or potential conflicts before putting this strategy into practice. In Cajamarca, this was achieved by implementing a participatory water resource inventory and planning of its use at community and micro-catchment-level which is described in Anten (2001). In four micro-catchments identification of a total of eight small and medium-sized sprinkler-irrigation projects was based on this base study and planning process.

Once small-scale pilot experiments have started to show results, water users of larger systems may get interested, especially in those areas where traditional irrigation practices do not prove to be satisfactory. In the Baños del Inca-district (Cajamarca province), it was feasible to convert three relatively large irrigation systems into sprinkler systems, involving a total of 197 families and a total flow of 24 lit./sec., only because various NGO's had already developed small- scale experiences in the same area, so all water users were aware of and interested in adopting this technology.

For interventions in these larger irrigation systems (not only concerning sprinkler irrigation but all interventions aiming at improvement of water management) a method for participatory analysis and planning has been developed: the "*Diagnóstico Enfocado de Sistemas de Riego*" (In-depth appraisal of irrigation systems) or DER (see Anten, 2001). This method allows external agencies to systematically analyse the organizational, infrastructural and agricultural aspects of an irrigation system and to make an assessment of the major problems, potentials and options for intervention and support, all based on dialogue with the water users. With this method the interest of water users in sprinkler irrigation could be identified, all positive and negative aspects could be discussed, conditions for support could be explained, and a quick evaluation of the technical feasibility could be made, before making final choices and decisions. From this point onwards, an interactive design process was initiated to restructure the irrigation system.

[12] Many institutions have a policy of supporting groups and not individuals. Nevertheless, it turned out that most farmers prefer individual irrigation systems or systems owned by very small, kinship- related groups.

Apart from what is said here about larger systems, in which the change to sprinkler irrigation usually requires intervention and support from external agencies, spontaneous adoption on an individual base in the surroundings of a pilot project has been observed in the Shirac micro-catchment: implementation of a small pilot sprinkler project involving eight families served as an example to an increasing number of individuals who started to buy their own sprinklers and tubes to use with their tanks and cisterns.

Priority areas

It has been made clear in the previous chapters that pressurized irrigation requires capital investment on a much higher level than traditional irrigation, and thus its introduction and adoption might only seem feasible in areas near towns, major roads or markets, involving the better-off farmers.

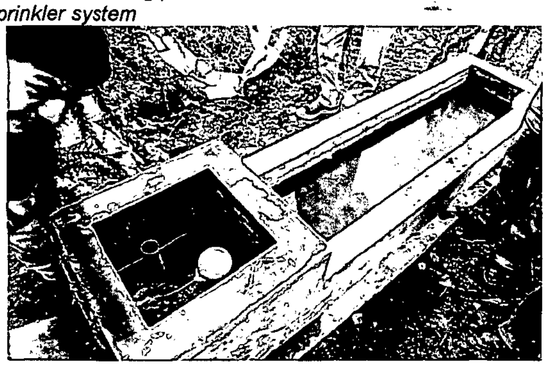
In Cajamarca, the widely extended network of milk- collecting routes used by the dairy companies offers a relative advantage in this sense: farmers who use irrigation primarily for pasture and fodder for dairy cattle do not need to transport their products over large distances and may be located at considerable distances from towns or markets as the routes penetrate deeply into the Sierra. Moreover, they have a small but constant income from the milk which enables them to finance a significant part of the investment through credits. However, the value of improved irrigation in farming systems which are mainly based on subsistence should not be underestimated: as already mentioned, migration might provide financial resources to invest in irrigation equipment, and for the economic value of produced crops the commercial value on the market is to be considered, because families may be able to produce crops to include in their diet which they would otherwise have to buy on the market.

