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HISTORICAL ANALYSIS OF IRRIGATION AND ENVIRONMENT IN TWO ARID REGIONS IN SOUTH AMERICA

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ABSTRACT

Much historical research conceptualizes irrigation technology as artefacts “without history”, as if artefacts enter society in a final shape. For example, many scholars assume that large ancient irrigation works were constructed in one phase, requiring strong central state supervision (based on the well-known hydraulic thesis of Wittfogel). It is more likely, however, that irrigation works emerged from purposeful but uncoordinated (series of) human activities. The two cases discussed in this paper illustrate these nuances of the Wittfogelian thesis. The case of the Pampa de Chaparrí (pre-Columbian Peru) shows that it is perfectly feasible that adaptations to water availability on scheme level were realized by individual farmers. The case of the Proyecto Río Dulce shows that large-scale irrigation development in this area needs to be understood in terms of series of actions by smaller groups of stakeholders within a context of changing positions of central state authority. This paper suggests that development (of management) of irrigation infrastructure needs to be understood as a longer term process, in which irrigation infrastructure becomes concrete through human action in continuous use, design and construction. Irrigation systems are result of actions and the material context of new actions. An historical perspective not only provides the data for optimization of models, but also helps to increase our understanding of the nature of the relations between water availability and human intervention within natural environments.

Key words: Peru, Argentina, irrigation, hydrology, arid environment

INTRODUCTION

Human beings are rather unique among other living organisms in that their adaptive specialization lies not in some physical form or skill specific to a ecological niche, but in identification with the process of adaptation itself. Human survival depends on our ability to adapt, not just in the reactive sense, but also in the proactive sense of shaping the environment. A major instrument for human society to adapt (to) the environment is the development of technology. Technology conceptualizes a relation between

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artifacts/instruments, (human) actions and (human) goals. It is employed to support instrumental actions of human actors. Technical (and dull) irrigation may appear at first, its development is the story of the history of mankind. A most fascinating aspect of irrigation is the close connection between human civilization, natural environment and irrigation, as many of the important civilizations in world history had to use irrigation to feed their growing population. The manipulation of water flows, thereby adapting the availability of water in both time and space, by constructing irrigation systems, permits both the intensification of land use, for instance through double or multiple cropping, and the spatial expansion of arable land (Carlstein 1982). This intensified expansion provides a relatively secure food source for a larger population as it enables the peasant population to produce a surplus to support the non-peasant population. Food security enabled development of urban kingdoms occurred in a number of regions: Mesopotamia (after 3500 BC), Egypt (after 3400 BC), the Indus-valley (2500 BC), China (1800 BC), Mexico (500 BC) and coastal Peru (300 BC).

The importance of hydrology and ecology comes to the front when studying the formation of these civilizations. All of them are located in hydrological distressed regions, usually arid plains with a single (rain dependent) large river running through them. Within such an agricultural landscape, water is the natural variable par excellence. Thus, irrigation has played a crucial role in cultural development, and in the formation of these states. In the (semi-) arid regions of early civilizations with their large rivers water is not only highly mobile, but also quite bulky. This bulkiness relates to mass organization; as such a large quantity of water is supposed to be channelled and kept within bounds only by the use of mass labour. Although he was certainly not the first to stress the importance of irrigation and water control in societal development, Wittfogel was the first to develop a general theory about this importance. Wittfogel appears to advocate a deterministic role for the influence that water management played in early states, arguing that state controlled bureaucracies evolved as a consequence of expanding irrigation systems (Scarborough and Isaac 1993).

