IRRIGATION SYSTEM OPERATIONS INTENSITY AND RELATIVE WATER SUPPLY

The Asian Case

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INTRODUCTION

Managing irrigation systems entails both planning and operation. Planning involves scheduling of cropping systems based on potential available water flows; operation includes making decisions regarding the daily allocation and distribution of water. The quality of these decisions is usually contingent upon the intensity of important water-based information that is monitored, collected and evaluated from strategic points within the system. The frequency of monitoring, the number of collection points, and the thoroughness of evaluation of information for water allocation and distribution defines operational intensity.

Among the water-focused activities for managing irrigation systems, allocating and distributing water reliably are perhaps the most important for optimizing benefits from irrigation. But they can also be the most significant factors in poor system performance. The performance of an irrigation system should be rated according to how closely it attains its objectives in the face of external operational constraints. System objectives may vary from attainment of national food self-sufficiency to achievement of regional equity. Operational constraints may range from insufficient operation and maintenance funds to unreliable system water supply.

But, in reality, the operational performance of an irrigation system is rated based on the results of water allocation and distribution under the given physical, technical, economic and social milieu in which it operates. Three indices that nearly all evaluators of irrigation system performance employ to characterize performance are productivity, equity, and water use efficiency.

OBJECTIVES OF IRRIGATION SYSTEM PERFORMANCE

In order to perform satisfactorily, an irrigation system should be able to maintain an appropriate balance among the objectives of productivity, equity, and efficiency.

Productivity

New irrigation systems are being built and outmoded ones rehabilitated in order to increase reliability of water supply for crop production. Ultimately, the end users will rate water distribution performance based on crop productivity and convenience to obtain irrigation supplies. Reliable system water supplies increase production in three ways: (1) intensification of land use through multiple cropping, (2) expansion of irrigated areas by bringing rainfed areas under irrigation, and (3) more importantly, increased yields per unit area due to more intensified farming practices (Obedoza, 1976). Consequently, high productivity accrues from the combined effects of expanded service area, intensified cropping, and increased yield per unit area.

Productivity can also be expressed in terms of water use efficiency: yields (output) divided by water (input). In water-scarce situations, irrigation should be reckoned with as an input in assessing water productivity. Besides its direct impacts on crop physiology and growth, reliable irrigation supplies induce farmers to adopt complementary yield-increasing technologies such as modern crop varieties, fertilizers, pesticides, and labor. This complementarity between water and the other managed inputs complicates isolating the magnitude of contribution of improved water distribution to productivity. Further complication in clearly separating the specific effects of improved water distribution on water productivity arises because (nonmanaged) natural production inputs like solar radiation, rainfall, insect and disease incidences also affect productivity levels. For these reasons, productivity is a crude index of system water distribution performance.

A complete accounting of the direct impact of improved water distribution on crop yield, plus its indirect effect on the level of use of other managed inputs that in turn affect crop yield, will enhance the significance of yield productivity of water as an index of irrigation system performance. Its predictive value will improve and can be used to compare performance of systems across sites because it will be possible to ascertain the magnitude of contribution to productivity of improved water supply reliability. Low productivity may result even if water distribution is greatly improved as long as the negative effects of inputs other than water override the wholesome impacts of improved water supplies. But to fully ascertain the specific contribution of improved water supply to productivity will entail large expenditures for the monitoring, control, and measurement of many variables.

Although the reliability of water delivery shapes the crop management behavior of the farmers, crucial decisions they make about crop intensification often depend on other factors beyond their control. This further confounds singling out the effects of water on productivity. That is why only the complementary effects of water and other inputs are well-understood. A multidisciplinary undertaking is needed to comprehend the singular contribution of water and of other inputs to crop productivity; this suggests the need for a multidimensional productivity criterion.

Assessing system water distribution performance on the basis of yield productivity of water alone could be inadequate as crops do not produce by water alone. Although most decisions irrigators make relating to crop production are germane to the nature of system water supply performance, these decisions are also influenced by factors beyond their control. The availability of credit, machinery, and labor and the prevailing or future prices of production inputs and outputs, or some existing national agricultural policies also influence farmers' investment strategies.

Closely keyed to productivity is water supply adequacy relative to water requirements. Typical seasonal water requirements in Asia for a 100-day rice crop range from 1,000 mm to 1,700 mm. Estimating water adequacy for rice is less difficult than for other crops because rice thrives well over a wide range of water regimes. Water supply for rice is generally adequate as long as soil moisture does not drop below saturation and standing water does not exceed 15 cm. If field moisture conditions are below saturation or fields are flooded to a depth greater than 15 cm, rice yield will start to decline (De Datta and Williams, 1968).

For years, water adequacy for rice has been estimated by stress days in field research. Stress days are the number of consecutive nonflooded days beyond three in the paddy (Wickham, 1972). The three-day threshold was used because soil is assumed to still contain three centimeters of water on the first day after standing water disappears. Three centimeters of water is sufficient to supply the water needs of rice for about three days. The stress day measure has proved its practicability as an index of water adequacy in many farm-level production analyses; stress days have quantitatively demonstrated the decline in rice yields due to limited water supply quantities and inappropriate timing of water deliveries. The duration and timing of water shortage affect the magnitude of the decline in yield. Researchers have successfully used stress days in simulation studies to characterize irrigation performance (Wickham et al., 1978). But the stress-day criterion does not consider differences in soil moisture-holding capacities nor does it reckon with the depth to water table in relation to depth to root zone--factors that are particularly important for irrigating crops other than rice.

Also, since crop water needs at some growth stages are more critical than at other stages,[1] a water adequacy criterion should have dimensions of both quantities and timing of deliveries. Therefore, water adequacy at the farm level is conditioned by the reliability of system water supplies; dependable system water supplies can guarantee timely delivery of adequate water to the farms. Both farmers and irrigation field personnel appreciate the security and convenience of a reliable water supply. Adequate and dependable water supplies minimize some of the production risks and uncertainties farmers face with fluctuating water supplies. So reliable water supply delivery will boost credibility of irrigation personnel in the eyes of the farmers and will minimize operations conflicts. On grounds of enhancing farmer confidence and building government irrigation staff credibility, irrigation managers should consider both the timing

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[1] Water stress caused by both water shortage and excessive supplies produces more serious crop yield declines during the reproductive growth stages than that in any other crop growth stages.

and quantity dimensions of water adequacy. Disregard for either of the two dimensions could blunt the utility of a water adequacy criterion.