Adequate support structures

A package of facilities is necessary for a more effective extension of sprinkler irrigation, including the following components:

- Credits for the acquisition of irrigation equipment: with interest rates of 4,5% on a monthly base for agricultural loans, the cost of capital in Peru is high and therefore hardly accessible for Andean smallholders. Although some NGO's in Cajamarca offer credit facilities with easier conditions, financing policies for credits need to be adapted, especially where access of individuals to credits is concerned.
- Technical assistance for design and use of sprinkler irrigation: specific expertise is required to design appropriate systems for mountain areas: small, located on steep slopes, low- cost and simple to operate, making optimum use of available cheap labour, multi-purpose (see figure 8). SNV has provided various training sessions, in which more than 20 professionals have been taught the necessary skills. Several PRONAMACHCS engineers have been backstopped while designing their own projects, as well as other professionals who are now working as consultants.

Figure 8: A watering place for cattle with float valve connected to a sprinkler system



- Availability of adequate materials and accessories on the local markets: "ferreterias" (hardware) stores and other retailers need to be stimulated to sell adequate sprinkler products, and wholesalers in Lima have to extend their distribution networks to regional and provincial capitals. In Cajamarca, as more and more institutions are adopting common design principles and are using the same type of equipment, availability of required materials is growing.

Financing / subsidy strategy
It starts to be commonly accepted amongst most of the institutions involved in sprinkler irrigation development nowadays that this technology cannot be introduced in the Sierra on a 100% subsidized base, and that beneficiaries, if unable to support the total costs, should contribute at least part of it, including the financial investments[13]. How much, is still a matter of discussion, and various criteria are used by different institutions.

A basic assumption proposed within PRONAMACHS for communal irrigation systems (that is, involving more than one individual family) is to have the "communal" part of the infrastructure (headworks, conveyance- and distribution- canals, distribution boxes, a.o.) financed through external funds, while the "individual" part of the system (individual tanks, pressure pipelines in the farmers' fields, mobile sprinkler equipment, etc.) should be financed by the water users, either proportionally, according to each farmer's needs, or through a fixed quota for everybody. In various cases a successful deal could be made between the water users and various institutions:
In Pedregal, (Celendin province), for example, funds were obtained from the Netherlands Embassy and from the district municipality to finance the construction of the communal infrastructure, while design and technical supervision were done by PRONAMACHS (with SNV support). CARE- Peru provided credit facilities to the farmers so that they could finance their share (16%) of the project.
In the Baños del Inca-district (Cajamarca province) a similar deal could be made between PRONAMACHCS, the municipality, the Yanacocha Association, and the beneficiaries of two sprinkler projects who were supposed to financially contribute 12% of the total costs[14].

In the case of one- family irrigation systems, experiences are currently being developed by the *Junta Usuarios* of the Upper Jequetepeque valley, in which 100% of the investment is paid by the farmer, while the Junta provides technical assistance for design and construction. Due to the lack of adequate credit facilities, these experiences only include farmers which have relatively strong financial capacities.

Until 2000, the Peruvian Government applied an indirect way of subsidizing pressurized irrigation by issuing a decree that all related materials and accessories were to be sold tax-free. Unfortunately this was recently reversed, making investments even more difficult for the Andean smallholder.

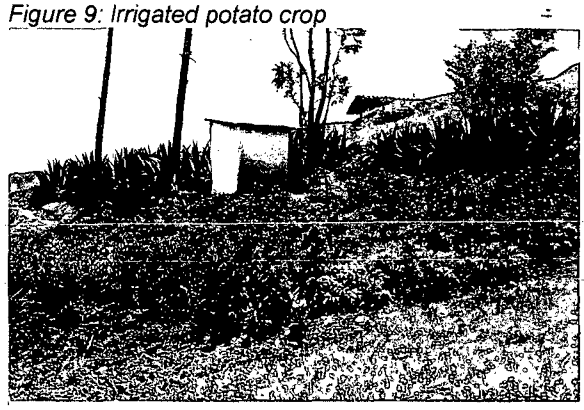
Follow- up: the "Fase Verde"
Sprinkler irrigation means new irrigation practices for the farmers and sometimes means new options for crops to be grown. It also means a new way of operating the system and of distributing the water, and maintenance requirements are different. Conflicts may rise at other levels than in the traditional situation.
If institutions have been involved in the introduction of this technology and in converting irrigation systems into it, they bear a responsibility in providing adequate guidance at the moment water users start to use the new system.

