PERSPECTIVES ON ASIAN IRRIGATION

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ABSTRACT

In what some may regard as an overly ambitious exercise, we have chosen in this paper to present some salient aspects of the evolution of Asian irrigation. The focus is on South and Southeast Asia. It is argued that geo-politics has provided the main driving force for the development of public irrigation systems in Asia. Three geo-political eras are identified – the Colonial Era (1850 to 1940), the Cold War Era (1950 to 1989), and the new Era of Globalization (1990 onward).

The objectives of irrigation development set forth by colonial regimes, national governments, and development agencies in each of these time periods have been rather similar. The focus has been on the often conflicting goals of poverty alleviation and food security on the one hand and profitability and revenue collection on the other.

Irrigated agriculture, however, has changed dramatically and has in turn fostered change and economic development in the rural communities. Irrigation has evolved in each of these periods through a dialectic interaction among resources, technologies, institutions, and culture. Land and water, once abundant, have become scarce. Surface and groundwater technologies have been developed to facilitate the expansion of irrigated area and intensification of irrigated agriculture.

But the success of these endeavours has brought new problems. The intensification of irrigated agriculture has led to an increase in pollution and environmental degradation. Food grain prices have plummeted with the result that the benefits of irrigation have gone largely to consumers. Farm households have looked to other sources of income from both farm and non-farm sources. The rural economies are undergoing social as well as an economic transformation and the rural-urban frontier is getting blurred.

There has been a serious lag in the development of appropriate institutions to deal with the new environment of water scarcity. The challenge ahead lies in creating the institutions that can: (i) allocate water equitably among competing uses and users, (ii) integrate management of irrigation at farm, system, and basin level to reduce upstream-downstream and head-tail conflicts, (iii) integrate the management of ground and surface water irrigation, and (iv) address the problems of irrigation development, including use of waste water, in environment and health.

This agenda represents an important component of *integrated water resource management* (IWRM). The central point in institutional reform is to define entitlements or ‘rights’, in order to determine the allocation and access among users and uses at the basin, system, village, and farm level. The growing importance of common-pool groundwater resources adds greatly to the complexity of then problem. The task is monumental. It is likely to take years, perhaps even decades, to establish enforceable water rights and the complementary set of institutions for IWRM.

1 INTRODUCTION

Over 60 percent of the world's irrigated area is in Asia. Approximately two thirds is devoted to cereal grain production, rice and to a lesser extent wheat. Irrigated area has expanded rapidly over the past half century through the construction of canals and storage dams and the exploitation of groundwater. Now the potentials for further expansion have become limited, water has become scarce, and cereal grain prices have declined. Attention has turned to improving management and control to increase water productivity and facilitate diversification to higher valued crops.

This paper presents a broad overview of irrigation development in Asia, emphasizing the current problems and challenges. The focus is on the interaction between socio-economic and bio-physical factors that have been the determinants of growth and development in selected time periods. First, we provide a framework for viewing the transition in Asian irrigation. We discuss the antecedents of modern day irrigation – the communal irrigation systems and the large hydraulic works – and the lessons to be learned from this historical experience. Then we cover the development of modern Asian irrigation in three different time periods identified in terms of their geo-political significance – the Colonial Era, the Cold War Era, the New Era of Globalization. Our Colonial Era extends from 1850 until World War II, a period which saw considerable activity in irrigation development. The Cold War Era extends from the end of World War II to the fall of the Berlin Wall (1989) and encompasses the period of the *green revolution.* The Globalization Era begins in a period when water has become scarce, water pollution is increasing, yield gains in cereal production in most of Asia have slowed or stagnated, but profits from cereal grain prices have declined and income from non-farm activities has increased in many Asian farm households. Finally, we discuss the challenges ahead – alternative ways to increase water productivity, and the need for new institutions to support *integrated water resource management* (IWRM).

2 A FRAMEWORK FOR THE EVOLUTION OF ASIAN IRRIGATION

A framework for economic development is presented in Figure 1 (Hayami, 1997). The development of irrigation fits very well within this framework, which shows a constant interplay between resources (land, labor, water), technologies (dams, tubewells, pumps), institutions and policies (water rights, management) and culture (values and value judgments) as irrigation evolves over time in a community, a basin, a country, or a region.

Allan (2000) distinguishes several phases in the development and use of water resources. A first pre-modern phase includes development constrained by limited technical capacity and what Tanaka (1991) has coined "environment-adaptive adaptations", that is the development of different types of agriculture attuned to the characteristics of each ecosystems. The use of floating rice in deltaic areas of the Mekong, Chao Phraya or Ganges-Brahmaputra basins, or receding irrigation around the Tonle-Sap in Cambodia (van Liere, 1980) provide good examples of such adaptations. Other traditional systems involving a degree of land development included ponds and run-of-the-river communal irrigation systems. A second phase, based on the ideas of the 18th Century Enlightment that capital, engineering, and science could harness nature for the benefit of industrial economic development, gave way to the so-called "hydraulic mission", that is considered to be still partly alive in the South, where it started mainly after WWII. Following Tanaka, this “environment-formative adaptation” phase consisted in widespread 'artificialising' of the landscape and waterscape, reshaping them by extensive diking, damming, leveling, canalling, etc. Subsequent phases reflect the emergence of environmental concerns, the need to reason the allocation of water between sectors taking into consideration the economic value of water, and a more recent focus on how institutions must evolve to face the challenge of integrated water management.

This shift in concern and paradigm was the reflect of a process experienced by many major river basins and termed ‘basin closure (Keller *et al.*, 1998; Molden et al., 2000; see Figure 2). In the *construction* phase, supply is increased through the construction of large reservoirs and, sometimes, the tapping of underground water. Water use is generally little constrained and resource development generates new uses, such as the expansion of irrigated areas. As population grows, water abstraction increases and punctual shortages appear, and a new phase emerges where a more effective *utilization* of water at the farm and system level is sought. Then, as the basin begins to close and water supplies are limited, more attention must be given to the *allocation* of water among competing users and uses at farm, system, and basin level. In particular, the economic benefit of alternative uses must be considered and an increased formalization of water entitlements or rights becomes critical.

This evolution has also been described in economic terms as shown in Figure 3 (Hayami et al., 1976, Kikuchi et al., forthcoming). A point is reached (point t_1) where the marginal cost of opening up new lands exceeds the marginal cost of developing irrigation. This point was reached much earlier in East Asia than in South and Southeast Asia. In the *construction* phase, the cost of surface irrigation systems rises as irrigation expands into increasingly marginal areas. However, the development of new technologies specifically adapted to irrigated agriculture (*green revolution* technologies) shifts the marginal cost curve downward from I to I’. Eventually, a point t_2 is reached where the cost of new irrigation exceeds the cost of investment in effective *utilization*. Depending on the situation, more effective utilization can be achieved in a number of ways including better control and management of surface water flows, recycling water by pumping from drainage ditches, and development of groundwater resources. At the same time, saturation in irrigated areas leads to a new phase of agricultural expansion in marginal upland areas (de Koninck, 1997).

The evolution can also be defined in geo-political periods that to a large extent parallel the hydrological and economic periods described above. We believe that in all three periods geo-political forces have been dominant in establishing the direction of change in the development of irrigation and irrigated agriculture. Table 1 is divided into three phases – the Colonial Era, the Cold War Era, and the new era of Globalization. In each column we list the changes taking place in irrigation construction and utilization and parallel changes in irrigated agriculture. We also identify the major determinants of change including geo-political objectives, resource constraints, technological advances, and defining events such as famines and droughts and the opening of the Suez Canal. In the sections which follow, we build upon this framework to describe the development of irrigation in each time period.

It is important to emphasize that we are painting with a very broad brush. There have been marked differences in the pace of development of irrigation and irrigated agriculture within Asia. Many events overlap between time periods and many areas don't fit the time frame. For example, population pressure dictated an earlier development of irrigation in East Asia. There are similarities and important differences in the East Asian experience. The earlier East Asian development of irrigated agriculture in conjunction with varietal improvement, use of chemical fertilizers and mechanization helped to establish the direction of change in South and Southeast Asia after World War II.

Before describing irrigation development in each of the three geo-political eras, we discuss briefly irrigation in Asia before the colonial period. We still marvel at these centuries-old achievements in irrigation, both community and large-scale systems. It is often suggested that we should follow the examples set by these societies of antiquity. As one considers the challenges of modern day irrigation, particularly the struggle to develop viable irrigation institutions and organizations, there are indeed lessons to be learned from the past.

3 ANTECEDENTS

Community irrigation systems and large hydraulic works - *why were they successful, why did they fail?*

We discuss here community irrigation systems and large hydraulic works managed in what Wittfogel (1957) describes as Hydraulic Societies. These systems over a considerable period of time, often centuries, are said to have achieved most of the objectives desired in modern day irrigation – productivity of water, equity in the distribution to users, stability in maintaining water supply over the years, carrying capacity in sustaining population at an acceptable level of living, although this is open to debate.

3.1 Community irrigation systems

Community irrigation systems have been pervasive in Asia and even today serve a third or more of the total irrigated area. Many of these community systems have existed for centuries. While most are small, it is not unusual to find those serving 1000 hectares or more. They have generally developed in mountainous or hilly areas based on the diversion of small/medium streams, most especially in the Himalayan, the Philippines, Northern Thailand and Laos, in China and Japan. The success of a community irrigation system depends most importantly on the felt need of the community of water users. The need for community cooperation is most evident in areas of intense population pressure and/or limited water supplies in order to gain access to and share water and to minimize conflicts.

Lewis (1971) describes the *zangjera* irrigation societies of the densely populated Illocos region of the Philippines. He compares the behavior of farmers in the *zangjera* with those who migrated to the less densely populated province of Isabela and finds in the latter case no evidence of functioning irrigation associations. He concludes that the behavior of Illocanos is reflected in the differences in the respective natural and social environments. By contrast a group of Illocano farmers migrating to Mindinao established a 2,500 hectare community managed irrigation system in Davao del Sur that has functioned successfully for decades (personal communication A. Mejia, National Irrigation Administration, April 2002). Siy (1988) studying the *zangjera's* and Yoder et al. (1987) studying the performance of irrigation organizations in the foothills of Nepal concluded that the need to periodically mobilize labor to gain access to water through the construction and maintenance of canals and dams was among the most important factors accounting for sustainable farmer managed irrigation systems. Leach (1961) describes the *bethma system* in Sri Lanka that enables all farmers in a given tank command to share the limited water supply during the dry season irrespective of the location of their paddy fields. Geertz (1980) on the Balinese *Subak* illustrates some of the same points.

Although traditional communal irrigation schemes are often praised for their endogenous mix of local wisdom and social cohesion,[1] and sometimes romanticized (Goldsmith, 1998), these systems are now exposed to new threats, as communities opened to the world, agriculture moved from subsistence to commercialization, and villagers diversified their economic activities. Increased socio-economic heterogeneity as well as the intervention of the state in construction/maintenance of weirs have often weakened social cohesion and collective action.

It is hypothesized that irrigation began with small dams, tanks and ditches where cooperation among neighbors met the managerial needs. Particularly in the arid areas, however, irrigation could not be used extensively until it was possible to construct large dams and this required corvée labor and a full time supervisory class (Steward et al., 1955).

3.2 Hydraulic societies

Wittfogel (1957) states that he had "long been impressed with the developmental lessons to be learned from the study of agrarian societies based on large scale and government-directed water works. These societies covered more territory, lasted for more years, and shaped more lives than any other stratified agrarian society". Wittfogel succumbed to the temptations presented by large scale irrigation requiring, as he saw it, totalitarian organization in order to muster the labor force necessary for huge flood-control works and irrigation systems (Chambers, 1977). But Wittfogel's hypothesis challenges others to produce alternative explanations that are more than accounts of the uniqueness of individual cases.

How did these societies manage to succeed for so long and why did they fail? Large waterworks were created for both production and protective purposes (irrigation and flood control). Irrigation made it possible to acquire the food surpluses and to release labor for other cultural activities. Among the non-hydraulic installations that grew with hydraulic installations were defense works, far-flung roads, tombs, temples, and pyramids. Improvements in farming and increase in food supply permitted population growth, the limits of the growth being determined by the limited

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[1] "People's Irrigation System (PIS) [in northern Thailand] can be viewed as an integrated system consisting of an intricate intertwining of local village technology with human commitment of cooperation, and a supportive philosophy which lends this system its coherence and cohesiveness" (Tan-Kim-Yong, 1995).

water supply to a society equipped with pre-industrial techniques (Steward, 1955). In some areas efforts to continue the intensification of irrigated agriculture led to environmental problems such as salinity and disease epidemics such as malaria. Crop productivity stagnated or declined. As the productive limits of irrigation were approached, the hydraulic societies frequently moved urban centers or conquered new territories in search of new resources for sustainability. But without the constant stream of technologies that characterize modern day agriculture, the limits to growth must eventually have been reached.