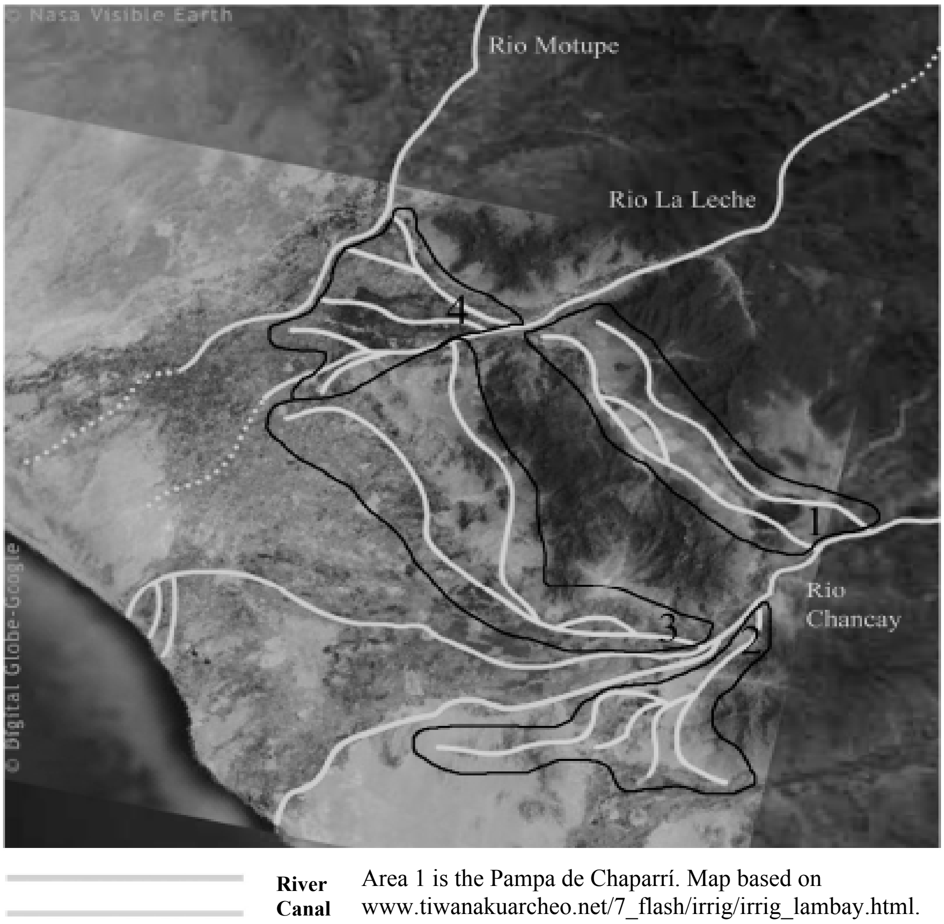
A crucial argument of Wittfogel is that the required mass labour must be coordinated and disciplined: it must subordinate itself to a directing authority. "*Primitive man has known water-deficient regions since time immemorial; but while he depended on gathering, hunting, and fishing, he had little need for planned water control. Only after he learned to utilize the reproductive processes of plant life did he begin to appreciate the agricultural possibilities of dry areas, which contained sources of water supply other than on-the-spot rainfall. Only then did he begin to manipulate the newly discovered qualities of the old setting through small-scale irrigation farming (hydro-agriculture) and/or large-scale and government-directed farming (hydraulic agriculture). Only then did the opportunity arise for despotic patterns of government and society.*" (Wittfogel 1957). Small-scale irrigation farming involves a high intensity of cultivation on irrigated fields too, but Wittfogel preserves central control for situations when large quantities of water have to be manipulated: "*Too little or too much water does not necessarily lead to governmental water control; nor does governmental water control necessarily imply despotic methods of statecraft. It is only above the level of an extractive subsistence economy, beyond the influence of strong centers of rainfall agriculture, and below the level of a property-based industrial civilization that man, reacting specifically to the water-deficient landscape, moves toward a specific hydraulic order of life.*" (Wittfogel 1957).

Up to today, many scholars studying development of large irrigation works in ancient civilizations assume, in the spirit of Wittfogel, that these irrigation works always were constructed in one phase. This would require a strong institution (a central state) to supervise and organize such massive work. It is quite likely, however, that larger systems are the result of many smaller scale actions in a longer time period (Ur 2002). Furthermore, "large scale" does not necessarily mean "strong central authority" (Hunt and Hunt 1976; Hunt 1988). In two cases these issues will be discussed in further detail. The first case presents the Pampa de Chaparrí (pre-Columbian Peru), the second case focuses on the Proyecto Río Dulce in Argentina.

PAMPA DE CHAPARRÍ, PERU

The Pampa de Chaparrí is located on the arid Peruvian north coast (figure 1). Despite its harsh and arid environment pre-Colombian civilizations have prospered, at least partly because the rivers provide the fertile coastal plains with irrigation water from the Andean mountains. The irrigation system of the Pampa de Chaparrí has been dated as being used between 900 AD and 1532 AD. It has been used by the Sicán, Chimú and Inca civilizations (Nordt e.a., 2004). In the 16th century the system was abandoned. Several publications on the Pampa are available on different issues. Téllez and Hayashida (2004) conclude that canals and walled fields on the Pampa were constructed with organized labour replacing taxes. Nordt et al (2004) discuss soil fertility and show that infiltration capacities of the coastal soils and low salinity levels in the irrigation water would have given no problems related to salinization. What has been less intensely studied is how the irrigation systems have functioned both in terms of hydraulic behaviour (in relation to canal operation and management) and hydrology (water demand in relation to availability). What is clear is that irrigated agriculture must have depended heavily on the strongly varying discharge of the Río Chancay, caused by rainfall in the Andean mountains.

