Water Distribution in Farmer Managed Rice Irrigation Systems, Fujian, China

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Abstract: Much rice grows on land served by irrigation systems where water moves to fields through canals and ditches. Some irrigation systems have plenty of water. Others do not. This study examines three systems which almost every year experience moderate shortages of water and occasionally experience severe shortages. Water distribution within the systems is managed entirely by farmers. The water diversion structures on the canals and ditches are highly manipulatable. The farmers have devised water distribution procedures that are readily adaptable to the varying needs of fields and varying levels of water availability from place to place and time to time. Therefore, crop losses owing to water shortages have been minimal.

Key words: irrigation, water distribution, farmer managed, rice, south China

Introduction

Rice is southern China's great food crop. It grows there mostly on fields irrigated by canals and ditches where flows of water are managed importantly by farmers. In large irrigation systems which supply water to thousands of hectares of land, and in small systems where canals cross township boundaries, government officials regulate water flows in major canals, farmers in minor canals and ditches. However, in small systems which serve fewer than several hundred hectares of fields, farmers alone may manage all flows.

Early in the 1980s, the household responsibility system of farm management was introduced across south China. Before that time, organizations of farmers called production teams controlled most agricultural production. The adults of a village with fewer than 50 or 60 households comprised a single production team, the adults of larger villages, two or more teams. Each team worked a farm of 10 to 20 hectares. Two or three team members managed irrigation activities. So as to procure equitable amounts of water for their farm, the irrigators worked closely with irrigators of other teams in the same irrigation system. Since the early

1980s, individual households have had responsibility for agricultural production. The clusters of households that had been a production team came to be called a villager group (cunmin xiaozu), except that some large teams chose to divide into two or more villager groups. Pieces of the land formerly farmed by the production team were then assigned to each household of the villager group. As a result, instead of team farms of 10 to 20 hectares there are now household farms of about a quarter hectare; and instead of few persons managing flows of irrigation water, there are now many people.

The farmer managed irrigation systems of Asian rice producing areas have been examined in a substantial literature (references cited in Coward 1980; International Rice Research Institute and Agricultural Development Council 1976; Tang 1992; Sampath and Young 1990; Manor et al. 1990; Uphoff 1992; Hunt 1988; Bromley et al. 1980; Bottrall 1978; Shanani 1992; Mondal et al. 1992; Burns 1993; Chambers 1988; VanderMeer 1968, 1971, 1988). Generally in the irrigation systems, water moves by gravity from a source such as a river, through canals and ditches, first into areas of fields at relatively high elevations, then into lower areas. Fields in high areas commonly have a more easily obtained and more securely available supply of

water than fields in low areas toward the tail of the system. The literature reveals, in addition, that systems have a range of water availability conditions. Some receive abundant water so that few, if any, farmers must devote much labor to irrigation activities. Others almost always have plentiful water, but occasionally experience reduced supplies when some farmers must work extra hours for water. Still others generally receive adequate water, but at times every year experience shortages, occasionally extreme, so that many farmers give considerable effort to irrigation. The Asian irrigation systems also have various types of water diversion structures along their canals and ditches. Some have highly manipulatable structures which allow farmers to devise flexible water flow patterns that are easily changed from hour to hour, even minute to minute. Others have less manipulatable structures. They may force farmers into rigid water flow patterns where, for example, all upper fields of a system receive water during daytime hours, all lower fields during nighttime hours.

The irrigation literature on China includes several studies that encompass interests in the south prior to 1980 (Nickum 1979, 1980, 1981; Vermeer 1977; United Nations 1979). Recent contributors on China include Jin and Xue (1987), Nickum (1982, 1995), Xu (1986), Jiang (1990), Mao (1989), Svendsen and Vermillion (1992), and Yoder (1988), of whom Nickum, Svendsen and Vermillion, and Yoder deal with farmer involvement in water management. Nickum (1982) mentioned water disputes among farmers where the household responsibility system had just been introduced. Yoder featured a rice producing county where farmers manage over a thousand gravity irrigation systems. He wrote that the farmers in a system "meet two, three, and even more times a year to organize their irrigation effort. They elect a... committee for day-to-day operation and appoint members to fulfill special functions.... The committee oversees the maintenance work and supervises water distribution. In many... systems contracts are given" for individual farmers to manage parts of an irrigation system, for example pumps or reservoir releases, as directed by the committee. For the tail area

fields of at least one system, an extra pump drew supplemental water from a river. Svendsen and Vermillion wrote that "reforms during the late 1970s and through the 1980s have... led to dramatic institutional and management changes in [irrigation and] little is known outside of China about these changes and their consequences."

