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HYDRAULIC'S FUNCTIONNING OF FARMER-MANAGED IRRIGATION SYSTEMS IN NORTHERN ECUADORIAN ANDES

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ABSTRACT

In the Ecuadorian Andes, most of the irrigated areas (between 75% and 80%) are supplied by hydraulic systems managed by farmers organized in Water Councils.
After noting their specific characteristics, the autors describe the role of this "particular irrigation" in the national economy, its historical evolution, and the productivities obtained for the main crops. The low productions observed are mostly justified by the dysfunctions in the chain of water mobilization (water supply, transport, allocation between areas, distribution and application in the parcels).
The analysis is based on precise multidisciplinary studies in representative zones, studies completed by a systematic inventory (localization, organization and characteristics of each system) elaborated on watersheds.
The presented results are issued from the study on the Mira catchment (3,500 km2) situated in the northern part of the country:

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FOREWORD

Most of the irrigated surface in the Ecuadorian Andes has been managed since centuries ago by peasants organized in Water Management Councils. Very little is known about the functioning of these "FMIS" (Farming Management Irrigation System), which are now being studied by a multidisciplinary team of the French Institute of Scientific Research for Development in Cooperation (ORSTOM) and the Ecuadorian Institute of Hydraulic Resources (INERHI). The project has several chapters:

- Inventory (location, organization and characterization) of all the FMIS of the Andean region, which includes hundreds of systems that provide water to 75% of the 500,000 hectares under irrigation. Characterization is done at climatic, hydraulic and technical levels as well as at social, agricultural and economic levels.
- Hydric balances at several scales (from the water intake points to the hydrographic basin) in order to find the most deficient sectors.
- Study of several FMIS in pilot zones (Zones of Analysis and Recommendations for Irrigation) in order to discover and quantify actual performance problems and their dynamics.
- Research about real productivity reached, both at the agricultural performance level and at the production systems level (gross and net products, benefits per hectare and per worker).

The objective is the proposal of technical references and realistic recommendations to INERHI, useful for the establishment of a Plan for the support and development of FMIS (called *private irrigation* in the Ecuadorian case). Results have been fully analized in the northern region of the country (Mira watershed) and only the integration of the conclusions is pending.

1. STATE OF PRIVATE IRRIGATION IN THE MIRA WATERSHED

In the northern Ecuadorian Andes, the Mira watershed embraces a total surface of 348,000 hectares (ranging from 1,800 mosl to 4,200 mosl), an agricultural area of 149,000 hectares and an irrigated surface of 50,340 hectares (86% by private irrigation, 9% by State-owned irrigation and 5% by a combination of the two systems); irrigation water benefits directly 15,900 users and indirectly 158,000 inhabitants (this means half the population of the basin).

Dispersion is a main characteristic of the "FMIS":

altitudinal dispersion
Perimeters occupy 3 bioclimatic levels: the cold level (>2,700 m with 970 mm of rainfall/year and ETP of 1,020 mm/year); the temperate level (2,300 m-2,700 m with 795 mm of rainfall/year and ETP of 1,165 mm/year); and the subtropical level (<2,300 m with 540 mm of rainfall/year and ETP of 1,400 mm/year).

spatial dispersion
A total of 274 irrigation systems dam more than 20 m^3/s from the rivers using 308 direct intakes (94% of a rustic construction) and take the water to 279 perimeters along 1,099 km of canals (96% over the soil).

A "mean" FMIS has an irrigation channel with 4 km of dead canal, transporting 75 l/s and irrigating a perimeter of 180 hectares where large farms, estates, small holdings and minifundia lie.

In the Mira River basin, the pilot zone of Urcuquí is one of 18 ZARI that have been historically affected by irrigation. It has 30 FMIS that irrigate 4,500 hectares in three bioclimatic levels. The oldest ZARI is the central peasant perimeter of Urcuquí-San Blas, with 320 hectares and 600 parcels. The *Big canal of Caciques* that feeds it was built in 1582. Currently its management is in the hands of three peasants' councils: Urcuquí, San Blas and Cáciques, the latter enjoying the benefit of a special tratment in the water distribution frequency.

2. ROLE, EVOLUTION AND PRODUCTIVITY OF THE FMIS

Depending on conditions for production, agriculture undergoes development or enters into crisis. It is subject to unstable and succesive balances that depend on prior balances as well as on posterior factors of change in the agricultural environment.