Figure 1 shows that three areas had to be irrigated from the Rio Chancay. Area 1 in the figure is the Pampa de Chaparrí. A fourth irrigated area derived water from the Rio La Leche north of the Chancay. Water from the Chancay river was diverted to the Rio La Leche when it was not used in the Pampa de Chaparrí. Assuming proportionality between water use and surface area between the three areas taking water directly from the Chancay river the Pampa de Chaparrí would have derived maximally about 1/3 of the discharge. 30% would be a reasonable target value (as is explained below). What amount of land was planted is an uncertain factor: the more cropped area, the higher the risk of insufficient water availability to irrigate all crops later in the season. When crops were planted is not easily determined either, although the main cropping season would have fallen within the Peruvian summer (January – April) when river discharges are generally highest. Obviously, measurements and observations of pre-Colombian river discharges are unavailable. In modern times, after 1960, several tunnels have been constructed which linked several rivers in the Andes. Therefore river discharge figures after 1959 are not usable for our purpose. However, it is not unreasonable to assume that the discharges before 1960 are representative for the period of interest. Therefore available discharge data for the period 1914 – 1959 were used (figure 2, upper left and middle).



Area 1 is the Pampa de Chaparrí. Map based on www.tiwanakuarcheo.net/7_flash/irrig/irrig_lambay.html.

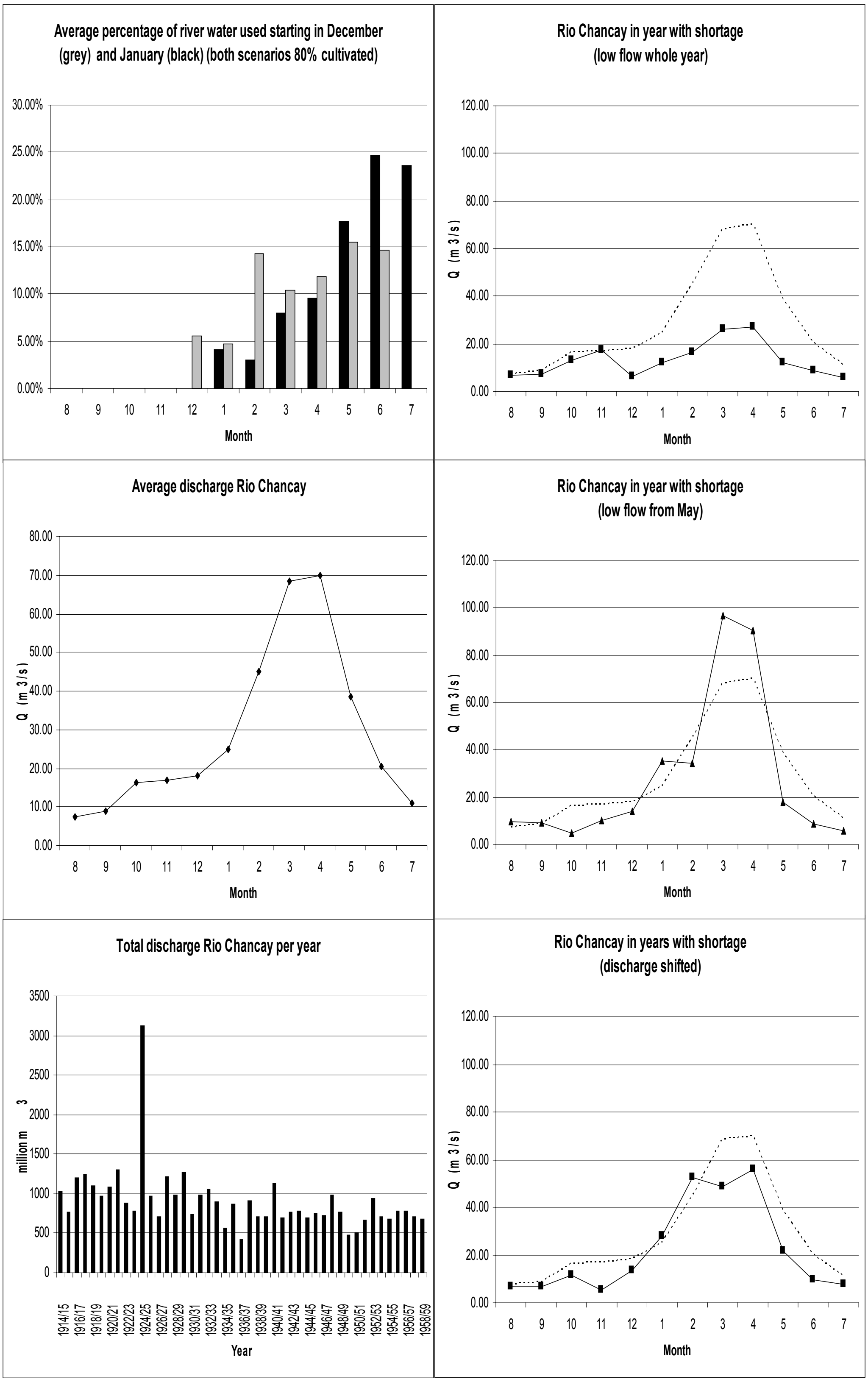
Figure 1. Irrigated areas along the Rio Chancay and Rio La Leche