Equity

Irrigation system performance is also a function of the extent to which the system allocates and distributes water equitably. Operational measures of equity differ from one system to another, but generally follow the rules of proportional equality. For some systems, equity criteria are satisfied when water is delivered to hard-to-irrigate parts of the command area during water-short periods. More common measures of water distribution equity include estimating variability in quantity and timing of water supplied relative to demand, yields and cropping intensities, and, more significantly, income per hectare among different locations within the service area (Lenton, 1982). The "head vs. tail" and the "rainfed vs. irrigated" difference in variability of these measures is often used to describe the extent of water distribution equity (Lenton, 1980).

Equity is rarely an expressed objective of government systems, but it is often the guiding principle in water allocation and distribution in traditional irrigation systems.[2]

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[2] Most agency-managed irrigation systems address the equity objective at a more macro level as irrigation projects being conceived and constructed to effect a regional balance in irrigated areas.

In many traditional irrigation systems farmers view equity within the institutional environment or principles that define social behavior for local water control. Equity issues revolve around water rights and are usually taken in terms of "what is fair" relative to the society's norms. Usually, equity is defined as a farmer's right proportional to the total rights of all farmers (the holding size of an individual as a percentage of the total service area, or a number of "shares" relative to the "total water shares", etc).

Equity can also mean a close correspondence between services received from and obligations required in the operation of irrigation systems, as in the case of the irrigation zanjeras in Northern Luzon, Philippines (Siy and Early, 1982). A zanjera, or communal irrigation organization, receives a quantity of water roughly proportional to its prior rights plus the amounts of financial, material, and labor resources it contributes to the operations of the irrigation system.

That the farmers in these traditional irrigation systems perceive a close correspondence between the irrigation fees they paid and the amounts of water they received is clearly shown in these studies. Although water flow rates were never measured in these systems, the irrigators know the amounts of water they receive relative to those of the others. And they apparently contribute labor and material resources proportional to the amounts of irrigation they received. There is strong reason to believe that this close correspondence between water received and resources contributed (equity) is intrinsic in their operations. Since equity concepts and forms differ from one system to another, it is difficult to use them in characterizing irrigation system performance.

Water Use Efficiency

Commonly, system water distribution is rated not only according to criteria of technical efficiency--engineering and agronomic--but also according to economic efficiency. The technical efficiency index usually refers to the input-output ratio, and for water distribution in lowland rice, this is usually given as the ratio of the water requirements to total water supplies.[3] The engineering efficiency index denotes how well irrigation supply is controlled in relation to water demand, whereas agronomic efficiency indicates yield per unit of water, which is a measure of productivity.

In the dry season, the absence of the confounding effects of excess water from rains upon regulating water supplies to closely match the water demands, makes water use efficiency a goood indicator of management control efficiency. But in the wet season, unwanted water from heavy rainfall compounds problems of operational control. Most existing open-channel irrigation

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[3] For lowland rice cultivation, the water requirements comprise evapotranspiration and seepage and percolation; at the same time, total water supplies comprise effective rainfall and irrigation.

systems have little flexibility and lack communication facilities to deal with the spatial and temporal variations in system water supplies brought about by rains.[4] As a result, unregulated water flows from system canals end up in farmers' fields. Compounding further the excessive water problem in the fields is the inability of farmers to use rainfall effectively; most farmers seldom use even half of the total rainfall[5] (Sen, 1977; Acoba, 1981). On average, farmers use a small percentage of the total rainwater. Inevitably, the larger fraction of the unutilized rainfall drains away from the command area as surface runoff and is usually treated as a water loss. Excess rainfall, if not reckoned with carefully, can considerably reduce wet season water use efficiency and may be misconstrued as an indicator of poor system management by operations staff, when in fact farmers may not be using effective rainfall and therefore contributing to the apparent low efficiency.

Thus, to enhance the utility of the efficiency index for evaluation of system performance, one must discount effective rainfall (the fraction of total rainfall that is used to meet water demand) from the water requirements of the system and then

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[4] When newly-constructed, some modern irrigation systems in South and Southeast Asia were equipped with some level of communication facilities, e.g., telephone lines. These facilities, however, have generally not been maintained, in part because of the frequent and severe damage done to them by monsoon season typhoons and other natural disasters.

[5] Other factors that influence rainfall use efficiency in the fields include duration and intensity of rainfall, water delivery method, and farmers' management of paddy spillways.

divide the remainder by the irrigation quantities alone. Water use efficiency can be calculated daily or weekly to correspond to water delivery scheduling:

$$WUE = (ET + S\&P - RN_eff)/IR$$

where WUE = weekly water use efficiency,

ET = evapotranspiration, mm/wk

S&P = seepage and percolation, mm/wk

RN_eff = effective rainfall, mm/wk, and

IR = irrigation supplies, mm/wk

The quotient will indicate the degree to which the water supplies have been controlled to match the water demands, and it can be used to compare water use efficiencies among systems regardless of rainfall patterns. Discounting effective rainfall from the total system water requirements will amplify the applicability of a modified WUE. But measuring effective rainfall in the field is not only complicated but also costly.[6] Only when the added benefits to operating the system with a modified WUE exceed or equal the total costs of measuring effective rainfall will an irrigation system consider it in WUE calculations.

The utility of WUE depends on the opportunity costs of water losses. Operating irrigation systems at low WUE, where the opportunity costs of water are high, generally indicates poor system performance. Water savings from rainfall and cutbacks

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[6] Field measurement of effective rainfall involves monitoring and measurement not only of rainfall, but also of evapotranspiration and seepage and percolation from more stations than the operation staff actually use.

from irrigation releases often have higher economic value for reservoir systems than for diversion systems. Reservoir systems can store excess water from wet-season operations for crop production in the following dry season, whereas diversion systems can not impound wet-season water savings for dry-season cropping. Similarly, water savings in pump irrigation systems have appreciable economic value because of the operation costs associated with pumping. Hence, lower water use efficiency is less consequential for diversion systems than for reservoir or pump irrigation systems, unless overapplication of water will flood the downstream command area or other irrigation systems depend on the same river for their supplies.

What about the farmers? Do they worry about water use efficiency? Most farmers highly value the convenience and security afforded by ample water supplies (Robinson, 1982). Consequently, they are more preoccupied with activities to increase water supplies to their turnouts than with efforts to economize water use (Svendsen, 1983). This provides them with a two-tiered security. First, they stock up as much water as they can and then use the water as efficiently as need be. Most irrigators also cut down their rice production expenses by storing greater water depth in their fields, because deep water suppresses weeds and reduces management labor costs. Perhaps even more important, greater water depth in the fields reduces farmers' worries about uncertain water supplies. Farmers would rather trade lower fertilizer utilization efficiency due to increased seepage with greater water depth than risk losing fertilizer and rice crop altogether due to water shortage.