The present study examines water management practices in three small, farmer managed irrigation systems in south China. The systems are located in Tongan County, Fujian Province. Two are juxtaposed in one township; the third is in another township. One serves approximately 100 hectares of fields, the others 70 and 20 hectares. Each has readily manipulatable water diversion structures. Each commonly receives water in amounts sufficient for good crop growth. Then farmers devote little labor to irrigation. However, there are also days and weeks when water supplies drop to levels requiring farmers in some locales to work much more than other farmers do; and low water conditions occasionally require such effort from many farmers. The study identifies reasons for the water shortages, which occur more commonly and intensely for some kinds of field conditions and also for some stretches of canals and ditches than others. It additionally describes ways farmers obtain water for their fields during the shortages, ways that require much more labor for some fields than others.

The Contexts of Irrigation

Tongan County is largely mountainous so that only about a quarter of its total area is cultivated. Of the cultivated land, close to two-thirds is irrigable. Nearly 535,000 people reside in the county, approximately 90 percent officially registered as members of villager groups. Some villagers work part or full time in nearby cities. The cultivated land area per person in the county is 0.041 hectares, an area smaller than the Fujian provincial figure of 0.05 hectares (Tongan Agriculture Department 1994; Zhu 1990).

The three irrigation systems receive water from small rivers that drain nearby hills and mountains. The rivers have variable flows.

When full, they provide the irrigation systems with abundant water. At times however, they have little or no flowing water. The irrigable fields lie on land that slopes very gently from adjacent uplands. Canals and ditches, mostly earthen but stone-lined along some stretches, convey water from the rivers to the fields, each one a level surface surrounded by dikes. Field soils generally have a high clay content, but in places are loams with moderate sand content. Originally probably red earths, soils have been modified by long and intensive use, including amendments of animal manure, compost, and night soil, so they are now mostly dark gray or black (Zhu 1990).

Temperatures in Tongan include a frost free period of about 325 days, and generally permit year around cropping. On irrigable fields, many farmers raise two crops of rice, one March to July, the other June to November. Thereafter, fields carry vegetables. The first half of April has vegetable harvests followed by preparation of fields for transplanting rice beginning in mid April. Sugarcane, peanuts, sweet potatoes, bananas, and several tree fruits are also important.

Rainfall averages 1600 millimeters annually, but occurs in varying amounts through the year, from year to year. Because the amounts are inadequate for two good rice crops, irrigation is essential. Farmers know rainfall is usually low in October, November, December, and January. In fact, in the 14 years 1980 to 1993, rainfall averaged under 50 millimeters for each of those months. Farmers know rainfall increases in February and March; the averages actually were 150 and 185 millimeters. They know rainfall is heaviest from April through September; averages were a bit over 200 millimeters for each month, except 270 for June and 190 for September. Farmers know too, however, that rainfall amounts at any time may be much more or much less than usual: for example, 345 millimeters in one April, 62 the next April, and 178 the next; 98, 76, 242, and 421 millimeters in consecutive Junes; 367 millimeters in one July, 82 the next; 350, 236, 72, and 85 millimeters in consecutive Augusts; and 498, 293, 190, and 26 millimeters in consecutive Septembers (Tongan Water Resources and Electric

Power Department, 1994).

The three irrigation systems have supported the crops through nearly all periods of low rainfall. Only when low rainfall has extended over prolonged periods has the irrigation water been insufficient. For the two rice crops in Tongan, the important months are March through October. Rainfall figures for the years 1980 through 1993 reveal that among the 112 months of March through October during those 14 years, there were 26 months in which actual rainfall was less than half the average amount. However, only once were there three consecutive months of such low rainfall, and only four other times were there two consecutive months. The three months were March–April–May 1991. The two months were September–October in 1982, 1983, and 1984, and August–September in 1986. Water was also especially short in July–August 1991 because those months together received only 40 percent of their combined average rainfall. During such periods, many farmers devoted considerable effort to obtain water which would supplement that offered by rainfall and by their irrigation system.

Tongan farmers served by the three irrigation systems cultivate their land year around. They fertilize fields heavily, now with organic and chemical amendments. They can choose to plant several varieties of rice, but favor ones with short growing seasons of about 120 days. On fields that are commonly difficult to irrigate, farmers may decide to raise only one crop of rice and plant vegetables the remainder of the year. They do so at least partly because vegetables demand less water.

Rice yields best with water standing on its fields during parts of its growth cycle. At times, farmers want three or more centimeters of standing water. At other times, they want less standing water; or they want soils wet but without standing water. On the other hand, farmers also never want water to cover rice plants or to overflow field dikes. And because rainfall occasionally causes flooding, especially on heavy clay soils, farmers need drainage systems. Each rice field has a drain, a notch in its earthen dike through which standing water can flow out of the field and into a drainage ditch. Commonly

farmers keep the notch closed with rocks and mud so that water will remain on the field.

