

CHAPTER 8

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INTRODUCTION

Irrigation offers the only practical means to enhance the physical environment by providing crops additional water, when this essential crop input is not available from natural means. As such, *irrigation offers the opportunity to extend growing seasons*, providing the producer additional flexibility in crop management, the opportunity for additional crops, and stabilizing the potential yield at a high level.

However, it does greatly increase the complexity of crop management with the need to manage the water and maintain the delivery and drainage canals with their associated control structures. When well-managed, irrigation schemes can have a positive impact on the environment through flood protection. The storage structures can effectively retain considerable floodwaters, while the canals and field can effectively dampen a flood hydrograph to protect urban areas. In rice schemes, this can often be accomplished with a minimum of crop damage, as most rice varieties can withstand a few days of submergence while a storm system passes through and drains off. In contrast, upland crops will suffocate within 24 hours as the soil microbes consume all the trapped air and the soil becomes chemically reduced.

Many developing countries have invested heavily in irrigation schemes, as a means of improving food security and self-sufficiency. Donors, until recently, have willingly contributed to financing these projects. Irrigation is the most expensive agricultural infrastructure investment, with a high potential economic recovery in terms of increasing the total value of crop production. Two of the world's largest irrigation schemes, the Egyptian and Pakistan systems, are almost exclusively for smallholder producers.

However, despite all the investments and potential for efficient

water use, the following hypothesis may be worth considering evaluating irrigation schemes: *More combined research and extension time, effort, and money has been spent on irrigation and related issues by engineers, agronomists, economists, and sociologists for less user-acceptance by farmers than any other crop production activity!*

Compromises of Developed Countries

The reason behind the rather bold statement has more to do with the way different systems operate than farmers' desire to deliberately mis-manage water. Much of the research investment has been on refining various crop water requirements; often to a higher accuracy than most systems can comply with, particularly the surface systems normally available to smallholders.

An Internet exchange on the irrigation list server on this issue brought the following comment: "Measure it with a micrometer, mark it with a grease pencil, and cut it with a chain saw."

Certainly, farmers in the western USA with their available consultants, personal computers, on-line services, and pre-packaged economic programs for computing profit margins, have the knowledge available for accurate water management, as well as the means to purchase any required equipment. Any decisions not to do so are deliberate and well thought out in relation to their total production costs, and the contribution of water to those costs. Some of the reasons, as conveyed to the author include:

- Desire to have a continuous flow of water and systematically move it around the farm in an internal rotation throughout the growing season and not having to call the ditch company every time they need water. No adjustments are made for any rainfall incidents, as this would disturb the logistics of the internal rotation (Northern Colorado Water Conservancy District).
- Ditch water is just too cheap, and there are up to seven demands on the tail water. To become more efficient would deny others their water right to the tail water. Average irrigation efficiency may be as low as 35% with a target of only 65% (Northern Colorado Water Conservancy District).
- Desire to only spend 0.5 hours per day managing their irrigation so they could concentrate on other activities, including off-farm employment (Grand Junction, Colorado).
- Water deliveries have to be requested five days in advance in

what is normally a 10 day irrigation frequency, thus making it impossible to factor in any abnormalities in consumptive use during the last half of the irrigation cycle. Farmers were more than willing to avail themselves of neutron probe information as long as the Natural Resources Conservation Service was subsidizing it, but lost interest as soon as charges for the neutron probe were levied. The farmers reverted to a simple fixed time frequency (Walton-Mohawk Project, Yuma, Arizona).

All of these are valid reasons reflecting the overall management economics of individual farms in which efficient water applications are in their proper perspective, and not necessarily the primary concern. Few have anything to do with the climate variables that affect the evapotranspiration rate and crop water use including incident rainfall. Serious concern for water-use-efficiency only occurs when the cost of water becomes very high as in San Diego, California, where irrigation water comes from the treated municipal supply and costs \$0.65 /m³.

Growers there have all converted to drip systems and concentrate on high value vegetable and fruit tree crops. They quickly became appreciative of increased access allowed by the drip system, as drip application only wets the rows, and they no longer had to wait for the soil between the rows to dry following irrigations.

When possible, USA farmers have multiple sources of water, such as ditch water and well water, as well as different methods of irrigation. The efficient conjunctive use of the different water sources and the irrigation methods used very much depends on the relative cost of each.

The Lyn Fagerberg Farm in Eaton, Colorado is an example. They manage 640 Ha of mixed irrigated crops. The irrigation is divided between surface, center pivot sprinkler, and drip.

Except in years of extreme water shortage, such as 2002, they use the cheaper ditch water for surface irrigation turning the water on at the beginning of the season and rotating internally during the season until finally turning it off at the end of the season. The well water is used for the sprinkler and drip areas. If the ditch water is insufficient, they will divert the well water to the surface area. The drip system saves as much as 30% of their water use.

Compromises of Smallholders

While these above examples are for larger growers, the smallholders have other problems that prevent them from being more water use efficient, even if provided with the technical knowledge and

sophisticated databases available to the larger growers. Some of their concerns are:

- Integrating their crop water needs into a rotational delivery system determined by scheme managers;
- Waiting for up to six weeks for contract tractor operators to prepare their land for planting, and thus growing their crops completely out of phase with the irrigation authorities' master plan for water-use of specific crops;
- Being required to accept water even when they have no need for it, as with the Warabandi system of South Asia, resulting in considerable flow through of water going through the system and into the drains, or being applied to fallow fields and crop stubble.

In all, irrigation has to be considered as just another crop production input *to be integrated into total farm management*. One of the problems in transferring experience from large farm environments of developed countries to smallholders schemes of developing countries is that the expatriate advisors, who come to assist the smallholders and their supporting institutions, are normally chosen from the scientists, engineers, and extension personnel that develop and promote efficient water management, rather than the users, who have to integrate the water management ideals into practical crop management economics. These advisors often imply a far greater use of highly efficient water management techniques in home areas within the developed countries than the farm level reality.

SMALLHOLDER IRRIGATION SCHEMES

Irrigation schemes for smallholders come in all sizes from individual or small groups of producers sharing a well or diverting a stream into their fields, to schemes such as those in Egypt and Pakistan that cover most of the nation's agricultural lands.

Most of the larger systems serving smallholders are publicly owned surface systems in which up to 100 or more farmers share a common tertiary watercourse. Often, the land served by publicly owned civil works is privately owned or on long-term lease. Frequently, the physical works associated with irrigation systems, particularly the large storage dams, are multipurpose structures used for electrical power generation and flood control as well as irrigation.

Large Public Sector Irrigation Schemes

Large public sector schemes have had the most public or donor funding for construction and technical assistance. With the exception of Egypt and Pakistan, most of the smallholder schemes are based on rice. In Asia, where rice is the staple crop, this would be expected. However, in several African countries, such as Malawi and Tanzania, where maize is the staple crop, many of the irrigation schemes are still intended for rice, which is the secondary staple crop. The exception would be the Gizera Scheme in Sudan that was developed by the British primarily for cotton. Often the irrigation schemes are developed in conjunction with land allocation and resettlement efforts like the Mahaweli Project in Sri Lanka. When part of settlement schemes, the producers will usually have uniform consolidated irrigated allocations, at least initially.

When growers manage several parcels distributed on one or more neighboring watercourses, individual fields to which water has to be applied can range from 0.05-1.0 Ha resulting in as little as 10 m fronting the canal, and with individual turn-outs every few meters. Such fragmentation makes it very difficult to deliver specific volumes of water to an individual parcel or, perhaps more importantly, to prevent individuals from taking water.

Farmers often have no clear water rights and thus no specific entitlement to water. The actual concept of a water right, as defined in the USA, is usually not understood by farmers or irrigation authorities alike. In its place, most developing countries have a much vaguer concept of equitable opportunity for water, a sharing of water among neighbors, or water as a natural gift from God for all to utilize. There is little farmers can do if they have been deprived their share of the water.

Most often, water is made available to the growers on a rotational basis where the water is available for a few days and then off for another few days. Such rotations provide some degree of reliability in planning irrigation, but may only broadly relate to actual crop water-requirements.

Informal Irrigation Schemes

In addition to the large public schemes, there are also numerous small, private schemes built and maintained by individuals or small groups of farmers. They are normally run-of-the-river diversions with no storage structures that command anywhere from 1 - 2 Ha up to a couple of hundred Ha. They are normally very simply designed with little or no

professional engineering applied, and no concern for the tail water or returning excess flows to the source for others to utilize. Often these schemes are unrecorded and are, in effect, stealing water planned for other uses. They also are often remote and curbing them is virtually unenforceable.

An example is the Usangu Plan in the southwestern portion of Tanzania. Here rice irrigation is blamed for the progressively early drying of the Great Ruaha River, limiting the water for the wildlife in the Ruaha National Park, as well as for filling the major hydroelectric reservoir that provides both power and municipal water for the capital, Dar Es Salaam. A consultant's report confirmed this by noting that the government sponsored three major and a couple minor irrigation schemes totaling no more than 12,000 Ha, but the total rice area was estimated in excess of 40,000 Ha (Baur *et al*, 2000). The 28,000 Ha of non-government sponsored schemes were all informal schemes that farmers developed themselves. Even though they may officially be illegal, it would be very difficult to try to tell some impoverished farmers they have to forfeit the water flowing past their land to benefit the wild animals enjoyed primarily by foreign tourists.

EXAMPLES OF SMALLHOLDER IRRIGATION SCHEMES

There are many ways to design and manage irrigation schemes. Most countries have developed their irrigation schemes to suit their specific needs, or they are locked into specific operational procedures determined by the initial design at the time of construction. They have continued with this procedure as the system expanded or was rehabilitated. It is normally cheaper to renovate the original design specifications than redesign to a more modern basic procedure requiring completely replacing most control structures. Below are brief descriptions of the salient features of several smallholder schemes, which will serve as examples for further discussion.

Irrigation in Egypt

Egypt has the oldest continuously operating irrigation scheme dating back to Paranoiac times. Modern Egyptian irrigation began some hundred years ago during the period of British influence. It started with the construction of the main barrages across the Nile and canal systems leading from them.

Perennial irrigation became possible with the original Aswan Dam

in the early 20th century. It has now been dwarfed by the new Aswan High Dam upon which the country is totally dependent. Both are in the extreme southern part of the country with the High Dam being multi-purpose as the primary source of hydroelectric power in the country.

The High Dam is effectively the only storage structure, holding two years of average Nile River discharge. The High Dam has resulted in the full flow of the Nile being available for irrigation. In the unlikely event of the High Dam spilling, the spillway discharges into the Western Desert to infiltrate into the water table, the Nile River bed is effectively an irrigation canal from Aswan to the Delta Barrage, just north of Cairo, and a drain from the Barrage to the Mediterranean Sea. The high dam provides sufficient water for perennial irrigation of all the old lands in the Nile Valley and Delta plus considerable new lands in the desert on both the east and west side of the valley.

One Nile River Scheme

Because it is the only storage structure, Egypt's entire irrigation system can be considered as one large system serving some 4,000,000 Ha and requiring 14 days for water released from Aswan to reach Alexandria on the Mediterranean Sea. There are several barrages downstream that divert water into the various canals, but none are storage structures. Thus, once released from Aswan, the water must be utilized or wasted. Likewise, additional water can not be added to a release. This makes it physically virtually impossible to compensate for the extra evapotranspiration associated with an abnormal heat wave.

The system contains one of the world's longest canals and accompanying drains. The Ibrahim Canal and El Nadi Drain stretch some 300 km irrigating and draining the west bank of the Nile from Assit, past the pyramids in Giza until the drain discharges back into the Nile below the Delta Barrage. As this is the last major diversion, the return flow can no longer be conjunctively mixed with river water and utilized.

While there are some large farms, most land is privately owned and has been in the same families for generations, subdivided among descendants, and partly reconsolidated through marriage, sales, lease agreements, etc. until the average holding is less than two Ha subdivided into three to five parcels.

The Sub-Tropical Climate of Egypt

Egypt has a sub-tropical climate with year-round cropping, divided

between mutually exclusive summer and winter annual crops, and thus has extensive crop conversion periods in spring and fall. Typical winter crops are berseem (also known as Alexander Clover, a cool season forage legume), wheat, and faba beans, as well as flax and sugar beets. In summer, the major crops are cotton, maize, and rice. The latter is primarily in the northern delta where it is intended as a saline reclamation crop. In addition, there is substantial acreage in annual vegetables as well as citrus, date palm, sugarcane and other perennial crops.

Box 8.1 Rice as Salt Reclamation Crop

While rice is not particularly salt tolerant, a good irrigation system with high quality water will allow a less dense fresh water lens on the surface that will exert hydrostatic pressure on the more dense saline water, leaching it out. This can effectively reduce the salt concentration by 30% during a rice season.

Rotational Delivery in Egypt

Water delivery is rotated in the secondary canals and allowed to flow freely into the tertiary canals by open pipes with a diameter proportional to the command area. Farmers then freely take water without any restrictions. Although not illegal, there is virtually no night irrigation, as farmers are reluctant to be in the fields at night for fear of poisonous snakes and other general hazards of limited visibility. This allows the tertiary canals, which have become enlarged over time, to refill during the night and provide some storage, and an equitable start to each day's irrigation. Water is provided below ground level requiring farmers to pump water onto their fields with a lift that usually varies from 20-80 cm. The lift system is intended to encourage farmers to use less water. Traditional lifting was done by animal powered *saquias* (Photo 8.1) or water wheels, but in recent years these have virtually all been converted to low lift diesel pumps, mostly imported from India (Fig. 7.4).

The heavy swelling clay soils have a tendency to completely seal 30% of the time, necessitating some surface drainage to remove excess water before the soil becomes chemically reduced and the non-rice crops suffocate (Litweller, *et al.* 1983). This condition effectively discourages farmers from over-irrigating. It also encourages farmers to subdivide fields into very small irrigation basins of approximately 10 x 10 m for better water control in the imperfectly leveled fields. This increases the amount of labor associated with irrigating, as the farmer

has to remain near the field to make adjustments between basins and cannot simply start the irrigation, proceed with other farm work, and then return at the end of the irrigation.



Photo 8.1 Blindfolded water buffalo turning saquia to lift irrigation water in Egypt. Photo Credit: W. Shaner.

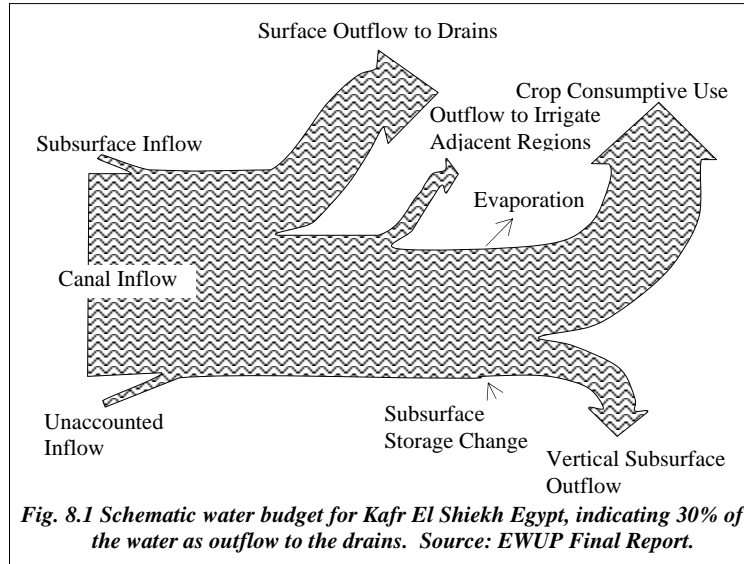
Water rotation is adjusted periodically to accommodate the difference in evapotranspiration between summer and winter. Finally, there is a one-month closure period for maintenance in January, when the evaporative demand is lowest. The water is provided free to the farmers, except for the cost of lifting it to their fields. Thus, the operation and maintenance costs come from the national general revenue funds, although the government is looking at various ways of charging the farmers enough to at least cover the recurring costs.

Water Budgets in Egypt

Most of the time, farmers are suspected of using too much water. However, on closer analysis, the water releases are not well synchronized with the growers' needs and approximately 30% of the annual volume of water is flowing out of the system through the drains (Fig. 8.1). While generally attributed to deep percolation and salt removal, most is actually "flow-through" that passes through the system and over the tail, escapes into the drains without ever being applied to a farmer's field. This is particularly true during the crop

conversion periods in spring and fall. For this reason the quality of the water in the drains is only slightly less than the canal water and well within irrigation quality standards.

Thus, farmers in the lower delta will frequently pump water from the drains, with fixed rotary pumps installed in brick and concrete structures beside the drain to be operated by belt drive connected to a normal farm tractor (Fig 7.20). It is a procedure the irrigation administrators frown on, but can do little to prevent. The lift from the drains is 2-3 m, which would be difficult with the normal diesel pumps used for lifting water from the irrigation canals to the fields, and necessitates the more powerful tractor power.