Agriculture under irrigation has a factor that modifies environment: water. Its distribution among several groups of producers has a preponderant influence over the abovementioned balances. If a net of irrigation channels allows, at the beginning, a stability of hydric conditions in agriculture, development problems or external interventions can occur along its history that act upon agricultural activities in a big scale. Every malfunctioning takes a major importance and ends up being a life-or-death factor for productive systems, and sometimes for the people involved.

Long ago, the main goal of small farming in the Ecuadorian Andes was to feed peasants, while some large estates produced foodstufs for the urban population that before 1970 represented a small part of the Ecuadorian population. The development of an economy based on agricultural exports in the Pacific Coast, new communications between Coast and Sierra (railroads since 1909, highways since 1930) and especially the development of a petroleum-based economy (since 1970) acted as factors of integration of the andean peasant economy to the national markets. Twentieth-century demographic explosion follows along these changes.

On the one side, land property of marginal zones went from the old large holding system (*hacienda*) to minifundia (which doesn't allow peasant families to earn a livelihood from agricultural work) while the central part of the *hacienda* stayed in the hands of the original owners and was put under extensive production systems (cattle raising on natural grass).

At the same time, part of the peasants started to build and develop new production systems, placing their products in the market as a means for payment of agricultural work.

On the other side, some *haciendas* were also turned into capitalist agricultural enterprises with important investments in machinery and buildings and changing production techniques in order to satisfy the new urban demands of the country.

And so it happened that in the fifties new productive systems appeared, a result of the prior, poorly specialized ones. Nowadays several specializations coexist in every ecologic level, sometimes contradicting one another.

In the cold level, agricultors can choose among 3 development trends: extensive cattle husbandry, stapple grain cultivation (wheat or barley) and cold-level horticulture with crops like potato, onion or others, that need sustained care and work.

In the temperate level, side by side with natural grasses grow corn (basic foodstuff since long ago), cereals (wheat, barley) as in the cold level, horticulture based on beans among others, and orchard-level agriculture with avocado.

In the subtropical level the specialization on sugar cane coexists with cattle husbandry, corn, mandioc, and vegetable gardens.

If production systems have changed in the last decades, agricultural productivity, on the contrary, hasn't varied to any extent: hopes for production are still low, with or without irrigation.

Table 1 reflects this premise: beans and the most important cereals have a mean performance between 500 and 800 kg per hectare and potato has a performance between 7,000 and 10,000 kg per hectare.

These performances are the same as those expected by the first agronomists of the country in the first years of the 20th century. The stability in the wages for agricultural work confirms the stagnation of productivity (the daily wage of an agricultural worker has been the equivalent of 1 US dollar since 1945).

Productivities	Activities	Corn	Beans	Potato	Wheat	Barley
NO IRRIGATION	extensive	200-300	50-100	1,000-1,200	250-350	250-350
	moderate	350-500	150-250	3,000-6,000	400-500	500-600
	intensive	550-650	450-550	7,000-13,000	800-900	1,100-1,200
IRRIGATION	extensive	300-400	200-300	3,000-5,000	450-550	450-550
	moderate	550-650	500-600	7,000-10,000	600-800	600-800
	intensive	1,000-1,100	1,000-1,100	11,000-22,000	1,300-1,500	1,300-1,500
POTENTIAL	agronomic	4,000-4,300	2,000-3,000	18,000-36,000	2,000-2,500	2,000-1,500

Table 1 - Performances of the main crops in pure arrangement in kg/ha

There are numerous elements that can explain this low productivity, factors unrelated to irrigation ranking first.

Species and varieties used by producers generally lack quality, their productive potentials are low and their repetitive cultivation, year by year, has ended in an impressive growth of plagues. Another problem is the lack of adequate fertilization with organic fertilizers (combined use of agriculture and cattle raising is poorly applied) or chemical fertilizers. This could be related to seeds of poor quality and the lack of response to the dosages of fertilizers as used under actual production conditions.

The marketing system also doesn't encourage agricultors to engage in more intensive production; economic risks are important in front of the absence of organized markets and in the context of a very high inflation. We won't talk about assistance to peasants investment because credit aids are not available to small agricultors.

But all these problems can be found in agriculture in general. Crops under irrigation have more specific problems related to intake, transport and utilization of water, that limit the increase in productivity to a reduced level, as can be seen from Table 1. Without a prior knowledge of the location of some important limiting factors, we shall now undertake an overall analysis of irrigation systems from intake to furrow.

3. MAIN OPERATIONAL PROBLEMS IN TRADITIONAL IRRIGATION

3.1. Water application in the parcels

Most users (68%) irrigate their parcels day and night; the main technique is the use of furrows or ditches (75% of the irrigated surface). This is followed by an almost uncontrolled flooding of pastures (13% of the surface), aspersion irrigation, mainly for sugar cane and only in the *haciendas* (10% of the surface) and finally, by means of quarrymen (2% of the surface).