The Tongan farmers devote much more labor to irrigation than to drainage. For some, irrigation is a high effort activity. The remainder of this study features the irrigation water management practices of the farmers, the ways they distribute water from the intake gate of their irrigation system at the river, through canals and ditches, and to their hundreds of farms encompassing many hundreds of fields. All villager group members have rights to irrigation system water. Farmers work to obtain water for their fields under several general rules. And they take water utilizing procedures that accommodate changing conditions of water availability, whether water is plentiful, in moderate supply, or in short supply. Each of these topics will be considered on the following pages. The descriptions are based upon our visual observations of the canals, ditches, and fields, and of the water flows in the three irrigation systems, and upon interviews we conducted in April and May, 1994, with 66 farmers whose fields are served by the systems.

Labor, canals, ditches, and fields

Many households with fields watered by the three irrigation systems have minimal amounts of family labor for farm tasks because businesses in Tongan City fairly nearby and in Xiamen City farther away have attracted their young adult workers. In fact, when water supplies are low, some households experience labor shortages. They are households whose fields are located in the tail area of the irrigation system, whose fields take water from long ditches that have little gradient and lie only slightly lower in elevation than the canal segments that bring their water, and whose fields have fairly sandy loam soils. Fig. 1 depicts two imaginary irrigation systems which exemplify important features of the three Tongan systems. Shown are water intake gates, canals, and irrigable land areas. One system has two main canals, East Main Canal and West Main Canal. Those canals obtain water from a short canal that extends to the intake gate on the river. At the point where the two canals join the short canal, there is a water division structure de-

signed so the two canals continuously receive amounts of water in approximate proportion to the irrigable land areas they serve. The other system has one main canal, South Main Canal. The amount of water received by a system can be adjusted by raising or lowering its intake gate.

In the area portrayed in Fig. 1, the canals send water to farms of 12 villager groups (cun-min xiaozu). Each villager group is a member of one of four administrative villages (xing-zheng cun). A villager group encompasses some 20 to 70 households whose dwellings are near each other. The dwellings of most groups are located in one cluster, but some have two or three clusters. Assemblages of 10 or 12 villager groups comprise an administrative village. Eight of the 12 villager groups in Fig. 1, those identified by the letters B through I, belong to one administrative village. Groups J and K belong to another, while A and L are parts of others. Each villager group has irrigable land in only one area, except C which has land in three areas, and H in two. The elected heads of the 12 villager groups and four administrative villages are active farmers with leading irrigation roles.

Farmers divert water from a main canal to their fields through three types of structures, a junction, a ditch inlet, and a field inlet. A junction is an earthen or stone or concrete feature which joins a main canal to a secondary canal. It commonly has the form of a Y or T. Many junctions can be blocked with rocks and mud, or with wooden boards, to prevent water from flowing into the secondary canal. A ditch inlet is a U shaped cut in the side of a canal which allows water to flow into a ditch. Although ditches are not shown in Fig. 1, they extend as curving channels from the canals across small areas of fields for the purpose of delivering water to individual fields. Some ditches are short and carry water to only a few fields. Others are long and supply many fields. A field inlet is a U shaped cut in the side of a ditch. It allows water to flow into a field. Ditch inlets and field inlets are generally closed with rocks and mud. Nearly all fields receive water from ditches; few if any obtain water from other fields.

Figure 1. An imaginary area with features illustrative of the three irrigation systems in Tongan County.

Water can move readily by gravity from the intake gate of a main canal all the way to a field if the canals and ditches have substantial gradients. With respect to the irrigation systems of Fig. 1, such is the case for nearly all fields served by South Main Canal and by the upper and middle stretches of West Main Canal and East Main Canal. In contrast, some fields irri-

gated by lower stretches of West Main Canal and East Main Canal lie at elevations only slightly lower than the canal segments that supply their water and also take water from the end stretches of long ditches. In those areas, water at times flows sluggishly in the ditches and to the fields. Farmers there may then work long hours for water.

Water rights

Each person officially registered as a member of a villager group, including babies and retired persons, has agricultural land use rights to a portion of the group's land. The size and productivity qualities of the portion are comparable to those of every other member's portion. If the land is irrigable, the person also has rights to a portion of the irrigation water belonging to the villager group; and the amount and time-availability of the portion are comparable to those of every other member's portion. A villager group of 200 members in 40 households in the three Tongan irrigation systems might well control 10 hectares of land, all irrigable. If the irrigation system serves a total of 100 hectares, the villager group would, at any time—that is, in any period of several days—have rights to 10 percent of the water in the system. Each group member would then have rights to $1/200^{\text{th}}$ of the group's land and $1/200^{\text{th}}$ of the group's water; and the productivity qualities of the land and water would be approximately equal to those of every other member.

For purposes of actually farming the land, each member's land and water rights are combined with those of other members of her or his household. In the imaginary villager group, a household of five members would have a quarter hectare of irrigable land, generally in four separate pieces; and it would have rights to $1/40^{\text{th}}$ of the group's water. The pieces of land assigned to a household are quite easily and precisely identified and measured. By contrast, the $1/40^{\text{th}}$ of the group's water that belongs to a household is very difficult to identify and measure. In recognition of that fact, and also of the fact that their irrigation system almost always carries enough water for all fields, villager groups generally strive to allow each farmer sufficient water for the crops on the fields.