Irrigation in Pakistan

Pakistan, like Egypt, has a single large system encompassing the entire Indus River basin and most of the country's agricultural lands. It also has its origins in antiquity. It is perhaps the world's largest system, comprising some 12,000,000 Ha. The system contains two major storage structures on separate tributaries of the Indus River. Like Egypt's High Dam, both dams are multipurpose. Both structures are in the extreme northeast of the country, where the water originates from

the Himalayas. It requires approximately one month for the water, once released from either dam, to transverse the entire system to Karachi. Also, like Egypt, once released, the water can neither be withdrawn nor supplemented to compensate for shifts in evapotranspirative demand associated with heat waves, cool spells or incident rainfall. The discharge of the two dams is interconnected through a series of link canals to make one integrated system.

The storage capacity of both reservoirs equals only 1/6th of the annual irrigation requirements. Additional canal water comes from the base flow of the tributaries, which is derived from the snowmelt from the Himalayas and incident monsoon rains during summer. The entire system is designed to deliver less than the crop water requirements of the command area. *Thus, the basic principle in managing the system is to equitably distribute a scarce resource.*

Like Egypt, Pakistan is a subtropical country with year-round cropping, divided between summer and winter crops, with spring and fall conversion periods. The crop mixture is similar to Egypt's.

The system serves predominately smallholders, many of whom are sharecropping tenants. Water is delivered continuously on a gravity basis, entering the tertiary watercourses via ungated flumes, the sizes of which are adjusted in proportion to the command area. There is little or no effort to adjust for differences in evaporative demand or integrate the irrigation water with incident precipitation. Given the lead time of up to 28 days, and the inherent variability in rainfall as discussed in Chapter 2, it would be very difficult to integrate canal operations and incident rainfall, even if the information was available.

The Warabandi Distribution System of Pakistan

To distribute the scarce water, the "Warabandi" system is utilized. Under this system the farmers along a watercourse are provided the full flow of the watercourse for a specific time each week in proportion to their holdings. The rotation starts at the beginning of the watercourse and allocates water down-stream to each farmer in turn until the last person receives the residual flow in the watercourse. There is no compensation for any conveyance losses, which on a long watercourse meandering over 1-2 km with a corresponding large exposed surface area, can amount to 30 -50% of the inflow. Despite these problems, this is perhaps the closest concept to a specific water right available in smallholder systems, as well as the best organizational structure to equitably distribute water to smallholders.

The "Pakistan On-Farm Water Management Projects" that existed

for over 20 years from the mid-1970s into the 1990s, were major efforts to reduce the conveyance loss by inserting pre-cast concrete outlet structures for farm turn-outs and lining portions of water courses (Photo 8.2). It was also expected that once the watercourses were improved, the farmers would take more interest in maintenance. All farmers along the watercourse were obligated to join Water Users Associations (WUA) to ensure the effective operation of the watercourse and repay the cost of the improvements. This was the first effort to developing WUAs to give farmers an input into the operation and maintenance of irrigation systems, or at least the tertiary watercourses.



Photo 8.2 Lined irrigation canal in Pakistan as part of an On-Farm Water Management Project. Photo Credit: W. Shaner.

Deliberate Lack of Drains

There are no drains in the Warabandi system and no tail escapes. Thus, the farmers must accept the water each week, whether they need it or not. During the early spring or fall crop conversion periods, when there is little need for irrigation water, farmers will apply water to fallow fields, such as cotton stubble, just to get rid of it. They cannot effectively apply it to another of their non-contiguous parcels further down-stream that might still have a crop in need of water, as this would break the sequential rotation of the Warabandi delivery.

Also, during this time the farmers may block the inlets to the watercourse so the water will continue down the main canal with its

diminishing conveyance capacity.

This results in some serious flooding in the lower sections of the main canals. At other times farmers remove and discard a small block in the inlet structure to allow as much water as possible to enter the watercourse.

The Warabandi system provides each farmer a fixed block of water against a rather variable crop and irrigation requirement. Thus, while in total the irrigation water may be a scarce commodity, there are times when there is considerable surplus in the system that is wasted.

The government made considerable efforts to design cropping systems that more effectively utilize the water in spring and fall, while keeping the Warabandi system intact. Since sub-tropical climates allow continuous cropping, this is very difficult to accomplish.

Supplemental Tube Wells

As irrigation water from the main irrigation ditches are basically a scarce resource, in many areas it is supplemented by tube wells allowing farmers more flexibility in irrigation. The tube wells provide a means of adjusting water applications to incident rainfall and lowering the groundwater.

Many of the tube wells are privately owned and managed. Tubewells will typically serve about 20 Ha and be shared among a small group of farmers, although one farmer may be the owner and provide water to the others on a pure cash basis. From the farmers' perspective the tube well water is more expensive than the free canal water. The diesel or electricity is directly billed to the farmer, and becomes the most efficient means of direct volume charges for smallholders, particularly for the private wells.

In addition to the Indus River system, Pakistan has several smaller irrigation schemes outside the Indus River valley, most of which serve a single village or a small group of villages.

In Baluchistan, they also use the "Karez" system in which a line of wells are dug and connected by a tunnel that intercept groundwater at the base of a mountain and conveys it several km to the fields.

Irrigation in Sri Lanka

Sri Lanka has one major system plus many minor systems based on a multitude of reservoirs that are regionally referred to as "tanks". Some of the Sri Lankan tanks date back several thousand years. These tanks are sequenced down the natural watersheds with the tail water of one

tank becoming the recharge for the next tank.

Mahawali Trans-Mountain Diversion

The major system in Sri Lanka is the Mahawali Gangus. It is relatively new with initial construction completed in the mid-1970s. It is a trans-divide diversion of 56.6 m³/sec. from the Mahawali Gangus River at Kandy to recharge existing tanks in the Northern Dry Zone. The new diversion and tank recharge now allows double rice cropping on the already established lands below the tanks as well as the expansion of the existing paddy lands.

As the various tanks provide local storage and thus the potential for local control, the Mahawali can be viewed as several inter-linked, but independent, small schemes, each with its own storage tank and paddy command area. The local control provides the potential to respond to incident rainfall, as well as variation in crop establishment, and minimizes the hydropower generation from the diversion's impact on irrigation management below individual tanks.

Much of the area is organized into settlement projects with fixed allocations to individual farmers on 99-year leases. The size of land allocated depends on the time of initial allocation and varies from 0.8 - 2 Ha. With the double cropping potential made possible by the Mahawali project, and the command area now covering much of the landscape, those farmers within the scheme are expected to be full-time rice farmers with only minimum cropping activities outside the scheme.

Water is distributed by gravity to the top of the catena and flows to the bottom. It is released in two water issues per year corresponding with the "Maha" and "Yala" cropping seasons, the major and minor rains. The Maha issue is longer with the expectation of growing medium maturity BG 11-11 rice, while the Yala is shorter for growing BG 34-8, an early maturing variety. There are two phases to each issue. The initial phase is one month of continuous flow to allow extra water for land preparation. This is followed by a rotational flow for the balance of the issue corresponding to the main rice-growing period, from transplanting to maturity.

The farmers are organized into cultivation committees that are promoted as having inputs into the management of the scheme and timing of each water issue. The irrigation officials do meet with the cultivation committee prior to each issue. These become general meetings that allow the farmers to voice concerns. At the end of the meeting the irrigation authorities simply stated when the water issue would begin irregardless of the discussions. It was very much imposed.

Traditional Small Irrigation Tanks in Sri Lanka

In areas outside the Mahawali scheme, there are still a large number of small- and medium-size tanks representing the more traditional smallholder irrigation systems of Sri Lanka. In most of these systems, the farmers operate a combination of paddy lands below the tank and upland crops in the lands to the side of the tank (Fig. 8.2). The upland area may be 2-3 times the paddy area.

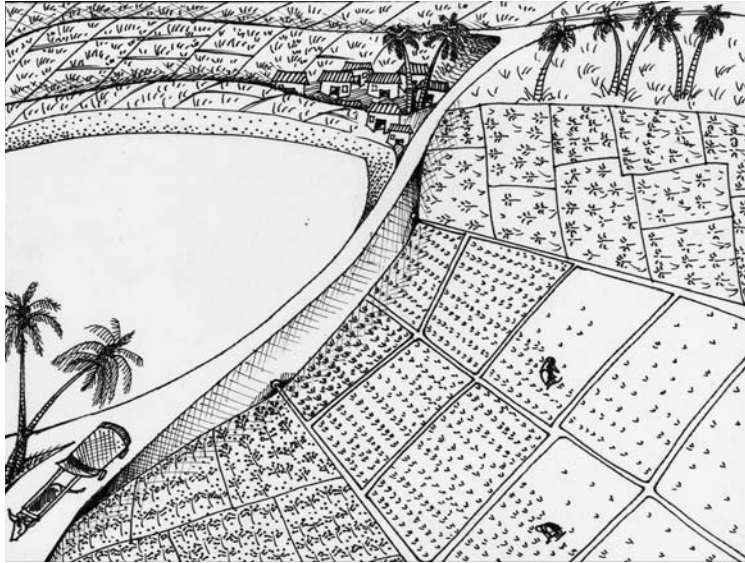


Fig. 8.2 The tank system of Sri Lanka combining late planted paddy below the tank and early planted upland crops surrounding the tank.

At the beginning of the season, there is competition between the upland and the paddy for the available operational resources, such as labor and power. As the tank extends the growing season, and thus provides flexibility not available to the rain-fed upland lands in the Cheina, farmers must give initial priority to the Cheina crops or the opportunity will be lost. Only after the Cheina is established and under control will the farmers become interested in paddy production using the tank water to extend the rice cultivation into the dry season. The delay prior to paddy cultivation could be as much as two months after the onset of the rains.

The government's rice production program concentrates entirely on

rice production while ignoring the Cheina production. The government promotes early establishment of rice in expectation of getting two crops, one rainfed while the tank fills, and the second, irrigated. However, they only offer the farmers a suppressed ceiling price for the rice. Meanwhile, the farmers concentrate on their Cheina crops during the rainy season and only become interested in rice after the rainy season using the tank water. They thus appear to be not co-operating with the government's rice production program. However, the farmers are most likely simply optimizing their total returns including the value of chilies as a cash crop. The government needs to appreciate the Cheina's contribution to the farming system and adjust their expectations accordingly.

The Small Irrigation Systems of Malawi

Rather than a single large system, Malawi has a series of small systems located on streams coming off the Rift Valley escarpment and flowing into Lake Malawi. These systems vary from 100 - 400 Ha with a total of only 1,100 Ha. Most of the schemes were developed with Taiwanese assistance. The command areas are uniformly allocated to farmers in one-Ha allocations. They are all run-of-the-river diversion systems with no storage structures and thus have a rapidly declining water supply during the dry season. There are plans for a medium-size scheme in the lower Shire Valley serving some 26,000 Ha, but the plans are postponed because of environmental assessments. Even though maize is the staple crop of the country, the irrigation schemes are devoted exclusively to rice. There is also some 30,000 Ha of rain-fed rice grown near the lakeshore.

The government has committed considerable resources in their attempt to get these schemes operating effectively. This includes more extension workers and research efforts focused on the 1,100 Ha of irrigated lands than the 30,000 Ha of rain-fed rice. However, farmers rarely start preparing the irrigated paddies until 6-8 weeks after the irrigation managers anticipate.

In what may be comparable to the paddy versus Cheina lands in Sri Lanka, the farmers are giving priority to their rain-fed holdings outside the scheme, either maize or rain-fed rice. Only after these crops are established, will attention be given to the irrigated land. For this reason, the dry season utilization tends to be higher than the rainy season, but never exceeds 50%.

As in Sri Lanka, the flexibility provided by the irrigation water results in the farmers giving the irrigated land second priority to the

surrounding rain-fed areas even though the potential yield is higher under irrigation. If they did not give priority to rain-fed areas, the opportunity would be lost. Again, they *are optimizing their total returns to all potential farm enterprises*. To get farmers to give priority to the irrigated areas, the land allocations would have to be increased sufficiently for irrigated rice cultivation to be the full-time crop enterprise. That would require approximately 5 Ha and would reduce the number of settlers by 80%. Five Ha is typically what full-time rice farmers in Thailand manage.

Irrigation in Thailand

Thailand has developed a series of medium- to large-scale irrigation schemes along the Chao Phraya River, multipurpose schemes designed for rice production, power generation, and flood protection for Bangkok. The intent is to provide two rice crops per year. However, the farmers have improved on this so they are producing five crops every two years, while reducing the area cultivated to lower-yielding intermediate deep-water rice.

While the water release is organized around two cropping seasons, most of the time it is possible to see rice in all stages of development. This is accomplished by some informal reallocations of water within the system. Farmers, particularly in the tail areas, pump water from the drains or from shallow wells, and shift to early-maturing varieties, which save approximately one month of crop time and water use.

The WUAs, which were decreed into existence, are basically defunct with many farmers not aware that they are members. Canal maintenance is minimal with many canals silted at the tails, the water diverted to the drains at some point in the system, and the tail farmers pumping from the drains. Also, farmers with large areas directly outside the command areas of the main canal will frequently pump water directly from the canals. The irrigation managers seem unable to curb what is basically stealing water.

Irrigation in Tanzania

Like Malawi, most of the irrigation schemes in Tanzania are intended for rice as the secondary staple crop. Most of the official schemes are medium-size with an average command area of 3,000 Ha, originally intended to be state farms.

When state farms proved ineffective, the newer ones were

designated for smallholder use with allocations of 1 Ha/farmer. These allocations were anticipated to be in addition to the other primarily rain-fed lands the farmers were already managing.

Often, the management staff is allowed to cultivate several Ha within the scheme for personal use. The schemes are upstream, rather than downstream, of major storage structures designed for hydroelectric power and municipal use.

The diversion to an upstream scheme limits the water available for hydroelectric generation and other urban needs. The schemes are basically run-of-the-river diversions, without storage facilities, and thus good only for one rice crop per year. The cool temperatures associated with the 1,000 m elevation also restricts the second non-rice crop potential that was originally envisioned in the feasibility study that justified the donor loan.

The Madibira Smallholder Agricultural Development Project is the most recent of these schemes. The 3,000 Ha-scheme is divided into 100 30-Ha tertiary blocks intended for 30 individual farmers. Water is delivered by gravity to the high point of the block and the farmers are responsible for constructing the tertiary canals plus three field canals and then take responsibility for distributing the water among the 30 farmers and maintaining the canals.

The land is owned by the government, which would, in principle, provide opportunity to evict any farmers not meeting their obligations to the project in terms of user fees. During the first two seasons no fees were charged, but this is expected to change during the third year after donor funding ends.

In addition to these medium-sized official schemes, there are a multitude of unofficial schemes that farmers have developed on their own and that are basically stealing water from the rivers. The authorities cannot effectively prevent this. One of these is just downstream, and across from the Madibira Project. It involves some of the farmers who later joined the Project. It was built without any engineering assistance about five years prior to the Madibira Project by a group of 70 farmers and includes two concrete diversion weirs for diverting water. It commands some 200 Ha (Photo 8.3).



Photo 8.3 Concrete diversion into informal irrigation scheme near Madibira in Tanzania.

Summary of Smallholder Irrigation Schemes

Different countries adopted irrigation strategies unique to their needs. The only common features are that larger schemes are publicly owned and managed with the farmers usually dealt with more as a group than individuals, and with little concern for the actual amounts of water delivered to individual farms. They are usually surface systems, using “level” basins, more often under gravity than lifted, and with the irrigation management somewhat out of touch with the producers. The farmers in turn have adjusted with some informal modifications to the system, but not exerting much effort on maintenance of canals or drains. Thus, while the original engineering designs have often been compromised over the years, water flows through the systems in some manner and is eventually utilized by some means, and crops are produced.

THE LINKS BETWEEN MINISTERIES AND SMALLHOLDER IRRIGATION SCHEMES

As many publicly owned irrigation systems are associated with

multipurpose water resources development projects, the administrative links are often outside the Ministry of Agriculture, even though most of the water is ultimately for agriculture. Irrigation departments are usually part of a Ministry of Power and Water. Even in the USA, the large irrigation projects are more often than not developed by the Federal Department of the Interior or the US Army Corps of Engineers instead of the Departments of Agriculture. This makes for a major administrative division and unfortunate administrative distance between the irrigation administration and the producers using the water for growing crops.

Multi-Use Storage Reservoirs

With the irrigation operations in a ministry other than agriculture it is difficult to envisage smallholder farmers having much influence in the overall operation of the system, even if the stated policy is for irrigation to have priority for non-domestic water use, as is the case in Thailand. The internal government administration and communication links usually favor non-agriculture users. Requests for adjustments in water release coming from a colleague within their own ministry, and speaking in good clearly understandable physical engineering terms would carry more weight than someone outside their ministry.

In contrast, how could an engineer justify the request of any of a multitude of smallholders presumably acting as individual entrepreneurs? Even attempting to communicate effectively to this multitude is a bewildering task, if it implies directly contacting each smallholder.