Collecting volumetric water use fees by the irrigation agency should induce farmers to apply water more judiciously and efficiently, but the inability of most Asian irrigation systems to measure water deliveries at the farm gate makes it impossible to provide this incentive. Generally, when these irrigation fees are collected, it is on a basis of per unit irrigated area. However, some systems may levy water charges on a per application basis, particularly in the case of upland crop irrigation. Other systems charge water fees indirectly as a percent of annual land tax payments. In rare cases, farmers may make unauthorized payments to irrigation officials for improved water supplies. Only in the last case would farmers realize the correspondence of water fees to quantities of water received. Therefore, farmers usually apportion as much water as they can conveniently acquire and pay a blanket fee (as in the per unit area irrigated basis) or, even worse, waste water because they are totally unaware of paying any water fees as in the land tax scheme.

Farmer disincentives to economize water use and excessive surface runoff from unutilized rainfall may result from low opportunity costs to water, but low system operational efficiencies also indicate inadequate system control capacity and the need for operational or physical rehabilitation. For instance, low field WUE can be ascribed to rundown system physical facilities and incompatible operating procedures. Both operation and physical rehabilitation are needed in this instance.

WHICH CRITERIA TO USE

An irrigation system is opertionally stable if it can maintain an optimum balance among productivity, equity, and efficiency objectives (Table 1). These objectives are often incompatible; in fact, they are often contradictory. For instance, a telling contradiction exists between water use efficiency and productivity. Promoting high WUE, if carried to an extreme could result in low productivity due to water shortages.

Productivity, measured as relative yield per unit area, and water use efficiency data from twenty-two sites in Central Luzon, the Philippines were analyzed and results encapsulated in Figure 1. The results show that productivity losses increased with increasing water use efficiency (Wickham, 1973). As WUE increases beyond 70 percent (RWS equal to 1.43), total productivity decreased as well as yield per unit area. Similar results were reported by Oad (1982) for several Indonesian systems. The results show that when water supplies are dramatically reduced to raise WUE to near 100 percent, productivity will decline substantially. In the same manner, efforts to assure equity can result in reduced yields if water is required to be spread too thinly (Oad, 1982).

Table 1. Characteristics of common system performance indicators.

Indicators	Expression	Plus(es)	Minus(es)
• Productivity	• yield/unit area, yield/unit/	• often compatible with national goals and farmers' objectives	• crude indicator of system performance; crops do not live for water alone; very much farm-focused index
• Equity	• proportional allocation of water according to area, rights, relative investments;variance in amounts of water, yield, income among parts of a system	• carries social equality objectives; promises each one an opportunity of access	• different connotations and forms from system to system; generally elaborate and circumstantial; impinge upon productivity and efficiency
• Efficiency	• commonly expresed as water demands divided by water supplies in percent	• clean and useful index at technical and higher parts of the system; when appropriately measured, is a good indicator of management control	• ambiguous concept at the farm level; in practice does not correspond to water fee paid

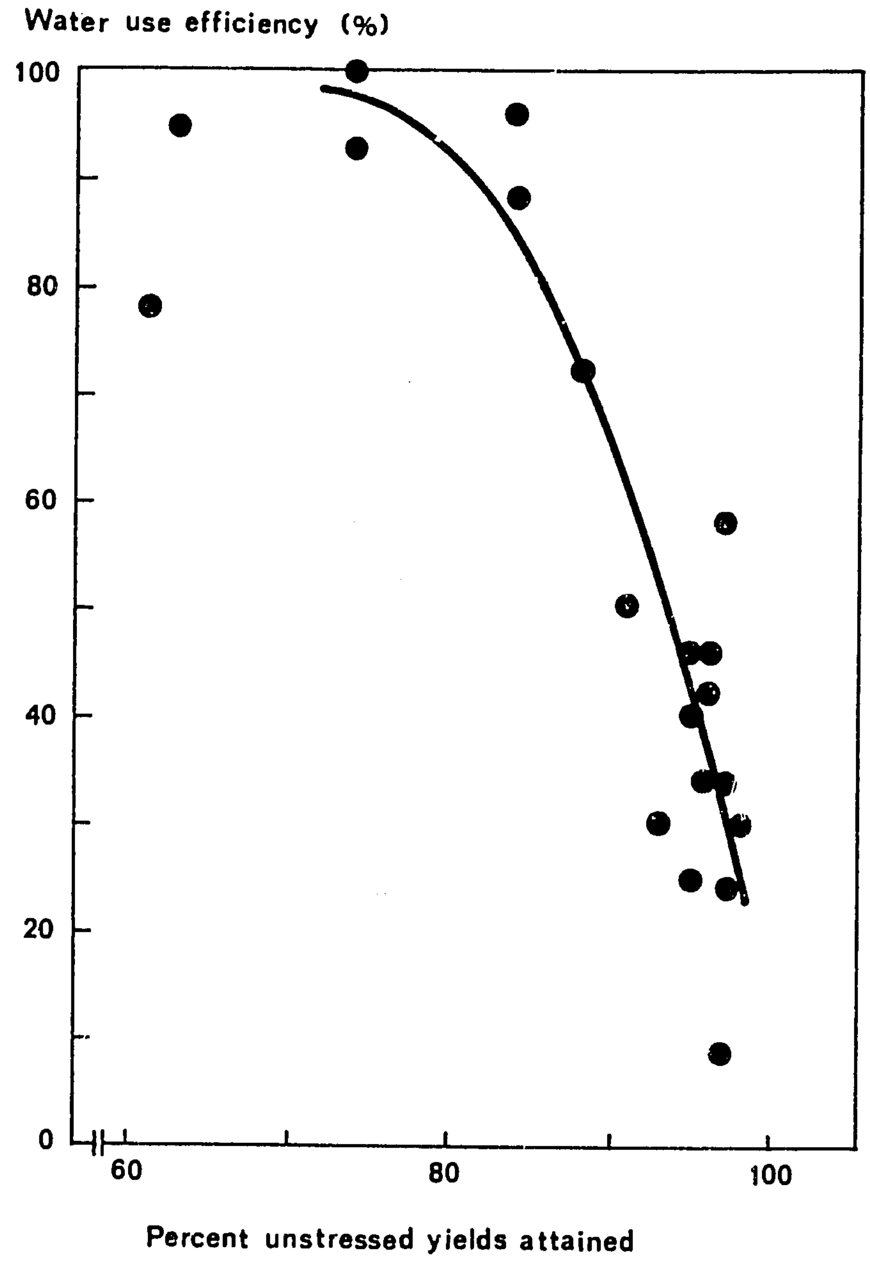

Figure 1. Relationship between water use efficienvy and yield productivity, 22 crop sites, Luzon, Philippines, 1969-1978.