The epitome of the hydraulic society in Asia is China (Wittfogel, 1957), although this is also object of debate (Masubichi, 197?), while northern Vietnam may provide another example. However, the intensity of the intellectual debate on Asian despotism in the post-war period has sent many researchers in a quest of hydraulic societies in Asia, which has not been always successful or convincing. Statgard, for example, deployed much effort to locate hydraulic polities in Southern Thailand and Central Burma; the 'case' of the Thai State has been unexpectedly examined by Chai-anan, and by Wijeyewardene (1971); even the paradigmatic case of the Khmer empire and its "hydraulic city" of Angkor are now increasingly seen to owe much to imagination (Stott, 1992; de Bernon; 1997). Other scholars have also questioned the existence of hydraulic societies particularly where imposing achievements seemed to point to the existence of strong states (Bali: Geertz, 1972; Lansing, 1987; Sri Lanka: Leach, 1961).

On balance, it seems that agro-hydraulic kingdoms have prospered in areas of higher population density. The centralization of the economy was sometimes paralleled by the achievement of large scale infrastructures (China, India, Northern Vietnam,...), but this was not always the case (Kingdom of Majapahit in Java, in the 14th century; Maurer, 1990). On the other hand, a large part of Southeast Asia long remained underpopulated and indigenous autonomous systems of irrigation were the rule.

4 THE COLONIAL ERA

River diversion schemes for assuring the main harvest, famine prevention and revenue collection – protective vs. productive systems.

Most revenues of colonial powers in Asia were based on agriculture. This included plantations (rubber, tea, coffee, etc) in rainfed areas, while irrigation was developed in lowlands in order to provide rice as a staple food for population as well as for export. Rulers had the twin and often conflicting objectives to produce food in order to control famine, unrest, and revolt, and to extract as much surplus as possible.

Irrigation in the semi-arid regions and in the monsoon areas had distinct characteristics. In the semiarid regions crop production is dependent on irrigation. Systems were designed and crop production planned on the basis of irrigation water availability often with the objective of maximizing returns to scarce water rather than to land. In the monsoon areas, however, the farmer planed his crop production primarily on the basis of expected rainfall. In years of good rainfall, farmers needed no irrigation and drainage could be the constraint. In years of low rainfall, supplemental irrigation was needed to protect the main harvest, normally rice. In the remainder of this section we discuss irrigation development first in the semiarid regions and then in the monsoon regions.

4.1 Semiarid irrigation

The semiarid regions consist mainly of what is today Northwest India and Pakistan. With the annexation of the Punjab in 1849, the British gained full control over the Indo-Gangetic Plain. They were quick to recognize the enormous potential of the area and initiated the construction of canals. The irrigated area grew rapidly to around 5 million hectares by the turn of the century (Bolding et al., 1995). Increasing the collection of land revenue was perhaps the primary objective. However, particularly after severe famines, famine-prevention took precedence. This had considerable influence on both the design and management of irrigation systems.

The impact on design and management is discussed by Jurriens et al. (1996) and is briefly summarized here. The dominant practice is to design irrigation systems in such a manner that the water supply covers the full crop water requirement either completely by irrigation or in addition to rainfall. Most large-scale systems in the Indo-Gangetic Plain, however, are based on an essentially different objective. The concept of *productive* vs. *protective* irrigation distinguishes between these two objectives. Protective irrigation systems are based on scarcity by design spreading the water thinly over a large area in periods of severe drought. Jurriens et al. argue that most of the systems in the Indo-Gangetic Plain even today are *protective*: they do not meet the water requirements of the full command area; they are supply based with continuous flow; there is a minimum of control structures; they tend to maximize returns to scarce water rather than land. The *warabandi* system, practiced in India and Pakistan for more than 125 years, typifies this design-management approach (Bandaragoda, 1998). In its original form the *warabandi* is largely an administered system requiring a minimum of management.

There was considerable debate over the suitability of *production* vs. *protection* designs. Consider the case of the Nira Canal near Bombay in India reported by Bolding and Mollinga (1995). Operating as a *protectionist* scheme at the beginning of the 20th century, the system was facing severe problems with inequitable distribution of waters, water logging, and salinity. To combat the problem of protective irrigation a plan was launched by the Indian Irrigation Commission in 1903 consisting of three steps:

1. Concentrate irrigated areas in blocks, fix the demand for irrigation water and promote high valued crops.
2. Control the distribution of water avoiding corrupt practices and cultivator interference.
3. Sell water by volume to cultivators to avoid waste of water and to see economic use of it according to market principles.

Although it is clear from various reports that the objectives were by and large not achieved, largely due to management not technical failures, the ‘success’ of the block system is subject to debate up to today. As we shall see in the next section, this debate has its modern counterpart in the debate over *supply* vs. *demand* driven systems.

In the *warabandi* system, British irrigation authorities attempted standard programs for water release subject to as little influence from events and personalities as possible. But there was often a conflict between the engineers and local authorities concerned with agricultural production. This is illustrated by (Ostrom, 1990, pp. 159-61) for Kirindi Oya, in Sri Lanka. From 1920 to 1958 the system was managed under a dual executive structure by the Irrigation Department which wanted a regular schedule and a set time for maintenance of canals, and the Revenue Department which wanted to save crops in periods of drought. The farmers, mostly tenants, had no voice in decisions.

4.2 Monsoon irrigation

In Indonesia, the *sawah* (irrigated paddy fields) that had developed in the 17th and 18th century to support the growing population were expanded in the late 19th by the Dutch to accommodate sugarcane. Huge hydraulic efforts to expand rice cultivation later occurred from 1900 to 1940, the paddy area growing from 1.26 million ha to 3.4 million ha (Maurer, 1990). In Vietnam, the French rulers improved flood control in the Red River delta but the bulk of agricultural expansion was achieved in the Mekong delta, a still largely virgin area in the mid 19th century. The use of new mechanical dredgers allowed the expansion of canals and paddy fields, from 350,000 ha in 1868 to 2,443,000 in 1930 (Henri, 1930; Brocheux, 1995; Dao The Tuan and Molle, 2001). Similarly, in Burma, the reclamation of the Irrawaddy delta gave rise to a spectacular increase in rice area and exports (Adas, 1974). In Siam too, despite the absence of formal colonization, the Chao Phraya delta was equally reclaimed between 1850 and the mid 20th century, thanks to the abolition of bondage and the expansion of the rice trade and economy.

From these examples, it can be seen that most of the expansion took place in deltas, with little or no technical change, and without any major hydro-technological works (Owen, 1976). Canalling also served the crucial purpose of communication (and provided places for homesteads), flood regulation allowed to better control flood-based agriculture, while river diversions of both small (Philippines, Java) and large scale (India) accounted for more classical gravity irrigation. In many instances, the intervention of colonial engineers in traditional irrigation conflicted with management logics they did not understand (see for example, Farmer (1976), for the small tanks in Sri Lanka; Kamal (2001) for the flood management in Bangladesh).

The colonial era also marks the expansion of peasantry in Asia, together with its gradual integration to the market economy. There has been wide debate on whether this period signaled the end of the moral economy of communities mainly engaged in subsistence production, or whether, on the contrary, it only developed or revitalized old forms of traditional commerce, although exposing farmers to higher risk and provoking higher socio-economic differentiation. Several studies have stressed that the second point may be more valid, especially in areas with good communication such as the deltas (see Bowie (1992) for northern Thailand, Huang (1990) for China, White (1991) for Indonesia, etc).

5 THE COLD WAR ERA

The construction of large storage dams and expansion of public irrigation systems to achieve food security.

As we entered the Cold War Era concern grew in the West regarding the population explosion and deteriorating food situation in Asia and its implications for political stability. Among the governments of Asia and the West and the west-dominated international development agencies the priority was clear—increase cereal grain production in Asia. A consensus gradually emerged as to how to get the job done as the pieces of the Green Revolution technology began to fall into place. Attention has focused on the success in the development and extension of high-yielding, fertilizer-responsive varieties. However, the huge investments by the development banks, donor agencies, and national governments to develop and expand the irrigation systems can easily be regarded as the *sina qua non* of food security in Asia today.

Two climatic events that led to shortfalls in annual rains throughout much of the world – so-called *El Ninos* - served to catalyze the commitment to the food security goal and the investment in irrigation. The first of these occurred in the mid-1960s in the Indian subcontinent, where a shortfall in grain production threatened famine. The second occurred in 1972, resulting in a shortfall in crop production, leading to a sharp rise in world rice prices (Figure 4) and forcing Thailand, the world's largest rice exporter, to ban exports for several months in 1973.

5.1 Expansion of irrigation

The growth in irrigated area is shown for the world and Asia in Figure 5 and by country in Table 2. More than 60 percent of the world's irrigated area is in Asia. From the early 1960s to the end of the century the irrigated area doubled. India, China, and Pakistan together account for three-quarters of the irrigated area.

Table 3 shows the growth in irrigated area by selected country groupings. After 1985 there was: (i) an increase in the rate of growth in irrigated area in Cambodia, Laos, Myanmar, and Vietnam, (ii) a significant decline in the rate of growth in Indonesia, Malaysia, Philippines, and Thailand, and in China, and (iii) an absolute decline in irrigated area in East Asia. This reflects the fact that for both political and technical reasons development of irrigation in the Mekong and Irrawaddy River Basins had been delayed.

Expansion in irrigation was facilitated by technological advances. Technological advances can be divided between: (1) those relating to the development of surface water or canal irrigation systems largely through public investment and (2) those relating to the exploitation of groundwater, largely through private investment. There is a natural link between the development of canal irrigation and the development of groundwater. Chambers (1988) notes that a major and perhaps the main beneficial effect of canal irrigation is to distribute water through the command area, allowing it to seep and so provide water for irrigation through wells. Dhawan (1993), for example, estimates that half of the crop output originating from tubewell irrigated lands in the Punjab is from groundwater, that is mostly of canal origin.

Advances in the technology of large dam and reservoir construction in the western United States before World War II became the foundation for surface irrigation system development in Asia in the post-World War II period. During the so-called *construction period* the expansion of irrigation occurred largely through the construction of dams, reservoirs, and a distribution network of canals. Of the more than 40,000 large dams (The International Commission on Large Dams defines a "large dam" as one measuring 15 meters or more from foundation to crest) all but 5000 have been built since 1950 (McCully, 1996). Figure 6 shows the dramatic increase in large dam construction in Asia in the latter part of the 20th century, the peak being reached in the late 1970s and early 1980s. During this period in most countries 50 percent or more of the agricultural budgets were devoted to irrigation, with only a small fraction of that total for operation and maintenance.

There were three factors that led to the decline in large dam construction. Cereal grain prices declined sharply in the mid-1980 to fifty percent of their previous levels (Figure 4) and this was accompanied by a rise in construction costs particularly as new irrigation sites became more costly to develop. The effect of these two factors was to reduce the benefit-cost ratios. Figure 7 for Sri Lanka, presents a fairly typical picture for much of Asia. The peak in large dam construction in the mid-1980s lagged approximately a decade behind the peak in the benefit-cost ratio reflecting the long gestation period in irrigation development. The third factor accounting for the decline in investments was the growing opposition of the environmentalists. Reflecting these environmental concerns, with yet a further time lag of more than a decade, the World Commission on Large Dams was created to review and report out on the positive and negative impacts of large dam construction and establish a framework for decision-making (World Commission of Dams, 2000).

A consequence of the dramatic expansion of irrigated area is that it has occurred on more and more marginal land, where the development costs are also higher. In countries like Thailand, India or Indonesia, the cost per ha of new irrigated areas approximately doubled between 1968 and 1988. In Sri Lanka, it jumped from 1470 $/ha to 5776 $/ha during the same period (Svendsen and Rosegrant, 1994). Meanwhile the cost of groundwater exploitation has been declining. With the gradual closing of river basins all water becomes committed. At this point investment or "overinvestment" often simply shifts the benefit of irrigation from one point in the basin to another, without increased productivity, simply robbing Peter to pay Paul. The decline in opportunities for productive investments together with the low price of food products, accounts for most of the decline in investments and external funding for irrigation in the 1980s and 1990s.

5.2 System design

The debate (referred to earlier in the Colonial Era) over the design of *productive* vs. *protective* has its modern counterpart in the debate between the advocates of *crop-based* or *demand-driven* design and *water-based* or *supply-driven* design (Jones, 1995). For the former the amount of irrigation water delivered is tailored to crops farmers choose to grow while in the latter farmers have to tailor their cropping to the timing of irrigation water deliveries. The *demand-driven* advocates argue that the evolution of the world economy points toward the need for this type of solution. The decline in the rice price has placed pressure on systems to provide water when needed to grow crops other than rice. If farmers in adjacent plots are to grow rice and chilies in the same season, neither the traditional, low-reticulation, field-to-field paddy systems nor the water-spreading warabandi type systems will do. On the other hand, *supply-driven* advocates point to the poor performance in practice of crop-based demand-driven systems. As more and more farmers have found ways to obtain water when needed, installing tubewells or pumping from canals and drains, the continuing debate between the advocates of *demand driven* and *supply driven* surface irrigation systems would appear to lack relevance.