Power demands tend to be far more uniform than the seasonal variation in crop water requirements, compromising the effectiveness of the water released for power when used for irrigation purposes. Flood mitigation has to be considered in macro-economic terms, in which diverting flood waters through an irrigation system onto agricultural lands is far less damaging than either the economic loss or human suffering in allowing wide-scale flooding in metropolitan areas downstream.

In addition, as mentioned previously, most government decisions are biased toward the urban sector with their increased population density, proximity to centers of authority, and potential for civil disruption. For these reasons, *multipurpose water management is more than likely to favor urbanites over rural dwellers.*

Limited Farmer Involvement in Macro-Management

Crop irrigation information utilized in irrigation management in operating a large multipurpose system will more likely come from the Ministry of Agriculture personnel than from an individual or group of farmers. The information obtained from the Ministry of Agriculture therefore often expresses the ideal on-farm conditions according to recommended crop husbandry, rather than the farm-level reality. Usually, there is a spread of 4 – 6 weeks between the anticipated time according to recommendations and the actual time for a given cropping activity.

With large multi-purpose water projects that include major irrigation schemes and involve multiple ministries, the following administrative division of responsibilities is the most logical:

- The irrigation delivery is handled by engineers with their understanding of hydraulics and water flow through canals.
- The water application is handled by agronomists in the ministry of agriculture.

Division of Responsibilities

The two components, delivering water and applying the water, to irrigated lands are really separate disciplines. Since crop water requirements depend more on climatic factors than a crop factor, there is little difference between the water demands for high-yielding and low-yielding crops. A difference which is usually less than most smallholder surface irrigation systems can effectively respond to.

Thus, while there may be some synergy in administratively combining the water delivery with crop production, it is relatively minor and rarely worth the extra effort to bring the two ministries together. Farmers seem able to adjust to the reliability of the water they are provided, and can be very resourceful in getting the water they need, particularly those at the tail of the canals.

The economic benefits to irrigation are best measured by crop yields, rather than the amount of water applied. With nearly equal amounts of water required for low and high yielding fields, the returns to water are greater for the higher yielding fields. However, for a given means of water management, yields are associated with soil type and other crop husbandry activities, none of which has an impact on water management, or at least a level of water management for which smallholder systems can adjust. Without a major concern for

measuring water to individual farms, the irrigation management is not really concerned with an individual's returns to water. They are more concerned with simply getting water delivered to the farm gate or at least to the tertiary canals from where individual farmers obtain their water and are expected to co-operate in its distribution.

The Egypt Water Use and Management Project's (EWUP) seven-year effort to develop a commonality between the Ministry of Irrigation and Ministry of Agriculture, starting with a common minister holding both portfolios, ended with the ministries even further apart.

LIMITATIONS TO PUBLIC SECTOR MANAGEMENT

As most large systems are publicly owned and operated, they are subject to the same limited-resource, high-overhead management common to developing countries' government. Resource limitations in which most funds are consumed by salaries so that there are very limited funds available for operational costs. This has resulted in a rather complacent management largely confined to offices, without the resources to communicate with the farmers, and with little incentive to do so.

The irrigation operation budgets are further restricted if the water is provided free to the farmers. Thus, the financial support for the actual management and maintenance of the irrigation systems often must come from central funds, vying with the rest of the government's budgetary needs. This is a situation that often results in insufficient funding and substantial deferred maintenance until a donor can be identified for a complete rehabilitation.

For these reasons, the *irrigation management is frequently out of touch with the producers*. This is illustrated in Thailand (Fig. 8.6), where the growers are lagging behind the anticipated paddy establishment by 2-3 weeks, typical of many smallholder systems. However, at the other end of the season the farmers have finished harvesting 2-3 weeks before the anticipated date. This can only be realized if the growers shifted to a new variety, which matures approximately 4-5 weeks earlier. Also, the paddy land was expanded by some 25% indicating an encroachment of paddy into areas originally intended for non-paddy use.

This is a rather typical occurrence within smallholder irrigation schemes. In Sri Lanka, the encroachment was into lands set aside for communal grazing within the settlement area, while in Thailand it could be the land outside the scheme that was receiving pumped water. The completeness of the shift to early maturing varieties and

encroachment of paddy areas shown in Fig. 8.3 would imply that this occurred several years earlier, while the management plodded along unknowingly using an out-of-date perception of farmers' cropping calendars and actual water needs.

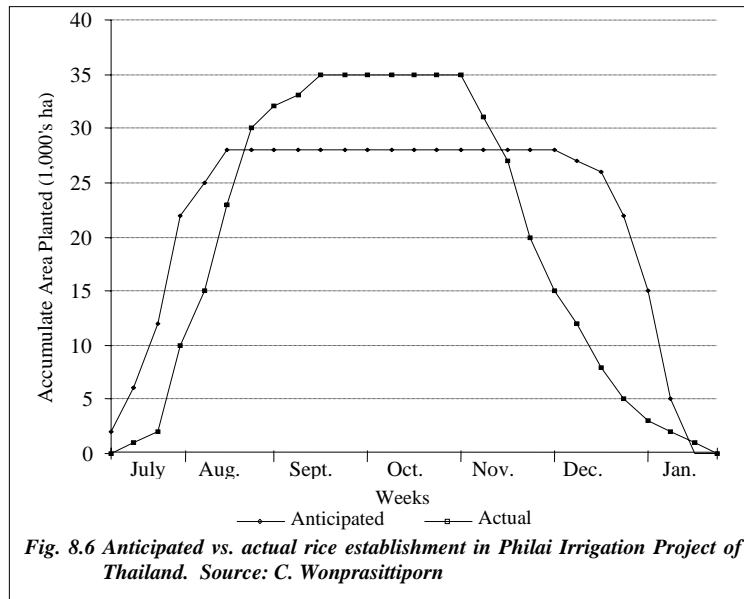


Fig. 8.6 Anticipated vs. actual rice establishment in Philai Irrigation Project of Thailand. Source: C. Wonprasittiporn

Another example of the difference between irrigation management and farmer crop management is the Tambraparani Irrigation Scheme in Southern India (Brewer *et al.*, 1997). This scheme continues to operate under rules established in 1935 when the scheme was first constructed and used exclusively for rice. However, most of the lower third of the scheme converted to bananas years ago. During the irrigation off-periods between the anticipated rice crops, the bananas are stressed which decreases market value. However, the irrigation management maintains their commitment to rice irrigation as the system was originally designed, and seems unable or unwilling to adjust their management to keep up with the evolving cropping systems.

PROFESSIONALS INVOLVED IN IRRIGATION MANAGEMENT

There are normally four professionals associated with irrigation management: engineers, agronomists, economists, and sociologists. Since few developing countries' education systems offer agricultural engineering degrees with a specialization in irrigation and water management, irrigation engineers are usually civil engineers, with some additional training in agricultural engineering and hydraulics.

Engineers

Irrigation engineers are usually more interested in the construction and operation of physical structures, than in crop management. Engineers are by far the most influential professionals working in irrigation management and normally hold the most senior positions. In some countries, engineers, because of their presumed technical skills associated with building physical infrastructure, can have an enhanced professional status over other disciplines.

In Egypt, engineers often use the honorary address "Bey" in discussions among themselves. In status-conscious societies, the enhanced professional status of the engineers over their non-engineer colleagues, combined with the normal top-down management style, can result in a basic contempt for the poorly educated "peasant" farmer. The general attitude is that "the irrigation engineers know best how to operate the system and the farmers had better comply with their water management program."

There is little appreciation for the compromises the farmers have to make that limits their ability to comply with the engineers' best efforts.

Economists and Sociologists

The second and third ranking professionals are normally economists and sociologists, as their contributions can directly affect the engineering operations. Economists are normally involved in cost benefit analysis of the crops. The engineers are very much interested in this analysis as a means of estimating how much farmers can afford to pay for irrigation.

The sociologists' intents are to organize the farmers. Again, with the top-down management style of developing country governance, this frequently means trying to compel the farmers to accept what

management – i.e. the engineers – deem appropriate, with little concern for farmers' opinions that could lead to more effective management, or better understanding of the farmers' compromises in basic crop husbandry.

Agronomists

At the bottom of the management hierarchy are the agronomists, whose role is to represent the crop. Their expected primary input is to determine the crop water-requirements or water duty. Normally this is done from experiment station evaluations and represents ideal timing. After this, they usually have nominal input into the actual management of the systems, which is consistent with the generally-accepted partition of responsibility between ministries of irrigation and agriculture.

With water flowing down the system, this transfer of responsibility comes at the field canal or farm gate. Getting water to the farmers is the engineers' responsibility, while applying water to the crop is the concern of the agronomists.

Thus, the agronomists only become concerned after the engineers' responsibilities are completed, and they have relinquished interest in what happens to the water.

This is also consistent with the limited differences in water requirements for low- or high- yielding fields, or difference in crop species other than rice.

The engineers managing irrigation schemes have only limited interest in the other aspects of crop management such as fertilizer, varieties, and plant protection as these do not have a major impact on crop water-requirements, at least within the limits the system can respond. The engineers will only again become concerned when excess water enters the drains and has to be conveyed out of the area.

CONSIDERATIONS IN MANAGING SMALLHOLDER IRRIGATION SCHEMES

To effectively develop and operate an irrigation scheme for a multitude of smallholders, it is necessary to consider several factors. Since most of these factors interact, it is always advisable to use a systems approach.

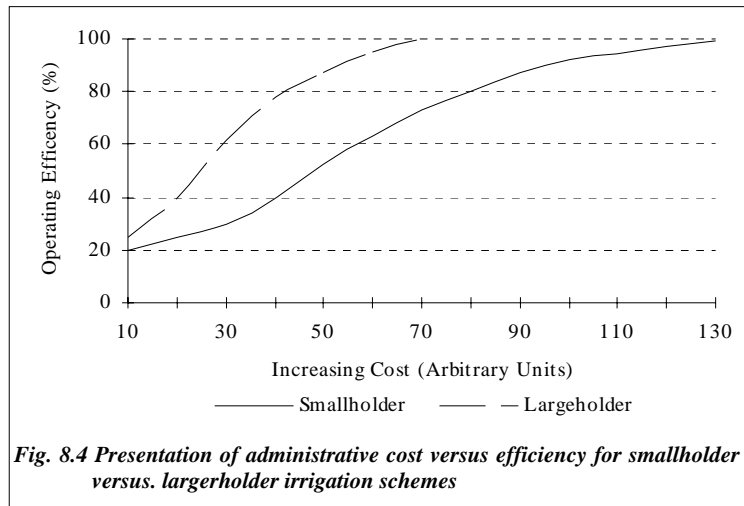
Administrative Costs

From the management perspective, an irrigation system can be operated at any level of water-use-efficiency, provided farmers and managers are willing to pay the cost associated with each increase in efficiency. The ultimate extreme is to let the water flow where it will, as in the wild flood irrigation for pastures in Gunnison, Colorado. The other extreme is the minute monitoring and replacement of what individual plants consume, as in a Japanese bonsai ornamental garden.

Similar to the problems of licensing and regulating crop protection chemical usage as discussed in Chapter 6, the administrative cost of any operation, including irrigation systems, is associated more with the number of people dealt with than the area covered, in what is most likely an exponential function.

Thus, a smallholder system will inherently have a higher administrative cost for the same level of efficiency than a largeholder system (Fig. 8.4), and the optimal operational level for smallholder systems will be both more expensive and less effective than for a corresponding largeholder system. At a reasonable administrative cost to the system as a whole, it is possible to provide water on demand to larger holders as is common in the USA. However, the administrative cost per individual served could be fairly high while the administrative cost per Ha served low. Transferring this intention to a smallholder system, the cost may become prohibitively high, and not recoverable from any increased agronomic output associated with the improved irrigation efficiency.

In developing a management strategy for improving a smallholder irrigation system, it is important that the administrative cost associated with improving the efficiency is less than the increase in agronomic output resulting from the improvement.



Administrative Costs in the Salt River Project

An example of how the administrative cost increases as the users become smaller, and how this impacts on the management of the main system, is the Salt River Project in increasingly urban Phoenix, Arizona, USA.

The Project takes pride in its computerized control room that remotely monitors and adjusts the flow according to the demand of individual users. In accordance with the historic water rights of the area, the Project is required to provide 60 cm of water per year to its entire command area, urban and rural alike. Unlike Colorado, the water rights are attached to the land and cannot be sold, bartered or traded. The Project has no problem in providing an “on-demand” delivery to its large agricultural users, but reverts to a two week rotational system when obliged to provide canal water to individual homeowners in urban subdivisions. In addition to the administrative costs associated with dealing with individual homeowners, there is also the physical concern for conveyance losses if an entire canal has to be filled to deliver water to one homeowner with a lot of 0.1 Ha. If homeowners were dealt with individually, such conveyance losses could easily exceed the water being applied.

The Project maintains a token concession to their demand framework with sign-up sheets to confirm that a homeowner really wants water at the allocated two week intervals. In the desert

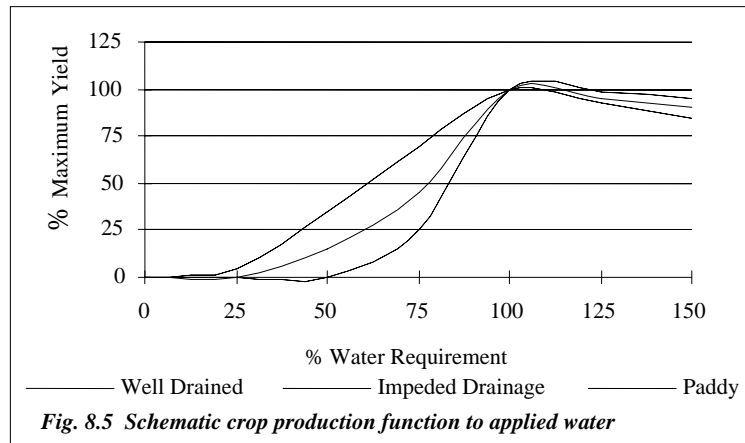
environment of Arizona with summer temperatures often exceeding 40°C, it is difficult to imagine anyone not accepting water offered only once in two weeks. Even then, many homeowners opt to hire small irrigation companies to manage their water at \$10 per delivery. This assures the homeowners that they do not have to get up in the middle of the night to apply a half-hour of irrigation water to their yard. The additional cost for managing the delivery to an individual home is not part of the Project operational cost, but certainly is for the homeowner paying it. Adding the cost of the irrigation distribution company to managing the water delivery, increases the overall cost of lawn watering to homeowners to perhaps some of the most expensive surface irrigation water in the country. More recent subdivisions have done away with the ditch water and water their lawn with municipally-treated water up to their 60 cm limit.

Crop Response to Water

In developing an irrigation management plan, an important input is the crop production function to applied water. This can be done generically by examining a plot of applied water as a percentage of the crops needs ranging from 0 – 150% of the requirement versus the maximum yield ranging from 0 – 100% (Fig. 8.5). By definition the graph would have no yield with zero water applied and 100% maximum yield at 100% of the water requirement. The graphs would decline on both sides of this value. The important sections of the graphs would be as they approach and exceed 100% of the water requirements. In this section of the graphs the yield loss is considerable higher for applying less than the required, than applying more than required.

For most upland crops growing in well-drained soils, there are normally very little yield losses for excess applications of water until the soil becomes saturated and anaerobic. The only yield loss is from leaching of nitrogen and other mobile nutrients, or perhaps excessive weed growth.

However, well-drained soils there can be severe yield losses associated with drought stress even when applying only 10 or 15% less water than required. These losses rapidly increase as the stress increases. For poorly drained soils the yield losses on the stress side are less, and that on the excess side more, but normally not sufficient to shift the emphasis to under-irrigation. The exception would be with severely impeded drainage with standing water for over 24 hours.



For rice, the tolerance to over-irrigation is even greater, while the losses for under-irrigating are more severe, primarily because many of the modern varieties were developed under well-ponded conditions resulting in an unintentional selection against extensive rooting systems and drought tolerance.

IRRI defines stress days for paddy rice as any day in excess of three that a paddy is not flooded. The stress days are accumulated over the entire season for each time the field falls dry and is closely correlated with yield. The three days correspond with the definition of field-capacity for a freely-drained soil, and the total amount of water normally available to upland crops.

Water Management Options

If smallholder producers operating within a rotational delivery system have the choice to irrigate early or wait until the next rotation when the crop will be stressed, they are, in view of the above, *better off irrigating early and applying excess water than waiting* and allowing their crops to become even slightly stressed. It is the most rational and economic option in the absence of fairly high volumetric water charges. However, while this may increase the number of irrigations farmers apply to their crops; it will not normally result in applying excess water during a specific irrigation.

Given the limited discharges normally available, the time required to get a wetting front to advance across a field, and the continued effort to redistribute water between small basins within fields, farmers are

normally anxious to finish the job and do not linger deliberately to apply excess water. The time spent channeling water among the small internal basins within a field may actually be the biggest disincentive for over-irrigating (Photo 8.4).