To a certain extent, the criteria used to evaluate system performance may be biased by the views (discipline) and objectives of the evaluator. An irrigation agronomist may understandably concentrate on the productivity of water when looking into system performance. With productivity of water as the major system performance criterion, however, a high probability exists that system performance will be equated to high WUE on the farm; other management activities taking place higher up the system that are equally relevant to achieving high WUE could be inadvertently overlooked. Such an assessment of irrigation system performance could end in misdiagnosis and, therefore, in palliative responses. It will surely fail to get at the roots of the problem.

In comparison, an experienced engineer will look for causes of low field WUE higher up the system because he knows that field problems often stem from poor system control. These causes are hard to pinpoint in the field, since the amount of water that finally reaches the farms is the result of a series of allocation and distribution processes at various decision points from the supply source to the fields. Careful problem identification can determine where problems occur, making it possible to prescribe more specific treatments. For instance, if water wastage in the fields is due to poor system control, it will be counterproductive to improve the farm without improving the system control first. Solving tailend field problems spawned by headend system deficiencies is like pushing water against gravity, which entails an enormous waste of energy.

It is expected that in most systems, where farmers' direct cost has little correlation to the water received, farmers will appraise system performance on the basis of convenience in obtaining water and on levels of output derived, regardless of quantities of water received. Convenience in securing water has associated costs in some systems. Convenience in securing water can have different connotations, but it usually means either that conflicts and difficulties in obtaining water are minimal or that little time is required to secure water and to irrigate. Thus, convenience implies adequate and timely water supplies. But in irrigation systems where farmers need to make substantial cash or labor contributions to pay for system operation (in the case of pump systems), cost becomes an important criterion for evaluating performance.

Because it is not possible to optimize performance on all fronts, improvement in system performance must reflect tradeoffs among the criteria discussed above. Improving irrigation system performance based on any single criterion may result in short-lived and uncalled-for solutions. The preceding discussion brings to the fore a need to explore other water-based system performance indicators that can integrate the salient features of productivity, equity, and water use efficiency. Moreover, these new indicators should be able to capture and reflect behavioral factors in system performance.

SPECIFIC WATER DISTRIBUTION INDICES

Some research conducted in the early 1980s explored the potential and practicability of using water supply and water demand quantities to characterize operational behavior of Asian irrigation systems. The results are summarized below.

Target Water Flow Achievement Index

Moya (1979) used a target water flow achievement index (TWFAI) in evaluating water distribution within the tertiaries of the Philippines' Lower Talavera River Irrigation System (LTRIS). TWFAI was defined as a ratio between total water supply--total rainfall (RN) and irrigation (IR) entering a certain section of a turnout area--and the target water flows (TF) for a particular time period. The TF comprised the water requirements--evapotranspiration (ET) and seepage and percolation (S&P)--corresponding to the ongoing farming activities and crop growth stages in a turnout section. In equation form, TWFAI is

$$TWFAI = (IR + RN)/ TFA$$

where

TWFAI = target water flow achievement index,

IR = irrigation supplies,

RN = rainfall, and

TFA = target water flow based on actual measured water demands from the previous week.

TWFAI can be calculated on a daily, weekly, or seasonal basis; however, in this study it was estimated weekly to conform to the weekly operational plan of the larger irrigation system management research program. A TWFAI of 1.0 implies that the amounts of water supplied fully match the amounts required, hence a 100 percent WUE for the turnout section. A value higher than 1.0 denotes overirrigation and WUE lower than 100 percent; whereas a value lower than 1.0 indicates water shortage in the turnout section. More than water adequacy, TWFAI implies a degree of system managerial control, system physical controllability, or a combination of both.

TWFAI was used to analyze rice yield variability across farms in LTRIS's three upstream tertiary areas in the 1979 dry season. To amplify its validity, TWFAI was calibrated against SD, the standard water adequacy measure at that time, using simple regression analysis.[7] A regression model of the form

$$SD = -3.979 + 6.112\ (1/TWFAI)$$

was significant at the 1 percent level and accounted for about 60 percent of the variability in stress days on the sample farms.[8]

These two SD regression functions will not predict the same

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[7] Prior to using TWFAI as a variable in further analyses, its relationship with stress day index (SD) had to be established, since SD was considered the standard index of water adequacy. Many irrigation and economic investigations have already employed SD as a measure of water adequacy and found it a potent variable (Tabbal and Wickham, 1978; Mandac and Herdt, 1979).