River discharges were generally high in January and stayed high enough in most years to provide sufficient irrigation water for the crops. Crops cultivated on the Pampa de Chaparrí will have included cotton, beans, mais and potatoes. The growing season of cotton is about two months longer than of the other crops. Assuming that cotton was planted in January and the other crops some months later would give an end of the growing season on July. Basic crop water requirements calculations showed that such a cropping scheme made higher relative demands later in the season (May to July) on the lower river flows than if cropping would start in December (figure 2; upper right). Planting in December would furthermore yield less water shortages in the growing season than planting in January would yield. The December scheme water shortages would be more severe, however, and more often in the middle of the growing season when crops are generally more vulnerable for water shortages. Furthermore, discharge fluctuations in the period between November and February are much higher than later in the season. Thus, predicting river flows in December would have been somewhat more difficult too compared to January. Figure 2 illustrates that predicting river flows of the Río Chancay was already quite difficult, even in January. It can be seen that water shortages are not just caused by generally dry years (lower right). Years with average flows could still cause water shortages in some months, because the distribution of flows within the (normal) season was irregular (lower left). Another possibility was that the rains in the mountains stopped early and river discharges dropped earlier than normal (lower middle). Calculations showed that in case the irrigators at the Pampa de Chaparrí would plant their cotton in January they would have suffered more water shortages in the 45 year period simulated, but these shortages would occur always at the end of the growing season, when crop damage is less severe (upper right).

Several indicative calculations relating to number of events (in terms of months per year) in which water shortages were to be expected were made (figure 3). Months or years with water shortage were defined as periods during which crop water requirements exceeded the 30% share of the river water (set as the water right for the Pampa earlier in this paper) plus an extra 5% to take into account uncertainties in the crop water requirement calculations (particularly with respect to the actual water demand of antique crop varieties). Assuming planting in January, the calculations showed that shortages always occurred in the period May – July. With respect to the percentage of the available area under cultivation, a value of 70% of the area resulted in 6 years showing (mainly) less severe water shortages (for example in July) out of a total of 45 years, a reasonable value. In case about 80% of the surface would have been cultivated, about 8 years out of 45 years would have shown water shortages (from 1 to 3 months). With 100% of the area irrigated this would increase to 11 years, with larger amounts and longer periods of shortages. It is not unreasonable to assume that values of 1 dry year per 4 years would be relatively high. Therefore the assumption of 70% cultivation seems fair.

All calculations discussed so far do not cover the issue of irrigation management. How the irrigation systems were controlled (in social and technical terms) needs further study. It is not unreasonable to assume that on main system level potential control over water flows was minimal, given the technology available at the time and the extremely fluctuating river flows. What the calculations do show, however, is that with relatively simple measures the central issue of water availability could be dealt with locally (on field or farmer group level) through adapting cultivated surfaces to hydrological circumstances.

The results presented above are the first from the Pampa de Chaparrí area, which is one of the case areas within of a larger research project focusing on the development of larger irrigation systems in semi-arid regions of South America. In modern historical times, the changes in this Peruvian region have been enormous, including construction of tunnels, reservoirs and lined canals; these need to be studied further, however. In the next case study, however, similar enormous changes towards (what has become known as) modernization will be discussed. This case shifts attention to the semi-arid northwest region of Argentina.