Smallholders are most likely also operating under substantial labor constraints and have ample other crop husbandry activities needing their attention.



Photo 8.4 Irrigating small in-field basins requires substantial labor and attention by the farmers and encourages them to finish as soon as possible as shown for Egypt. Photo Credit: W. Shaner.

Evapotranspiration and Crop Water Requirements

On the physical side of irrigation management, the starting point is an estimate of the basic crop water-requirements or water-duty. This is normally determined for an individual crop, with little attention to interactions between two sequential crops, and assuming a fully-recharged soil moisture profile at planting. The starting point is the evapotranspiration rate, which is the combination of water loss via transpiration from the plant and evaporation from the soil or ponded water surface in the case of paddy.

Physically, evapotranspiration represents a change in state of water from a liquid to a vapor. This requires energy, usually referred to as the “latent heat of vaporization,” approximately 535 cal/cm^3 or more than five times the energy needed to heat water from melted ice to just prior

to boiling.

This extensive amount of energy must come from external sources. The primary source is solar radiation, which falls uniformly over the entire landscape regardless of an individual crop or water surface, falling equally on well-managed high-yielding fields and more casually-managed lower-yielding fields. This is why *higher-yielding and lower-yielding crops require nearly the same amount of water*.

It is estimated that only three percent of incident solar radiation is captured in photosynthesis. Some of the non-adsorbed radiation reflects back toward space, depending on the albedo or reflective value of the crop canopy. Then the great majority of the radiation, particularly for agricultural crops, is utilized for evapotranspiration, which serves as the plants' cooling mechanisms.

If not utilized for transpiration, the energy is converted to sensitive heat and could result in heat build-up to hinder the metabolic processes within the plant. Since the stomata through which transpired water leaves the plant are also used for CO₂ entering the plant, and since most agricultural crops are selected for their ability to convert and store photosynthates requiring as much CO₂ as possible, most crops have similar green colors with similar albedo values, so they transpire freely at similar rates.

The Penman Formula

There are many formulas for computing potential evapotranspiration. The most common is the Penmen equation, including several modifications and refinements. Most of these equations require extensive climatic measurement which have to be obtained from the nearest meteorological station, which in developing countries could be far from the scheme.

Typical climatic measurements include temperature, relative humidity, wind, radiation, hours of sunlight, and pan evaporation, etc. This is very much a micrometer type measurement. The data collection is usually relatively expensive, particularly for the initial capital cost to purchase and install the equipment. The daily collection of data is relatively easy but does require some diligence to ensure readings are made every day at the same time. This is difficult to ensure, and most developing country climate databases have substantial missing values.

Box 8.2 The Penman Equation

The typical Penman equation is:

$$E_{to} = c[W * R_n + (1 - W) * f(u) * (e_a - e_d)]$$

Where: E_{to} = reference crop evapotranspiration, W = Temperature related weighing factor, R_n = net radiation in equivalent evaporation in mm/day, $f(u)$ = wind related function, $(e_a - e_d)$ = difference between the saturation vapor pressure at mean air temperature and the actual vapor pressure of the air both in mbar., and c = adjustment factor to compensate for the effect of day and night weather conditions.

Source: Doorenbos and Pratt, 1977.

Effective Utilization of Analysis

Communications are often too limited to make it difficult to use current data. Computations are thus usually based on long-term averages and do not take into consideration any seasonal variations. Even if current climatic information were available, *few systems can effectively adjust to the annual variations in evapotranspiration rates.*

There are usually some default values that are utilized for missing data. However, use of default values can only reduce the overall accuracy of the estimates. A “crop factor” is applied to these climatic computations of potential evapotranspiration. It measures canopy closure, a value that usually approaches one as the canopy closes, perhaps one month after planting, and remains one until crop maturity and senescence. Thus, in the middle of the cropping season most crop water-requirements are similar for unstressed-crops associated with irrigated agriculture.

Most of the differences in water requirements for crops grown during the same season are more related to the differences in crop duration than differences in daily rate of water loss. For example, a medium-maturing maize variety may require 120 days to mature while cotton will require 180 days.

Cotton thus requires more water and has a higher water duty, but during the middle of the season, while both are in the ground, they will transpire at similar rates. In addition to the basic estimate of crop water needs, a leaching factor is added to ensure that some water moves through the soil and removes any salt accumulations. *This rather nebulous factor reduces the detailed computations to a fairly rough estimate.*

Inherent in these computations is an assumption of the planting date. This information usually comes from agricultural research or extension staff, rather than farmers. With most smallholder producers the

planting date will range from the recommended date to six weeks late, with an average of four weeks late. Thus, the crop is actually grown in a somewhat different climate to that anticipated by the water-requirement estimation. This would be most apparent for the initial irrigations. Since most farmers at this time are still involved in land preparation, the water would flow directly through the system into the drains and be wasted.

These estimates of consumptive-use are generally *far more refined than a smallholder surface irrigation system can respond to*, even if all the data is available. For farmers to effectively utilize the information for mid-season adjustments in irrigation applications, it has to be communicated to the multitude of growers, who rarely have phones or other means to receive information.

It really takes a drip system or a low-pressure sprinkler system to effectively utilize a detailed estimate of crop consumptive-use. With the exception of Jordan, smallholder drip systems are rare in developing countries. Even in areas of predominately smallholder agriculture, drip and sprinkler systems are normally associated with larger farmers, and thus outside the scope of this manuscript.

Box 8.3 EWUP's Evapotranspiration Estimates

Since Egypt did not have a complete set of climatic data, the EWUP project's evapotranspiration estimates were taken from Tucson, Arizona. While this represented a similar desert climate with at a similar latitude, Arizona is continental desert in a rain shadow from the Rocky Mountains with a relative humidity of 10 - 15%, while Egypt is maritime desert with the prevailing winds from the North off the Mediterranean Sea and relative humidity from 50 - 60% with daily dew condensation that often is not fully evaporated until nine or ten in the morning, even in summer. Such condensation would substitute directly for evapotranspiration. This makes for substantial reduction in evapotranspiration rates for Egypt compared to Arizona.

Given that the evapotranspiration energy is external to the crop and uniformly blankets the entire crop production area, perhaps the best, and simplest estimate of consumptive use with a reasonably direct measurement would be simple pan evaporation. It would be a challenge to find a smallholder surface irrigation system that can effectively respond to more detailed estimates.

Rice Water Requirements

The above discussion applies to upland crops. For paddy rice, it is

necessary to separate the crops' physiological needs for metabolism and transpiration from that associated with the paddy soil environment which needs to maintain a ponded water surface. As the energy for evapotranspiration is still external to the crop, the physiological needs of rice are the same as any other crop.

The water requirements for rice are mostly associated with keeping the water ponded in the paddy. This is essentially a soil factor associated with the steady-state infiltration rate of the particular soil, which in turn is primarily related to the soil texture or clay content. For most of the medium-to-heavy clay soils normally associated with paddy cultivation the steady state infiltration will be fairly slow and approximately equal to the evaporation rate.

Thus, *a fast estimate of rice water requirements*, in the absence of any infiltration data, *is double the evapotranspiration rate* or double the pan evaporation. This assumes that the soils were effectively puddle (a process that partially disperses the flat plate-like clay particles and allows them to become oriented parallel to the soil surface as they resettle, effectively sealing the soil and reducing infiltration).

The initial ponding of water is actually the peak demand, requiring a single application of approximately 20 cm with the entire scheme requiring this amount over a relatively short period. Thus, in designing an irrigation system intended for rice production, *the ponding requirements become the design criteria*.

Another aspect of paddy irrigation designed to maintain well-ponded paddies is that, with the free water surface on top of the soil but under the canopy, the paddy will lose water at both the peak upward evapotranspiration and downward steady-state infiltration rate. Since most paddies represent a perched water table, the steady-state infiltration would be unsaturated flow.

With both these values at a maximum over the entire scheme, any additional water entering the system physically has no place to go except to gradually move laterally until it reaches some form of drain. This may be why many smallholder paddy systems designed to meet the peak demand associated with initial ponding, appear to operate at considerable variance to the operators' expectations, and with little maintenance or farmer control. With no place to go, the water eventually works its way through the system.

Smallholder Water Delivery Systems

Once the crop water-requirements have been obtained, they have to be converted to a delivery procedure for the farmers so they can schedule their field applications. This is really a very crude conversion. Often

the hydraulics of the canal system equitably distributes water only when running at full design-capacity.

Any other flow level will favor the fortunate growers at the head of the system at the expense of those less fortunate at the tail. Thus, canals can effectively be either fully “on” or completely “off,” with no intermediate flows. Therefore, the accurate computation of water duty cannot be readily translated into an accurate water management plan for operating a canal system.

In reality, the computed water duty is little more than an estimate of the water farmers are expected to apply to a crop, and a check to ensure that the canals can convey sufficient water to meet the crop’s needs. This is very much a “micrometer versus chain-saw concept”.

The most common means of delivering water to smallholders is by rotation, placed in the secondary canal, tertiary canals, or individual farms. Such rotations can only roughly approximate crop water-requirements.

In Egypt, the rotation is placed in the secondary canals with the water flowing freely into the tertiary canals via open un-gated pipes of a diameter proportional to the command area. From the tertiary canals, farmers use simple pumps to lift water onto their fields.

The rotations are a ratio of on-days to off-days that is adjusted periodically during the year. Typically, the winter on-off rotation ratios are 1:2 such as 5-on days followed by 10-off days. In summer, this converts to 1:1 such as 7-on days followed by 7-off days or 4-on days followed by 4-off days in the case of rice.

Essentially, this provides non-rice crops with a similar amount of water as rice. Except for the rice rotation, this is a very rough approximation of water requirements specific to no particular crop, and *results in 30% of the annual supply of water flowing out of the command area and in the drains* as noted in Fig. 8.1. Egypt makes detailed computations of the water duty for individual crops, but is by no means effectively utilizing the information in operating the secondary canals where the rotation is implemented. Conditions are similar in most other countries.

During the past four decades, millions of foreign consultants’ hours have been spent on doing very detailed calculations, little of which have ever been used.

The Warabandi Rotation System of Pakistan

The Warabandi system in Pakistan and India is a rotational system applied to individual farms. It allocates the full flow of the tertiary canals to individual farmers once a week in proportion to their holding

on the canal. As such, it makes no pretense of being related to crop water requirements. It assumes water is a scarce resource that will not meet the entire crops' evapotranspiration requirement for the entire area. The Warabandi system simply attempts to equitably distribute this scarce resource.

During the two cropping seasons, farmers are expected to compensate for the water shortage by either reducing the area cultivated, allowing some water stress to their crops with accompanying yield reduction or obtaining supplemental water from tube wells, rainfall, or other sources.

The detailed computation of crop water-duties are intended only to guide farmers into more effective use of the water rather than making adjustments in the delivery system. The irrigation authorities' assumptions are that efficient water-use is a major determinant of crop selection, and water management and irrigation scheduling should closely follow estimated consumptive use, which as discussed previously, is not very practical.

The irrigation authorities are also very concerned with developing cropping systems that more effectively use the water during the crop conversion periods in spring and fall. This is a time when the farmers routinely block the inlets and allow their allocated water to continue down the main canals to eventually cause major flooding and salt build-up in the lower reaches.

Developing cropping systems to better utilize this water is not very practical as prior to harvest there will be 3-4 weeks during which the crop will still be occupying the land but requiring no irrigation water. This is the period when the crop is drying to a safe storage moisture content. Applying water during this period will be detrimental to the crop.

This is followed by the crop conversion period. In order for the land preparation the fields have to be dry enough for equipment to work in them, and an irrigation simply to dispose of the water will hinder the process.

The only irrigation required is the initial heavy irrigation just prior or after planting, when the now very dry soil has to be completely replenished.

Inexact Water Deliveries in the Madibira Rice Scheme

Another example of how detailed computations translate to inexact deliveries for a rice specific scheme is the Madibira Smallholder Agricultural Development Project in the Southern Highlands of Tanzania, a new 3,000-Ha run-of-the-river diversion irrigation scheme

allocated in 1-Ha plots grouped into 30-Ha tertiary units.

Design Considerations: After detailed computations of the evapotranspiration according to Penmen, the infiltration rate, the probability of effective rainfall, etc., both the design engineer and the consulting operations engineer computed the water needed to pond the entire scheme within 15 days (Vernes, 1998). The ponding requirement, while required for only 15 days, represents the maximum water requirement and becomes the basis for designing the delivery capacity of the canals, including the main, secondary and tertiary canals.

The result was a designed flow capacity of 2.5 l/ha/sec or 75 l/sec per 30-Ha tertiary blocks, which, if shared by four users, would provide 21.6 mm in 24 hours. This is approximately three times the post ponding estimated peak daily demand of only 6.8 mm divided between 3.8 mm for evaporation and 3.0 mm for infiltration, plus 30% for conveyance losses.

The need to meet the peak ponding demand, even though only required for a brief period, *effectively swamps the detailed computations* of crop water requirements during the growing period so that, once all paddies are flooded and water-use is at the peak evapotranspiration and infiltration rates, 2/3rd of all the water entering the tertiary canal plus 100% of any rain has to be discharged through the drains.

With the sophisticated duck bill weirs on the secondary canal at each tertiary turn-out to ensure equitable distribution along the secondary canals, and farmers operating the gates to the tertiary units, there is no effective means of reducing the water destined for the drains with the control structures intended for the systems managers to operate.

The farmers' management of the tertiary inlet gates was to leave them fully open all season. Fortunately, the whole scheme is constructed in an elongated bow in the river so the drains rather quickly lead back to the main river channel where it can still benefit downstream users. Given the depth of the drains dug to provide the material for the elevated canals, and the original wetland ecology of the area, the Project was most likely increasing the outward flow of water into the river. The individual farm rotation system proposed allows each farmer access to the water for 24 hours once a week, starting from the tail of the field canals. After allowing for conveyance losses, this provides each parcel with a minimum of 140 mm of water against a weekly demand of only 70 mm.

It should also be noted that the maximum demand is anticipated for

the first half of December, or shortly after the anticipated onset of the rains, when the long-term averages indicate that the stream flow just reaches the 80% probability of sufficient water for ponding the paddies. Since the expectation is for transplanted rice, the promotion of early nurseries in November represents a commitment to provide the necessary water for initial ponding in early December. As discussed in Chapter 2, this is a period when the annual variability in monthly rainfall approaches 100%. For Madibira, the rainfall incidents in the upper catchments during this period result in only a 2-3 day increase in divertible river flow before returning to base flow levels. This would not be a reliable enough flow to commit the entire scheme to initial ponding irrigation, a commitment that originated with the promotion of nurseries in November.

Actual Farmers' Demand: The farmers actually do not really make their nurseries until early December with their rice paddies established from January - February, in accordance to the typical spread in crop establishment. This delay and prolonged establishment period places the establishment into a more ensured stream flow period as well as dampens the paddy establishment hydrograph. The peak demand now spreads over 30 days instead of 15 days with proportionally lower peak water required. This flow could be easily accommodated with the normal operations of the canals. As with the mixed rain-fed/irrigated farmers in Sri Lanka and Malawi, during the early rains, the farmers are more concerned with their rain-fed maize crop establishment prior to the irrigated rice.

Effective Water-Holding Capacity

Theoretically, water, which adheres to the soil surface as a film of varying thickness, is available to the plants between the Field Capacity and Permanent Wilting Point of the soil. Field Capacity is the water remaining in the soil after three days of free drainage following an irrigation or heavy rain. It is given the value of $1/3^{rd}$ bar of tension. The Wilting Point developed through a very old greenhouse study in which plants were denied water until they irreversibly wilted. It has a value of 15 bars of tension. These two moisture contents can be fairly accurately determined with simple laboratory procedures and equipment.

According to the initial experiment on Wilting Point, the water is equally available to the plant between $1/3^{rd}$ and 15 bar tensions. However, as expected, soil water outside the greenhouse becomes

progressively more difficult for the plant to extract as the tension increases and the water film thins. Thus, it is often possible to demonstrate a yield response to keeping the tension below three bars.

The graph of tension versus volumetric soil water is curvilinear (Fig. 8.6). In the figure the volumetric water content at wilting point is approximately 30% by volume.