Irrigation rules

Overall responsibility for operation of the three Tongan irrigation systems rests with the heads of the administrative villages which have irrigable land there. However, they delegate to the farmers almost all responsibility for distribution of water, and to the villager group heads

almost all responsibility for maintaining canals and ditches in good condition and for helping farmers obtain water. They retain responsibility for major repairs to the physical structures and for helping villager group heads help farmers obtain their fair shares of water. They have authority to declare a state of irrigation emergency when water shortages are severe, and then to impose on all farmers a prescribed set of procedures for obtaining water. Where more than one administrative village is involved, the heads make decisions by consensus and acknowledge a leadership role for the head whose village has the most land irrigated. Among the three Tongan systems, the largest serves land in four administrative villages, the second largest in two, and the third in one.

The head of each villager group oversees irrigation affairs in the group's land areas. He arranges for cleaning and repairing canals and ditches, and settles water disputes. When canals carry barely enough water to satisfy needs, he encourages cooperation among farmers for obtaining water. When water shortages arise, he asks the heads of villager groups located along the main canal above his group to encourage their farmers to take less water from the canal. If shortages persist, he asks his administrative village head for assistance.

All farmers should abide by a number of rules while procuring water for their fields. When water is not plentiful, they may take amounts of water only as needed by plants on their fields. They may not waste water when other farmers are having acquisition difficulties. Water is wasted when a farmer has water flowing into a field and at the same time has the drain open. Then another farmer may close the field inlet, but only after closing the drain. A farmer may not stop a flow of water into another farmer's field except in the circumstance described above. When a farmer is unable, by his or her own means, to obtain sufficient water for the plants on a field, assistance should be sought from the villager group head. And finally, each household must provide a worker for cleaning and repairing canals and ditches when called upon by the head.

Water Acquisition Procedures

The farmers' primary irrigation task is to keep water standing on diked fields when they believe the rice plants require it, and otherwise to keep soils wet for the plants. They do so partly by opening and closing the inlets and drains of their fields, and the inlets of ditches that serve the fields. Commonly the drain will be closed. Then the farmer needs only open the field inlet when the ditch is carrying water in order to send water into the field, and to close the inlet when the field has enough water. A field whose soils should be wet is considered insufficiently wet when small cracks appear on the surface, when walking on the field makes feet dusty, or when mud does not stick to feet. When standing water reaches a depth above three or four centimeters owing to heavy rainfall, the farmer needs only to open the drain for a while.

Not always is there sufficient water in the canal for farmers to obtain water so easily. Often the main canals are less than full. Then a few farmers may need to work extra hours in order to create volumes of water in stretches of canals and ditches that are large enough to reach their fields. At other times, the main canals have even less water. Then more farmers must work long hours; and some will be unable to establish a flow into their fields without assistance from other farmers. Occasionally even with assistance they are unsuccessful. Farmers in the Tongan irrigation systems have adopted somewhat different sets of water acquisition procedures for the various levels of water availability in their canals. We distinguish three sets.

Regular irrigation

Water is plentiful much of the time when rice plants occupy fields, possibly more than half the time. Rivers, canals, and rainfall offer enough water that farmers devote little labor to irrigation. And if there are a few days without rainfall, the canals still carry sufficient water to satisfy needs without additional labor. At those times, water flows continually in all canals, often also in many ditches, and farmers employ

regular irrigation procedures to acquire water. They may choose to have ditch inlets and field inlets open continuously for some hours, and concurrently have the field drains partly opened. Then several centimeters of water will stand on the fields while gentle flows pass out the drains. They may also choose to keep drains closed, and simply open and close the field inlets every few days to maintain desired water levels. Farmers generally visit fields at least once a day through the rice season for purposes of checking water conditions. If a field needs more water, its inlet may be opened during such a visit, and then closed with a special visit later. With some rainfall every few days over several weeks, a field of fairly heavy clay soils might need its inlet opened once in seven days, a field of sandier soils once in two or three days.

If little or no rain falls for a week or two, a few farmers may need to devote extra labor to water acquisition. Farmers whose fields receive water from points higher on a canal than other farmers, have opportunity to take water from the canal before the other farmers can. Thus, the first farmers to experience water shortages would likely have fields in the tail area of the irrigation system; and the fields would likely be ones that receive water from the tail stretches of canals and of long ditches which extend across land that is nearly level. Less canal water would flow into the tail area because more farmers in the upper and middle areas of the irrigation system would be taking water daily. Instead of there being one in six farmers taking water, for example, there might be one in four. And within the long ditches of the tail area, water would flow sluggishly, and more farmers would be competing for the water each day. In such areas, farmers might be able to wet their fields a bit, but not apply standing water.