5.3 Poverty alleviation

The role of irrigation in *poverty alleviation* is a theme that pervades the history of irrigation development. For example, during the Mogul period in India the Canal Act of Akbar (1568) detailed the Emperor's desire to "supply the wants of the poor" and to "establish the permanent marks of greatness" of his rule (Baker, 1849). (This is not dissimilar to the implicit objectives of many donor agencies or governments today).

Table 4 shows a close relationship between poverty incidents and irrigation development for East Asia and the Pacific and for North Africa and the Middle East (Lipton and Litchfield, forthcoming). The association between poverty reduction and irrigation investment is further illustrated in a study by Datt and Ravillion (1998a). The study links the reduction in rural poverty and growth in farm productivity in India. Figure 8 compares the downward trend in the squared poverty gap index (SGP)1 with the upward trend in yield. Significant poverty reduction in many parts of India is attributed to the availability of irrigation which not only increased agricultural production but also made possible the adoption of modern farm technology – seeds, fertilizers, and pesticides – that further reduced poverty (Lipton and Litchfield, forthcoming).

The study by Lipton and Litchfield (forthcoming) on the impact of irrigation on poverty and a recent literature review by Hasnip et al. (2001) on the contribution of irrigation to sustaining rural livelihoods reach very much the same conclusion. The positive impact of irrigation on poverty reduction and enhancing rural livelihoods is felt through increased employment, lower food prices, and more stable outputs. There are also multiplier effects that increase non-agricultural output leading to poverty reduction in both rural and urban areas. However, the distribution of ownership of water and water yielding assets determines who benefits from irrigation investments. These investments are likely to be less effective in reducing poverty when land and water rights are highly skewed and when low-cost technologies and/or associated credit needs are not available beyond the initial construction phase.

6 THE NEW ERA OF GLOBALIZATION

The control and management of water at farm, system, and at basin level for livelihood, food security, and environmental protection –i.e. Integrated Water Resource Management.

As we enter the era of globalization,

- We are also entering an era of global water scarcity with increasing competition for water among users and uses.

- Irrigation is becoming increasingly private through investments by farmers in pumps and tubewells and other micro irrigation technologies.

- The expansion of irrigation and improved cereal grain technologies coupled with government subsidies (free trade doesn't apply to agriculture) has driven down the price of cereal grains to less than half their level during most of the Cold War Era.

- Protection of the environment is a major concern and global warming is becoming a reality.

These forces are bringing about a rapid change in irrigated agriculture calling for new ways of managing our water resources and new institutions. In the sections that follow, we discuss each of the four areas outlined above. Then we examine the various practices that are being undertaken by governments and by farmers to cope with growing water scarcity and declining farm prices. Finally we consider the institutional changes needed to achieve more effective allocation and utilization of water resources in agriculture.

6.1 **Water scarcity-** *we used to believe that there would always be enough water*

Irrigation consumes an estimated 70 percent of the total developed water supplies, well over 70 percent in the developing countries. A projected 2.7 billion people, including one third of the populations of India and China, will live in regions that will experience severe water scarcity within the first quarter of this century (Seckler et al., 1998). Water shortages could lead to conflicts in the Middle East and North Africa but are likely to impact most severely on the poorest segments of the population in South Asia and Sub-Saharan Africa where incidents of poverty are already high.

However, the shortage of water will be pervasive, extending well beyond the semi-arid regions and affecting even populations in well watered areas. Expanding demand for water is draining some of the world's major rivers, leaving them dry throughout most of the year.

The growing scarcity and competition for water is dramatically changing the way we value and utilize water and the way we mobilize and manage water resources. With growing municipal and industrial demand for water and needed water requirements to protect the environment, there will be less water for agriculture in the future. We must produce more food and agricultural products with less water. Many people believe existing irrigation systems are so inefficient that most – if indeed not all – of the water needs of all sectors could be met by improved management of irrigation and transferring the water to the non-agricultural sectors. Others argue that the potential savings from new or improved management practices is not as great as frequently assumed. The merits of this debate notwithstanding, farmers, irrigation administrators, and others are already making adjustments where water scarcity has become a reality.

6.2 ***Advances in pumping technology and the ground water revolution*** *– from exploitation to overexploitation*

There is a tendency to associate irrigated agriculture in the developing world with canals, dams, tanks or reservoirs. By contrast, largely hidden from view and attention, a worldwide explosion has occurred in the use of wells and pumps for irrigation, domestic, and industrial use. Pumps are being used not only for groundwater extraction but also for providing flexibility and reliability in delivery of surface water. The three quotations below illustrate the current situation:

> "The near obsession of canal engineers with commanding the fields and avoiding pumping is only understandable if the system is a non-overextended desert system in contiguous operation, and the innovations of pumping technology in the last forty years are ignored". (Burns, 1993, p.16).
>
> "While there is probably no real prospect for removing existing high-canal systems in rice deltas (of the Chao Phraya), the alternative at least merits study, especially because of the widespread evidence that farmers in other delta rice systems spontaneously use low- lift pumps in an unplanned manner to overcome shortcomings in gravity systems that are unable to meet their demands". (Jones, 1995, pp.114-115).
>
> "While groundwater has contributed much to the growth in agricultural productivity, the overexploitation of groundwater is affecting both the quantity and quality of water available for agriculture, domestic use and other purposes". (Shah et al., 2000).

In discussing the development of groundwater, it is useful to distinguish three very different environments – (i) the semi-arid regions such as the Punjab and the North China Plain; (ii) the major river deltas such as the Ganges-Brahmaputra, Irrawaddy, Chao Phraya, and Mekong and (iii) the rest of monsoon Asia where rice is the dominant crop in the wet season. Each of these environments presents very different management problems. In addition, one must distinguish between shallow alluvial aquifers, which are tapped by farmers with suction pumps and usually replenished every year, and deep aquifers where recharge is low and groundwater is being mined.

The groundwater revolution began in the 1960s in the semi-arid regions of Asia, Pakistan, Northwest India, and the North China Plain. India and China together account for over two thirds of Asia's irrigated area. Table 5 partitions the growth in irrigated area between wells and canals in India. The growth in canal irrigation slowed appreciably after 1985 but irrigated area served by wells has continued to grow quite rapidly. Figure 9 illustrates the steady growth in pumps for irrigation in semi-arid Pakistan (India would be similar) and the more recent growth in the use of pumps in monsoon countries such as Vietnam and Sri Lanka.

In the semi-arid regions cereal grain yields grew rapidly during the years of the *green revolution.* But overexploitation of groundwater has led to serious problems. In many regions groundwater tables are falling a meter or more per year and overuse of chemicals has resulted in a decline in drinking water quality. In other areas groundwater tables are rising and the area affected by salinity is increasing.

In the major river deltas, the use of pumps and dykes to control the flow of water has made it possible to reduce the area planted to low yielding deep-water rice by planting and harvesting before and/or after the floods. This increases cropping intensity as well as securing access to water for cash crops. Pumping may be collective (Red River delta), contracted to operators (upper Mekong delta), or individual (lower Mekong, Chao Phraya Delta or Bengal). Tubewells have also appeared in shallow aquifers. With plentiful water, relatively cheap labor in many instances, and the application of new seed fertilizer technologies, the deltas are increasing productivity and gaining a comparative advantage in rice production and exports.

The monsoon areas outside of the deltas were among the first to benefit from expansion of irrigated area and the adoption of high yielding varieties of rice. Until recently groundwater has played a relatively minor role. However, with advances in pump technologies and the rising cost of canal construction the internal rate of return on investment in pumps and wells now exceeds that for storage dams and canal systems. As in the deltas, many farmers are finding ways of increasing incomes by using tubewells to extract groundwater and small portable pumps to better manage surface water. This provides greater opportunity for the diversification of agriculture and production of crops other than cereal grains.

We may yet be in the early stages of the groundwater revolution. With pressure to increase the productivity of water (more crop per drop) new and cheaper micro-irrigation technologies are becoming available.

6.3 ***Collapse of food grain prices*** *– nobody makes money growing rice anymore.*

At least two thirds of the irrigation in Asia has been devoted to the production of rice and wheat. In the 1980s cereal grain prices declined to 50 percent of their levels in the previous three decades (Figure 4). There are three reasons for this: (1) the extraordinary growth in production due to expansion of irrigated areas and adoption of *green revolution* technologies, (2) the decline in demand for cereal grains as incomes have risen, and (3) the continuing and increasing level of subsidies by the developed economies.

The decline has continued, with rice prices reaching historical lows in 2001. Equilibrium in the global rice market has little to do with either the marginal cost of supplying rice to consumers or willingness to pay for increased supply. At the margin it reflects the willingness (and capacity) of exporting governments to subsidize rice exports, of importing countries to restrict rice imports and protect domestic producers, and the degree of price and income volatility that governments in the major consuming nations are willing to tolerate (Tabor, 2002). The volatility of the rice market is also due to the very low proportion of world production that is marketed (around 10%), which makes every surplus production or bad year having critical impacts on the demand/supply ratio on the world market. Figure 10 gives an example of evolution of farmgate prices in Central Thailand, and shows both the fluctuations and the long term decline.

Low cereal grain prices are often cited as an asset in reducing poverty and maintaining low and competitive wage rates. The urban bias which results from the taxation of agriculture to the benefit of consumers and other economic sectors (Schiff and Valdes, 1992) and the low prices received for farm products questions the rationale to have farmers paying cost recovery for the construction of a facility and for frequently rather poor service. Importing developing countries are faced with the decision either to maintain an open market in keeping with WTO rules or to restrict imports in order to protect local farmers, bolster rural employment, and stave off social unrest. Presumed benefits from free trade must be balanced against the vulnerability to changes in the world markets and devaluation of national currency, that may critically raise domestic prices for food (Dawe, 2001). We have argued that *green revolution* did much to lower food grain prices and reduce poverty. However, given the set back of the Asian financial crisis and the inability of the non-farm sector to absorb surplus agricultural labor, a further lowering of food grain prices with its adverse affect on farm incomes, is not likely to result in further poverty reduction.

The downward drift of cereal grain prices is bringing greater pressure to bear for diversification. As previously noted, many canal systems were designed and managed as supply driven systems, which was suitable when the major objective was producing cereal grains. There is a growing incentive to invest in pumps to improve flexibility and reliability in water deliveries or in short obtain water on demand. Diversification is a crucial aspect of agricultural change but it is constrained by a host of factors, ranging from soil and water suitability, skill acquisition, capital and labor constraints, risk in marketing, and, foremost, by the development of adequate markets. In all Asian countries, policies have been designed to foster agricultural diversification, often seen as a panacea to low staple food prices, but they have been met with mixed success and it is doubtful that diversification can be boosted much beyond the level observed, which are mainly determined by the change in consumption patterns and by information technology that can put producers in more direct contact with export markets.

6.4 Growing environmental concerns

The closure of river basins, which means that less water is available for dilution and flushing of pollutants, together with the development of industries and cities, have had dramatic impact on water quality. Despite the frequent enactment of pieces of legislation aimed at controlling pollution, most Asian countries are faced with problems of monitoring, technical capacity, and law enforcement that make the laws remain dead letters. Agriculture is also responsible for non point source pollution by nitrates and pesticides but this problem is still widely seen as secondary compared with other sources of pollution (waste disposal, mines, factories, pig farms, etc).

The overdraft of deep aquifers is also causing disasters of critical magnitude. They include the intrusion of salt water into coastal aquifers, the drying of wells and rivers, but also land subsidence and the sinking of major cities such as Jakarta or Bangkok. One third of Bangkok, for example, is already under sea level and the costs of flood protection and damage are rocketing up.

Other environmental impacts of land and water development include water logging, salinisation (e.g. Pakistan), arsenic poisoning (Bangladesh), the release of acid (Mekong), the destruction of mangroves and coastal areas after contamination of shrimp farms (e.g. Vietnam, Thailand), not to mention the spread of vector borne diseases and the externalities associated with dam construction. Environmentalism is still incipient in Asia but there is evidence that organized groups are already achieving some success in opposing large-scale projects with flawed impact assessment. The abandon of the Narmada Project in India, the Three Gorges Dam in China, and the controversies around the Pak Mun dam and the Samut Prakan treatment station in Thailand provide clear examples. But the focus is on the highly-visible large dams, while many of the most serious environmental problems lie elsewhere.

7 THE CHALLENGES AHEAD

In this section we discuss: (1) the need to increase water productivity or augment existing supplies, and (2) the need to create the new institutions or reform existing institutions to facilitate integrated water resource management.