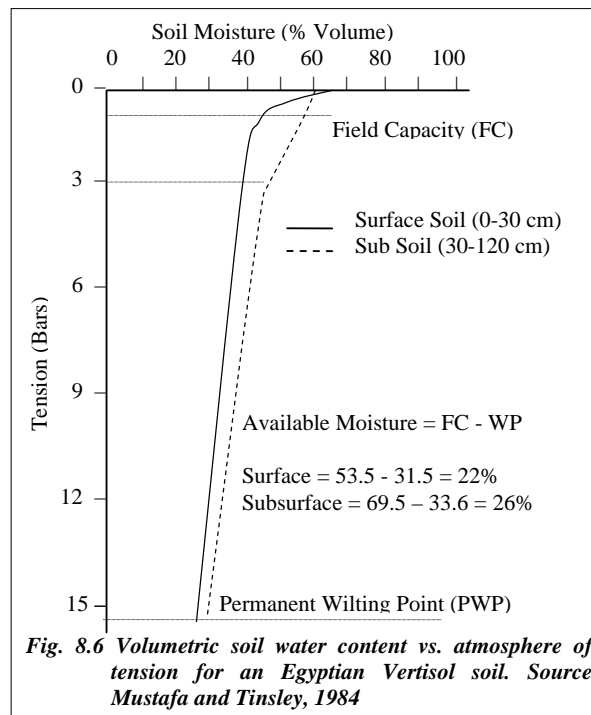


Fig. 8.6 Volumetric soil water content vs. atmosphere of tension for an Egyptian Vertisol soil. Source Mustafa and Tinsley, 1984

This increases to 54-60% by volume at field capacity ($1/3^{\text{rd}}$ bars) for the surface and sub soils, respectively. This represents a total available volumetric moisture content of 22-26% for surface- and sub-soils, respectively. However, at three bars the water content is 40-45% for surface- and sub-soils, respectively. The difference between Field Capacity and 3 bars represents nearly 70% of the total available water for both surface- and sub-soils.

Depth of Available Water

Soil water is three dimensional, and a big question is the depth of water extraction. Frequently, this is taken as one meter and assumed that all available soil water is equally extractable within that depth, which under rain-fed conditions may be the case. However, under irrigated conditions the root density varies considerably with depth in the soil profile, and perhaps more accurately reflects the soil water extraction pattern (Table 8.1).

Table 8.1. Root Recovery and Water Extraction for El Minya, Egypt					
Depth (cm)	Summer Crops		Winter Crops		
	Maize	Cotton	Wheat	Berseem	Faba Bean
Root Recovery (% per depth)					
1-10	59.6	65.9	44.2	30.0	30.6
10-20	21.3	19.1	3.9	18.9	16.7
20-30	6.4	7.1	36.5	22.2	11.1
30-40	4.3	3.2	3.9	7.8	5.6
40-50	8.4	2.4	5.7	5.5	2.8
50-60		1.6	2.0	4.5	8.3
60-70		0.7	1.9	2.2	11.1
70-80			1.9	3.3	8.3
80-90				5.6	5.6
Summary					
0-30	87.3	92.1	84.6	71.1	58.4
Water Extraction (% per depth)					
0-30		68.5	80.7		
30-60		19.7	8.7		
60-90		11.8	10.8		

Source: Moustafa and Tinsley, 1984

With the heavy clay Vertisols of Egypt, most of the roots are found in the top 30 cm of soil. This is particularly true for summer crops including normally deep-rooted cotton. As expected, the soil water extraction pattern closely follows the root concentration, and is also concentrated in the upper 30 cm. Thus, frequently, the soil is near Field Capacity between 60 - 90 cm depth, but near Wilting Point, and the crop under at least temporary mid-day water stress, in the upper 30 cm. For these reasons, the effective soil water-holding-capacity for heavy clay soils such as the Vertisols of Egypt may be limited to the upper 30 cm which means as little as 70 mm of water (Table 8.2).

Table 8.2. Operational Available Water for Egyptian Soils

Crop	Location	No. Irri.*	Cm Water/90 Cm Soil		Available Water
			Before**	After**	
Sugarcane	El-Minya	16	44.8 ± 2.3	50.6 ± 1.8	5.7 ± 1.5
Wheat		7	45.6 ± 4.0	51.1 ± 1.4	6.9 ± 2.3
Cotton		9	45.2 ± 2.0	51.2 ± 1.4	5.6 ± 2.4
Berseem	Mansouria	7	39.8 ± 3.0	44.6 ± 0.8	5.0 ± 3.1
Maize		7	36.4 ± 2.4	44.8 ± 2.3	7.4 ± 3.5
Wheat		5	40.3 ± 2.5	46.8 ± 0.9	6.5 ± 2.9
Wheat	Kafr El-Sheikh	5	40.9 ± 1.1	48.2 ± 1.3	6.8 ± 1.2
Sugarbeet		6	40.8 ± 2.8	48.5 ± 1.6	7.1 ± 2.8
Cotton		8	40.3 ± 1.6	46.8 ± 0.7	6.5 ± 2.0
Maize		8	41.8 ± 1.2	47.2 ± 0.9	5.3 ± 1.1

*No. Irri. is the average number of irrigations the crop received.

**The before and after represent immediately before the irrigation and three days after the irrigation, respectively.

Source: Moustafa and Tinsley, 1984

Minimum Irrigation Application

If the irrigation design parameters such as field size and available water were truly variable for smallholders as they are for large farmers, it would be theoretically possible to apply any amount of water a grower desires. However, with most smallholders field size is already fixed, and they have little control over the available discharge.

The only real variable under their control is the internal basins within a 0.5-Ha field; and that, only at the beginning of the cropping season. Rarely do smallholders have any control over the discharge reaching their fields during any specific irrigation. Such discharges can vary with the water source, and even during a specific irrigation as when someone either begins or ends an irrigation upstream.

Given the typical available discharge of 30 l/sec reaching a field or less, and field size of 0.5-Ha the minimum irrigation application to push a wetting front across a field will be 100 mm and take up to five hours to complete.

As this minimum irrigation was developed using the heavy clay soils of Egypt with very low infiltration rates, under normal circumstances for small basin irrigation, it would be a real challenge to apply less than 100 mm and have it equitably distributed across a field. It might be easier with furrow irrigation, but still a challenge. As this is usually done against only a 70 mm soil water deficit, as noted above, the 100 mm application depth is both the minimum and normal. It thus can be an effective planning tool for irrigation management, as well as

the 70% application efficiency it implies, for all but the initial application for each crop.

This represents application efficiencies considerably above the 35% typical of surface irrigations in Northeastern Colorado. The 100 mm minimum irrigation against a 70 mm deficit and the minimum relative yield loss to early irrigations versus more substantial losses to late irrigations greatly reduces the contribution of detailed crop consumptive-use computations.

The above discussion is for upland crops without any standing water. It will not hold true for paddy rice, as with the ponded water on the surface, it is possible to apply relatively small topping-up irrigations that will equitably spread-out across the paddy.

Crop Water Requirements versus Irrigation Requirements

In a continuous, all-year cropping environment, as found in the tropics or sub-tropics, there is a considerable difference between the crop consumptive-use as computed from a Penman formula and the irrigation requirements. This can make the computed water requirement misleading for irrigation planning. In temperate areas, where most irrigation technology was developed, there is a cold winter fallow in which there is minimal evaporation so that all incident precipitation from rain or snow readily infiltrates the soils and fully recharges the soil water profile at spring planting. This allows the irrigation season to begin with a fully-recharged soil profile from which consumptive-use accurately predicts the moisture withdrawal and irrigation scheduling can readily follow. However, in the tropics and sub-tropics with sequential crops occupying the land for most of the year, sequential crops strongly interact (Fig. 8.7).

The interaction relates to the irrigation needs to precede the consumptive use, the physiological changes in the crop at maturity, and the crop conversion periods. While crops are maturing, and the grain filling, they are transpiring water at their fastest rate and are most sensitive to water stress. As the grain filling reaches its peak, the crop physiological phase shifts to senescence and the drying of the grain to a safe storage moisture content. For most grains this would be from 25% moisture down to 13% moisture. This requires moisture stress for approximately one month prior to harvest. Harvesting grain prior to drying to a safe moisture content would require external drying facilities that are not readily available in most areas, other than for the last 2-3% that can be sun-dried spread on the ground.

Cotton requires some moisture stress to retain its flowers and promote

boll formation. If irrigated after flowers have developed, cotton will drop its flowers and return to vegetative growth. The result is that the last irrigation of cotton can be two months prior to harvest, and over three months before the initial irrigation of the following winter crops, such as wheat. Thus, the most rapid transpiration rate is immediately followed by a need to stress the plant at maturity to preserve the grain, etc. Additional irrigation water is not needed and rainfall can cause major problems. During the final grain filling and senescence period the crop severely depletes the soil water reserves.

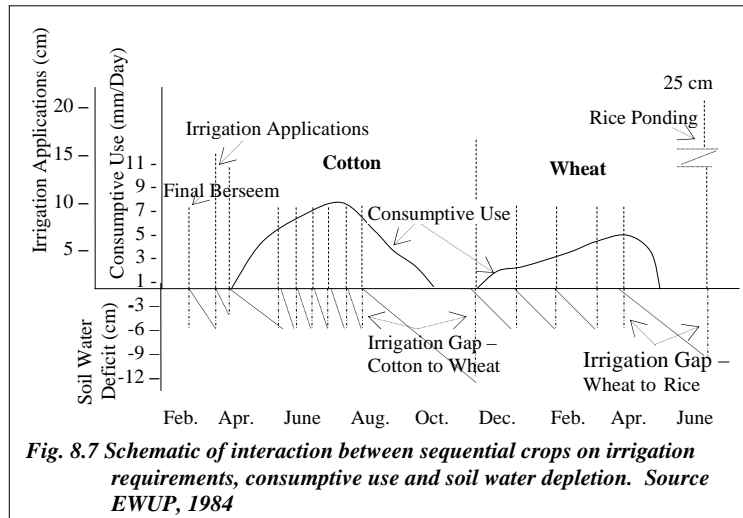


Fig. 8.7 Schematic of interaction between sequential crops on irrigation requirements, consumptive use and soil water depletion. Source EWUP, 1984

In order to establish the next crop, lost water should be replaced with a very heavy pre-planting irrigation at a time when the new crops' water requirements are minimal. The pre-planting irrigation is typically the heaviest of all, and normally the only irrigation that exceeds the 100 mm standard. Thus, during the two annual conversion periods between crops, totaling 5-6 months, *the irrigation requirements are the direct opposite of the consumptive use estimates*. Once the crop is established, the irrigation requirements will follow the consumptive-use estimates until flowering and grain filling.

Water Availability for Head- and Tail-end Users

It is virtually impossible to have any system serving large numbers of individuals that is truly equitable. The major inequality is usually

between the head and the tail of the different canals. The fortunate producers with holdings at the head of a canal have clear advantages in access to water over those at the tail. Those at the tail generally have to be more resourceful in getting an ensured water supply, endure some possible water stress, and may incur some additional costs.

Frequently, tail-enders resort to pumping water from drains and supplementary wells. Tail-enders tend to be somewhat later in their cropping activities than those at the head, often by an average of 2-3 weeks, and have measurably lower yields. Even the Wardibundi system of Pakistan and India with its proportional time allocation does not adjust for conveyance loss, leaving the tail-end with up to 50% less water, and heavier reliance on tube wells. All of this could result in some lower yields and most certainly lower profits.

Water is a physical entity that cannot be destroyed. Once it enters the system it can only leave as evapotranspiration, deep percolation, or run-off. The evapotranspiration losses associated with delay in water moving through the system are probably relatively small, as the entire area, canals and fields alike, lose water at near the potential ET rate.

Typically, canals including bunds or banks occupy about 10% of the area of which one third will be an evaporative water surface. Likewise, deep percolation will more than likely be under the slower unsaturated flow along the surfaces of the soil particles rather than the more rapid, saturated flow through the voids between soil particles.

Even paddies are normally not directly connected to the water table as indicated by the escaping air when an auger is pushed through the soil below the puddled layer. The deep percolation water will eventually recharge the groundwater and become available through wells.

Run-off water will usually move directly to the drains and be readily available to tail-enders for pumping. Thus, despite poor maintenance and limited organization, most of the water will eventually make its way through the system and be available to the tail-end users. Unfortunately, however, this is not always at the right time.

The Outflow of Irrigation Systems

For schemes that work with farmers collectively and with little concern for individual water rights, and individual cropping activities, the best means of evaluating the overall irrigation efficiency may be from the water leaving the system. It can be a good aggregate analysis of times when there is too much or too little water in the system, and thus an effective planning tool for future water releases. Removing any excess

water identified as going through the tail escapes should be the easiest water to remove from the system, as no one is interested in using it. Fundamental to this is the assumption that crop mixtures are reasonably stable from year to year, or at least evolving slowly.

While individual fields may rotate between crops, the total communal crop mix within a given watercourse remains fairly constant, particularly if grown primarily to field crops rather than horticultural crops. This reflects little more than the strong impact of market structure, including subsistence needs, as the final determinant in crop selection. The exception is for horticulture crops that can have some rather severe shifting with market conditions, as farmers rapidly respond to supply and demand pressures, often by over-correcting for shortages or surpluses from one season to the next. However, most horticultural crops are irrigated in a similar frequent manner consistent with the shallow root system and need for multiple harvests.

EVALUATING SMALLHOLDER IRRIGATION SYSTEMS

If the prevalent top-down approach to matching water-demand with water-supply results in the following:

- difficulties communicating with all the smallholder user;
- the need for only a collective approximation of farmers' irrigation needs;
- the spread of crop establishment over several weeks;
- difficulty in converting consumptive-use estimates to effective irrigation scheduling and canal operations; and
- substantial differences between consumptive-use estimates and irrigation requirements;

would a bottoms-up approach based on actual farmers' irrigation practices be a more effective management approach? Inherent in this approach is some confidence that the farmers will not abuse the system in terms of applying unnecessary water. Most detailed studies support this, if only because farmers are labor-scarce and do not have the time to spend applying excess water to their fields. They have other activities to attend to. The reality is that there may be no alternative to trusting farmers not to abuse the system, as it is impractical to supervise the multitude of smallholders operating within a system.

As it is equally impossible to assess all the individual needs of farmers, some means of sub-sampling are necessary; a simple set of farm records from a statistically sound sample of the area can be very effective. Such records could easily be collected and analyzed by the

irrigation managers with bi-weekly visits to the farmers or their fields. For irrigation management, farm records do not have to be as complex as the data sets typically required for full economic analysis. They only need to include the critical values needed for irrigation. This could be nothing more than crop, planting date, irrigation dates, and harvest date. In rice systems, it may only need to be planting date and variety, as modern non-photoperiod sensitive varieties have fixed maturity periods which can be projected within 2–3 days once the sowing date is known. It is also possible to extract the information from more detailed economic studies, as was the case with the example below.

It also does not require a large number of farmers to accurately represent an area. In Egypt it was possible for a 15-sample farmer case- study analysis, involving only 30 - 40 Ha, to represent 900 Ha or 500 individual farmers with an accuracy of over 95% for all major crops.

In addition, the farm records provided the critical time spread of crop establishment for each crop not readily available from a physical crop survey, but needed for accurate documentation of irrigation practices. The reason 15 farmers can represent 500 is, while 15 farmers do not make a sufficient statistical sample for economic purposes, the multiple parcels and subdivisions within the parcels they manage provide a statistically valid 60 agronomic samples. This, when combined with some simple monitoring of the water levels at the tail escapes to estimate the water leaving the area as an indication of when there is too much or too little water in the system, can become a simple effective irrigation management tool.

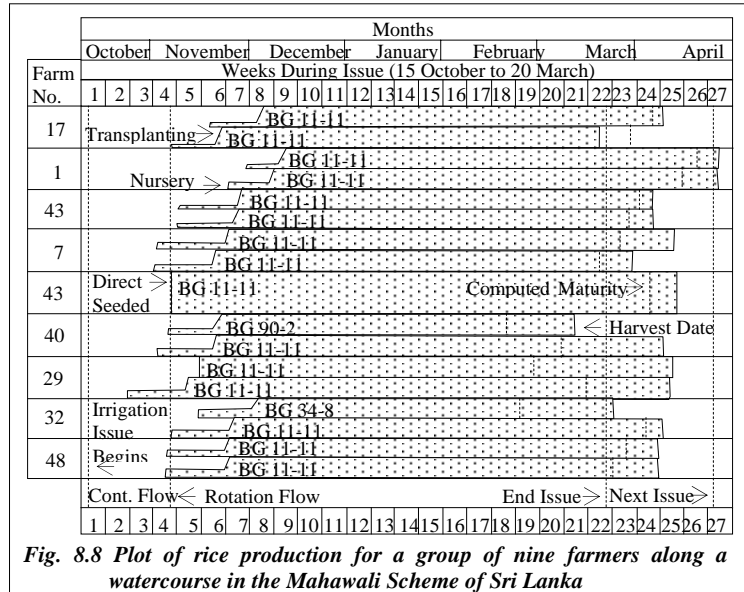
Example of Irrigation Management from Sri Lanka

In Sri Lanka irrigation is provided in two annual issues corresponding to the “Maha” or major and “Yala” or minor rains. The Maha issue is 22 weeks long designed for the medium-maturing BG 11-11 variety. The Yala issue is 18 weeks duration for the earlier maturing BG 34-8. Both issues are intended solely for producing rice. Each issue is also divided between a four week continuous flow periods to allow extra water for land preparation followed by a rotational flow for the balance of the issue while the crop is growing. Under these operational conditions a sample of nine farmers from the head and tail of the secondary canals were observed as to their sowing and transplanting dates, as well as rice variety. From the sowing date and variety, the maturity was computed. Subsequently, the actual harvest date was obtained.