If the flow of water into a field declines to a trickle at a time when rice plants need more water, the farmer must try to build up the volume of water within the ditch above his field inlet, and also within the canal above the ditch inlet. In order to do so, he or she walks upstream along the water channel to examine other farmers' fields that are receiving water. Where another farmer's field already has

sufficient water, he or she may close its inlet, but only upon ascertaining whether the field's drain is closed, and if it is not, upon closing it. Closing a field's inlet first requires breaking down a small weir of rocks that the field's farmer has placed in the ditch for the purpose of deflecting some of the ditch water into the inlet. Then rocks and mud are placed in the inlet to close it. The farmer does this first along the ditch upstream from his or her field, then along the canal upstream from the ditch. But along the canal, the farmer must also check the fields that are taking water from ditches whose inlets he or she wants to close. After spending two or three hours closing the inlets of 10 or 12 fields, the farmer may feel that there is enough water in the ditch to supply his or her own field. The farmer then returns to the field, there to stay until it has enough.

A farmer may be able to obtain water this way during daylight hours. But then if the farmers of the 10 or 12 fields visit their fields, they may wonder why the inlets are now closed. Especially might they wonder if they felt that the amount of water in their fields was only marginally sufficient. They could then reopen the inlets and thereby reduce or eliminate the flow of water to the field with the shortage. In order to avoid such occurrences, farmers with shortages seek water late at night.

If the period of low rainfall continues, more farmers would need to walk along the water channels in search of extra water, and several farmers could be walking along the same channel at the same time. Then not only could there be confusion about whose water was in the channel, there might also be insufficient water through several consecutive nights to satisfy field needs. Under such circumstances, farmers ask assistance from relatives and close friends. Three or four farmers walk up the channel at night, working together to develop a strong flow from the canal into the ditch that feeds their fields. When they succeed, they direct the water first onto their field that most needs water, next onto the second most needy field, and so onward until all fields have water. Or they direct water in the order of the fields' inlets down-slope along the ditch, highest first, next highest second, etc. They choose the neediest-

first sequence if some fields absolutely require water that night. They choose the down-slope sequence at all other times, partly because it is the easiest way to distribute water, but also because, with it, less water is lost to seepage in the earthen channels. So long as farmers obtain sufficient water with help from relatives and friends, regular irrigation procedures remain in effect.

Modified irrigation

Droughts creep up on farmers. As days with little or no rain become weeks with very little rain, all farmers gradually sense the possibility of an impending water shortage. And, as more tail farmers must walk upstream along channels in search of water, some will be unable, even with the help of friends, to find enough water. They then request assistance from the head of their villager group. The head, in turn, visits the heads of several villager groups higher along the canal. He asks them to urge their farmers to put only one or two centimeters of water on their fields, and to delay taking water by a day or two. Or he asks them to persuade their farmers not to take water at night, for example. Then each night he sends several of his own farmers up along the main canal to close the ditch inlets and field inlets of fields that have enough water. At the same time, he may organize his farmers towards a more conservative use of water that reaches the group's land. Instead of allowing farmers to take water on nights of their choice, he requires them to take water in the down-slope sequence, that is, in the order of the elevations of their ditch inlets along the canal, several ditches each night. When all needy fields have received water once, the sequence is repeated through another cycle for as long as water shortages continue. If a head feels that weeds are obstructing flows in canals and ditches, he can immediately organize a channel cleaning activity and require participation of all households.

There are two additional activities that villager group heads can encourage during low water periods. A head whose group possesses a pump can provide assistance for pumping water to fields. Several villager groups and a few households own portable engine-powered

pumps and hoses. A household with access to a reliable water source, such as a well or small pond, might own a pump if one of its members is employed off the farm so that it has relatively few workers for farm labor, if its group's rice land commonly experiences water shortages, and if much of the group's rice land is located within reasonable pumping distance of water. The latter condition relates to the fact that a household's right to cultivate any individual field is temporary, because the villager group's land is redistributed among its households every few years. A villager group likely owns a pump if water shortages occur regularly on much of its rice land and if a dependable water supply is located nearby. The water source might be a pond; or it might be a stream whose bed of gravel holds water even when no water appears on the surface. The pumps, most electrical, began appearing in the 1970s. Initially they were utilized quite sparingly owing to high operating costs. However, rising labor costs have prompted substantially greater use in the past decade.

The other activity that some heads can encourage is a form of scheduled water distribution called rotation irrigation. When farmers use modified irrigation procedures, water commonly flows in the full length of the canal. But if the flow is small, many tail area farmers may not be able to obtain enough water. The heads of the lowest villager groups along the main canal may together decide that all water in the canal which reaches the uppermost of their groups should be delivered to their land one group at a time. And after each group has been served, water would again be sent to their groups in the same order through additional cycles until the low water conditions end. The order is the down-slope sequence, highest group along the canal first, second highest next, etc., or a sequence determined by a drawing of lots. Each group receives water for a specified time period, 12 or 24 hours, for example. The sum of the hours in a cycle may be 24, 48, or 72. The time period for each group is approximately proportional to the extent of its irrigable land in relation to all irrigable land within the cooperating groups. Among the villager groups portrayed in Figure 1, such cooperation would

involve groups K and C along the tail of West Main Canal, and groups J, H, and G along the tail of East Main Canal.