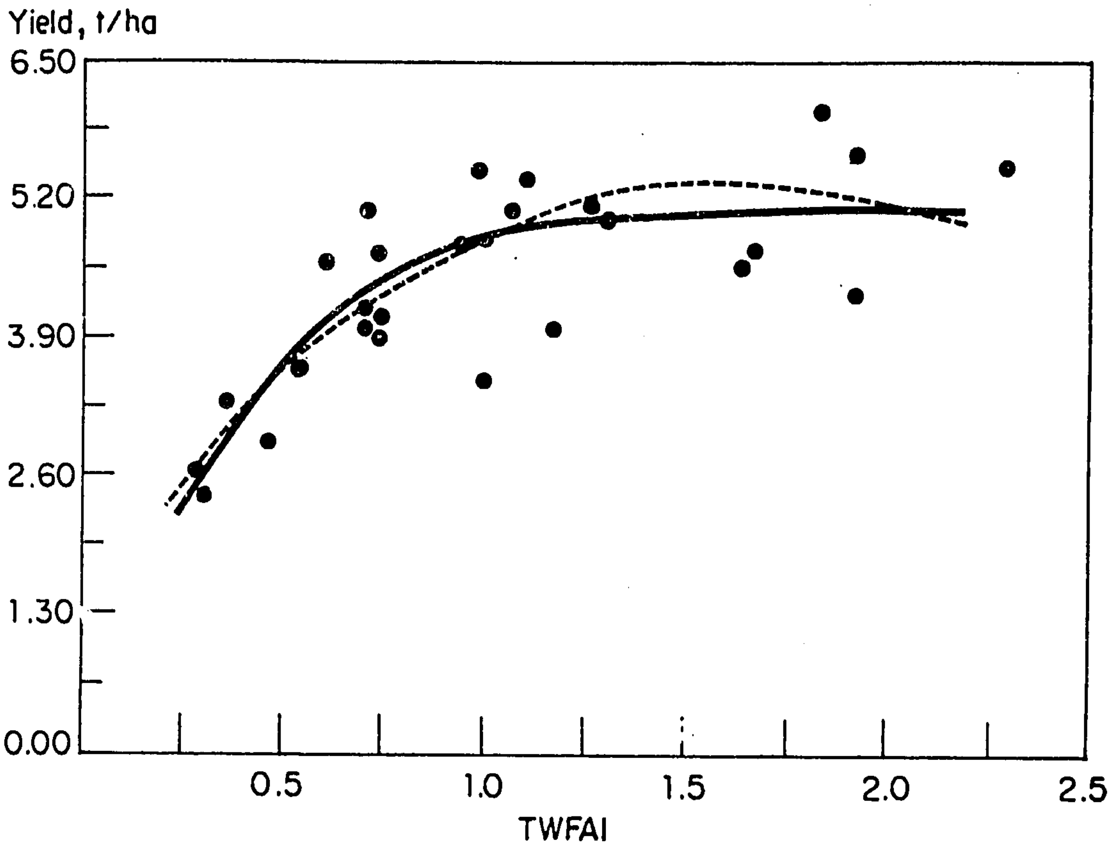
[8] Svendsen (1983) established similar a kind of relationship between SD and actual relative water supply (RWSA) four years later for a number of sample farms from Lateral C, Penaranda River Irrigation System, Philippines and arrived at a nearly equal regression coefficient of the inverse of RWSA;

$$SD = 2.18 + (1/RWSA).$$

number of SD for equal RWSA and TWFAI because their constant terms are not equal. It may be recalled that these two experiments were conducted four years apart in two different irrigation systems and the constant terms reflect effects of factors specific to sites and researchers. But what is underscored here is the similarity of the coefficient of the inverse TWFAI and RWSA in explaining the variability of SD.

Next, two significant production functions were computed to estimate rice yields from TWFAI (Figure 2). The quadratic production function explains more than two-thirds of yield variability simply by the constant and the TWFAI terms. However, there are other factors that strongly affect yield in different circumstances, so this result should be interpreted with caution. There are two reasons why a single water variable, like TWFAI, can acount for so much yield variability. One is that an adequate and reliable water supply has been shown to induce farmers to intensify crop husbandry, resulting in increased yields (Obedoza, 1976; Svendsen, 1983). The second reason has to do with the severity of water shortage. A TWFAI greater than 1.0 may not explain much yield variability, but its effect is stronger as it becomes critically reduced.

Thus far, TWFAI demonstrated its ability to account for water adequacy distribution on the farms. So it was employed in identifying important physical parameters of field-to-field water distribution in sample turnout service areas. Multiple regression analysis shows that TWFAI in the observation paddies is



——— $y = \dfrac{5.08}{1 + 3.70e^{(-4.36x)}}$

Std. error of estimate = 0.52

------ $y = 1.72 + 4.38x^{**} - 1.31\ x^{2**}$

R^2 = 0.66
n = 25
** Significant at the .01 level

Figure 2. Relationship between mean rice yield and target water flow achievement index (TWFAI) for areas served by Lateral A, Lower Talavera River Irrigation System, Nueva Ecija, Philippines, 1979 dry season.

significantly affected by the following four physical factors, in decreasing order of significance: (1) paddy elevation relative to the outlet to the field, (2) accessibility to farm irrigation ditches, (3) percent sand-sized particles, and (4) irrigation farm ditch density (see Table 2 for definitions of variables). In addition, the interaction term of overland distance x relative elevation is highly significant and contributes 19 percent of the explained variation, even though overland distance by itself is not significant. This suggests that physical distance becomes a problem in water distribution only when there is inadequate hydraulic head at the source to command even the topographically elevated fields. All in all, the estimated model is significant at the 1 percent level and explains more than 75 percent of total variation in TWFAI (Table 2).

The study also revealed that a number of physical imperfections in the system arising from design and construction flaws produced inadequate (potential) hydraulic head at the turnout.[9] In turn, insufficient hydraulic head caused much variability in farm water adequacy because some farms would not be reached by water supply at the turnout. Farmers acted on their own to minimize the variability. The most conspicuous actions were checking canals to build up enough head to command the highly elevated portions and constructing extra turnouts to

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[9] This study verified that some farms within the designed turnout service area could not be served by water because of incorrectly located turnouts, farm ditches, or poorly graded turnouts. Some topographically elevated farms were not provided with sufficient potential head at the turnout. See Moya, 1985.

Table 2. Parameters of a regression model of target water flow achievement index (TWFAI) on six variables of the physical environment. Three tertiary areas served by Lateral A, Lower Talavera River Irrigation System. Central Luzon, Philippines; 1979 dry season.

Variable	Means	Estimated Coefficient	T-statistic	Explained variation (%)
Constant		0.384		
Percent sand (%)	36.0	-0.012	-2.3**	13.3
Relative elevation (m)	1.6	0.461	3.6**	31.4
Farm ditch density (m/ha)	61.7	0.006	2.2*	12.4
Farm ditch gradient (m/100 m)	0.23	0.258	0.5	0.6
Overland distance (100 m)	0.23	0.258	0.5	0.6
Access to farm ditch	0.31	0.400	3.1**	23.1
Relative elev x overland dist	8.7	-0.041	-2.8*	19.2
Coeff of determination (R^2)				75.2
F-Statistic			7.8**	

Notes: Percent sand is the soil fraction made up of sand-sized particles. Relative elevation is the elevation of the outlet serving a tertiary area minus the elevation of the observation paddies. Farm ditch density and gradient are the length of ditch divided by the areas it serves, and the ditch slope, respectively. Overland distance is the straightling distance between the outlet to an area and the observation paddies. Access to farm ditch is a dummy variable equal to one for the paddies irrigated directly from a ditch, zero for all others. Regression based on data from 25 observation paddies. * and ** denote significance at the 5% and 1% levels, respectively.