Average percentage of river water used starting in December (grey) and January (black) (both scenarios 80% cultivated)

Rio Chancay in year with shortage (low flow whole year)

Average discharge Rio Chancay

Rio Chancay in year with shortage (low flow from May)

Total discharge Rio Chancay per year

Rio Chancay in years with shortage (discharge shifted)

Figure 2. Average river discharge, yearly discharges, water shortage scenarios and percentage of river water used for irrigation for two starting dates

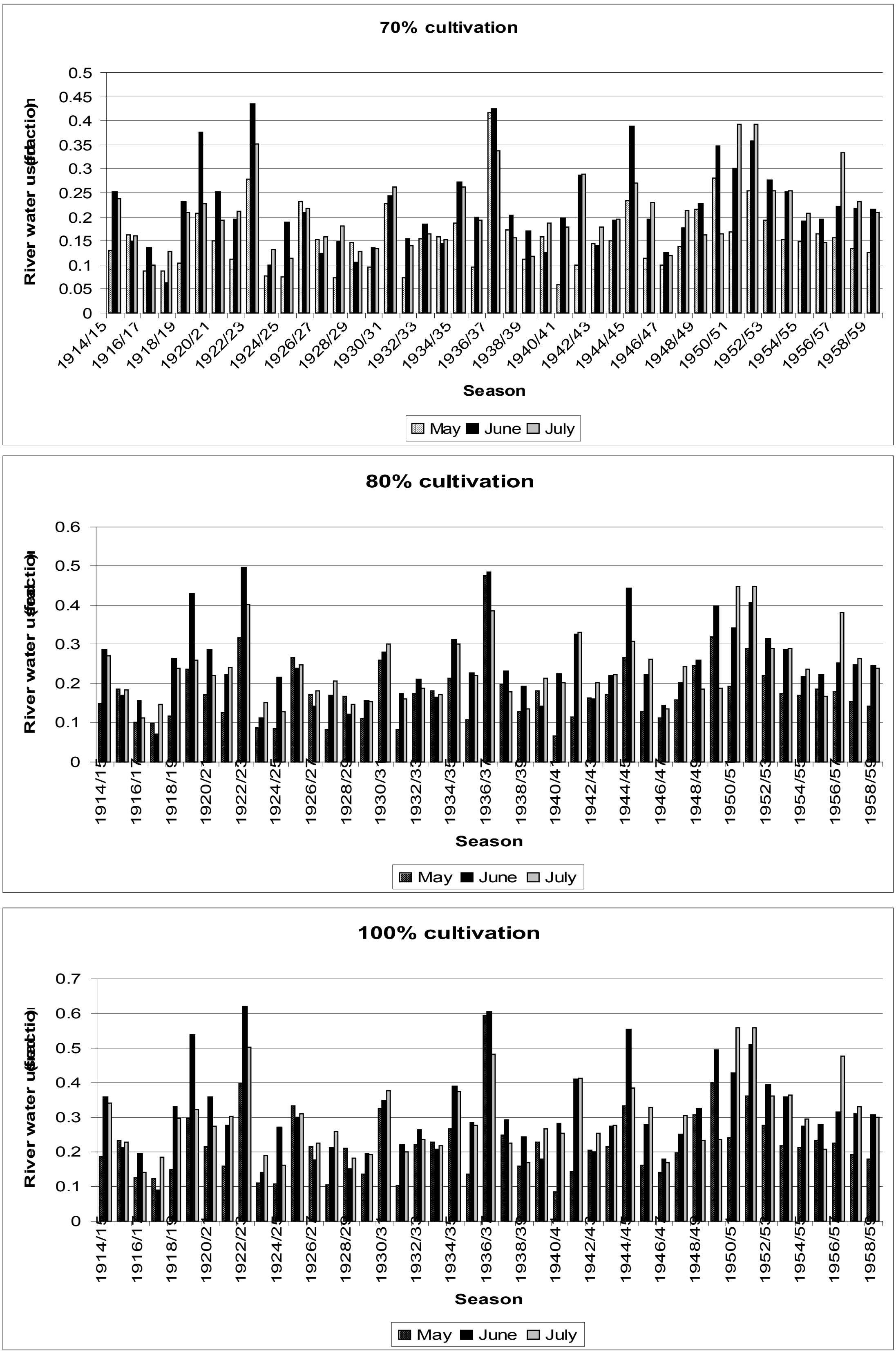


Figure 3. Indicative water shortages for different scenarios

PROYECTO RÍO DULCE, ARGENTINA

It is precisely this unpredictability which has been the drive for major changes in the Río Dulce irrigated area in Argentina. The Dulce River basin covers about 100,000 km^2. Within the basin, the area known as the Proyecto Río Dulce (PRD, irrigable area 122,000 hectares in a command area of around 350,000 hectares) is one of the largest irrigation schemes of the country and the most important irrigated area in the province of Santiago del Estero. This second case study discusses a common reaction of societies to water availability fluctuation described above: increasing control over water flows. Petts (1990) describes the relationship between water, engineering and landscape as a three-phase development. These phases are illustrative for developments in Santiago del Estero (figure 4; description below based on Michaud 1942 and Prieto 2006). The first phase, management of perennial water sources for local agriculture and domestic supplies and the opportunistic use of seasonal floods and rains for agriculture, extends until about 1875 in Santiago del Estero. In 1577, Spanish settlers built their first irrigation ditch (*acequia*) in Santiago del Estero. In 1583 this reached a length of 5 kilometres. In 1680 an irrigator's register was established. In 1873, 73 acequias existed. These canals were not the small ditches one would perhaps expect: most were longer than 10 kilometres, some extending even up to 50 kilometres with a width of 6 meters. Officially about 8,000 hectares were irrigated by the canals, but in practice this figure would have been higher.