With rotation irrigation, the water that arrives for a villager group is distributed among fields in accordance with procedures generally devised in a meeting of heads of households. We identified two configurations of procedures. Some groups decide that each field should receive just enough water during each rotation cycle to support its plants until the next cycle again brings water. That means a bit more water for fields with the sandier loam soils than with heavy clay soils. It may also mean less water for irrigable vegetable fields than rice fields. Those groups send water to their fields in the down-slope sequence. From the main canal, water passes first into the uppermost one or two ditch inlets for concurrent delivery to several fields along the ditches. When those fields have enough water, the flow is directed to the next fields along the ditches, or if there are no more fields there, to fields along the next ditches down slope on the canal. The process continues until all fields have been served, and is repeated the next rotation cycle. Often the group head supervises the water distribution himself. Otherwise he asks farmers known for their wisdom and fairness to supervise. The supervisors are important because they decide when to open and close the field inlets, and so determine how much water each field receives.

In the other villager groups, the meetings of heads of households produce a decision that each household's fields should receive the amount of water to which the household has rights. The amount is measured by minutes of water flow time within the main canal. Thus, for example, a household with three percent of the group's irrigable land has rights to three percent of the group's water flow time in each rotation cycle. Here the sequence of water deliveries is usually determined by a drawing of lots among farmers. The fields of the farmer who draws lot number one obtain water first, lot number two second, etc. Because most farmers have fields in two or more sectors of their group's land, water from the main canal would commonly require simultaneous direction to fields along two or more ditches. After those

fields have taken their rightful amounts of water, the next fields to receive water may be located along different stretches of the ditches or along different ditches. That creates complex water flow patterns, because a low field along a water channel will sometimes receive water just before a high field does. Then there is a tail of water that flows down the channel to the low field after the channel's water has been directed to the higher field. The supervisor must anticipate that tail, estimate its flow time, and include the time in the water allocation of the low field, all before he begins directing water to the higher field. The complex flow patterns, in turn, cause extra losses of water by seepage in the earthen channels, losses beyond those associated with the down-slope sequence of water distribution. Such losses are substantially reduced when farmers choose to share or exchange water allocations with other farmers. If a farmer has fields in widely separated places but near another farmer's fields, for example, she may share her water at one place with his field there, after which he shares his water at another place with her field. Then water is sent to those places only once instead of twice.

Between the early 1980s and 1994, tail area farmers utilized rotation irrigation as described above only occasionally. On the other hand, farmers every year walked upstream along their ditches and canals in search of water at night. A few did so more than 20 times a year, some an average of 10 to 20 times a year, others 5 to 10 times. Most of those efforts occurred during the second rice crop season, especially in September and October.

Emergency irrigation

When rainfall remains low for many weeks and near-drought conditions linger beyond a month or two, water shortages may force a system-wide change of irrigation procedures. Then several villager groups would be experiencing severe shortages, and their farmers would be carefully distributing the water that reached them for minimum crop losses. At the same time, many farmers upstream along the main canal from those groups would be taking the minimum amounts of water needed by their fields. They would be doing so in response to

requests that more water be allowed to flow down to the several groups.

Then if the heads of those several villager groups believed crop losses were imminent, they would ask the head of their administrative village for assistance. In that circumstance, the irrigation system might still have sufficient water to satisfy all field needs. The shortages could be occurring because some farmers in the high and middle sectors of the system would unwittingly be taking more water than they needed, and letting the excess flow into drainage ditches.

If the head of the administrative village feels that farmers in the several villager groups have exhausted opportunities to obtain water, he calls a meeting of the heads of the administrative villages served by the irrigation system. For the system with two main canals in Figure 1, the meeting would include the heads of administrative villages 1, 2, and 3. The heads would then determine whether the water conditions were cause to change distribution procedures from modified irrigation to emergency irrigation, which is essentially system-wide rotation irrigation. The determination is not made lightly because emergency procedures will disrupt the normal working activities of a great many farmers. If they favor emergency irrigation, they would prepare guidelines that include a schedule of water deliveries to the villager groups based on two goals, that the groups receive their rightful amounts of water, and that crop production losses be kept to a minimum. Completed guidelines are conveyed to the villager group heads who then manage the water delivery process.

Between the early 1980s and 1994, emergency procedures were employed in the largest of the three Tongan irrigation systems only in 1991, but then through several weeks of each rice season. They were utilized several times in the smallest system, and not at all in the third system. The variation of experiences stems from opportunities to use engine-powered pumps. That one irrigation system did not experience emergency irrigation owes to a commitment of funds by the tail area villager groups for installation of a large pump in 1987. Before 1987, it was only the tail area farmers

who experienced water acquisition difficulties; and they obtained enough using the modified irrigation procedures. Since 1987, the large pump has been able to send water from the gravels of a nearby riverbed to the main canal at the point where the canal enters the tail area, so that farmers there have received pumped water on demand upon payment of a fee. In addition, the other villager groups of the system have acquired portable pumps which can lift, into the main canal near the intake gate, water that pools in river gravels immediately downstream from the weir. Farmers in the other two irrigation systems have less pumping opportunity because pooled river-gravel water is less available during low water periods in proximity to their canals and fields. Thus, they have utilized emergency irrigation procedures.