Adapted: Moya, T.B. 1985. For evaluation of water distribution within tertiary areas of the Philippines' Lower Talavera River Irrigation System. Pages 28-46 in Agricultural Development Council. Irrigation Management: Research from Southeast Asia, USA.

take advantage of the low supplies that reach their farms in the shortest time possible.

All in all, TWFAI shows characteristics similar to SD. Just as SD can explain a modest fraction of the farm yield variability due to water, TWFAI singularly accounts for more than two-thirds of farm yield variability. The variability in TWFAI and SD across the farms is accounted for by physical parameters of water distribution. Because the TWFAI is a quantitative specific water-based performance index of water distribution, it is probably more accurate than SD.

The Pasten Number

In some Indonesian village irrigation systems, the pasten number is used as a tool for planning and operation.[10] Two kinds of water information are needed in computing the pasten number. These are (1) water supply, both historical and daily, at intake points or at turnouts, and (2) water demand established by relative irrigation requirements (RIR). A discharge curve for the intake gate of an irrigation system is established using historical flow records for the past ten years. The water supply expected to be available at the intake gate of an irrigation system in an operational year is estimated from the discharge curve. Then, based on the estimated water supply, a composite cropping and irrigation calendar is prepared.

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[10] Probably derived from the Javanese word meaning a fixed share of water flowing in a channel. See Pasandaran (1979).

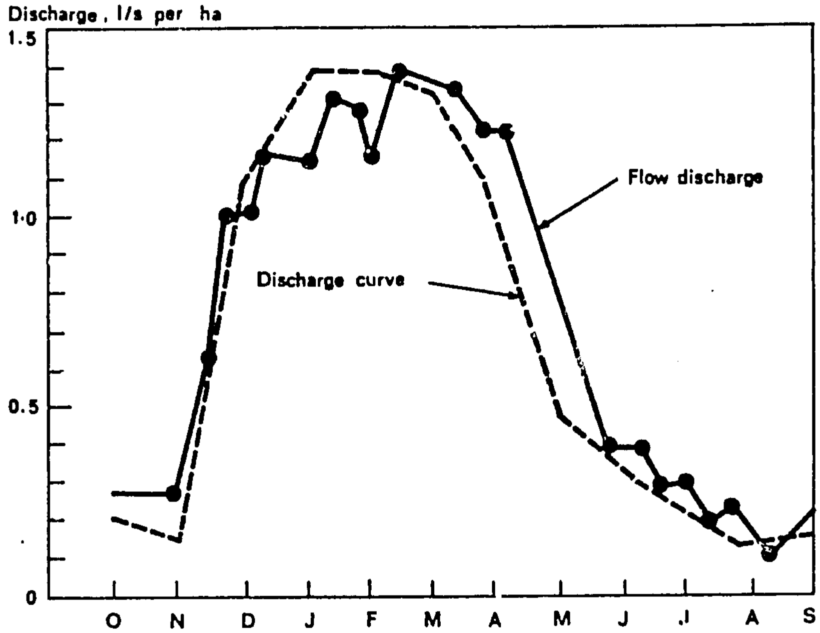

Figure 3a. Average discharge curve over 10 years and flow discharge curve for 1973-74, Bangsalari System. Pekalen Sampean Irrigation Project, Indonesia, 1973-74.

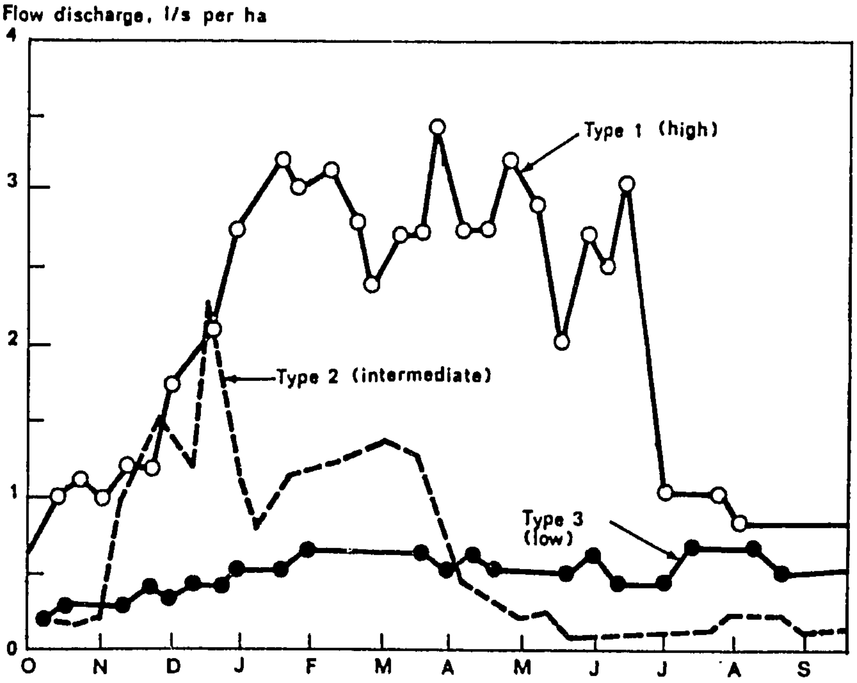

Figure 3b: Flow discharge curves for Type 1 flow in BW_4 tertiary, Mayang Irrigation System; Type 2 flow in Kijingan Kanan tertiary, Bangsalsari Irrigation System; and Type 3 flow in KS_{IV} tertiary, Sumber Pakem Irrigation System. Pekalen Sampean Irrigation Project, Indonesia, 1973-74.

For day-to-day system operation, flow rates, measured twice daily at different parts of the system, are averaged over ten days. The average 10-day flow rate at a particular time and location establish the flow discharge curve (Figure 3a). The shape of the flow discharge curve indicates the character of the water supplies (Figure 3b) and therefore the consequent cropping systems in a particular portion of the system. For example, a Type 1 tertiary block has a stable and abundant water supply during most of the cropping season, the highest cropping intensities, and the largest proportions of rice, while a Type 3 block has a limited water supply and, therefore, low cropping intensities and fractions of rice.

The relative irrigation requirement (RIR) indicates the water demand (relative to that of secondary crops) in various parts of the system planted to different crops at varying growth stages and/or in different phases of farming activity. The RIR for secondary crops is therefore equal to one and is used as an index for the other crops. These RIR values have been calculated from observation and experience for different stages of rice and sugar cane production (Table 3) (Pasandaran, 1979). Scattered and small rice seedbeds have an RIR of 20 because seepage and percolation losses are high. This means that the water supplied to meet the demands of a 1.0-ha rice seedbed can irrigate an equivalent 20 ha of secondary crops. Similarly, the water supplied to satisfy the water demand of 1.0 ha sugar cane will meet the water requirement of 1.5 ha of secondary crops.