In 1878 canal *La Cuarteada* was built, which starts a second phase, involving the management of rivers for informal regulation of seasonal floods for irrigation agriculture and drainage of wetlands. In 1886 an intake structure was constructed for La Cuarteada, which was renewed in 1898. In 1905 the existing irrigation infrastructure was further extended. From then on, the intake diverted water to a main canal, at the end of which (*La Darsena*) *Canal Norte*, *Canal Sud* and Canal La Cuarteada branched off. This was the first public irrigation system in Santiago del Estero, irrigating about 38,500 hectares (with 14,500 hectares being irrigated from private acequias). In 1913 a communal canal on the right bank was constructed: *Canal San Martín*, with a length of 64 kilometres. In 1947 the federal organization for water affairs *Agua y Energía Eléctrica* (AyEE) began building a permanent diversion weir in the river, the *Dique Los Quiroga*. San Martín continued to derive water directly from the river, as did the remaining private acequias. However, these canals downstream of Los Quiroga had difficulties getting water, in particular during periods of low flow, since almost the full flow was diverted to the La Cuarteada system on the left bank. Again, assistance from the National Government was looked for. As a solution, the San Martín system was connected to La Matriz through a siphon around 1954.

Dique Los Quiroga already marked a first step in the direction of a third phase, during which rivers have been regulated by large structures, often as part of a complex basin or inter-basin development, for hydro-electric power generation, water supply and flood control. In the Río Dulce basin, this period extends fully from 1968 onwards with the construction of a reservoir in northwest Santiago, the *Embalse del Río Hondo*. AyEE presented plans in 1957 and the reservoir was completed in 1968. The reservoir has shaped the potential for irrigation all year round, although its capacity is insufficient to provide more than annual regulation. Data from the PRD show that inflows per hectare are significantly higher after 1968 (the third period) compared to the second period, especially before Los Quiroga was built (and probably also compared to when Los Quiroga was in use, for which we have no data yet) (figure 4).