[13]Farmers' contribution through the providing of unskilled labour is already common practice in most irrigation projects, usually constituting 10-30% of the total costs.
[14] In both cases, SNV was involved from the identification of the projects onward and has facilitated co-ordination and collaboration between all parties throughout the process in order to develop pilot experiences in this field.

In Cajamarca, a post- construction or follow- up phase, called the "*Fase Verde*" or Green Phase, is presently being conceptualized and implemented, involving PRONAMACHCS and various other institutions. It integrates the following components:

- A review of the water users organization: it's rules, regulations and tasks have to be adapted to the new situation, the list of water users has to be revised, and these have to be officially recognized and registered by the local water authority, the Irrigation District.
- Adequate training has to be provided for on operation and maintenance of the system as well as on how to use the sprinklers (spacing between sprinklers and irrigation scheduling in a range of different pressures, cleaning, maintenance, etc.), especially focusing on women.
- Small experimental plots are to be established to investigate the possibilities for new crops, or to improve agricultural practices with existing crops, under the improved conditions offered by sprinkler irrigation. The farmers decide with which crops and which agricultural practices experiments will be conducted, while a NGO, a university, or a research institute provides know- how and methodological support[15]. In this way, various agricultural options can be tested at a small scale in order to find out the most feasible way of intensifying irrigated agriculture under the new conditions.
- An *economic analysis* of the project after the first year should evaluate its total costs and final results in terms of irrigated area, crops grown and their yields, etc. in order to provide inputs for cost- benefit evaluations and to learn lessons for new initiatives in this area. Apart from this, in the first two sprinkler systems constructed in Cajamarca using the design concepts presented in this document, a *technical evaluation* of the hydraulic performance has been done by university students. This revealed the need to reconsider certain assumptions in the design formulas that had been applied, and gave more insight in spacing between sprinklers to optimize efficiencies.

Figure 9: Irrigated potato crop



Interinstitutional coordination

From the above, the importance of a fruitful and effective collaboration between institutions is probably obvious to the reader. In practice however, this constitutes one of the major bottlenecks to the implementation of a sound strategy for technological change[16]. Each has its own institutional policy and interest, and much effort is still required from an organization like SNV to mediate and facilitate between the different actors in order to guide the process to satisfactory results. Nevertheless, the interest which many institutions have in the topic offers an interesting opportunity to give a practical body to inter-institutional consultation and co-ordination, which otherwise may remain abstract and theoretical. The challenge exists in

[15] The point of departure for this experimentation in Cajamarca is the Participatory Technological Development– approach, in which research is conducted entirely within the farmers' production system, using a maximum of local know- how and local inputs which is complemented with "scientific" knowledge where necessary.

[16] For example, in 2000, the mayor of one of the districts in Cajamarca initially agreed on supporting the policy that beneficiaries from sprinkler projects should make financial contributions to the investment costs. However, while projects were already being implemented under this condition, pressure of local political groups made him change his mind and he finally donated irrigation equipment to one of the communities involved, creating a precedent for beneficiaries of the other projects to refuse to contribute their share of the investment.

making optimum use of the specific expertise and capacities of each institution, and in making clear to each actor that in this way better results can be achieved, not only in general but also concerning their respective goals and objectives. For instance, district governments are becoming aware that, if water users contribute their share of financial investments, more people can benefit from the limited financial means which the districts can offer.

6. Some results so far and final reflections

Experiences with sprinkler irrigation using the design concepts and strategies described in this paper have only been developed during the last three years, starting with two already mentioned pilot-projects: a small, 1 hectare system for 8 families in the Shirac-microcatchment, tapping a spring of 0,25 lit/sec, and the Pedregal system, involving 18 families and using a source of 8,5 lit/sec to irrigate 20 ha.
In Shirac, one hectare can now be irrigated during the dry season with a great variety of crops, where previously only some 2000m^2 of pasture could be maintained, divided among 2 families. In terms of scale, this may seem a rather modest result, but the large quantity of similar small sources existing in the area offers a potential for numerous small-scale improvements at reasonable cost.
In Pedregal, the irrigated area (mainly pastures) was increased by 150%, and the increased milk production during the dry season was estimated to provide an extra gross income of some US$ 400 per hectare (PRONAMACHCS, 1999).