Emergency procedures give all water in the main canal sequentially to villager groups and to parts of villager groups. They receive water in order of their location along the main canal, highest first, second highest second, etc. Upon completion of delivery to the lowest group, water is again directed to the highest group, and the cycle is repeated. The amount of water given each group is proportional to the extent of its irrigable land. The amount is measured by the number of hours of water flow time in the uppermost stretch of the main canal. Because fields with the sandier soils may need water every three or four days, the sum of the hours in a water delivery cycle is usually 72 or 96. Where a system has two main canals, the administrative village heads will insure that each canal receives an amount of water proportional to the area of land it serves. In Figure 1 then, if villager groups E and F have 25 percent and 35 percent of the land served by their respective main canals, they are entitled to 25 percent and 35 percent of the flow time of water that enters the upper stretches of their main canals during each rotation cycle.

While the administrative village heads prepare emergency guidelines for the irrigation system with two main canals shown in Figure 1, they would possess good estimates of the irrigable land areas of each villager group, and they would consider a variety of factors. They would probably decide to prepare separate wa-

ter delivery schedules for West Main Canal and East Main Canal. One reason is that the farmers of each canal are accustomed to working with one another on irrigation matters, but not with farmers from the other canal. A second is that a schedule for one canal would be less complex. They would also want to allocate water in large blocks of time that would allow the villager groups to distribute water to all needy fields during each rotation cycle.

As the administrative village heads consider a water schedule for West Main Canal, they would know that in serving villager groups B, F, and K, and the two western parts of group C, the canal irrigates some fields near the river that have fairly sandy loam soils. They would also know that if those soils can receive only one or two centimeters of water during each irrigation opportunity, a water delivery every three days would be required. Thus, a three-day rotation cycle is desired. Then they would need to divide the entire area irrigated by West Main Canal into a number of sectors, with each sector to receive water for a specified time period in each cycle. Their decisions would be based upon their detailed knowledge of usual and unusual irrigation conditions in the various locales. Perhaps they would see a sector which encompasses villager group B and the uppermost western part of group C, an area amounting to about 35 percent of West Main Canal's irrigable hectares. Villager group F alone might constitute a second sector, also with 35 percent of the hectares. And group K together with the other western part of group C might be a third sector. Because those sectors have approximately the same amount of irrigable land, each reasonably could receive 24 hours of all water in West Main Canal during each three-day rotation cycle. And if, after experiencing a cycle or two, farmers in the upper and middle sectors seem to be receiving less than barely adequate water because they have a bit more irrigable land than the tail sector has, small adjustments could be made in the water schedule. That the administrative village heads might be comfortable with such an arrangement for West Main Canal farmers could rest partly on their knowledge that more land in the upper and middle sectors is planted to sugar-

cane and vegetables, which require less water than rice does.

East Main Canal in Figure 1 serves a larger irrigable area than West Main Canal, and always carries a proportionally larger amount of water. Few fields have the sandier loam soils; and most of the tail area has heavy clay soils that hold standing water for a relatively long time. As such, the administrative village heads might choose a four-day rotation cycle. One day all water would go to villager group D and the northern part of group C, the next day to group E. The remaining two days all water would belong to tail groups G and J and the western part of group H, where nearly all land carries rice because soils there are better for rice than vegetables.

Two additional features provide further complexity for the administrative village heads. First, Figure 1 shows some land that receives water not from West Main Canal or East Main Canal, but from the short canal that connects those two canals to their water intake gate. The land is all fields in villager group A and the very highest fields in group B. Because the extent of the fields is small, the administrative village heads could well decide to let farmers there take water at times of their individual choice, but with an exhortation to take it sparingly. They could also direct the farmers to take water at a specific time in either the three-day or four-day rotation cycle.

The second feature is a small area of fields low in villager group G which can be irrigated not only from East Main Canal but also from South Main Canal in the other irrigation system shown in Figure 1. The extent of those fields would be known with precision. Also, long experience would suggest to the administrative village heads that a certain portion of the water needed by those fields, one-third for example, would probably be obtainable from South Main Canal. They could then ignore that fact in their assignments of water because it represents very little water. Or, they could reduce by an hour the water flow time allotted to Groups G and J and the western part of H, and give that hour to group E or to group D and the northern part of C. Or they instead might tell farmers in group A to take water on the same two days that

groups G and J and the western part of H receive water.