Before discussing these two areas, we clarify the confusion surrounding irrigation system performance. There is a conventional wisdom held by many policy makers, academics, and others that Asian irrigation systems are poorly managed and perform very poorly. It is not uncommon to read that *irrigation efficiency* – the amount of water used by the crop divided by the amount of water diverted – is approximately 40 percent. But recently it has been pointed out that this measure of *irrigation efficiency* is extremely misleading. Taking into account return flows results in a much higher estimate of irrigation efficiency and leads to the conclusion that the scope for improving irrigation efficiency is much less than normally assumed (Keller and Keller, 1995; Keller et al., 1996; Seckler, 1996). For example, in attempting to assess system performance we may be overlooking the important relationship between surface and groundwater. Chambers (1988) writing on canal irrigation in India suggests that a major and perhaps the main beneficial effect of canal irrigation is to distribute water through the command area allowing it to seep and so provide water for groundwater irrigation. The continuing expansion of tubewells in the India command areas lends strong support to his contention. Furthermore, Molle (forthcoming) argues that as basins become closed (i.e. all water committed) during all of a part of the year, farmers and system managers respond to the shortage in many of the ways suggested above, leaving even less scope for interventions to improve irrigation systems performance.

7.1 ***Paths to increase in water productivity*** *– does participatory irrigation management, water pricing, or cost recovery increase water productivity?*

As water becomes scarce and the value of water rises, government agencies, communities, and farmers respond in different ways either to conserve or reallocate water or to expand supplies. In this section, we borrow from a framework developed by Molle (2002a) to show the various individual and collective options for responding to water scarcity. We then indicate which options appear to be most popular among farmers and among government agencies and policy makers. Based on existing evidence, which measures appear to be achieving economic gains in water productivity.

Responses to water scarcity are extremely varied and come under three different categories: (a) augmentation of supply, (b) conservation of water, and (c) reallocation of water. Figure 1l (Molle, 2002a) synthesizes some of the main strategies and distinguishes between those that are implemented by individuals and those that are collective, implemented primarily by government agencies or donor-assisted projects.

There is normally little if any coordination or communication between farmers and government agencies. That is to say, the decisions of both entities are made quite independently. For example, most government irrigation agencies are involved in the operation of canal systems and do not have information on the number of privately operated wells and pumps even within their own command areas. However, the response to water scarcity (whether drought or chronic shortage) tends to increase the interaction between parties.

7.1.1 Farmer/operators response

Farmers are often accused of wasting water. But farmer response to water scarcity and to declining cereal grain prices has been fairly dramatic. As noted above the taping of groundwater and the use of pumps for recycling has been growing rapidly. Where opportunities permit, farmers are relying in more flexible and reliable groundwater supplies to shift from cereal grains to higher valued crops. The development of on-farm storage is also becoming more prevalent in some areas. Thus, farmers are not passive: they are finding ways through both conservation and reallocation and through expanded supply to increase water productivity and income.

However, farmer response has not always led to positive results. Particularly in the semi-arid areas, unregulated exploitation of groundwater has led in some areas to falling water tables and in others to rising water tables and increased salinity.

Furthermore, the development of private farmer facilities may work against the development of collective action and undermine farmer irrigation associations. We visited a farmer in Sri Lanka who had recently installed a tubewell and was growing chilies. He said that the age-old *bethma* system, which allowed all farmers to have access to paddy land when water was short and acreage restricted, had collapsed.

Dam operators are also driven to improve their management when scarcity elicits growing scrutiny on how releases are made. They tend to curtail releases that are not followed by some productive use downstream, although this latitude is sometimes constrained by priorities for power generation, especially in countries such as Sri Lanka where hydroelectricity still accounts for more than half of the installed capacity. Responsiveness to rainfall is also an issue for dam management, but it generally requires a degree of automation and efficient management of information system.

7.1.2 Government, donor, and academician response

As noted previously there has been a sharp decline in the construction of large dams and reservoirs particularly for the purpose of irrigation. In some areas such as China or Thailand trans-basin diversion is either underway or being planned. But the primary focus of governments and donor agencies today is on conservation and on allocation.

The interest in interventions to improve irrigation systems *performance* continues, although the potential effect of these interventions on *water productivity* is seldom mentioned and even less frequently measured. Figure 11 shows four sets of activities undertaken by agencies and donors to save or conserve water: (I) canal lining, (2) water pricing and markets, and (3) water user associations and (4) development of water saving technologies and management practices.

Canal lining is extremely popular with both the donor agencies and recipient governments. They provide the donors with an opportunity to meet lending targets and irrigation agencies with the opportunity for “skimming” or what is politely referred to as rent-seeking (Repetto, 1986). A few years ago IWMI was asked to review a Project Completion Report of a number of World Bank investments in one of the world’s major irrigating countries (Perry, 1999). The loan was largely aimed at improving the “efficiency” of the irrigation system by lining, better control structures, improved management and so on. The investments costs totaled $500 million and none of the associated documents (appraisal reports and evaluations) included any form of water balance. The reduction in percolation and seepage loss may have been at the expense of farmers depending on groundwater. Thus, we do not know how much, if any, real water was saved by these investments, or whether water productivity was increased. It is safe to assume that neither the donor agency nor the recipient bureaucracy was interested in knowing.

Water pricing, water markets, and cost recovery have been an important focus for economists. In a market economy, prices should perform the task of allocating resources among competing uses. But when it comes to water, particularly water for irrigation, there are problems with this approach (Sampath, 1992; Perry *et al.*, 1997, Smith *et al.* 1997; Morris, 1996; Molle, 2001).

The World Bank has recently undertaken a comprehensive study, “Guidelines for Pricing Irrigation Water Based on Efficiency, Implementation, and Equity Concerns.” As a part of that study, Johansson (2000) has conducted an exhaustive literature survey on pricing irrigation water. More concise treatment of the issues can be found in Tsur and Dinar (1997) and in Perry (2001). The authors emphasize the fact that water (particularly water used in irrigation) is a complicated natural resource, a complicated economic resource, and a complicated political resource. Moreover, while water *supplied* is a proper measure of service in domestic and industrial uses, water *consumed* is the appropriate measure in irrigation, and this is particularly difficult to measure. Water pricing methods are more likely to have effect on cropping pattern (even though this is little observed in developing countries) than on water demand for a given crop (Tsur and Dinar, 1997). In fact, particularly with today’s low commodity prices, the politically acceptable level of charging for water is well below the point at which farmers would respond by saving water (Ray, 2002; de Fraiture and Perry, 2002; Molle, 2002b). If the objective is allocation, rationing (i.e. assigning water to specific uses either within system or at basin level) represents an alternative mechanism for coping with water shortages where demand exceeds supply (Perry, 2001).

Water user associations are seen by many social scientists as an essential element for improved irrigation systems performance. In the area of institutional reform, the devolution of management and financial responsibility from irrigation systems managers to local user groups has gained prominence. The popular terms for this are *participatory irrigation management* (PIM), and *irrigation management transfer* (IMT). These terms are defined as follows (Groenfeldt and Svendsen, 2000):

- PIM usually refers to the level, mode, and intensity of user group participation that would increase farmer responsibility in the management process.
- IMT is a more specialized term that refers to the process of shifting basic irrigation management functions from a public agency or state government to a local or private sector entity.

As observed earlier a great deal of Asian irrigation was developed through communal or locally managed systems that evidenced a high degree of what we call today *participatory irrigation management* (Coward, 1980). In many Asian countries irrigation has developed in a structurally *dualistic* mode, with the more recent state run systems being developed independently from the community managed systems. In the rush to construct large public systems, donors and national agencies have often ignored the presence in the command areas or neighboring regions of well functioning communal systems and the associated rich local experience in management.

The first major effort to introduce PIM in the management of public irrigation systems in Asia began in the Philippines in the late 1970s. Dissatisfied with the performance of the National Irrigation Administration (NIA), the enlightened leadership of NIA sought to transform the bureaucracy (Korten and Siy, 1988). Taking note of the successful operation of community systems they argued that PIM would result in better operation and maintenance and improved performance. The program lasted for a period of more than a decade, and was supported by the Ford Foundation, USAID, and the World Bank. The objective was to transfer full responsibility for maintenance of tertiary canals, fee collection, and management responsibility to water user groups gradually and step-wise over a period of time. The transformation appeared to be on stream in the mid-1980s but came to not due to change in leadership in NIA and lack of political support.

The interest in transfer of responsibility to user groups rests in large part on the desire of many governments to reduce expenditures in irrigation. IMT has become one of the cornerstones of World Bank water management policy (Groenfeldt and Svendsen, 2000). Recent experience in IMT seems to suggest that there has been considerably more success in transferring management responsibilities in more advanced countries such as Turkey and Mexico than in the developing countries of Asia (Samad, 2001**.** Where implementation has been successful, government expenditures and number of agency staff have declined, maintenance has in some cases improved, but there is little evidence yet that IMT has led to an increase in the productivity of irrigation water (Samad 2001, Murray-Rust and Svendsen, 2001).

One should not be surprised that the hegemonic approach of the development banks would meet with limited success. But even the more narrowly focused and carefully studied planned efforts in development of water user associations have not proved replicable and/or sustainable. The well documented Gal Oya project in Sri Lanka combined physical rehabilitation in combination with a highly successful establishment of farmer organizations using irrigation organizers working directly with farmer (Uphoff, 1992). The results of ex-post research has shown that physical and institutional changes contributed jointly to the significant increase in water productivity (Murray-Rust, 1999). However, in subsequent irrigation projects, the lessons from Gal Oya have never been repeated in Sri Lanka (Kikuchi et al., forthcoming).

Development of water saving technologies and management practices offer another potential for increasing water productivity. A distinction can be made between those measures that increase water productivity by increasing crop yield for a given ET or diversion as opposed to reducing the water diversion requirements. In the former case (e.g. increase in crop yields through varietal improvement) savings at the plant and field level are realized at the system and basin level. In the latter case (e.g. system of rice intensification – SRI) whether increased water productivity at plant and field level translates into increased productivity at system and basin level needs to be determined by water balance studies. This is referred to as "scaling –up" from farm to system and basin level.

Over the past three decades varietal improvement through plant breeding (aided by investments in irrigation and advances in fertilizer technology) has been the major source of increase in water productivity. However, the increase in grain productivity is in some ways deceptive. In almost all crops the greater grain yield is not due to an increase in biomass but almost entirely to an improved ratio of grain to biomass (harvest index or grain to straw ratio). Although the potential ceiling value for the harvest index is rapidly approaching in many crops, the only way to maintain increases in yield will be to increase biomass (Richards et al., 1993). There appears to be considerable potential for increasing yields by selecting cultivars for increased water productivity and a significant amount of research is now being focused in this area.

There is also rapidly expanding interest in management practices and technologies that can save water and increase water productivity – zero tillage, raised beds, alternate wetting and drying, aerobic rice, and system of rice intensification (SRI). Field trials are being conducted in countries throughout Asia through collaborative research between national and international centers. For example, IWMI is collaborating with IRRI, CIMMYT, and national research centers in China and India to determine the impact of some of these technologies on water savings and gains in water productivity at farm, system, and basin level (Barker et al., 2001). However, the potential impact of this research on gains in water productivity is as yet unknown.

In summary, what the above discussion reveals is that most of the public investments in irrigation and related research activities are still focused on improving the performance of canal irrigation systems. There are situations where canal lining, volumetric pricing of water, or development and/or irrigation associations are appropriate. But these situations are limited. To a large degree " the generals are fighting the last war" ignoring the impacts of water scarcity, private investments in pumps and tubewells, and declining food grain prices on irrigated agriculture and the related growth environmental problems. However, the focus is gradually shifting from the irrigation system to the river basin and from irrigation *per se* to *integrated water resource management* (IWRM). This change in focus and perspective will better enable us to address the emerging problems discussed above.

*7.2 **Integrated Water Resource Management**– the need for new institutions and water rights*

We adopt the concept of IWRM cited below from Jonch-Clausen and Fugl (2001, p. 501). This definition emphasizes in particular what is being integrated:

> "In the 'natural system' integration typically involves land and water; surface water and ground water; water quantity and quality; and upstream -downstream water related interests including the upstream fresh-water catchments and the down-stream coastal zone. However, equally important, but less traditional, is the integration of the 'human system' involving a holistic institutional approach; mainstreaming water in the national economy; cross-sectoral integration in national policy development; linkages to national security and trade regimes; and involvement of stakeholders across different management levels".

This is a broad agenda, in which integration of both the 'natural' and the 'human system' rests heavily of the development of institutions. In this section, we emphasize a few key points in the integration that relate specifically to our discussion of irrigation.

First, as water supplies become limited, we need to allocate among competing uses and users. These basin-level allocations will favor water for municipal and industrial use over water for agriculture and the environment. There will be less water for agriculture in the future. We are going to have to produce more food with less water.

Second, there is a need to integrate management of irrigation water at farm, system, and basin level. Are the practices at farm level consistent with basin-level water use efficiency? This question becomes critical as more and more basins become *closed.* That is to say when all water resources are fully committed and no water of unusable quality is flowing to the sea.

Third, there is the clear need to integrate the management of ground and surface water irrigation. This is particularly urgent in the semi-arid regions where problems exist with both *rising water tables* leading to salinity and water-logging and *falling water tables* leading to over-exploitation of the aquifer. In general it is desirable to maintain the water table between the upper extreme above which crop yields are affected and the lower extreme where pumping becomes excessively expensive or where there is a threat of lateral inflows from saline aquifers (Perry and Hassan, 2000). We need information on the effect of different water management practices on both water balance and salt balance and in turn their effect on crop yields.