Since the harvest is normally 2-4 weeks after maturity and

represents a period when no irrigations are required, the estimated maturity date is more important than the actual harvest for planning the end of an irrigation issue.

The lag time between the last irrigation at maturity and harvest is associated with the need to allow the grain to dry to a safe moisture content. The time for drying is relatively easy to estimate, but the harvest date can vary up to 2-3 weeks depending on individual farmer's ability to muster the necessary harvesting resources. All this information was plotted and compared to the irrigation issues (Fig. 8.8).



The comparison indicated that most farmers were 2 – 4 weeks late in getting their rice established, as all were planted after the shift to a rotational delivery. This brings into question the need for the one month of continuous flow. Most of this water may actually be wasted. Most farmers split their management into two units with approximately one week between them. This is most likely an expression of resource flow associated with contracted tillage as discussed in Chapter 7.

The companion set of farmers closer to the source did get their crops established earlier by a week or two. They established their rice only 1 – 2 weeks after the shift to the rotational delivery. Those farmers, that are particularly late, shift to the earlier-maturing variety, BG 34-8 or BG 90-8, and to direct-seeding rather than transplanting. This largely

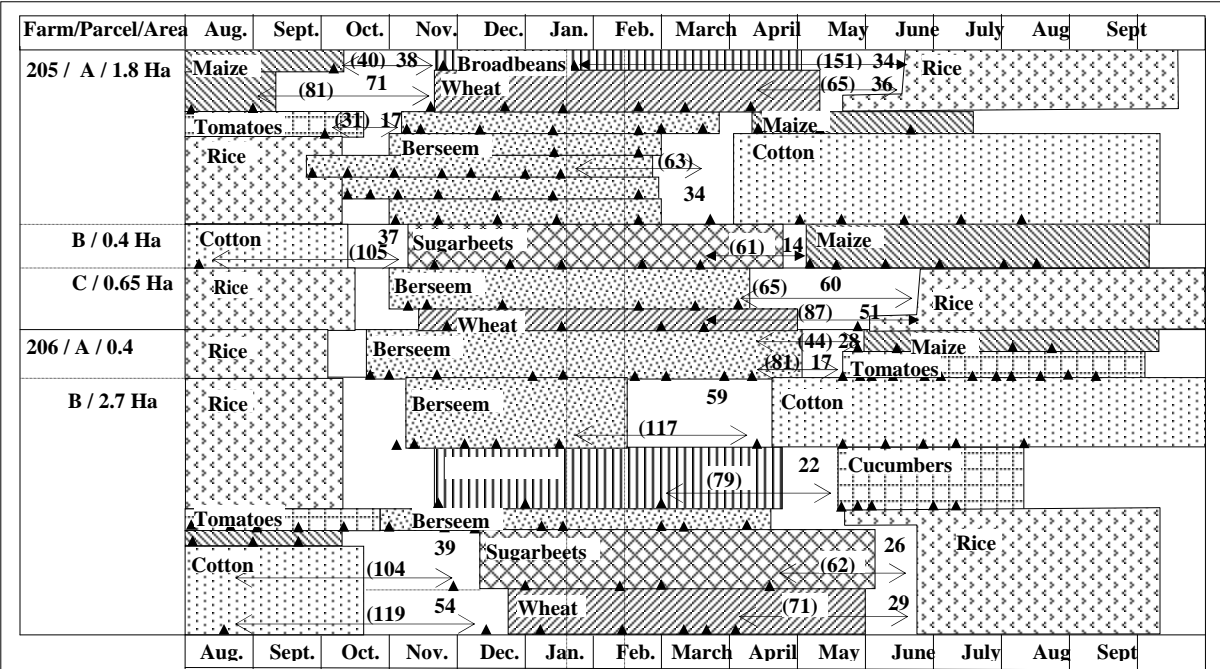
compensates for the lateness, and allows their rice to mature nearly on time.

As all this information was available by approximately week eight of the irrigation issue, it can be used for estimating the conclusion of the issue, and, after allowing for a reasonable time for harvest and post harvest processing, for planning the beginning of the next season's issue. The localized storage and control via the recharged tanks in the Mahawali systems makes this reasonably practical. In this instance, it is possible to immediately use the information within the current irrigation issue.

Example of Irrigation Management from Egypt

Egypt presents a much more complex situation than Sri Lanka, as there is continuous cultivation with a complete mix of crops in both summer and winter. However, an effective bottoms-up evaluation suitable for future irrigation planning is still possible. The data utilized in Fig. 8.9 was derived from a comprehensive set of 15 economic farm records. The information extracted was limited to crop, planting date, irrigation dates, and harvesting date. The data was again plotted on a crop calendar analysis similar to that used in Sri Lanka. The analysis indicates that, as with the farmers in Sri Lanka, planting dates were typically 3-6 weeks later than anticipated (Table 8.3).

In addition, farmers normally applied the expected number of irrigations. There was no abuse in terms of number of irrigations. It also showed considerably more rice than anticipated according to a government-mandated acreage allocation that was partly intended to prevent rice placing excessive demands on the irrigation delivery



(81) Irrigation ▲ Individual Irrigations Winter Closure 21 Turn Around Periods

Fig. 8.9 Crop Calendar for two farms in Kafr El Shiekh, Egypt, showing the complexity of the cropping system and the irrigations farmers applied to each field. Also shown are the irrigation gaps and turn around days between crops. Rice irrigations are excluded because they are too numerous.

system. Somehow, most of the rice paddies remained flooded throughout the growing season, even when grown at the tail of the tertiary canals.

Table 8.3. Egyptian Farmers' Planting & Irrigation Practices					
Crop	Anticipated*		Actual		
	Planting Date	Number of Irrigations	Range of Planting Dates	Average Planting Date	Number of Irrigations
Summer Crops					
Abu Raya, Kafr el Shiekh (Nile Delta)					
Cotton	16 Mar	9-11	25 Mar - 12 Apr	3 Apr	6-9
Maize	15 May	7-9	14 May - 7 July	9 June	6-9
Rice N.	1 May		18 Apr - 5 June	22 May	
Rice T.	1 June		15 June - 10 July	25 June	
Abyuha, El Minya (Nile Valley)					
Cotton	15 Mar	9-11	10 Apr - 2 May	24 Apr	9-12
Maize	15 May	7-9	16 May - 19 July	17 June	6-8
Soybean			29 Apr - 14 May	7 May	7-9
Winter Crops					
Abu Raya, Kafr el Shiekh (Nile Delta)					
Wheat	25 Nov.	5-6	7 Nov - 8 Dec	29 Nov	4-5
Berseem	1 Nov	9-11	14 Sept - 7 Nov	26 Oct	5-11
Faba Beans	20 Nov	5	12 Nov - 28 Nov	20 Nov	1-3
Abyuha, El Minya (Nile Valley)					
Wheat	23 Nov.	5-6	22 Nov - 19 Dec	30 Nov	5-7
Berseem	1 Nov.	9-11	5 Sept - 15 Nov	8 Oct.	9-15
Faba Beans	10 Nov.	5	25 Oct - 19 Nov	6 Nov	4-5

* Source for the anticipated information Master Plan for Water Resource Development and Use, MOI 1981.

One of the more important irrigation practices identified by the analysis was the “irrigation gaps” of up to four months when farmers were not interested in irrigating specific fields (Table 8.4). The best example was from the last irrigation of cotton in mid-August until the planting irrigation of wheat in December. The average cotton – wheat irrigation

gap was 105 days, nearly 3.5 months. Part of this is associated with the need for cotton to be water-stressed for boll retention and maturity.

First Crop	Second Crop	No. of Fields	Average Date		Days Between
			Last Irrigation	First Irrigation	
Winter to Summer					
Berseem	Rice	12	1 May	27 June	57
	Maize	6	18 April	7 June	50
Wheat	Rice	12	10 Jan.	24 March	73
		10	3 April	25 June	83
Faba Bean	Rice	2	4 March	25 June	113
	Maize	3	8 Jan.	26 May	138
Sugar Beets	Rice	4	10 May	23 June	53
Summer to Winter					
Maize	Berseem	7	6 Sept.	1 Dec.	41
	Wheat	2	7 Sept.		85
	Sugar Beets	1	11 Sept.	27 Nov.	77
Cotton	Wheat	8	10 Aug.	23 Nov.	105
	Sugar Beets	8	13 Aug.	10 Nov.	89
	Berseem	5	10 Aug.	7 Nov.	89

Source: Adapted From EWUP 1984

Similar gaps were noted for other crop conversions in both fall and spring; here, the total time for which no irrigation was applied could exceed five months.

Time Period	Ratio On-Days/Off Days	Total On-Days
Original		
16 Oct. to Closure	4/8	31
Closure		0
Closure to 15 March	5/10	10
16 March to May 25	7/7	35
26 May to 15 Oct.	4/4	71
	Total	147
Revised		
1 Oct. to 20 Nov.	4/12	13
21 Nov. to Closure	5/10	19
Closure		0
Closure to 15 May	5/10	30
15 May to 14 June	2/4	11
15 May to 30 Sept.	4/4	54
	Total	127
Percent Savings $[(147 - 127)/147] * 100 = 13.6\%$		

Source: EWUP 1984

The irrigation practices of individual farmers were combined into an aggregate demand for irrigation (Fig. 8.10). This showed that the lowest demand for irrigation was in October, at the beginning of the fall conversion, the time when most crops were still in the field drying or waiting for the multiple picks required for cotton. It is in contrast to January when the potential evapotranspiration is at its lowest, the irrigation demand was expected to be at its lowest, and the system is closed for a month of maintenance.

The aggregate demand also showed that, normally, in a two week period consistent with a complete on-off cycle, only about 50-60% of the area received irrigation. The exception is rice, which had multiple topping-up irrigations within the two week intervals of less than the 100 mm standard irrigation, and resulting in the irrigated area exceeding 100%. The aggregate demand analysis became a planning tool for revising the irrigation rotation schedule.

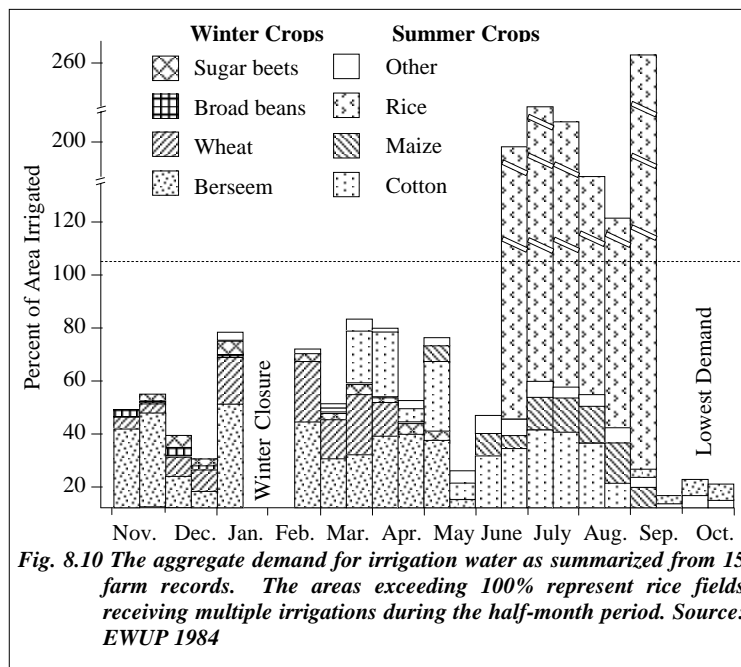


Fig. 8.10 The aggregate demand for irrigation water as summarized from 15 farm records. The areas exceeding 100% represent rice fields receiving multiple irrigations during the half-month period. Source: EWUP 1984

Such a revised rotation for Egypt's Nile Delta reduced the number of on-days by 20 days a year or over 13% (Table 8.5). The entire analysis was reflected by float recorders on the tail escape of the watercourse (Fig. 8.11). The first graph in April shows continuous overflowing

from 11 through 15 April even during the off-period.

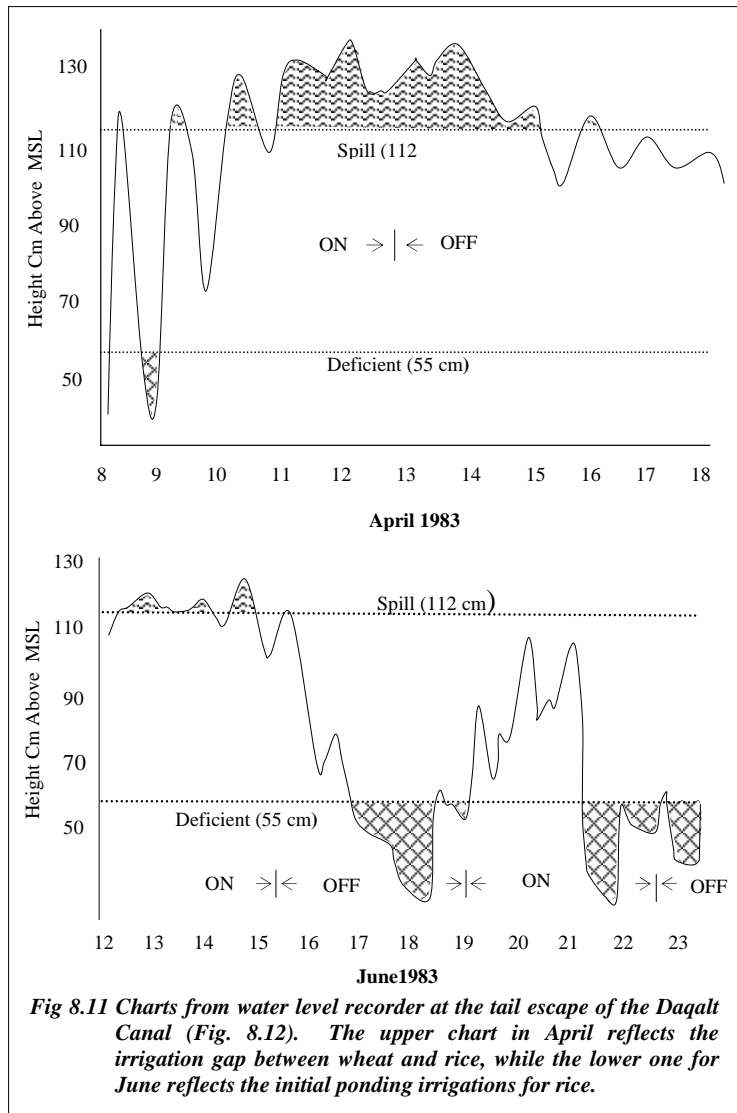


Fig 8.11 Charts from water level recorder at the tail escape of the Daqalt Canal (Fig. 8.12). The upper chart in April reflects the irrigation gap between wheat and rice, while the lower one for June reflects the initial ponding irrigations for rice.

The time corresponds to the irrigation gap following the last irrigation of wheat and prior to the first irrigation of rice when there is so little demand that the normal seepage water around the gate at the head of

the canal is sufficient to fill and overflow the canal.

The second graph in June shows an on-period with continuous overflowing, followed by an off-period and a second on-period in which the water never overflows, even during the night. This is the impact of the ponding irrigation for transplanting rice that required a single application of 200 mm, and the highest water demand in the entire year.

The overflow from the tail escape represents surplus water in the system that is flowing into the drains for lack of use. By adjusting the rotation system on the secondary canals, the water is high enough in the delivery system to be easily re-allocated down the main canal to other areas in critical need, if they can be identified. Since nobody is interested in surplus water, it should be the first water to be removed in an overall effort to improve the efficiency of the irrigation delivery system. The bottoms-up approach based on users actual irrigation practices as indicated by a small, but representative, sample of users, may be an administratively cost-effective means of managing a smallholder system. It could represent the optimal level of operational efficiency for smallholder systems with an obligation to the users, more collectively than individually.

IRRIGATION CHARGES

While many public sector irrigation schemes in developing countries historically provided water free to the producers and operated the schemes from central funding, there is a growing interest to demand some fees for water, at least to recover the recurring costs of operation and maintenance, often under pressure from donors.

Farmers, as businessmen, are normally willing to pay reasonable costs for water, provided they can clearly see the benefits in terms of a well-maintained and operated system. However, it is difficult to ask farmers to pay for the initial construction costs of an irrigation scheme, or excessive overhead charges normally associated with public sector enterprises, particularly if the farmers are receiving a deliberately-suppressed price for their produce.

Their total profits are just too small to absorb major irrigation charges. It also must be recognized that the beneficiary farmers most likely did not have any input into the design of the scheme or the supporting infrastructure such as mills, storage facilities, vehicles, and construction equipment for maintaining the canals and roads. In reality, it is very difficult to effectively get farmers' input into the initial design, simply because most smallholders have difficulty

conceptualizing the proposal, and equal difficulty effectively organizing their contributions.