Generally the parcel is divided into regular lots; the peasant distributes the flow entering the parcel between them to irrigate groups ("*entables*") of 6, 8 or 10 joined furrows (depending on the available module).

But there also exist zigzaging furrows, used in steep slopes (more than 50%) that can be more than 300 meters long.

Technical elements of water distribution are most variable:

- The module used in each furrow ranges from 1 to 60 l/s (zigzaging furrows), but usually lies between 4 and 7 l/s.
- Mean irrigation time is 8 hours per hectare but values oscillate between 2 and 72 hours per hectare (the periods for 15% of the irrigated surface are greater than 12 hours per hectare).
- Frequency of application varies between 3.5 and 70 days; the mean is 14 days. In the subtropical level, 40% of the surface is irrigated with a frequency greater than 8 days. Things get a little better in the other levels, because only 16% of the surface in the temperate level has a frequency higher than 14 days (6% higher than 30 days in the cold level).

It is almost impossible to get a precise diagnosis of every perimeter with so extreme variations, especially when climatic data don't show the required consistency or simply don't exist.

However, the project has been able to determine the main characteristics for each type of irrigation (crop systems, soil depth and capacity for useful retention, monthly chronological rainfall series and ETP) and to estimate the maximal admissible frequency. This calculation is complemented by the analysis of 7 parcels that were observed daily during more than a year and where water intakes (from rainfall and irrigation), as well as superficial losses were controlled. Recollected data have been processed with IRSIS (FAO) software.

From the abovementioned analysis, irrigation frequency as practiced by farmers appears to be the most inadecuate factor: it is almost always less than calculated.

Under these conditions intensive farming cannot be practiced, nor can short-cycle crops with shallow roots be used. So peasants are still adapting vegetative cicles to rainy seasons, using irrigation water only as a complement and to secure water supply.

This inadequate frequency of irrigation stems, not only from the lack of technical criteria, but also from a historic background.

3.2. Degeneration of water assignment turns

When water was nationalized in 1972, INERHI confronted the uneasy task of granting water concessions and in the majority of cases only legalized long ago-acquired rights. In those times, with only 6 years of life, the Institute did not have the institutional strength necessary to update water distribution without provoking serious protest. This means that most of the actual water assignments still obey technical criteria ellaborated in the first half of the century and reflect social, technical and legal rules of that time.

But socio-economic conditions, environment and production systems have evolved, while water distribution generally has followed an inverse evolution: application frequency has grown lower due to the increment of irrigation time per hectare (in Urcuqui, this time went from 3 to 5 hours/ha in 45 years), which is due in turn to land division (because of inheritance or transactions) or to the incorporation of new users.

Accumulated historical rights have created several types of users ("normal", "*cáciques*", "third parties") whose particular requirements cause weekly modifications in the distribution. Peasant inertia and the interests of each group paralize every idea of change, or simply the current complexity of distribution precludes water councils from clearly posing the adaptation problem.

Rehabilitation of water turns is a fundamental task of INERHI and the project is designing an adapted methodology to ease its calculation. But technical criteria must be supported by social consensus and the acceptance of peasant organizations in order to achieve success.

3.3. Water distribution

Fictitious flows also have big variations (from 0.1 l/s to 3.8 l/s) that not always follow technical criteria. In Figure 2 three big classes, uniformly distributed in the three ecological levels, can be seen. Two thirds of the irrigated surface have inadequate supply (33% with a low volume and 31% with a high volume). Only a third of perimeters have an adequate supply.

A higher water supply can be justified in the presence of salinized soils that need frequent flooding. But this situation has only been found in 5 or 6 perimeters.

Cases of defficient supply are more visible in the country and create different reactions depending on the type of production unit. A perimeter with minifundia will distribute deficit between all the users, while a big landowner will correctly irrigate part of his property, giving water to the rest only when there is a surplus. Tensions grow higher in perimeters where both types of unit coexist.