Table 3. The relative irrigation requirements (RIR) for various crops and stages of production Pekalen Sampean Irrigation Project, Indonesia, 1973 - 1974.

Crop Production	RIR Index [a]
• Paddy rice	
Seedbed	20
Land Preparation	6
Growth	4
• Sugarcane	1.5
• Secondary crops	1
• Unauthorized rice[b]	1
	1

[a] water duty in liters per second per ha relative to an index value of 1, the water duty for secondary crops such as maize, soybeans, and tobacco.

[b] Rice excluded from the cropping system plan

Adapted: Pasandaran, E. 1979. Water management decision-making in the Pekalen Sampean Irrigation Project, Part Two, Indonesia. Pages 47-59 in International Rice Research Institute. Irrigation Policy and Management in Southeast Asia. Los Banos, Philippines.

Apparently, RIR values are weights used to normalize (scale) the system water demand equal to that of the diversified (secondary) crops.[11]

The pasten number for a particular point of interest in the system is calculated by dividing water supplies by water demands. In equation form

$$P = Q/A$$

where P = pasten number,

Q = water flow rate, in liters per second (lps) taken from a discharge curve, and

A = irrigated area, in hectares.

The RIR concept applied to this equation is as follows:

$$P = Q/[\quad RIR\ (A)] = Q/[\quad (RIR_i * A_i)]$$

where i refers to different crops or to different stages of farming activity for particular parts of the system. It follows that the pasten number is expressed in units of liters per second per hectare (lps/ha) or the duty of water for secondary crops. Since the pasten number accounts for the differences in water demand for various crops, implicit in its application is an attempt to promote equity by sharing the potential utility of water supply. The equity objective is achieved by controlling the extent of area to be planted to rice to accommodate as large an area of secondary crops as possible with the anticipated water

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[11] The water requirement of secondary crops is generally considered 0.3 liters per second per hectare (lps/ha). Personal communication, S. Miranda (1988).

flow rate. Therefore, the benefits from a given water supply are spread to as many farmers as possible.

Because the whole service area is typically planted with rice in the wet season, the pasten number is usually employed for planning only the dry-season cropping systems. The major planning objective is to maximize the dry-season service area, given the constraint of potentially available dry-season flows. Maximizing the dry-season service area involves iterative adjustment of the extent of area planted to rice in order to accommodate the planting of secondary crops. To safeguard equity, the village authority relies on other criteria based on experiences with the previous cropping cycles to decide on the choice of crops to be grown. These criteria can be either or a combination of the following considerations: which sections cultivated rice, or which incurred production losses in the previous cropping cycle, or which parts of the command area the water can physically reach.

With a given supply rate estimated from the flow discharge curve at the intake point the composite irrigation and cropping calendar for an operational year is charted. As a matter of operational error tolerance, the pasten number at the turnout is never allowed to be lower than 0.25 for light soils or 0.20 for heavy soils. Thus, enough water supply (lps), is available to satisfy the system water demand at these pasten levels.[12] During

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[12] Stated differently, the relative water supply (RWS) level at the turnouts corresponding to these pasten values is approximately 1.0 based on 0.3 lps/ha water duty of secondary crops.

the planning stage, when the pasten number falls below these tolerance limits, the area to be planted with rice is iteratively reduced and the secondary crop area expanded until the maximum service area is arrived at.

For day-to-day system operation, the pasten number is also an important management criterion. Its magnitude is directly linked to water management procedures, particularly at times of water crisis. When the pasten number falls below 0.25 or 0.20 (RWS below 1.0), irrigation field personnel and village officials are alerted that additional water sources (such as drainage from upstream areas, flows from creeks, springs, and streams or, if possible, water from water-surplus sections) will be transferred to water-deficient sections in the service area.

When sources of additional supply cannot be tapped, water is distributed by rotation; pasten numbers between 0.20 and 0.25 denote rotation at secondary levels, while numbers between 0.10 and 0.05 activate rotation at tertiary levels as well. Lower pasten numbers will imply intensified management actions to distribute water to the fields.

Relative Water Supply

Levine (1981) introduced relative water supply (RWS) as a useful concept to describe water distribution performance of the irrigation system. The explanatory power of RWS lies with the realization that irrigation system performance is dependent on both technical and human behavioral factors. RWS is based on the assumption that "behavior" of the participants in the irrigation process is conditioned by the amounts of water appearing (or, expected to appear) in relation to the perceived needs at specific locations in the system. This behavior may be institutionalized, with different rules and organizational activities established for expectations of different levels of available water supplies, or it may be ad hoc in direct response to the observed situation.

Since water availability depends to a great extent on physical controllability of irrigation systems, RWS integrates both the "hardware" and the "software" aspects of irrigation management that influence irrigation system performance. In equation form, RWS is expressed as

$$RWS = (IR + RN)/(ET + S\&P)$$

where RWS = relative water supply;
IR = irrigation supplied, mm;
RN = effective rainfall, mm;
ET = evapotranspiration rate, mm; and
S&P = seepage and percolation rate, mm.

The numerator consists of the total water supplied through IR and RN; while, the denominator accounts for total water requirements from ET and S&P.

Two forms of RWS have been used: theoretical relative water supply (RWST) and actual relative water supply (RWSA). RWST is defined as the ratio of water supply at the location of interest to the water demand associated with maximum production of the