Designs are mostly done with expatriate consultants from a developed country and to a developed country's standard. This can result in some fairly expensive per Ha development costs that may be difficult to repay under the suppressed financial economy of developing countries. Also, it must be recognized that one of the reasons for concessional interest rates, grace periods, and long repayment periods from development banks and donors to cover the initial construction cost is for the repayments to come from the additional general revenue funds resulting from the overall economic impact of the project, rather than fees charged to the beneficiaries.

Box 8.4 Commitment to Farmers' Participation

While the author is fully committed to farmers' involvement, whenever possible, not seeking their input at the early design stage of major irrigation projects is understandable. Most schemes will comprise several smallholder communities and thus exceed an individual community's frame of reference. Also, which group of farmers offered access to irrigation is going to say no? Once constructed, the farmers need to be fully involved in the schemes operations and maintenance.

It is also unlikely that farmers are willing to support extravagant overheads in terms of physical facilities, staff transfer from outside and administrative procedures typical of most public sector economic enterprises. Particularly if this represents supporting a life style for the irrigation management that substantially exceeds the farmers' life style. Nor will farmers be happy to pay extensive fees when management staff members are granted access to more irrigated land than officially allowed to the designated beneficiaries.

Thus, the first item to consider in assessing irrigation charges is to minimize the project's overheads, including hiring as many staff locally as possible and training them to undertake most of the administrative needs of the project, minimizing the amount of equipment to be purchased and maintain in favor of contracting the maintenance work to local construction companies.

When fund is collected, they should be held and managed locally, without going through the government treasury. Such collected funds should cover reasonable operating costs to fully sustain the infrastructure, and not just simple minimal recurring costs like the electricity bill for the pumps, as was the case in the Chapula scheme in Zambia, a 100 Ha scheme developed for 50 retired civil servants

families. It had a combination of sprinkler and surface irrigation with concrete-lined canals and rubber-lined temporary storage tanks, for which water was pumped from a river rather than diverted.

Over the years, as the sprinkler equipment and the pumps fell into disrepair, the storage tank liner deteriorated, and the concrete cracked, but there were no funds to cover the repair cost. Unable to make these repairs, the only other option was to reduce the command area and relocate the parcels to accommodate the same number of farmers on the reduced area.

The balance was used for rain-fed cultivation, while the project and the government approached donors for a complete rehabilitation of the system back to the original design with the expectation that they would not make any major adjustments in their accounting procedures that would ensure more sustainability. If a donor were found, the whole process would begin again and require another round of donor-assisted renovations within a decade or less.

In recent years, many institutions now proclaim to pay ample attention to sustainability, but the sort of situations as described above, still occur often.

Enforcement of Irrigation Water Charges

Charging smallholder farmers for irrigation water has to be done in as cost effective and equitable a manner as possible. This largely depends on how to effectively enforce the charges. In most cases this is difficult, particularly if it is necessary to curtail services to non-paying participants. If a public irrigation system serves highly fragmented private land in which an individual parcel can be as small as 0.2 Ha and outlets as close as every 10 m, how can non-paying farmers be denied water while providing water to their neighbors. It is not realistic to evict them from their own land. Actually, with fields as narrow as 10 m, it would almost be feasible to irrigate with seepage from their neighbors.

If the government owns the land as well as the civil irrigation works, and farmers are effectively leasing the land from the government, as is the case in Madibira, it may be possible to evict non-paying farmers, assign the plot to another beneficiary farmer, etc., and thus ensure payments. However, usually this is not the case because it is politically difficult to enforce. For these reasons most smallholder systems in developing countries have difficulty collecting irrigation fees.

The only countries with smallholder systems that seem successful in

collecting irrigation fees are Japan, Korea and Taiwan. However, in these countries rice prices are inflated well above world market prices so the smallholders are reasonably well-off, and often are only part-time farmers.

Purpose of Irrigation Water Charges

Charging farmers for irrigation water also depends on the purpose of the charges. Are the charges to generate operating funds for the maintenance of the system, or are they intended to promote more efficient water-use? If intended only to meet operating costs, the prospects for collecting irrigation fees are fairly good. However, if intended for promoting more efficient water use, most likely this cannot be done, as the cost of water required to do so will exceed the farmers' ability to pay, and the administrative costs to implement and supervise the fee collection procedures would exceed the benefits.

Also, even if used only for operation and maintenance, the administrative costs for collecting the fees have to be factored into costs prior to allocating funds for the intended purpose. To be effective, the collection of irrigation fees really requires some detailed economic analysis. If such an analysis indicates that fee collections are not economical, it is better not to charge fees and continue operating the systems from central funds, or look for indirect means of charging.

If charges are levied, it is important that they be reasonable and do not become an excessive financial burden to the farmers. If they do, the farmers will have no choice but to either go out of business or become involved in civil disobedience such as vandalizing the metering devices as has occurred in Jordan and Pakistan. Smallholders still have limited resources and limited disposable income from which to pay irrigation charges.

As mentioned previously, in many countries, farmers are subject to a controlled fixed and suppressed ceiling price policy on staple commodities such as rice and maize with a policy objective of ensuring reasonable food prices for urban populations. In such cases, the suppressed prices have substantially eroded profits upon which irrigation charges can be levied, and are effectively an irrigation charge. Additional charges can be a serious financial burden. Under such circumstances it will be more difficult to collect fees than continue to provide the service free of direct charge.

Methods of Charging for Irrigation

Some methods of charging for irrigation water are more practical and cheaper than others. The administrative costs combined with the difficulty of enforcement results in many smallholder irrigation schemes indirectly charging for irrigation water.

Charges Based on Area Irrigated

If water charges are to be levied, the simplest method is according to area irrigated. This is reasonably cost effective to administer and a good means of generating operating funds. It will not be effective in promoting more efficient water use. Area cultivated charges can save the administrative costs of actually measuring water to individual parcels.

Charges Based on Area Plus Crop

A frequent modification to the simple irrigated-area-charge is to charge by area and crop grown, charging more for rice or longer season crops like cotton compared to crops like sunflower or maize. This essentially assumes that farmers will approximately apply the calculated water duty. It represents an extrapolation of a volume charge, and is sometimes promoted as a volume charge. The crop-by-area charges incur the extra administrative cost of conducting an annual or seasonal crop survey and tabulating the results. This has to be done in a timely manner to avoid co-mingling of crops from different seasons and avoid the crop conversion periods when the land is fallow. With staggered planting as occurs in Egypt, the total of both the spring and fall crop conversion periods can amount to 4-5 months. For example, in the EWUP project, one winter crop survey was delayed until it included both broad beans – a winter crop – and cotton, a summer crop. Since, the area and crop charges will still have little influence on water-use or system operations, it may be difficult to justify the extra administrative cost compared to a flat area served fee.

Charges Based on Volume

Volume charges tend to have ideological appeal as a means to encourage water conservation and increased application efficiencies. They are the only real means of doing so. In the USA, which can provide volume deliveries on demand to its large farms, volume charges can ensure highly efficient delivery of water to the farm gate,

but does not necessarily encourage efficient application of water to the crop. It is just another production input to factor into the entire crop production economics as discussed at the beginning of the chapter.

To be effective in influencing application efficiency, the price has to be high enough to approach the economic return for water in comparison of other crop management inputs, including labor. For limited-resource smallholders this is considerably higher than they can afford and it makes the irrigation costs a substantial financial burden.

While domestic water is normally metered and charged by volume, the unit price is substantially higher than for irrigation water. An example is Fort Collins, Colorado, where the difference between irrigation water and treated domestic water is 12 fold going from \$ 0.031 /m³ to \$ 0.55 /m³.

Additional Administrative Costs. Volumetric charges add considerable administrative costs to the systems' operations. To be effective, volume charges require:

- Measuring devices distributed throughout the area, preferably to each individual parcel, perhaps averaging every 0.5 Ha and 4-5 devices per user, depending on the number of parcels cultivated;
- Someone to regularly take readings on the water delivered;
- Someone to tabulate the results and prepare bills;
- Someone to distribute the bills or at least post them to the farmers;
- Someone to collect the funds; and
- Someone to enforce and curtail future use for non-payment.

For the scheme to be financially viable, all of these administrative costs must be passed on to the producers as part of their charges, and must come from the farmers' profit margins thus adding to their financial burden.

Preliminary Evaluation. Before embarking on a volume charge structure for irrigation water, a serious and detailed cost benefit analysis needs to be undertaken to determine whether:

- The farmers are deliberately applying too much water, or are they simply responding to an inefficient delivery system;
- The system can actually respond to the individual demands of farmers without increasing the flow-through to the drains;
- Any water recovered from a volume charge can be effectively

diverted to an area where it is needed, or will it simply contribute to the flow-through going into the drains; and

- *Will the profit margin*, as separate from the gross proceeds, for the increased agronomic productivity from the water saving *exceeds the administrative costs* incurred by the volumetric charge structure. This would mostly have to come from utilization of the recovered water further downstream.

Much of the previous discussion indicates that these conditions might be very difficult to comply with. It would take a considerable amount of water saving from each small parcel to justify these administrative costs in a smallholder system. If the benefits do not exceed the costs, then the volumetric charges will become more a tax burden than a production stimulus, and could result in farmers simply giving up and going out of business or resort to some form of civil disobedience, and the scheme collapses.

Volume Into Tertiary Command Area. Measuring water to a command area such as the tertiary blocks at Madibira, watercourses in Pakistan, or tertiary canals in Egypt may be possible, with the users responsible beyond the entry point. However, this may really be a “buck-passing” operation, saving the irrigation management the cost of dealing with individual farmers, because there still is the need for individual coordination, and someone will have to incur the administrative costs of doing so.

Such costs could be financial if the group hires some outside person to manage the water for the group. More likely it will be non-monetary, as a simply priority the organizers provide for their lands, and very real cost to the non-organizers, who may get less water and lower yields. This could also become a major hassle for the individual trying to coordinate the water deliveries, for which some compensation is really justified. The extent of hassle would normally be underestimated by the neighbors being served as noted later regarding subdivision irrigation in the USA discussed earlier.

The major exception to the problems surrounding volume charges is when tube wells supplement surface water, as is the case in Pakistan. With private tube wells the energy costs associated with either electric- or diesel-powered pumps provide an effective volumetric charge for water. However, these are all highly local with limited conveying systems to maintain.

Indirect Charges for Irrigation

In some cases this may be justified. The operational funding of the system then tends to come from central government funds. Indirect charges can come from suppressed prices on commodities, or price differences between a fixed buying price of a crop like cotton and the government export price.

Egypt is an example where this may be unofficially taking place. Egyptian cotton production is controlled by acreage allocations that change each year. During their turn for cotton production, farmers have to market the cotton through the government facilities.

The profits from cotton production are considerably less than for other crops like rice. The government exports much of the cotton at substantial profit to Russia as payment for the Aswan High Dam. In this case the cotton producers are effectively charged more for irrigation than non-cotton producers.

Similarly, the rice export tax of Thailand is used to fund irrigation systems operations.

INVOLVING FARMERS IN IRRIGATION MANAGEMENT

Much effort has gone into getting farmers more directly involved in operating and maintaining public sector irrigation schemes. Farmers' involvement can be sought for determining irrigation needs, distributing water within the tertiary canal system, and organizing the maintenance for the tertiary and field canals.

In addition to these issues, if charges are to be levied, farmers' inputs into determining the charges, and review of accounting, could be essential to their acceptance of the fees.

Ideally, farmers' involvement in irrigation operations and management is good, but how to effectively involve them remains a sensitive question that has to be handled with due consideration to their status as individual entrepreneurs.

Also, effective farmers inputs has to be representative in an environment in which democratic institutions are normally fairly weak; and not imposed by a few larger, more political influential farmers, or the management staff.

Determination of Irrigation Needs by Farmers

If farmers' involvement is intended to determine water needs with the idea of developing a demand system similar to the USA, while dealing

with farmers collectively rather than individually, then the examples presented earlier in this chapter indicate how this can easily be done passively through a simple farm irrigation record analysis of past irrigations. This can be more effective than trying to estimate water needs based on the ideal conditions of planting dates and consumptive use estimations, etc. It may represent a passive farmer involvement, but it is statistically sound and unbiased and requires less than 5% of the farm community.

Is there a need for additional crop information on water needs; can it be obtained in a sufficiently cost effective manner; and are there sufficient control structures to effectively utilize the information? Asking the farmers their detailed irrigation needs in advance could provide an honest intention of irrigation plans, but these would immediately be subject to the normal compromises farmers make in managing their lands, and most likely not complied with in the details needed to manage an irrigation system.

Involving Farmers in Water Distribution

If farmers are expected to become involved in the equitable distribution of water within their tertiary canal, then this requires some very clear understanding of what each farmer is entitled to and what the recourses are if they do not obtain their entitlement. Without this, water delivery becomes a free-for-all, which, since few farmers will ever acknowledge they have received enough water, will heavily favor the head farmers over the tail farmers.

Also, it is always difficult to expect farmers to supervise their neighbors. If required, they would most likely resort to self-serving hording reflecting their status as individual entrepreneurs. The Warabandi system of India and Pakistan is the best example of farmers self-enforcing the equitable distribution of water in a tertiary watercourse, with a clear statement of entitlement expressed as time for accessing the full flow of water in proportion to their area on the watercourse.

It does not however take into consideration the conveyance losses which can equal up to 50% of the original flow and provide those closer to the head more water than those near the tail.

Involving Farmers in Irrigation Scheme Layout

Whenever possible, a scheme should make the farm layout as

convenient as possible for farmers to facilitate the equitable distribution of water. Hardware is more reliable than people here. The more investment in the brick and concrete of control structures such as drops and check controls, the more effective the final operation of the system. Such controls will normally be respected by all. Furthermore, usually, more donor funding is available during initial construction to install the extra structures than is available for rehabilitation and post construction of additional control structures.

Examples of a good layout for minimizing the coordination among farmers are found in some parts of the Philippines and Indonesia where irrigated farms are often long narrow strips that stretch from the canal to the drain, providing each farmer direct access to both (Photo 8.7). It also facilitates equipment access for rice power tillers or contract threshing. The individual farm strips are as narrow as 10 or 15 m and up to a km in length. This contrasts to Madibira where the farm layout is square, equipment access limited, and water control coordinated over three field canals, with drainage often going through neighbors' fields.



Photo 8.5 Aerial view of rice irrigation in Central Luzon Philippines showing long narrow fields running from canal to drain minimizing coordination needs between farmers.

Involving Farmers in Canal Maintenance

Canal maintenance is traditionally one of the more difficult things to get farmers to cooperate in doing (Photo 8.5). To be effective, canal maintenance has to be done in the farmers' interest as individual

entrepreneurs. It also needs a clear mandate as to what the farmers are entitled to do including the right to intervene above their respective turn-outs.



Photo8.6 Typical weed-filled watercourse in smallholder irrigation scheme. This photo is from Pakistan. Photo Credit: W. Shaner.

Usually, farmers' maintenance of canals, including removal of weeds, sediment and debris, is envisioned as a collective effort, with the farmers taking care of the area beside their respective lands. The latter may not be the most effective expectation, as weeds and other obstructions in a canal adjacent to the farmers' fields, but below their individual turn-outs, are actually beneficial to the farmers, since it will create a backflow that will retard the flow of water and allow more of the water that reaches their turn-out to enter. Removal of these weeds encourages the water that finally reaches their turn-out to quickly move past to their downstream neighbors. One would not expect farmers to

remove weeds for the benefit of their downstream neighbor and at their own detriment.

Farmers are far more interested in the weeds immediately above their turnout and adjacent to their up-stream neighbor's fields. However, for them to maintain this up-stream section requires a clear mandate that they are entitled to do so, including the right to obtain soil material from immediately beside the canal to repair rodent holes or other leaks. Without the clear mandate to intervene above their turnout, their upstream neighbors would resist the intervention. After all, the upstream farmers are enjoying the extra water leaking into their fields, without having to account for it.

Another possibility is to have the turn-outs at the bottom of the fields. This is possible only if the field's frontage is small and the overall drop is 10 cm or less, so a simple check structure could raise the water high enough to irrigate back to the top. The field would also have to be reasonably level. In this case, maintenance of the weeds adjacent to the field would be in the immediate interest of the farmer, and most likely readily done.

Review of Irrigation Fees by Farmers

Perhaps the most important input for farmers to have in the operations and management of irrigation schemes would be reviewing any fees charged. This is also an area in which the management, particularly public sector management, would least like to have inputs from farmers, because they will always try to minimize the charges. This could actually be very beneficial as it is unlikely that the farmers will be interested in funding any excessive overhead cost, such as excessive staffing, fancy housing, and vehicle operations. However, the farmers would be more than willing to fund normal cost for operating and maintaining the system where the benefits are clearly visible. They also might have some good inputs into how this could best be organized. Some things farmers' inputs might lead to is:

- Clear statements of entitlements, and recourses that will ensure reasonably equitable distribution of water and maintenance of the canals and drains;
- Reduction in the research and extension component of a project as the benefits are normally outside their economic time frame, and most information is communicated informally;
- Reduction in overall project staffing, particularly that transferred into the area and requiring housing and other logistical support.