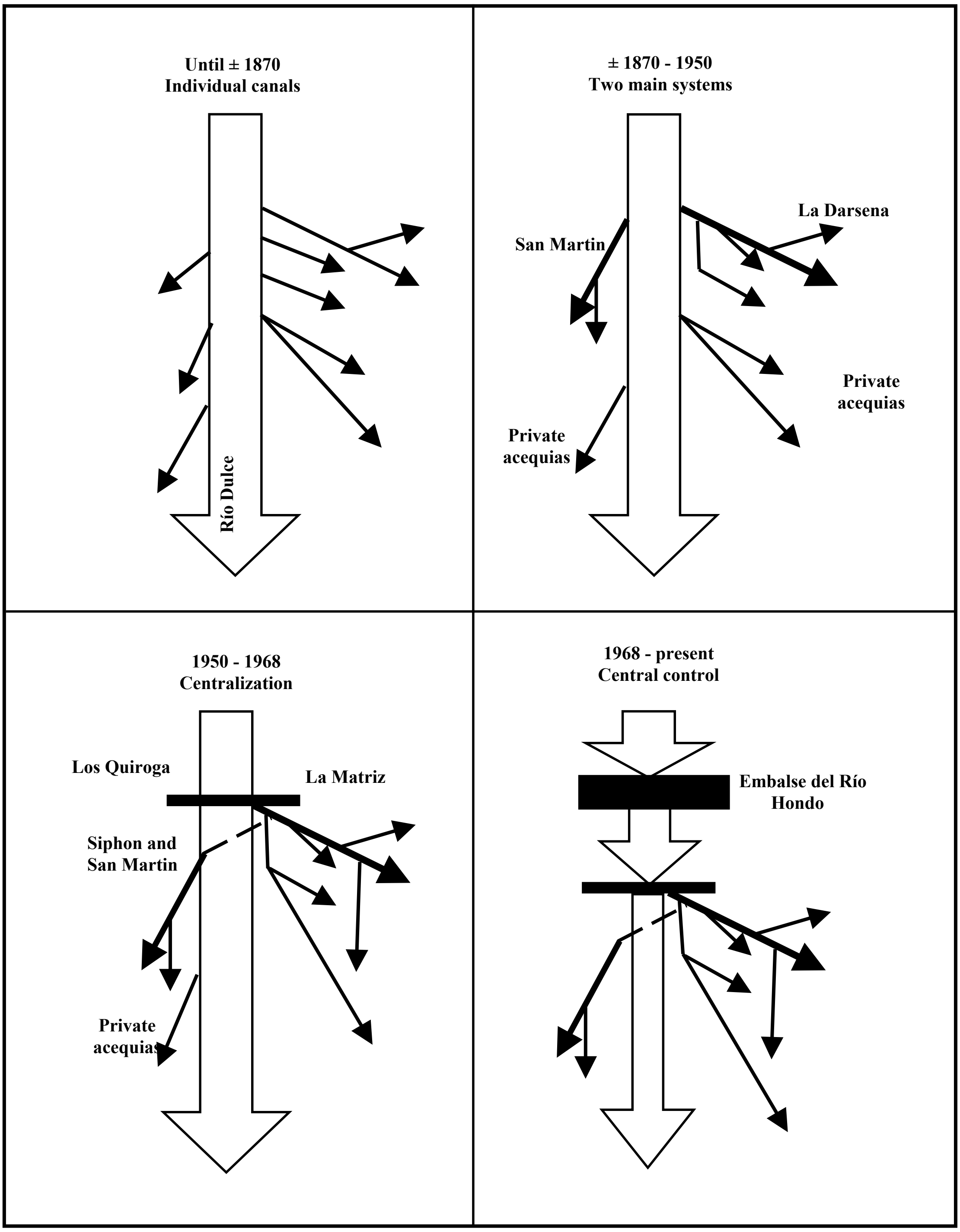


Figure 4. Schematic representation of development phases in the PRD area

In actual practice, smaller farmers irrigate their cotton or alfalfa on average three to four times per year and use about two and a half times more water per turn than allowed (240 mm/event). Smaller farmers reproduce the former distribution schedule from the second period in the development process of the PRD area. Before the reservoir the irrigation infrastructure provided two or three irrigation turns for each farmer in late spring and summer, when water levels in the Río Dulce were sufficiently high. The larger farmers, with more diversified cropping patterns, take advantage of the new potential made possible by the reservoir. They combine the irrigation strategy of the smaller farmers (irrigating crops a few times), but take water during 6 to 8 turns because they irrigate only a fraction of the area available to them each turn. They sometimes irrigate a larger area than officially allowed. (Prieto 2006)

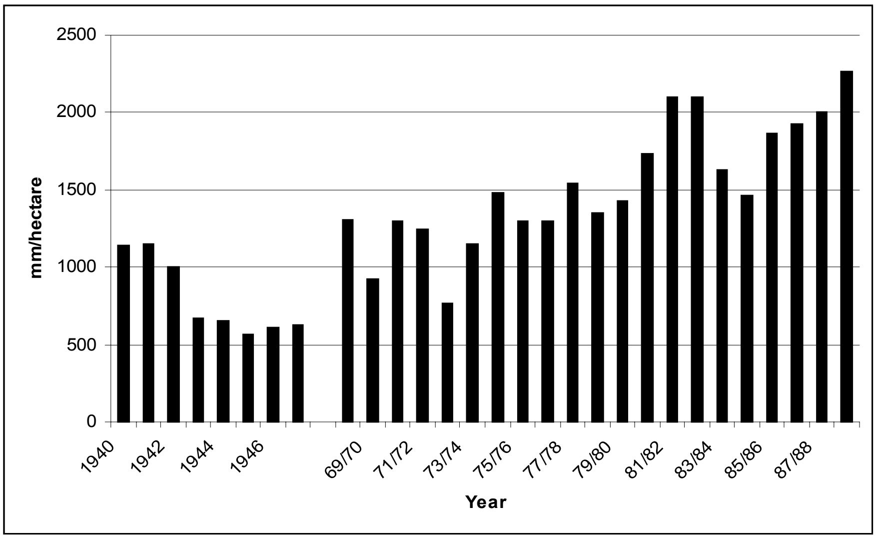


Figure 5. Water use in the PRD area in different years (data used from Ertsen et al 2004; Prieto et al 1994)