Finally, the impact of irrigation, including the use of waste water, on environment and health needs to be assessed. The dislocation and environmental damage caused by large dam construction currently receives the headlines. Less publicized examples include the deterioration in the quality of drinking water caused by overexploitation of groundwater and nitrate pollution, the damage to wildlife sanctuaries and fishing grounds caused by uncontrolled drainage water, and the increasing incidents of malaria associated with irrigation development.

The above discussion serves to emphasize the complexity of the institutions needed for IWRM. The present institutions were created in an era when water was plentiful. They deal with water resources in a fragmented manner. The state irrigation departments are not well informed on groundwater use even within their own command areas. The irrigation departments typically do not coordinate their activities with other agencies to manage effects of irrigation development and management including damage to the environment and threats to human health. The Asian

Development Bank is actively supporting initiatives by some governments to develop water resource boards and related organizations that will coordinate the planning for water use and management of water resources at national and at river basin level.

The starting point in institutional reform must be the definition and security of water entitlements, or ‘rights’. Water rights are needed to determine the allocation and access among users and uses at the system as well as at the farm and village level. Reference is often made to the strictly defined and enforced system of water rights in developed countries such as the United States (Perry et al., 1997) but the Asian context of numerous small holders and the predominance of rice cultivation make it difficult to envisage the definition of individual rights. Rather, it seems more appropriate to pave the way for the definition of bulk entitlements that would specify how much water goes to groups of users (such as in Turkey or Mexico). The crux of the matter is to establish a basin level mode of water management where seasonal water entitlements are defined in a multi-leveled process, down to the bulk allocation to groups of users under a main or secondary canal, with the involvement of users representatives. While such an arrangement may seem a matter of good will, it has in reality far-reaching and multi-faceted implications that include (see Molle, this workshop): 1) the need to register users and control free-riders, 2) the technical capacity to deliver the agreed upon discharges at different points in the network; 3) the establishment of a process of collective decision-making where groups of users are federated in higher hierarchical levels, with corresponding representatives; 4) the definition of a ‘partnership’ between users and irrigation officials, where a service fee contributes to payment of field staffs; 5) a legal framework to support this new institutional setting; 6) a strong commitment from the administration and from politicians. Up to now, such overall reforms have not been successful, as line agencies have generally retained their power and not effectively embraced the rhetoric of decentralization, Water Laws have remained enabling legislations with little impact (see Malano *et al.* 2000, for Vietnam), water fees are still conceived or perceived as flat taxes, and water allocation is still centrally defined and ridden by political intervention.

The growing importance of common-pool groundwater resources adds greatly to the complexity of the problem. The task is monumental. It will likely to take years, perhaps even decades, to establish enforceable water rights and the complementary set of institutions for IWRM.

7.3 Irrigation and agrarian change

The future of irrigation in Asia is tightly linked with agrarian change, itself a reflect of wider transformations of national and world economies, and cannot be considered in isolation. The pressure on land/water resources, the man/land ratio and the per capita farm income are strongly linked to demographic evolutions. One of the most significant changes in the last three decades is the demographic transition observed in many countries. Thailand’s fertility rate, for example, has shifted from 5.6 in 1970 to 1.7 in 2000! The mobility of labor is high and migrations also tend to remove people from the countryside, irrespective of whether this is a pull or push process. In the ten years preceding the 1997 economic crisis, the labor force engaged in agriculture in the central region of Thailand dwindled down from 3.5 to 2.5 million. This shift concerned the age class under 35 and all socio-economic strata, since investment in the education of children also motivates movements to cities.

In addition to inter-sectoral mobility, rural households economies have also become more composite and pluri-activity within the family as well as at an individual level has emerged as a general phenomena. Farmers are responding to new opportunities (see Preston's (1989) study on centra Java "Too busy to farm') and in many rural areas of Asia the household income from agriculture is now lower than that coming from non-agricultural occupations (Rigg, 2001; Estudillo and Otsuka, 1989).

As emphasised by Rigg (2001), "the distinctions between rural and urban are becoming blurred as households increasingly occupy, or have representation in both the rural and urban worlds and, more to the point, earn a living in both agricultural and non-farming activities…This requires a re-thinking of the rural economy and rural life, a re-appraisal of policy initiatives and planning strategies, and a reformulation of theories of agricultural and rural development." Farmers are engaged in and draw income from a wide portfolio of activities, or receive remittances from relatives: this prompted Koppel and Zurick (1988) to observe that this "rural employment shift" suggests "that an increasing proportion of rural labour relations are not connected directly with traditional agrarian processes, but rather with more complex socio-economic relationships in which agrarian processes may be only one part."

This emphasizes that the evolution of irrigation, as well as of agriculture, cannot be considered independently of changes occurring in the wider economy. The management of water resources, and of irrigation in particular, will also be shaped by on-going political processes of democratization, which constantly redefines the relationships between the state and the citizenry and has a bearing on the conditions of access to resources.

8 CONCLUSIONS

In this paper we have traced the evolution of irrigation in South and Southeast Asia identifying three separate geo-political time periods: the Colonial Era from 1850 to 1940, the Cold War Era from 1950 to 1989, and the new Era of Globalization from 1990 onward. The development of irrigation, whether by colonial administrations or more recently national governments and lending agencies, has been pursued with a fairly common set of objectives – poverty alleviation, food security, employment, livelihood, increased revenues, growth in value of agricultural outputs. The theme of conflict also runs through the entire time period – conflict in the goals of equity and productivity, conflict among professionals as to how systems should be designed, conflict between irrigation bureaucracies and local administrations in the management of systems. Throughout the entire period, however, farmers have had very little say in the design and management of public irrigation systems.

Against this background, the rapid development of irrigated agriculture has helped to foster extraordinary growth and change the rural economies of Asia. The development of irrigated agriculture and of the economies as a whole reflects the dynamic interaction between resources, technology, institutions, and culture. Land and water once abundant have become scarce. During the Cold War period, surface and groundwater technologies have been developed to facilitate the expansion of irrigated area and increase in crop yields. But the success of these endeavors has brought new problems. The intensification of irrigated agriculture has led to an increase in pollution and environmental degradation. Food grain prices have plummeted with the result that the benefits of irrigation have gone largely to consumers. Farm households have looked to other sources of income from both farm and non-farm sources. The rural economies are undergoing a social as well as an economic transformation.

As we enter the new era of Globalization, farmers and systems operators have adjusted to the challenges posed by growing water scarcity, exploiting ground water, recycling from drains and canals, changing cropping patterns, adjusting the timing of water releases. Tubewells and pumps have become commonplace giving producers greater flexibility in obtaining water when needed. But particularly in the semi-arid regions overexploitation of groundwater has affected both the quantity and quality of water.

However, irrigation bureaucracies and donors continue to focus on improving the performance of canal irrigation systems by lining canals, encouraging greater farmer participation, calling for water pricing and cost recovery. We argue that these efforts have not been very successful in the past and are likely to be even less so in the future given not only the growing importance of groundwater but also the social and economic changes occurring in the rural communities of Asia.

There has been a serious lag in the development of appropriate institutions to deal with the new environment of water scarcity. The challenge ahead lies in creating the institutions that can: (I) allocate water equitably among competing uses and users, (ii) integrate management of irrigation at farm, system, and basin level to reduce upstream-downstream and head-tail conflicts, (iii) integrate the management of ground and surface water irrigation, and (iv) address the problems of irrigation development, including use of waste water, in environment and health.

This agenda represents an important component of *integrated water resource management* (IWRM). The allocation and access to water among users and uses at the basin, system, village, and farm level must be defined through a negotiated and formalized process that leads to the definition of entitlements. The growing importance of common-pool groundwater resources adds greatly to the complexity of then problem. The task is monumental. It is likely to take years, perhaps even decades, to establish enforceable water rights and the complementary set of institutions for IWRM.

Figure 1. Interrelated developments in the social system

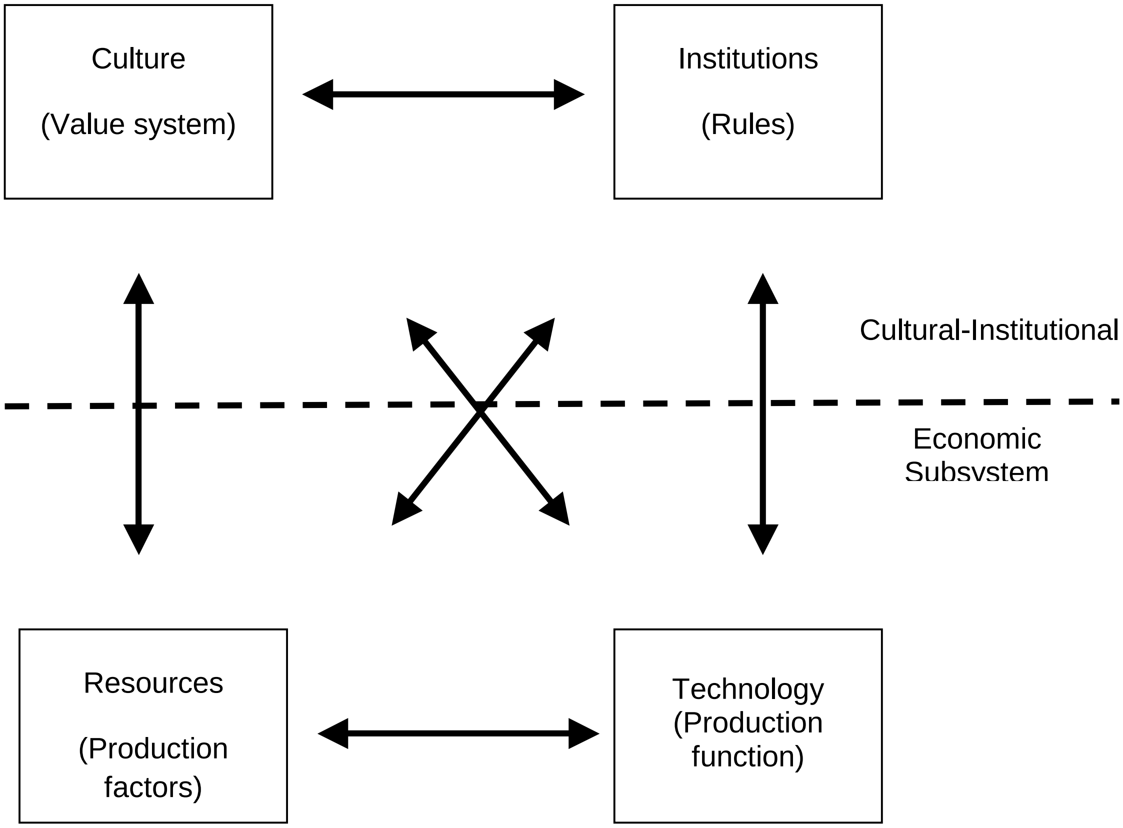


Figure 2. Phases of river basin development

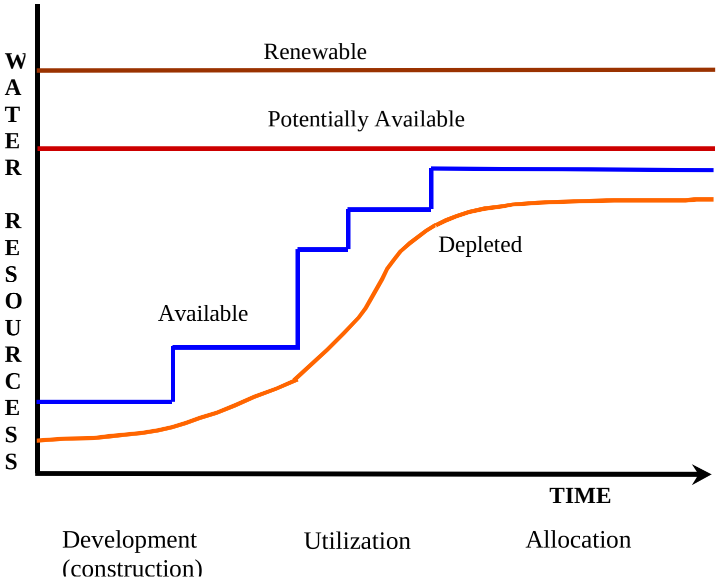


Figure 3. Hypothetical development paths of land based agriculture by means of land and water development