The emphasis might shift to training local people. Also, restrictions on staff personal cultivating within the scheme, particularly if the staff are allocated more acreage than the beneficiaries, as happened in Madibira;

- Contracting out of major maintenance activities such as sediment removal. This replaces project owning and maintaining backhoes, draglines, rollers, dump trucks, etc.;
- Making provisions for farmers to be hired during the off-season as casual laborers for some of the maintenance work such as weed and sediment removal that cannot be done with machinery thereby creating an opportunity for some farmers to earn a portion of their fees; and
- Overall accounting transparency, with clear line-item budgeting.

Obtaining this level of farmer input into the operations of a scheme can reasonably be done with a Steering Committee of representative farmers chosen from the ranks of farmers with appropriate individual constituencies.

WATER USERS' ASSOCIATIONS

An organizational structure that has become the standard for many smallholder irrigation systems is "water users' associations" (WUA), often mandatory organizations imposed on the farmers by the irrigation authorities to accept water, equitably allocate it to the members, organize the maintenance of the tertiary canals, ensure fee payments, etc. As state-mandated organizations, they are very much analogous to co-operative societies designed to provide inputs, credit, and marketing as discussed in Chapter 4.

Like co-operative societies, WUAs go against the foundation of smallholders as individual entrepreneurs and push the farmers toward communal farming. Although given the major shared resource in the canal, the need for communal coordination is considerable greater than in cooperatives or other farmer organizations involved in inputs and marketing, and thus more justified.

As imposed organizations, WUAs have had very limited success with only a few being sustained beyond donor funding. As such, *the continued emphasis on developing and depending on them should be carefully reviewed by donors for future projects.*

The Origins of WUAs

The concept of WUAs originated perhaps with the ditch companies of the western USA, where, in the 1860s, farmers got together to dig run-of-the-river diversions for irrigating their fields, with each ditch serving several farmers and extending many kilometers inland from the diversion and commanding thousands of Ha of irrigated land. This was then followed in 1890 by various storage reservoirs until the network of the irrigation reservoirs around Fort Collins, Colorado, look very similar to the tanks in the Dry Zone of Sri Lanka. Finally, seeking even more water, tunnels were constructed in 1901 diverting Laramie River water destined for southeastern Wyoming, three kilometers through the mountains into the Cache La Poudre River to irrigate Northeastern Colorado.

These were all private efforts, but backed by what eventually became the legal concept of appropriated water rights usually referred to as “first in time, first in right.” Thus, once a water resource is developed, it belongs to the people who developed it as an annually renewable resource, determined by the yearly snow pack, and now supported by over 70 years of snow pack run-off records. The concept ensured the people, who invested heavily in the irrigation infrastructure, that they would be able to recover their investment. This was then backed by the courts to prevent anyone upstream from diverting and stealing their water. Water became a renewal commodity denominated in shares and freely bought and sold independent of the land. Such ditch companies are very effective in ensuring highly-efficient delivery of water to the farm gate, but as mentioned at the beginning of this chapter, not always very good in ensuring efficient application of the water to the crop.

The North Poudre Irrigation Company of the USA

Typical of the ditch companies serving Northeast Colorado is the North Poudre Irrigation Company. It is classified as a Mutually Owned Company that was founded in 1894. It is owned by its shareholders, for which the shares are freely traded at competitive cash value currently approximately \$10,000 per share.

North Poudre manages nearly 400 km of canals, and 15 storage reservoirs with a total command area of over 9,000 Ha. This makes it larger than most developing countries’ irrigation schemes. One of the storage reservoirs is also used to collect sewage effluent from one of Fort Collins’ wastewater treatment plants, effectively recycling

wastewater into the irrigation system. It also can buy or exchange water with the Colorado-Big Thompson Project. There are currently over 600 shareholders or users including some municipal shareholders, and housing subdivisions.

North Poudre delivers water to major users on demand and within the physical capacity of the canals to deliver it. This is usually not a problem, but when it occurs, water deliveries are delayed. The criteria for delivering water are simply what the users are entitled to in accordance to the shares they own, or are willing to buy from other sources. None of the discussions between the Ditch Company and users is related to crop water requirement. That is left up to the users. About 50 users will request water to be turned on at the beginning of the season and left on for the entire season while they rotate the water internally between fields. These are the larger users operating 300 Ha or more.

As mention earlier, North Poudre does provide water to a few subdivisions that have large enough lot sizes for “weekend” farming, producing hay or grazing a few cattle or recreational horses. In this case North Poudre requires a designated contact person and will not deal with anyone other than the contact person. The company manager considers dealing with the subdivisions a bother.

Federal Water Projects in the USA

In addition to the ditch companies there are large federally-funded water development projects from the first half of the 20th century. These include the Colorado-Big Thompson Project that diverts Colorado River water on the Western Slope through the Rocky Mountains to irrigate northeast Colorado and provides sufficient additional water to ensure an adequate supply virtually every year, but with a different price structure for the ditch water versus project water. These large projects combined with the urbanization in areas such as Fort Collins, where several ditch companies were completely absorbed, and no longer have any irrigation users, have to some extent rendered the ditch companies a relic of times past in an area sorely in need of some fundamental revisions in its basic water laws.

Application of USA-Experience to Developing Countries

The originally private irrigation systems of the USA backed by rigid water rights that require working with farmers on an individual basis

are worlds apart from the publicly owned, smallholder systems with much vaguer water rights, which deal with farmers collectively rather than individually. The WUAs as applied to the smallholder systems are definitely a *donor-imposed innovation with a bit of arrogance attached*.

The concept of WUAs was first applied to public-sector smallholder systems, with Colorado State University's initial effort in improving on-farm water management in Pakistan, during the second half of the 1970s. The Warabandi allocation system already had the farmers served by a watercourse well-organized in the allocation of the water they were legally entitled to.

In Pakistan, the primary purpose of the WUA was to provide a legal entity to accept ownership of the watercourse improvements and arrange repayments for the farmers' share of improvement costs. The cost of collecting these repayments often took more time and consumed more fuel to collect than the value of the payment. The government would have been financially better off to simply provide the improvements free of charge. The expectation was that the WUAs would operate similarly to cooperative societies as they are known in developed countries. However, they tended to operate more like cooperative societies in developing countries with similar difficulties as discussed in Chapter 4.

From this original initiative, the WUAs were caught up in the normal project promotions of all innovations being successful regardless of how much effort was really required to make them work during the life of a donor-funded project, or their sustainability once donor funded ended. Host country irrigation managers are happy to endorse them as they provide an opportunity to pass responsibility for water delivery and maintenance to the farmers and hold them responsible for failures in equitable distribution of water or canal maintenance.

This is very much a "buck passing" operation that may save the irrigation management some expenses, but not necessarily the farmers. The administrative coordination still needs to be done and the costs incurred passed on to the farmers, either financially or through priority access. However, given the limited follow-up resources available to most managers, the WUAs, like many developing country initiatives, were decreed into existence and then assumed to be functioning according to their mandates.

Post-Donor Funding

Most WUAs became defunct as soon as the donor support for their

establishment ended (Photo 8.7). In Thailand, a survey conducted by a German Doctoral student, indicated that most farmers were unaware that they were even members of a WUA, let alone become involved in decisions on water allocation, canal maintenance, collections of funds, etc.



Photo 8.7 *Once-improved watercourses in Pakistan managed by a WUA, but with the concrete turn-out, installed by the On-Farm Water Management Project that mandated the WUA, eroded out and functionless. Photo Credit: W. Shaner.*

Most of these activities just did not get done as noted earlier when the canal water was shifted to the drains and canals silted closed to the extent that they could not be readily identified. WUAs always require an extensive effort to initially get organized, and may have done more to provide employment opportunities for rural sociologists and their advisors than anything else.

In some cases, such as Pakistan, where most of the WUAs leaders appeared to be the financially better off members of the watercourse, the WUAs may have provided an additional opportunity for larger farmers to coerce their less fortunate neighbors. *Regrettably this is more the norm than the exception in developing country governance.*

WUAs go very much against the concept of the smallholder farmers being individual private entrepreneurs, and drive them towards communal farming. It also implies a notion of farmers supervising their neighbors, which may be difficult for all to accept, even if there is a reasonable amount of overall synergy in operating the system through

WUAs. Unfortunately, project promotions, the desire for irrigation administrators to shift responsibility to the farmers, and the lack of post-project follow-up on their long-term sustainability leads to their wide acceptance for new projects and no real innovative thinking on alternatives that may be more effective and more sustainable, or perhaps just more up-front and open.

To be effective, WUAs need a solid legal backing in terms of clearly stated entitlements concerning water distribution, right to intervene above their outlets, recourse to project management if an individual, or a minority of the users, is unable to obtain their water entitlement, as well as some solid infrastructure that will make farmers' co-operation easier. The concern for the long-term effectiveness of WUAs is also recognized by the International Water Management Institute (IWMI), the international center mandated to assist with irrigation management (Shah, et al., 2002).

An Example of Farmer Cooperation from Madibira

An example of how farmers interact within tertiary blocks of a medium-size irrigation scheme, without a clear mandate for either equitable distribution of water or canal maintenance, is the tertiary blocks in Madibira. Here an individual farmer from one of the five beneficiary villages would arrange with 29 friends and relatives to register for a 30-Ha tertiary block. While not formally organized into WUAs, the tertiary blocks effectively serve as such.

Once designated, the block leaders then allocate the 30 plots among the group including providing themselves with the first plot beside the inlet where water is most ensured. The farmers then proceed with project assistance to manually construct the tertiary canal including installing the three concrete field canal outlets structures to control water into the field canals, plus manually build three field canals that each serve 10 farm plots, in what was basically a square layout. For the typical tertiary block, this totals some 400 m of tertiary canal and 1,500 m of field canals.

Farmer Management of Tertiary Blocks in Madibira

Once the season begins, farmers usually fully open the inlet gate and leave them fully opened for the duration of the season, regardless of how much water is really needed. The water then flows freely through the system without any control, except perhaps a daily rotation between

field canals. No check structures are installed across the field canals to allow a farm-level rotation within the field canals.

The farmers only receive the water that naturally flows into their plots as the water flows down the field canal. In addition, because the land is not fully leveled, in low areas, field canals overtop, but no effort is made to correct them, as no clear right of intervention above an outlet has been established, and adjacent farmers were happy to receive the extra water. It is very much all farmers for themselves, consistent with all acting as individual entrepreneurs, even when a group of farmers join as a unit and are assumed to be well-known to each other.

Disposal of Excess Water in Madibira

Excess water in the first and second field canals is usually allowed to flow directly into the drain, rather than being checked off, allowing the water to move further down the tertiary canal where it might be used. Often farmers would put small pipes through the tertiary canal banks so their fields receive a continuous flow. Water was often allowed to flow directly into the main drain in such volumes that over the first two seasons gullies of over 10 m long and three meters deep were eroded into the drain bank (Photo 8.10). The net result was that, despite three times the amount of water needed for maintaining ponded paddies for all 30 plots, many fields did not have sufficient water, while large volumes of water were discharged from the fields into the tertiary drains (Photo 8.8) and then into the main drains (Photo 8.9). This resulted in some people plugging the drainpipes and irrigating from the tertiary drains.

The project really needed to make some solid statements to the effect that all farmers were entitled to an equal share of the water, some



Photo 8.8 Gullies allowed to be eroded into a main drain in the Madibira project in Tanzania.



Photo 8.9 Full pipe discharging water from tertiary drain into main drain in Madibira despite other farmers needing water within the tertiary block. The discharge from the pipe is approximately 50 l/sec or two thirds the design inflow.

means of recourse for addressing conflicts within the block, and the right to intervene above the outlets to prevent inserting pipes through

the canal bank or overtopping, etc.

The Rudimentary Organization of Madibira

Despite the problems, some rudimentary organizational structures were possible in Madibira, including collecting funds for contract tillage of the entire 30 Ha blocks, locks for the gates, record books, as well as fines for failure to fully participate in construction activities or repairing breeches. However, even with these organizational accomplishments, numerous farmers expressed interest in shifting to other tertiary blocks.

Just prior to the end of the donor-funded advisory contract, an effort was made for facilitated small group workshops to allow farmers to consider how to improve the organization within the tertiary blocks to ensure better water distribution and maintenance. While this made a start in establishing entitlements and getting improved water management, it is expected that it would take several iterations before the water would effectively flow throughout the blocks.

IRRIGATION ADVISORY SERVICES (IAS)

A means of involving farmers is through irrigation advisory services (IAS), essentially an extension effort focused on irrigation. How effective such services will be has to be questioned. If the service is developed because of the difficulties of the regular extension programs as discussed in Chapter 6, then it is unlikely that they will contribute very much: the same civil service limitations that hinder the effectiveness of extension programs will also limit the effectiveness of an IAS, and like most other government efforts will stall.

If the expectation is to follow the same traceable administrative link to each individual farmer using the World Bank Training and Visit (T&V) system or something like it, the IAS will just create another bureaucracy, which, without donor assistance, will have difficulty maintaining staff and operating budgets. It would really be better to invest in improving the capacity of the existing extension effort. Also, if the IAS is going to be primarily a top-down imposition of ideal irrigation practices that neither the farmers nor the scheme physically and operationally can implement, then, whatever information extended, will be ignored, and the whole effort will become a burden on the society.

Box 8.5 Operational Proposal for Madibira

The total proposal put forward by the author for organizing the tertiary blocks in Madibira include:

Entitlement

Every farmer to be entitled to an equal share of the water entering the block. Admittedly this is a weak and nebulous statement but all that was really available under the circumstances.

Right to Intervene

All farmers have the right, either singularly or as a group, to physically intervene above their inlet and adjacent to their neighbors' fields to ensure that they receive their equitable share. This would include removal of pipes, smearing the canal walls to reduce seepage, adding material to the top of canal banks, removing weeds and sediment from the canal, etc. They would also be entitled to obtain any necessary fill material from the first 30 cm of a field (1 transplanted rice plant) as well as from the bottom of the canal, to assist with raising the canal bank.

Recourse

Any 10 of the 30 farmers in a tertiary block could partition the management to intervene in the tertiary block management. If so partitioned, every member would be charged TSh 1000 (\$1.50), just to avoid frivolous complaints. It represents less than one day's wage for a project-hired casual worker. Once it received a complaint the irrigation management would suspend the leadership of block and appoint a 3-person panel to review the problem. The panel would consist of one member from management, one farmer from another tertiary block and one member from the community at large. Each person would receive TSh 5,000 for the effort, with the other TSh going to the project as overhead. The panel would then investigate the complaint listen to the plaintiffs and defendants, visit the block, check to make certain it was receiving the allotted 75 l/s of inflow, and make certain no unnecessary water was being discharged into the drains, etc. The panel would then render a decision that could include fining individuals, dismissing the block chairman and calling for new elections, expelling individuals from the block and scheme, or simple recommending more effective rotations systems, including the use of check structure in the field canals during an individual turn.

To be effective, an IAS has to appreciate that *water management is just one of many inputs into crop management*, and normally not the primary concern of the farmers. The IAS must then understand all the compromises the farmers must make in water-management, much of which reflects the system's operation rather than the farmers deliberate ineffective water-management. Thus, before undertaking the

development of an IAS, there is the need to go through the same extensive detailed evaluation as previously suggested for volume charges for water.

Then, unless there is a clear plan for accommodating all the concerns mentioned under volume water charges that will ensure sufficient return from the IAS inputs to cover its operational costs, *donors should be very hesitant to support their development*. If not, the IAS will simply become another tax burden on society while producing little if any benefits to the farmers or society at large. As with volumetric water charges, it would be very difficult for these conditions to be met, and thus very difficult to justify an independent IAS.

CHAPTER SUMMARY

Irrigation is highly beneficial to smallholders by providing additional flexibility to their crop management, extending the growing season, and stabilizing yield at a high level. However, irrigation increases the complexity of the farming system. Most large irrigation systems that serve smallholders are publicly owned and, as such, are subject to the normal limitation of public sector management. This has resulted in the irrigation managers becoming progressively out-of-touch with evolutions in crop management and crop mix. The farmers often may not practice the best water-management, but this is more often a result of the system not being in tune with irrigation needs than any deliberate effort of the farmers to mis-use water. These compromises in water management need to be taken into account before major efforts are made to charge farmers for water, impose WUAs, or develop extensive IAS to extend ideal knowledge that just cannot be effectively utilized.

Farmers may be willing to financially contribute to the operation and maintenance of the systems provided it is done in their best interest and the accounting is transparent. The more control structures that are installed to minimize the need for farmer cooperation, the more effective the overall operations.

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