An important conclusion from these first experiments is that the implemented systems appear to be technically appropriate for the conditions they are designed for: the oldest system of the two, in Shirac, showed only minor faults caused by unproper dismantling of some sprinklers, and relatively few signs of wear, after two years of intensive use. Thus the costs of replacing accessories, most of which are manufactured in high-quality plastic, will not be excessive, while on the other hand the performance of the systems is satisfactory, as shown by the analysis of irrigation efficiencies by Horstman (2000) and Adank (1999).

An interesting phenomenon observed in various sprinkler systems, including some which have been initiated in former years by NGO's, is the fact that farmers tend to extend the irrigated area beyond the design area, which is based on conventional calculations of crop water requirements. This means that farmers choose to under-irrigate their crops and maximize the area rather than apply optimal irrigation, which can be understood if one takes into account the fact that optimal irrigation will only lead to high production levels if other conditions like soil fertility and pest control are also optimized. With the poor soil quality and limited financial resources in most Sierra farming systems, the only way to obtain maximum production levels is to maximize the irrigated area. This once again underlines the need for an integral package of measures to improve crop production to come with improvement of irrigation, if one strives for agricultural intensification.

The "Fase Verde" or follow-up phase, which started to be conceptualized in 2000, will need further elaboration to make it an institutional tool for PRONAMACHCS, the Irrigation District and other institutions involved in irrigation development, not only regarding sprinkler irrigation but all interventions concerning improvement of irrigation systems.
Up to now, practical experiences exist in two sprinkler irrigation systems:

- In Pedregal, during a series of interactive sessions with the water users and a facilitator, the internal regulations have been adapted to the conditions of the new irrigation systems and have been approved by the Irrigation District. Farmers have been trained in the use of the sprinkler equipment, based on the recommendations of Horstman (2000). On-farm trials have been conducted on the issue prioritized by the farmers (soil fertilization for the irrigated pastures raygrass and clover), and, before the investigation was finished, several farmers already adopted some of the tested methods and received agricultural loans for it from CARE.
- In Shinshilpampa, during a session in which water users and various institutions participated, a selection of crops has been made for which farm trials are to be conducted in 2001, including irrigated pastures, garlic, aromatic herbs (oregano), green peas, and "tomatillo". The Cajamarca National University will provide scientific support.

Stimulated by the increasing rural demand for sprinkler irrigation projects, by the satisfactory results of the first two experiments, and with the support from SNV in training and backstopping, PRONAMACHCS-Cajamarca undertook 23 new projects in 2000, most of which are currently entering in their first irrigation season.
It is still too early to draw any conclusions about the impact of these systems, but it is a fact that more than five hundred water users have decided to transform their irrigation system in a radical way, investing their resources (labour, money, land) and resolving conflicts over water rights, distribution, conveyance, etc. This indicates how great their interest is and how much they expect these projects to respond to their needs.

With this rapid increase in the implementation of sprinkler irrigation projects by PRONAMACHCS, the need for evaluation of impact of these projects at the communal and household level imposes itself. A short assessment of the actual situation in five systems which have been constructed in 2000, recently done by a team composed of PRONAMACHCS engineers, the Water Board, SNV experts and Irrigation District representatives, reveals the following:

- In four systems, the construction has been completed and the systems are ready to be used. A few minor problems in the conveyance canals are being resolved, and one detected technical deficit has lead to interesting new design recommendations. Farmers are generally enthusiastic and eager to put into practice new irrigation methods. In one system, some crucial problems still have to be solved with the support of the District Government. PRONAMACHCS bears its responsibility in this.
- There is still a general need for training in how to use the new irrigation equipment. However, training sessions will be more effective if farmers have had some opportunity to experiment themselves so that they have a little experience to share with the trainers.
- In one system farmers are paying off their share of the financial investment through a credit, while in another system the water users wait to start paying off until the conveyance problems are resolved and the entire system is functional. In four out of five systems, farmers have made greater or lesser financial contributions. There is a call for a more consistent and uniform institutional policy in this respect, to be able to present clear and coherent conditions to beneficiaries of future projects. Moreover, in order to avoid envy and other social problems between beneficiaries and non-beneficiaries on the long run, auto-financing of sprinkler systems by farmers should remain the final goal of agency policies.
- In two cases, the transition to sprinkler irrigation has stimulated formalization of users organizations at the farmers' own initiative, while in the other cases they await institutional support for this.
- In two systems farmers already indicate a significant increase in irrigated area, while in one case farmers doubt if there will be any increase. However, this can only be correctly evaluated at the end of the first irrigation season.

In the longer term, apart from cost/benefit and other economic aspects, evaluations have to give more insight into the way sprinkler irrigation has an impact on the following issues:

- Equity/equality with regard to access to water and its distribution: Although in many cases small quantities of water have been distributed to relatively large numbers of beneficiaries on a basis of small, equal flows for each of them allowing each water user to irrigate an equal area, it has to be investigated to what extent this principle of equality will hold out in the local society with it's internal power relations.
- In the design concept used, water is distributed between parcels of land or between "sectores" on a fixed, proportional base, and within the individual plots only those parts which are within the reach of the pipelines and mobile sprinkler equipment can be irrigated. The possibility to rotate irrigated crops between different parts of the plot from year to year is reduced, unless farmers make investments to extend the pipelines network to every corner of their plot. Changes in land ownership through inheritance or

buying/selling may cause irrigated plots to be split into two or more parts, in which case more water users will have to share the same water flow. The way farmers deal with these issues has to be monitored to see what kind of solutions they will find.

- Sprinkler irrigation, compared to surface irrigation, requires short, light and frequent work. This change in labour investment will have an effect on the division of tasks between men, women and children within the family and on the influence which each of them may have on decisions to be made. Although it is likely that women and children will get more involved in irrigation practices, care should be taken as to avoid that they will therefore experience a disproportional increase in productive tasks.

It will take some years before the peasant families have made these sprinkler systems their "own", developing and acquiring habits and necessary skills. They will inevitably adapt the technology to each distinct reality, making greater or smaller modifications to the initial designs. For engineers and development agencies, the challenge is to get as close as possible to these realities with their design concepts and strategies for future projects. Therefore, they need to learn as much as possible from this already wide range of experiences.

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IRC
Att. Mrs. L. Postma
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From : SNV-BDB, Han Baartmans

Subject : Paper "Development of Sprinkler Irrigation in Mountain Environments"

Dear Mrs. Postma,

It is a pleasure for me to send you a copy of the paper mentioned as subject, which has been written by one of our experts on water-management. For SNV, Integrated Water Resource Management is part of its professional core qualities, and adequate technological development within an interactive, process-oriented approach, constitutes one of the key factors on the way to sustainable, equitable and rational use of water recources.
SNV is now an active member of the Netherlands Water Platform, and seeks to contribute to the international debate on water-management, amongst others by publishing experiences from the field.

This paper presents a strategy to be implemented and a series of preliminary results obtained in a process of technological innovation of irrigation practices by means of the introduction of sprinkler irrigation in Andean farming systems. Although experiences in this field have been generated in various parts of Peru as well as in Ecuador and Boliva, this paper focuses on Northern Peru. Here SNV has been involved in the reinforcement of institutional capacity to guide and facilitate the process of technological change, and has also worked on adequate design options.

This paper will be of use for professionals who are working in countries in which similar mountaineous agro-ecological and environmental conditions can be found.
It may help them to judge whether similar developments are feasible and whether action should be taken to stimulate these, or they may make comparisons with their own experiences and start a diccussion in which SNV is always interested to participate.

Yours sincerely,

Han Baartmans