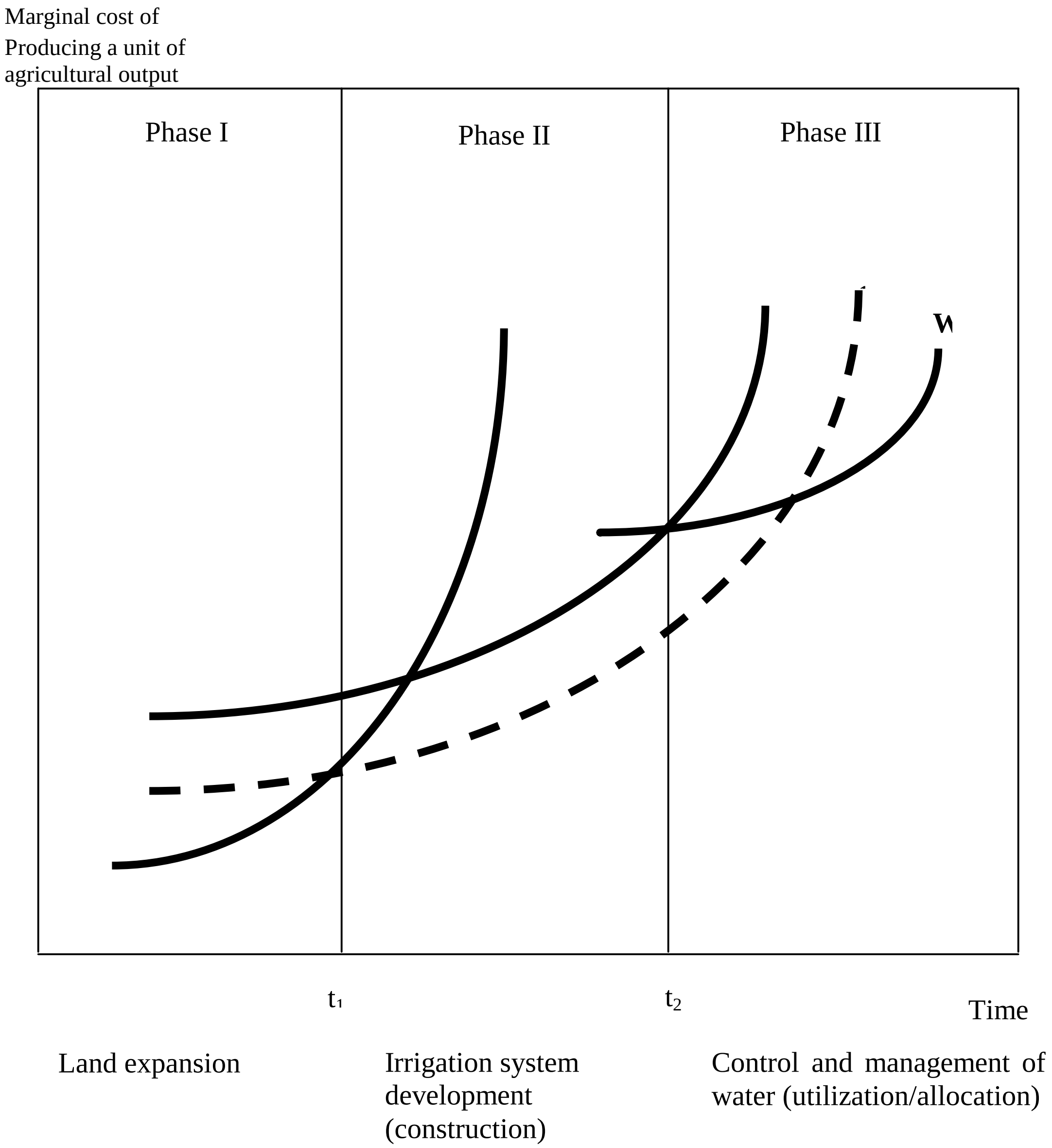


Figure 4.

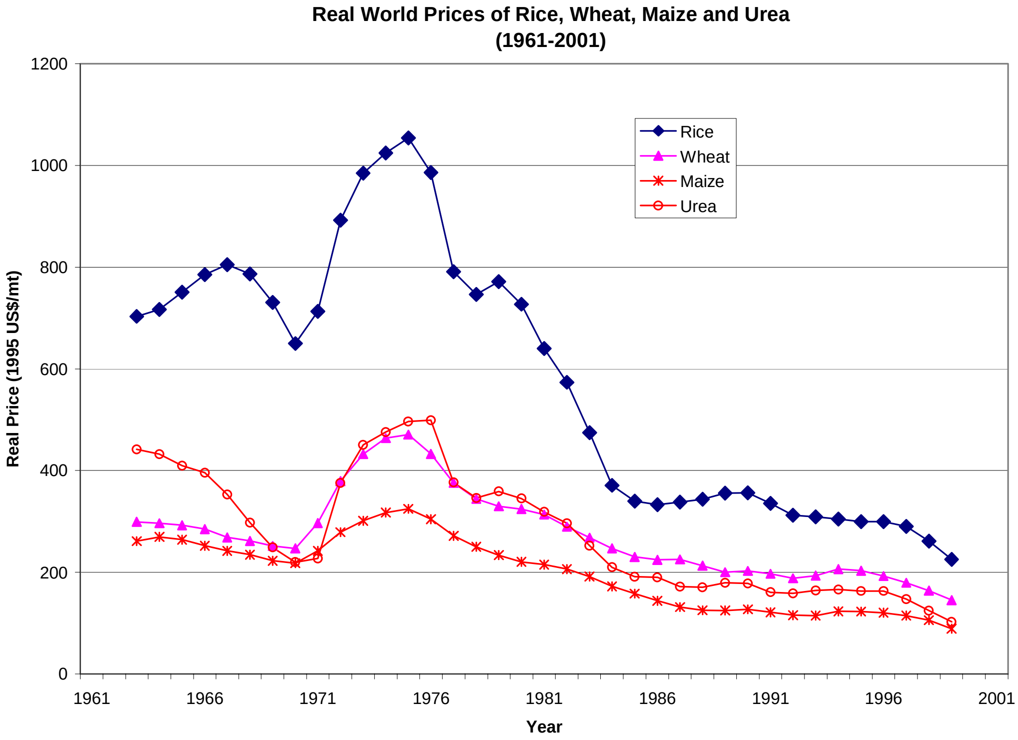


Figure 5.

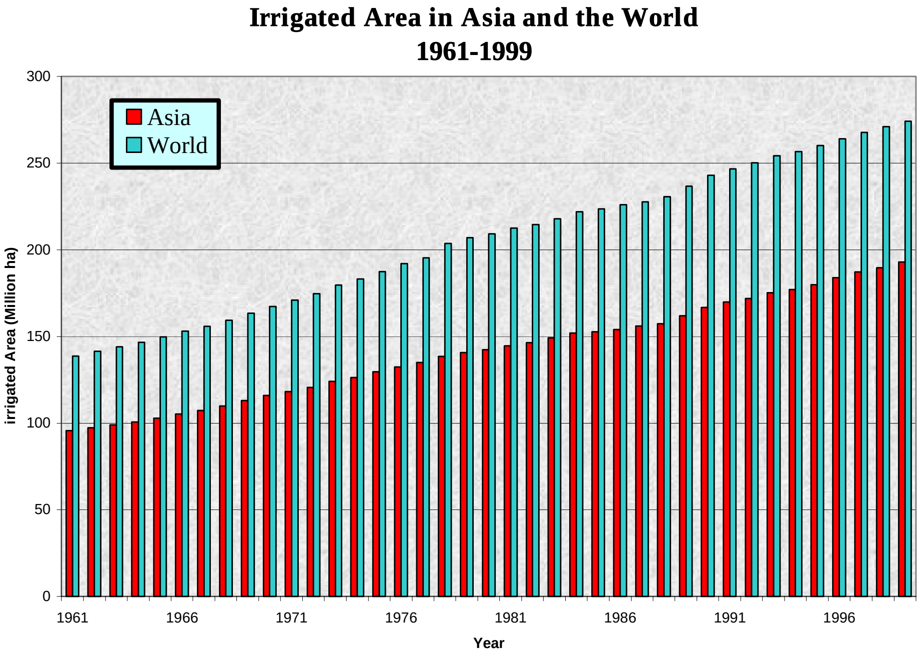
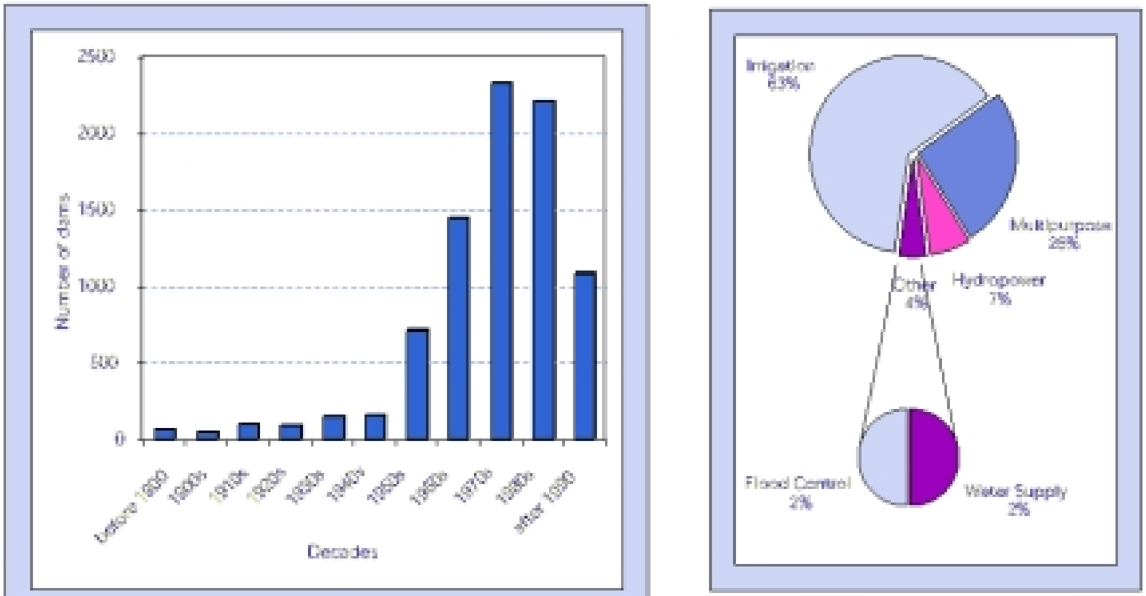


Figure 6. Historical evolution of dam construction in Asia (Source: WCD, 2000)



Source: ICOLD, 1998.

Source: ICOLD 1998. Note: Rates of dam commissioning in the 1990s are underreported. Figures above exclude China

Figure 7. Changes in benefit-cost ratio of new irrigation construction investments evaluated at current world prices and total new irrigation construction investments in 1995 constant prices (five-year moving averages, 1960-1995)

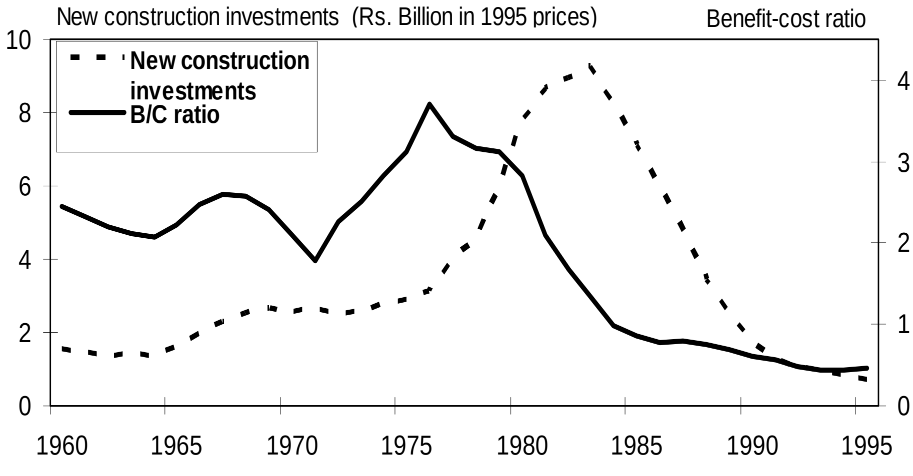
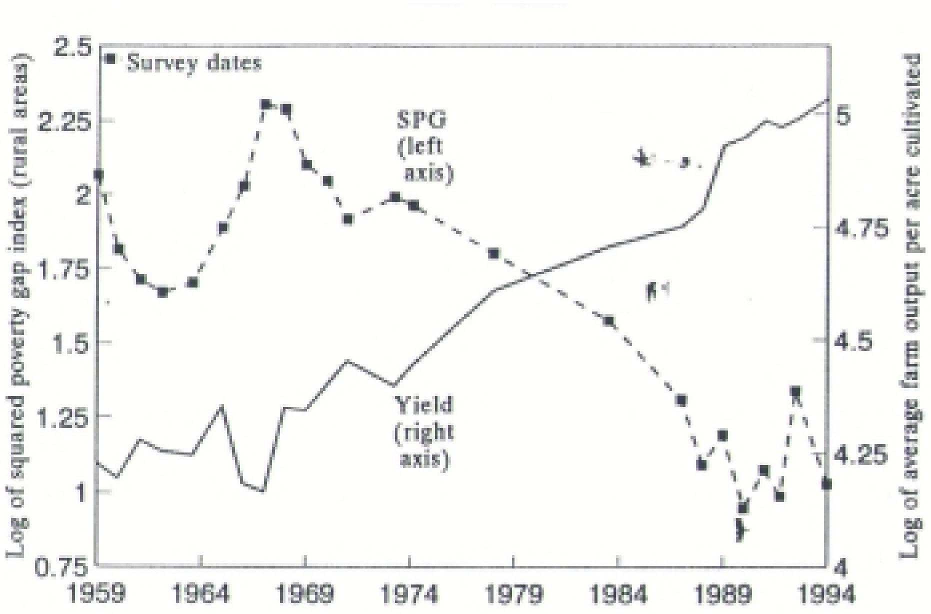


Figure 8. Squared poverty gap (SGP) index and average farm yield in rural India, 1959-94



Source: Datt and Ravillion, 1998

Figure 9.