Altitudinal levels	Low dotation	Mean dotation	High dotation
Cold level > 2,700 m	0.1 l/s/ha (1,500 has) 26%	0.25 l/s/ha (2,200 has) 38%	0.4 l/s/ha (2,100 has) 36%
Temperate level 2,300 - 2,700 m	0.2 l/s/ha (5,000 has) 36%	0.45 l/s/ha (5,200 has) 37%	0.7 l/s/ha (3,800 has) 27%
Subtropical level < 2,300 m	0.3 l/s/ha (3,000 has) 33%	0.6 l/s/ha (2,900 has) 32%	1.0 l/s/ha (3,100 has) 35%

Table 2 - Fictitious flows observed in 200 irrigated perimeters and surfaces (has and %)

This lack of coincidence between alloted concessions and real needs can be explained, in the first place, by an overall lack of knowledge about private irrigation. INERHI actually knows little about irrigated surfaces (localization, extension, cultivation pattern, type of irrigation, soil characteristics, climatology). The project aims to update all these parameters with systematic inventories, mathematic modelling of cultivation and production systems, efficiency measurements and climatic regionalization. Under present conditions the Institute is technically able to readjust all the alloted volumes of the Mira watershed but will face difficulties in doing so.

In the first place, concessions are granted for 10 years and cannot be modified during this period without first modifying the Water Law. This provision is unfavorable to dynamic agricultors that have achieved an intensive production system, thus increasing their water requirements.

In the second place, a good deal of concessions have been legalized taking into account old time rights or legal buys without considering the surface to be irrigated. At the time of legalization, many users prefered to buy rights higher than their real needs, in order to insure a satisfactory supply. In addition, a surplus supply enables a comfortable margin for its utilization: an approximate irrigation can be practiced without parcel adjustments and with minimum work, which means with less costs.

Users have nowadays 20 years of concession and think of the allotted flow as inalterable property. In order to establish balanced concessions within a technical criterion and in accordance to the evolution of agriculture, INERHI must show a firm political will to enlist social acceptance of the modifications and to achieve legal modifications without being afraid of electoral consequences.

3.4. Intake and transport infrastructure

Development of production in FMIS is closely related to the infrastructure of water intake, transport and distribution. A farmer won't try to intensify his production (improved seeds and fertilizers, summer crops,...) if he isn't sure of having water, at least in reasonable amounts and frequencies.

This depends heavily on the good performance of transport channels (mostly lying right on earth) and of places of intake which are mainly made by heaping stones in the shore (we call them rustic intakes).

Peformance estimates are done taking 2 fundamental aspects into account: the percentage of time that the channels provide the anticipated flow, and their efficiency in conducting water from the intake to the entrance of the perimeter. In both cases the goal is to find meaningful indicators so as to design adequate recommendations for a policy seeking the systematic rehabilitation of the traditional irrigation systems.

3.4.1 *Infrastructure performance*

Around 60 limnimetric reglets are placed in several representative irrigation systems along the interandean valley. Water levels are observed twice a day during at least one year and the causes of problems are registered. Although results vary from reglet to reglet, the following conclusions may be made:

- During 5% of the time (18 days per year) channels don't transport any flow.
- During 16% of the time (58 days per year) channels transport less than half the normal flow.
- During 32% of the time (117 days per year) the transported flow is less than 75% of the normal flow.

Detected problems stem from two main causes: landslides and destruction of intakes.

But a detailed analysis, supplemented with interviews to water-carriers, shows that, even if rustic intakes are destroyed several times a year, they can be fixed in only half a day (with the work of 2 persons), so their destruction disturbs the water turn but doesn't cause excessive damage to the farmer.

On the contrary, landslides upset water transportation for several days (sometimes more than 15 days) and are the real cause of lack of water.

These landslides are caused by (in order of importance):

- Excessive load and breaking of the irrigation channel due to the lack of control means (lateral relief) after the intake and along the course of the channel.
- Sliding of fragile parts that clog the flow, causing overflowing and rupture of the channel,
- Rupture of a channel at a higher altitude; its water destroys other channels lying down the way.

3.4.2 *Transport efficiency*

Several sections (25) of the channels have been selected based on their longitude and flow (more than 100 l/s). With a permanent regime, simultaneous gaugings are done at the start and end of the section and also before and after each alteration (superficial increase, located loss), in order to differenciate between global efficiency and strictly linear efficiency. Also the parts that need rehabilitation are registered.

Results are amazing!

Linear efficiency (without taking into account isolated modifications) has a mean value of 99,7%/km (ranging from 89% to 111%/km) and global efficiency has a mean value of 99,9%/km (ranging from 85% to 121%/km).

Efficiency values are not related with the type of soil traversed, nor with maintenance of the brook, but seem to have a slight relation with channel altitude (higher ones having a higher efficiency, always more than 1,005/km).

Results of the sample are confirmed all along the Mira watershed. In the legal concession process, INERHI technicians register their observations about the conditions of the channels. Only 11 veredicts make reference to important losses due to filtration in short sections. Besides, and taking into account the 274 existing systems, there is no correlation between the extension of conduction channels and transported flow; this means that any amount of water can be transported over any number of kilometers.