CONCLUSIVE REMARKS

An important issue in irrigation is the nature of unstable water availability during seasons and over the years. Many rivers have an irregular flow pattern, with large fluctuations in and over seasons and very low flows in the dry season. In such a setting it is difficult to match water availability with actual water requirements. Rational water use requires (to a certain extent) knowledge of river flow predictability. This requires both physical and socio-political arrangements: some kind of distribution facility is needed to transport water and some kind of coordination between actors is needed to manage water flows. Both case areas discussed in this paper are located in arid regions with fluctuating rivers in South America. The case of the Pampa de Chaparrí on the arid Peruvian north coast (900 AD - 1500) discussed how irrigators may have dealt with fluctuations in water availability over the years. It shows that it is perfectly feasible that adaptations to water availability on scheme level were realized by individual farmers. The case of the Proyecto Río Dulce shows that large-scale irrigation development in this area needs to be understood in terms of series of actions by smaller groups of stakeholders within a context of changing positions of central state authority. All this has not necessarily resulted in stronger central management. Within the process, irrigators steadily increased their control over similarly fluctuating surface water flows. This has increased incoming flows into the PRD per surface unit.

The cases discussed cannot be fully appreciated if irrigation technology is conceptualized in terms of a "physical network" of "artefacts" without history. Developing and managing irrigation infrastructure is a social practice; irrigation (infra) structures become concrete through human action in (continuous) use, design and construction. Irrigation systems are both result of actions and the (material) context of new actions. Actions and infrastructure together create spatial and temporal patterns of water flows, which are very likely to provoke new actions on either individual and/or collective level, which are constrained by hydraulic properties, etcetera. If we accept that (ancient) irrigation systems emerged from purposeful but uncoordinated (series of) human activities, we need to study their "*structuring properties providing the 'binding' of time and space in social systems.* […] [t] *hese properties can be understood as rules and resources, recursively implicated in the reproduction of social systems.*" (Giddens 1979; 64).

Social and material structures are both medium and outcome of social practices, coined as '*structuration*' by Giddens (1979, 1984; although Giddens does not discuss technological development in detail and probably never intended to apply his structuration thesis to physical structures). In the process of structuration '[r]*epetitive activities, located in one context in time and space, have regularized consequences, unintended by those who engage in those activities, in more or less 'distant' time-space contexts.*' (Giddens 1984; 14). The "distantness" of space and time in irrigation systems can be extremely varied. Irrigation systems can be the result of series of actions within longer time frames, as in the PRD where canal building activities before 1700 partly set the constraints of the modern system. On the other hand, a change in gate settings can have consequences for neighbouring gates and/or canals within minutes, hours or days. Because of such short-term actions, canal flows usually show changes in water level and discharge over time (which is defined as non-uniform behaviour). Whatever the timeframe, it is important to take into account that irrigation systems have histories; many modern systems have changed and/or grown over time.

Offering interpretations of the past is a main goal of the historical discipline. Responses from the professional irrigation community, including the continuous dedication to create historical seminars, shows that a historical approach is not only valued by professionals because it offers nice reading in airplanes, but also because historical work provides good case studies for some of the theoretical and practical concerns within the irrigation engineering domain. '*History does not repeat itself in detail, but drawing analogies between past and present allows us to see similarities. For this reason, generals study military history, diplomats the history of foreign affairs, and politicians recall past campaigns. As creatures in a human-built world, we should better understand its evolution.*' (Hughes 2004). In the present time, irrigation still is one of the key resources for many groups in the world. The irrigation systems encountered today, the practices of actors involved and the different institutions surrounding them are the product of history. '[…] *knowledge of the past is necessary to understand the fundamental structures of, and the background to, established patterns of water use. Knowledge of how the past weights on the present is a precondition for escaping the power of history.*' (Tvedt 2004). Although success is not guaranteed, one would expect that engineering interventions will improve when the irrigation context in which these interventions need to take place is better understood.

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