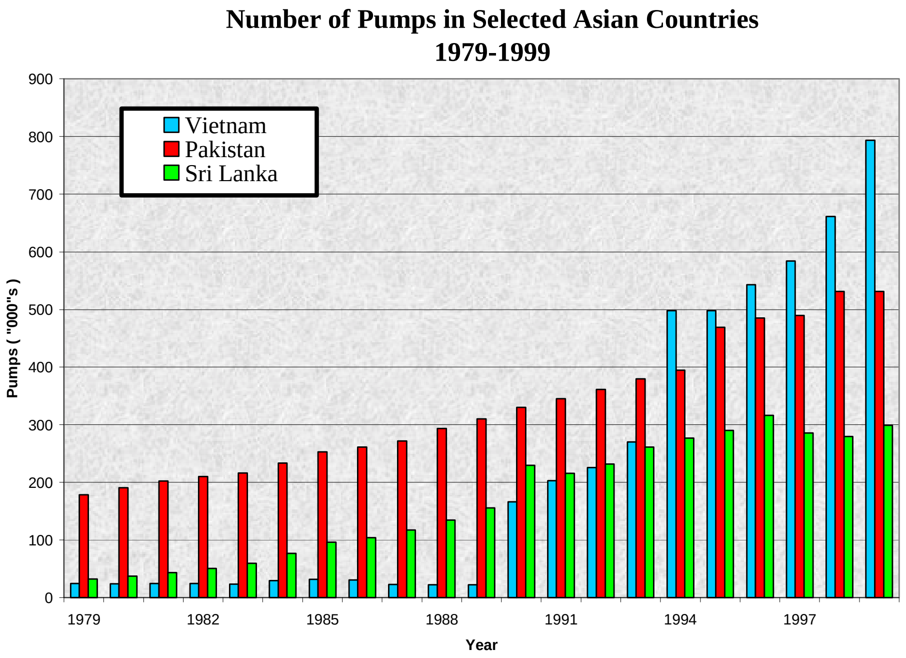
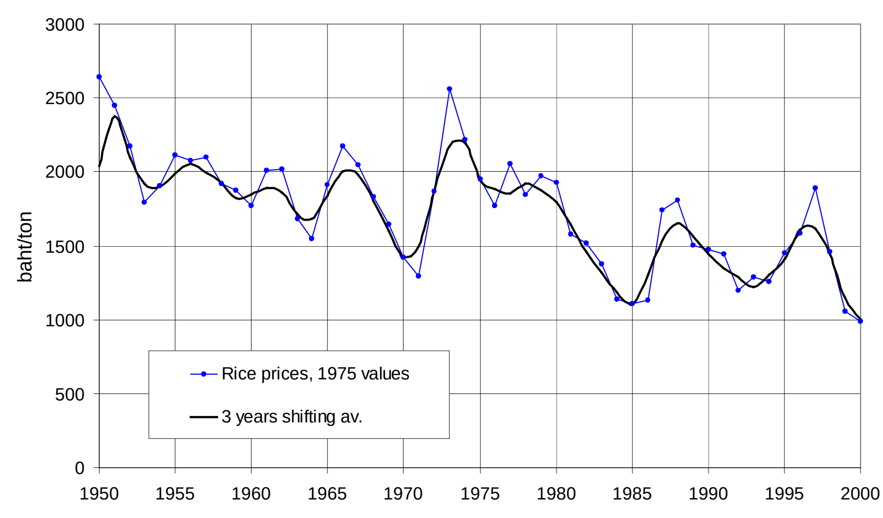


Figure 10: Historical evolution of farmgate prices for rice, Central Thailand



Source: F. Molle (forthcoming)

Figure 11. Types of responses to water scarcity (Molle, 2002)

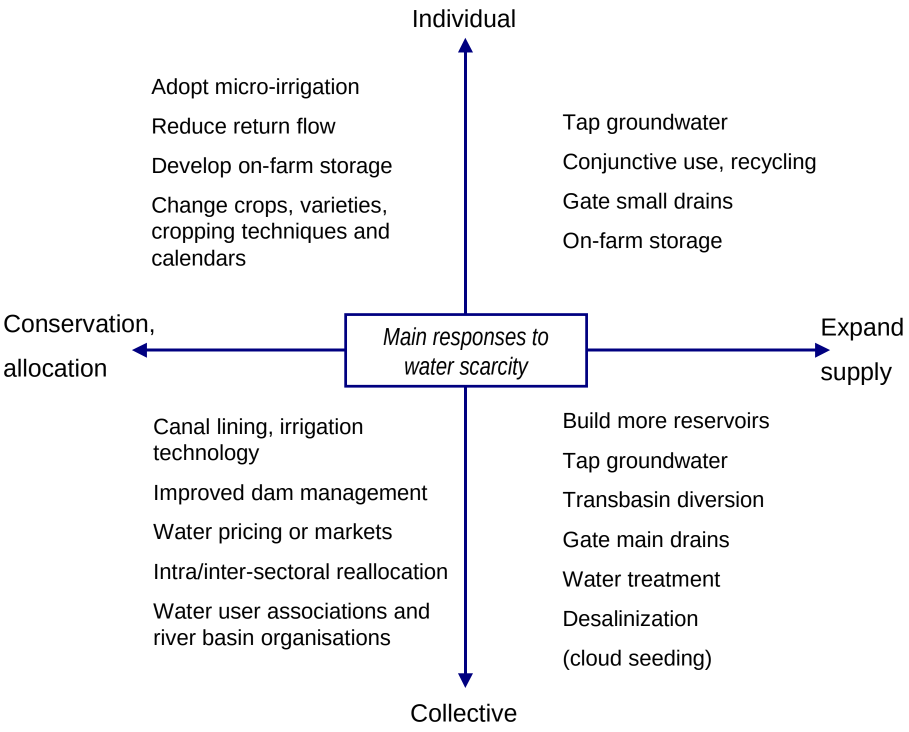


Table 1. Evolution of publicly managed irrigation in South and Southeast Asia

GEO-POLITICS	COLONIAL ERA 1850 TO 1940	COLD WAR ERA 1950 to 1990	GLOBALIZATION 1990 onward
Primary goal of national and international agencies	Famine protection/ revenue/exports	Food security	Livelihood/protection of environment/exports
Defining events	Famines, Suez Canal	Droughts (1965; 72/73) Population growth	Grain price decline Global warming
Resource availability	Land/labor plentiful	Land becoming scarce	Water and labor becoming scarce
Hydro-economic stages	Construction/utilization	Construction/utilization	Utilization/allocation
Professional orientation	Civil engineers	Agricultural engineers	Multi-disciplinary
Dominant irrigation development	River diversion, flood control, canalling of deltas	Storage dams, gravity irrigation	Pumps and wells
System design	Protect/supplement	Supply driven	Demand driven
System management	hydraulic	agricultural-based	farmer-oriented
Crops	Cereals/cotton	Cereals/cotton	Diversified
Cropping intensity	one crop	two crops	multiple cropping
Livelihoods	Subsistence/Colonial surplus extraction	Increasing mobility and economic diversification	High economic diversification
Value of water	Low	Increasing	High
Environmental degradation	low	increasing	High

Table 2 Growth in irrigated area in Asian countries 1961-1999

Country	Irrigated Area 1998 " 000" ha	Increase in total Irrigated Area 1962-1998 " 000" ha	Irrigated Area in 1998 as a % of irrigated area 1962	Average Annual Growth 1962-98 %	Irrigated Area as a % of harvested area 1998
India	58333	33255	233	3.7	28
China	52714	21736	170	1.9	28
Pakistan	17843	6915	163	1.8	75
Thailand	4836	3131	284	5.1	30
Bangladesh	3841	3369	814	19.8	28
Myanmar	1663	1042	268	4.7	15
Viet Nam	2767	1767	277	4.9	25
Nepal	1135	1062	1548	40.2	22
Philippines	1550	850	221	3.4	11
North Korea	1460	960	292	5.3	42
Indonesia	4815	915	123	0.7	16
Cambodia	270	206	422	8.9	12
Laos	167	154	1351	34.8	19
South Korea	1160	0	100	0.0	54
Sri Lanka	638	277	177	2.1	39
Malaysia	357	126	155	1.5	9
Bhutan	40	31	429	9.1	19
Japan	2680	-261	91	-0.2	82
Asia	189971	92609	195	2.6	30

Data Sources: FAO

Calculations are based on three year averages centering on the year shown

Total harvested area is the sum of cereals, coarse grains, pulses, oil crops, fiber crops, fruits, tree nuts, roots and tubers and vegetables

Table 3 Growth in irrigated area in Asia and its sub-region countries 19761-1999

			Share of total net irrigated area in Asia
Country	**62—85**	**85—98**	**1998**
Asia	2.3	2.0	1.00
SEA I	2.2	1.3	0.07
SEA II	3.7	4.2	0.03
China	1.9	1.4	0.34
India	2.9	3.0	0.37
East Asia	0.9	-0.3	0.03

Notes: Calculations are based on three year averages centering on the year shown.

Table 4 Poverty incidence and irrigation in developing regions

	$1-a-day poverty[a] 1998			% irrigated area per HA cultivated area (arable + permanent cropland) 1999
	Incidence (millions)	% of total population	% change in incidence 1987-98	
E.Asia and Pacific	278[b]	15[b]	-33[b]	20%
Latin America and the Caribbean	78	16	22	12%
N.Africa & M. East	5	0.04	-44	27%
South Asia	522	39	10	6%
Sub-Saharan Africa	291	44	34	3%

[a] People living on less than $1 per day in 1998 (1993 PPP $US) (Estimates)
[b] East Asia

Sources: Poverty figures from World Bank (2000,2001), Irrigated land from FAO Statistical Database www.apps.fao.org/default.htm.

Table 5 Growth in different sources of irrigation, India 1961-1997

	1962—1985	**1995--1996**
Net irrigated area	3.0	2.5
Wells	7.3	4.6
Surface water	1.2	0.7
Canals	2.3	0.7
Tanks	-1.2	-0.4
Other sources	0.9	2.2
(surface water consists of canals, tanks and other sources)		

Data source: Fertilizer Association of India. Fertilizer Statistics: New Delhi

References

Adas, Michael. 1974. *The Burma delta: economic development and social change on an Asian rice frontier*, 1852-1941. The University of Wisconsin Press.

Allan, Tony. 2000. *Millennial water management paradigms: making IWRM work*. SOAS, draft.

Bandaragoda, D.J. 1998. *Design and practice of water allocation rules: Lessons from warabandi in Pakistan's Punjab*. Research Report 17. Colombo, Sri Lanka: International Irrigation Management Institute.

Bolding, A., P.P.Mollinga, and K.van Straaten. 1995. Modules for modernization: Colonial irrigation in India and the technological dimension of agrarian change. *Journal of Development Studies* 31 (6): 805-544.

Bowie, Katherine A. (1992) Unraveling the myth of the subsistence economy: textile production in nineteenth century Northern Thailand, *Journal of Asian Studies* 33(1): 67-86.

Brocheux, Pierre. 1995. *The Mekong Delta, ecology, economy and revolution, 1860-1960* (University of Wisconsin Madison, Center for Southeast Asian Studies Monograph No 12, p 270).

Burns, R.E. 1993. Irrigated rice culture in monsoon Asia: The search for an effective water control technology. *World Development,* Vol. 21. No. 5, pp.771-789.

Chambers, Robert. 1988. *Managing canal irrigation. Practical analysis from South Asia.* Oxford & IBH Publishing Co. Pvt. Ltd, New Delhi.

Coward, E. Walter, Jr. 1980. Irrigation development: Institutional and organizational issues. *Irrigation and Agricultural Development in Asia.* USA: Cornell University.

Datt G. Ravallion, M. 1988b. Why have some Indian states done better than others at reducing rural poverty? *Economica* 65:17-38.

Datt G. Ravallion, M. 1998a. Farm productivity and rural poverty in India. *Journal of Development Studies*. 34:62-85.