Although channels do lose water along their path (losses can be noticed by the heavy growth of vegetation along their borders), they do also receive sub-superficial increments that are not noticed.

There exists a heavy stratum of cemented volcanic ash –"*cangahua*" or "*talpetate*" in Central America– at shallow depths (several meters to several centimeters), impermeable except through cracks. The excess water that falls over higher parts (or "*páramos*"), where precipitation is higher, cannot penetrate deeply and flows over this hardened mass, entering the hydrographic net at lower altitudes.

So irrigation channels act as a draining net and dam a good deal of this sub-superficial drainage. In this case it is normal for higher portions to receive a larger volume of water, that step by step is later reintegrated to the hydrographic net.

In what refers to improvement works, it is estimated that only a mean of 5 meters by kilometer of channel need rehabilitation (dikes, embankments, small tunnels,..).

Studies about transport and intake infrastructure show that the building of modern inlets (generally of the "*caucasian*" type) and the systematic coating of traditional channels are expensive and have a limited interest. State should lower its inversion in these two items and concentrate it more on:

- the installment of lateral watersheds to avoid overloads;
- joining channels with similar paths;
- doing specific, small repair works to reinforce weak portions of the channels that can be easily located through water carriers.

3.5. Water supply

Lack of water in a third part of the irrigated surface not always obeys to an erroneous estimation of the demand, but also to lack of water from the river. It is evident that the State overestimates hydric resources, generally to justify the building of projects.

In private irrigation, this lack of coincidence between demands and resources stems from an ignorance of hydrologic characteristics that is a consequence of a bad distribution of the hydrometric net and of the lack of consistent studies. Before aproving a water concession, INERHI makes only one determination (during the summer) in the selected place of the river.

In order to have the best possible estimation of existing superficial hydric resources in any point of the hydrographic net, the project designed several basic operations:

- A spatial structuration distributed in demand zones (ZARI) and intake zones (hydrologically homogeneous microbasins). This zonification corresponds to a micro-regional level.
- A linear codification of the various intakes that places them exactly over the hydrographic net and estimates their mutual influences.
- A climatic regionalization (rains, ETP), based on the regional vector model that allows the generation of statistically possible monthly chronologic series in any point of the region.
- Simultaneous callibration of a rain-flow transformation model over the microbasins.

This methodological effort has achieved good results in the first three phases; the fourth is being completed. It also allows for the making of concrete diagnoses over hydroclimatic nets.

3.6. Structure of Water Councils

Water Councils sometimes exist since a century or more. They have always had several main functions:

- Determining the rules for the water turns
- Registering each family's rights
- Organizing distribution by sectors and watering places
- Administering daily distribution through paid water-carriers
- Reinforcing the application of rules and registers and penalizing infractors in several ways
- Organizing regular maintenance of the works and channel beds, generally through calls for working meetings (*mingas*), with the assistance of users, depending on their rights.
- Solving minor and major incidents
- Finantial administration of all these activities

Problems found at this level can be traced to a certain weakening in the power of the Councils.

On the one side, the Water Law gave part of the Councils' functions to the Regional Water Administration of INERHI. This particularly includes concessions (of water turns and particular intakes, in those times), control and sanctions (that now must go through a long administrative process).

On the other side, external interventions also contribute to an atomization of power; this means there exists a tendency to divide irrigation organizations into smaller ones that don't obey a central Council in problems related to water management and maintenance. Because of this, everyday conflicts ocurring in a water distribution system don't have an adequate and clear answer for both parties. On the contrary, these conflicts can degenerate and even end up in "water wars" between communities or groups of users.

Technical rehabilitation of FMIS must be joined with a structuration and "profesionalization" of peasant organizations, in order to establish a certain uniformity in water management.

4. CONCLUSION

Irrigation has not been able to substantially raise the productivity of traditional systems.

The rehabilitation of these systems requires first of a detailed knowledge of their functioning, based on multidisciplinary and precise scientific studies and not in aprioristic conclusions.

Modern techniques like satellite imaging can contribute with interesting information, although the scattering of small parcels in steep slopes difficults its use (an essay with the SPOT satellite is in process).

But, as has been proved, water management also obeys to inherited social rules that don't fit in the actual situation and that in many cases prevent any evolution of productive systems.

As a consequence, technical rehabilitation must be joined with a social change through the Water Councils, the only peasants' organizations able to introduce the necessary modifications.

This means reinforcing the Water Councils, therefore means modifying State intervention from the institutional and legal point of view.

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