The completed guidelines would have a water flow schedule of three or four days duration for each main canal. The schedule would assign all water in the canal to villager groups and parts of groups for long periods, half days and full days for example, and would include a directive that the schedule be repeated in cycles until rainfall alleviates the water shortage.

Upon receipt of the guidelines, the villager group heads control irrigation activities. If a group is alone in securing water during a watering period, its head manages water distribution in the period. On the other hand, if two or three groups receive water during a period, their heads devise a schedule that gives water to each group in approximate proportion to its irrigable land area. Water is usually sent from the main canal to the groups in the down-slope sequence. However, the heads may favor a sequence determined by a drawing of lots.

For distribution of water within their own villager groups, the heads utilize the procedures described above for rotation irrigation in tail area groups. They send just enough water to fields either in the down-slope sequence or in the sequence established by a drawing of lots among the heads of households. Respected and knowledgeable farmers supervise activities. Representatives of households commonly observe the activities as their fields receive water.

Conclusions

The farmers of the three irrigation systems in Tongan County desire that all irrigable fields in a system should be able to receive approximately the same amount of water per unit area within any period of a few days. They also desire that the crops on irrigable fields should always be able to obtain enough water for good production. They have generally met those standards. Despite occasional severe water shortages lasting for weeks at a time, losses of rice and vegetable production owing to lack of water have been uncommon. No farmer with whom we spoke mentioned major losses.

The water distribution procedures devised by the farmers are well adapted to local environ-

mental conditions: to the various land slopes on which their water channels and irrigable fields are located; to the soils of their fields which range from moderately permeable loams to quite impermeable clays; and to rainfall amounts which, although generally sufficient for rice growing, range widely for the same month through periods of years. Most days, water is plentiful. Farmers work alone or with a few friends to supply their fields utilizing regular irrigation procedures. But when shortages occur in several parts of a villager group's land, the head of the group may modify irrigation procedures by providing a number of kinds of support. He may organize his farmers to close ditch inlets upstream on the canal, and to remove weeds in canals and ditches. He may request that farmers upslope on the main canal take less water. He may arrange for a pump to deliver water. And if his is a low villager group on the canal, he may institute rotation irrigation with neighboring groups. Modified irrigation procedures such as these were used during almost every rice crop season in each of the three Tongan irrigation systems between the early 1980s and 1994. By contrast, the heads of the administrative villages rarely called for emergency irrigation procedures. With them, all villager groups participate in rotation irrigation, and supervisors in each group direct water to several fields at a time.

Both rice crop seasons of 1991 were extremely difficult in the three systems. Many farmers worked long hours closing ditch and field inlets along the tail and middle stretches of canals, trying for many nights to build flows of water that would reach their own fields. Sometimes they failed. Villager group meetings were held to discuss ways of enhancing water deliveries to many locales. The administrative village heads of two of the three irrigation systems instituted emergency irrigation. All villager groups with access to sources of supplemental water pumped water. Some farmers carried water in buckets on shoulder poles from shallow wells they had dug in dry riverbeds, the wells too distant for pumping. The result was that some farmers received slightly lower yields of rice than usual, and a few experienced moderate losses. But most farmers obtained

yields comparable to those of normal rainfall years.

The irrigation water distribution procedures created by the Tongan farmers may be judged effective because they almost always allow all farmers sufficient water for the crops on their irrigable fields; and they do so despite substantial variations in the availability of water from time to time. It seems to us that their effectiveness may be attributed partly to two features. One feature is that the ditch inlets and field inlets of the irrigation systems can quickly be made to accept more water, or less water, simply by widening or narrowing them, and by raising or lowering the small weirs that deflect water into them. The opportunity for such manipulation allows farmers to send canal water to any number of fields at a time—to many fields, or to just a few needy fields. And the amounts of water can be different. The second feature is that the irrigation procedures allow for considerable flexibility. So long as farmers comply with two basic rules—no wasting water, and no reducing or stopping a flow into another farmer's field unless the field already has enough water—they may work to acquire water at any time and in a variety of ways. They may walk up a canal in organized groups in search of water at night. They may seek ideas from other farmers and from the villager group head on how to find more water within the next few days. They may strongly encourage their group head to call a meeting for an airing of ideas or to initiate a group-wide water acquisition effort. And if there is a water source near the needy fields, they may encourage use of a group owned or rented pump, for which they would pay a fee. Their water distribution procedures encompass a variety of choices, and, in addition, encourage initiatives for devising new procedures.

The irrigation successes of the farmers also owe partly to rapid growth of the local economy during the past decade and a half. Increased wealth in Tongan City and Xiamen City has expanded market demands for vegetables. Farmers have therefore been gradually devoting less land to rice and more to vegetables, which need less water. Especially have farmers with some of the sandier fields made

the change during the second crop season. Increased wealth has also allowed more farmers and more villager groups to purchase pumps. In effect then, enhanced economic welfare has slightly reduced demands for water on some irrigable fields and also expanded opportunities for acquiring irrigation water for other fields.

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