Dawe, David. 2001. How far the path to free trade? The importance of rice price stabilisation in developing Asia, *Food Policy* 26 (2001) pp. 163-175.

de Bernon, Olivier (1997) Note sur l'hydraulique théocratique angkorienne. *Bulletin de l'Ecole Française d'Extrème Orient*, Tome LXXXIV, Paris pp. 340-348.

De Fraiture, Charlotte and Chris Perry. 2002. *Why is irrigation water demand inelastic at low price ranges?* Paper to be presented at the workshop "Irrigation water policies: macro and micro considerations", Agadir, Morocco, 15-17 June 2002.

De Koninck, Rodolphe. 1997. Agricultural expansion as a tool of population redistribution in Southeast Asia, *Journal of Southeast Asian Studies*, Vol. 28, pp. 26-44.

Dhawan, B.D. 1993. *Indian water resource development for irrigation: Issues, critiques, reviews.* New Delhi, India: Commonwealth Publishers.

Estudillo, J. P. and Keijiro Otsuka. 1989. Green revolution, human capital and off-farm employment: changing sources of income among farm households in Central Luzon, 1966-1994. *Economic Development and Cultural Change* 47(3).

Farmer, B. H. 1976. *Pioneer peasant colonization in Ceylon: A study in Asian agrarian problems.* Connecticut, USA: Greenwood Press Publishers. 387 p.

Geertz, Clifford. 1980. Organization of the Balinese Subak, in: Coward, E. Walter Jr. (ed.): *Irrigation and agricultural development in Asia. Perspectives from the Social Science*. Ithaca/N.Y./USA: Cornell University Press, pp. 70-90.

Goldsmith, Edward. 1998. Learning to leave with nature: the lessons of traditional irrigation. *The Ecologist* 28(3).

Groenfeldt D., and M. Svendsen. (Eds.) 2000. *Case studies in participatory irrigation management.* Washington, DC, USA: World Bank Institute. Xii, 157p. (WBI learning resources series).

Hasnip, N., S. Mandal, j. Morrison, P. Pradhan, and L. Smith. 2001. *Contribution of irrigation to sustaining rural livelihoods.* Report OD/TN109. HR Walingford.

Hayami et al. 1976. Agricultural growth against a land resource constraint: the Philippine experience. *Australian Journal of Agricultural Economics*, Vol. 20.

Kikuchi, M.; Barker, R.; Weligamage, P. and M. Samad. forthcoming. *The irrigation sector in Sri Lanka: recent investment trends and the development path ahead.* Research Report 62. Colombo, Sri Lanka: International Water Management Institute.

Henry, Y. 1935. *Economie agricole de l'Indochine*, Hanoi, 1932.

Huang, Philip C.C. 1990. *The peasant family and rural development in the Yangzi Delta, 1350-1988*. Stanford University Press, Stanford, California.

Ishikawa, Shigeru. 1967. Economic development in Asian perspective*. Economic Research Series No. 8*. Tokyo, Japan: The Institute of Economic Research, Hototsubashi University.

Johansson, Robert J. 2000. *Pricing irrigation water: A literature survey.* Working paper 2449. Washington, D.C.: The World Bank.

Jones, William I. 1995. *The World Bank and irrigation.* Washington, D.C., USA: Operations Evaluation Department, the World Bank.

Jurriens, M., P.O. Mollinga, and P. Wester. 1996. *Scarcity by design. Protective irrigation in India and Pakistan*. ILRI.

Kamal, Ahmad. 2001. The history of water management in Bangladesh: a study in sustainable development. Paper presented at the IWHA conference, 10-12 August 2001, Bergen, Norway.

Kikuchi, M. R. Barker, P. Weligamage and M. Samad. (forthcoming). *The irrigation sector in Sri Lanka: Recent investment trends and the development path ahead.*

Koppel, Bruce and Zurick, D. (1988) "Rural transformation and the future of agricultural development policy in Asia". *Agricultural Administration and Extension*, Vol. 28, pp. 283-301.

Korten, Francis W., and Robert Y. Siy Jr. 1988. *Transforming a bureaucracy – The experience of the Philippine National Irrigation Administration*. USA: West Hartford, Conn.

Kurien, Mathew. 2002. *From project to process: Participatory watershed management in the Himalayan foothills.* The Hague, The Netherlands: Institute of Social Studies.

Lansing, J.S. 1980. "Water temples" and the management of irrigation. *American Anthropologist* 89(2), pp. 326-341.

Leach, Edmund Ronald. 1961. Pul *Eliya, a village in Ceylon: A study of land tenure and kinship*. Cambridge: University Press.

Lipton, Michael and Julie Litchfield. 2002. *The impact of irrigation on poverty*. Sussex: University of Success for FAO.

Malano, H.M.; Bryant, M.J.; Turral, H.N. 2000. Management of water resources: Can Australian experiences be transferred to Vietnam? *Water Resources Journal*, 24(4):307-315

Masubichi, Tatsuo**.** 197?. Wittfogel's theory of oriental society and the development of studies of Chinese social and economic history in Japan. *The Developing Economies*.

Maurer, Jean-Luc. 1990. Irrigation, riziculture et gestion de l'eau en Indonésie: la modernisation des traditions agro-hydrauliques à Java et Bali. *Revue de Géographie de Lyon*, 65(1), pp. 27-37.

McCully, P. 1996. *Silenced rivers: The ecology and politics of large dams.* London, UK: Zed Books.

Molden, David, R. Sakthivadivel and M. Samad. 2001. *The evoluation of insotitutions for river management.* Paper presented at the International Workshop on "Integrated Water Management in Water-

Stressed River Basins in Developing Countries: Strategies for Poverty Alleviation and Agricultural Growth," Loskop Dam, South Africa, 16-21 October 2001.

Molle, François. 2001. *Water pricing in Thailand: Theory and practice*. Research Report No.7, DORAS Project. Bangkok: Kasetsart University. 78 p. http://std.cpc.ku.ac.th/delta/conf/Acrobat/Papers_Eng/pricing.pdf

Molle, François. 2002a. *Development trajectories of river basins: a preliminary conceptual framework.* IWMI Research Paper. draft.

Molle, François. 2002b. *To price or not to price? Thailand and the stigma of "free water*". Paper to be presented at the workshop "Irrigation water policies: macro and micro considerations", Agadir, Morocco, 15-17 June 2002.

Molle, François (forthcoming) The closure of river basins: a perspective on technical and institutional adjustments in the Chao Phraya River basin, Thailand.

Morris, J. 1996. Water Policy: economic theory and political reality, in Howsam, P. and R. C. Carter (eds.): *Water Policy: allocation and management in practice*, pp. 228-234

Murray-Rust, H. and M. Svendsen. 2002. Performance of locally managed irrigation in Turkey: Gediz case study. *Irrigation and Drainage Systems* 15: 373-388.

Murray-Rust, Hammond, R. Sakthivadivel and Upali A. Amarasinghe. 1999. *Impact assessment of organizing farmers in the Gal Oya Left Bank Irrigation Scheme, Sri Lanka.* Water Resources Development, Vol. 15, Nos. 197-217.

Ostrom, Elinor. 1990. Governing the commons. Cambridge University Press.

Owen, Norman. 1976. *The rice industry of mainland Southeast Asia, 1850-1914*. Siam Society, Bangkok.

Perry, C.J. 1999. The IWMI water resources paradigm: Definitions and implications. *Agricultural Water Management.* 40 (1): 45-50.

Perry, Chris. 2001. *Water at any price? Issues and options in charging for irrigation water.* Irrigation and Drainage 50:1-7. UK: John Wiley & Sons Ltd.

Perry, C.J.; Rock, M. and David Seckler. 1997. *Water as an economic good: a solution, or a problem?* Research Report 14, IWMI, Colombo, 17 p.

Perry, C.; Mehmood al Hassan. 2000. *Control of groundwater use: The limitations of pricing, and a practical alternative.* In GWP; Pakistan Water Partnership, Proceedings of Regional Groundwater Management Seminar, October 9-11, 2000, Islamabad. pp.67-73.

Pingali, P.L., and Rosegrant, M.W. 2001. Intensive food systems in Asia: Can the degradation problems be reversed? In D.R. Lee and C.B. Barrett (eds.). *Trade-offs or synergies? Agricultural intensification, economic development, and environment.* Wallingford, Oxon: U.K., NY. CABI Pub c2001.

Preston, david A. (1998) 'Too busy to farm: under-utilisation of farm land in central Java, *Journal of Development Studies* 26(1): 43-57.

Ray, Isha. 2002. *Farm-level incentives for irrigation efficiency: some lessons from an Indian canal*. Draft.

Repetto, Robert C. 1986. *Skimming the water: Rent-seeking and the performance of public irrigation systems*. Washington, D.C: World Resources Institute.

Richards R.A., C. López-Castañeda, Gomez-Macpherson, A.G. Gordon. 1993. Improving the efficiency of water use by plant breeding and molecular biology. *Irrigation Science* 14: 93-104.

Rigg, Jonathan. 2001. *More than the soil: rural change in Southeast Asia*. Prentice Hall.

Samad, Madar. 2001. *Impact of irrigation management transfer on the performance of irrigation systems: A review of selected Asian experiences.* Paper presented at the ACIAR Water Policy Workshop, 8-9 June 2001, Bangkok, Thailand.

Sampath, R. K. 1992. Issues in irrigation pricing in developing countries. *World Development*, Vol. 20, No. 7, pp. 967-977.

Schiff, Maurice and Alberto Valdés. 1992. *The plundering of agriculture in developing countries*. The World Bank, 36 p.

Seckler, David (1996) *The new era of water resources management: from "dry" to "wet" water savings.* Research Report 1. Colombo, Sri Lanka: International Irrigation Management Institute (IIMI).

Siy, Robert Y. 1955. *Community resource management: Lessons from the Zanjera.* Quezon City, Philippines: University of the Philippines Press.

Smith, Laurence E.D.; Franks, T. and Jay Melvyn. 1997. Water – An economic good? : Theory and practice. *ICID Journal*, Vol. 46 No. 2, p. 1-13.

Stargardt, Janice (1986) 'Hydraulic works and Southeast Asia polities', in *Southeast Asia in the 9th and 14th centuries*, edited by David G. Marr and A. C. Milner,ANU, pp. 23-49.

Steward, Julian H., Robert M. Adams, Donald Collier, Angel Palerm, Karl A. Wittfogel, and Ralph L. Beals. 1955. *Irrigation civilizations: A comparative study.* Social Science Monographs I. Washington, D.C., USA: Pan American Union.

Stone, Ian. 1984. *Canal irrigation in British India. Perspectives on technological change in a peasant economy,* Cambridge: Cambridge University Press.

Stott, Philip (1992) Angkor: shifting the hydraulic paradigm, in *The gift of water: water management, cosmology and the state in Southeast Asia*, edited by Jonathan Rigg, London: SOAS, pp. 47-58.

Svendsen, Mark and Mark Rosegrant. 1994. Irrigation development in Southeast Asia beyond 2000: will the future be like the past? *Water International*, Vol. 19, pp. 25-35.

Tabor, S.R., H. Sawitt and H.S. Dillon. 2002. *Rice Policy and the Choice of a Trade Regime for Rice in Indonesia*. Paper presented at the INDEF Seminar on Rice Trade in Indonesia, February 2002, Jakarta.

The World Commission on Dams. 2000. Dams and development: a new framework for decision-making. Earthscan, London.

Tsur, Yacov and Ariel Dinar. 1997. *The relative efficiency and implementation costs of alternative methods of pricing irrigation water.* The World Bank Economic Review, Vol. 11, No. 2: 243-62.

Tuan, Dao The and François Molle. 2000. The Chao Phraya Delta in perspective: a comparison with the Red River and Mekong deltas, Vietnam. Proceedings of the International Conference "*The Chao Phraya Delta : Historical Development, Dynamics and Challenges of Thailand's Rice Bowl*", December 2000, Kasetsart University, Bangkok, 35 p.

Uphoff, Norman. 1992. *Learning from Gal Oya.* Cornell University Press, Ithaca, USA.

Vaidyanathan, A. 1999. *Water resources management: institutions and irrigation development in India.* Oxford University Press, Delhi.

Van Liere, W.J. 1980. Traditional water management in the lower Mekong basin. *World Archeology*, Vol. 2, No. 3.

White, Benjamin (1991) Economic diversification and agrarian change in rural Java, 1900-1990. In Paul Alexander, Peter Boomgaard and Ben White (eds) *The shadow of agriculture: non-farm activities in the Javanese economy, past and present,* Amsterdam: Royal Tropical Institute, pp. 41-69.

Wijeyewardene, Gehan (1971) *Hydraulic society in contemporary Thailand?* Camberra: ANU, 29 p.

Wittfogel, Karl A. 1957. *Oriental Despotism: A comparative study of total power.* New Haven & London: Yale University Press.

Yoder, Robert, Edward D. Martin, Randolph Barker, and Tammo S. Steeinhuis. 1987. *Variations in irrigation management intensity: Farmer-managed hill irrigation systems in Nepal*. Paper prepared at Cornell University for the Water Management Synthesis II Project. WMS Report 67.