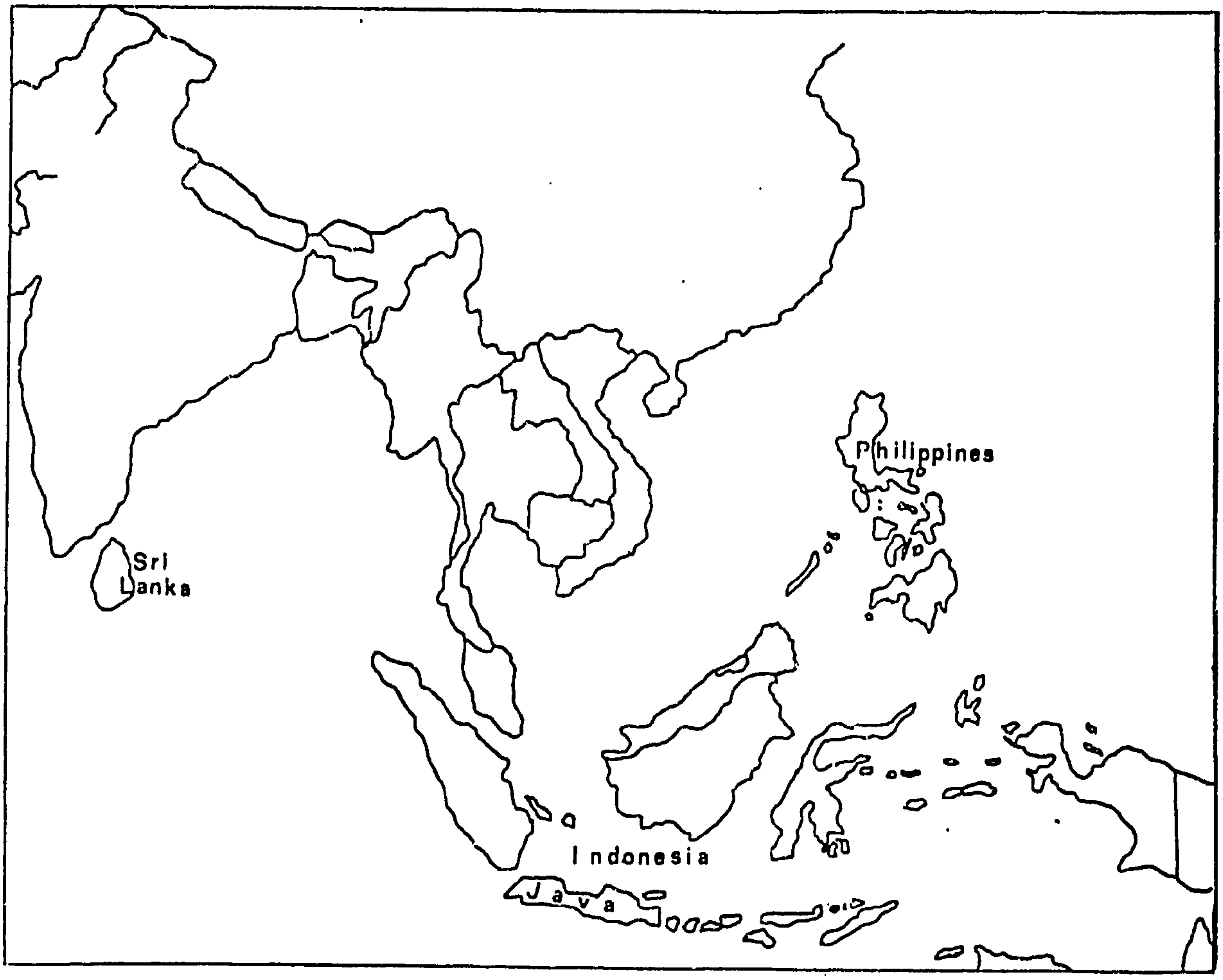

Figure 4: Location of irrigation systems analyzed in this study.

optimal crop or cropping pattern grown using appropriate cultural practices on the total irrigable area designed or intended to be served from that location. On the other hand, RWSA at a point of interest, is the total water supply at that point scaled by water demand associated with the crops actually grown, with the cultural practices actually used and the actual irrigated area.

Generically, TWFAI, the pasten number, and RWS are related to one another in that each represents water supply scaled by water demand. TWFAI is, in fact, RWSA, and the pasten number is RWST because it used theoretical (unmeasured) water demand. The TWFAI and RWSA stand for actual water supply scaled by actual water demand, whereas the pasten number represents RWST--available supply scaled by generalized or theoretical water demand. In subsequent analysis, TWFAI was literally translated into RSWA without any modifications; only the label was altered (Moya, 1985).

The following sections will discuss the applications of RWS in irrigation management studies in Sri Lanka, Indonesia, and the Philippines (Figure 4). The discussion will focus on how RWS can be used to explain irrigation and crop management decisions of these irrigation systems operating under different environments.

SUPPLY-DEMAND RATIO: WATER ALLOCATION AND LAND AUTHORIZATION IN THE GAL OYA SCHEME, SRI LANKA

In a retrospective study, Murray-Rust (1983) analyzed the pattern and policy of water allocation from 1969 to 1981 among three divisions of the 50,000-ha Gal Oya Irrigation Scheme in Sri Lanka. This section derives mostly from this study and discusses the significance of RWS in explaining allocation of tank storage and authorizing land for cultivation within the irrigation scheme.[13]

Three major irrigation divisions--the Right Bank, the Left Bank, and the River Division--comprise Gal Oya. These divisions are served by Senanayake Samudra, the largest reservoir in the country, which has a capacity of 950 million cubic meters (mcm). The Right and Left Bank divisions are served by conveyance systems fed directly from the reservoir headworks, while the River Division is served by a series of diversion weirs across the Gal Oya River. Discharge into the river is controlled at the reservoir. The majority of the scheme is devoted to rice production. Less than 10 percent of the command area is planted in sugar cane (3750 ha), all of which is concentrated in the central portion of the Right Bank. Two rice crops are obtained during the year: a wet-season crop associated with the northeast monsoon during which about 1,200 mm of rain falls and a dry-season crop during the southwest monsoon when rainfall is about 200 mm.

A combination of limited water supply in the main reservoir, which has only filled twice since its completion in 1950, and a

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[13] The whole discussion on Gal Oya relates to the water management practices during the period 1969-1981 only, before the Gal Oya Water Management Project. The practices after this project are not reflected in this research; it may be worthwhile to compare the new practices with those of the pre-project period.

deteriorated conveyance system restricts the irrigated area. Although rainfall is sufficient in all areas for a wet-season crop, during dry periods, supplementary irrigation can only be provided to about two-thirds of the scheme. In the dry season, tailend areas never receive irrigation water, and only about one half the scheme can rely on adequate irrigation water for crop production.

From a series of technical notes,[14] it is apparent that Gal Oya's irrigation network was originally designed for rice irrigation according to the following criteria:

1. field channels, 30 acres (ac) per cubic foot per second (cusec) or 2.3 lps/ha and 20 percent conveyance loss;

2. distributary channels, 36 ac/cusec or 1.9 lps/ha and 25 percent conveyance loss; and

3. main channels, 50 ac/cusec or 1.4 lps/ha and 35 percent conveyance loss.

The large value of the water duty for the field channels is to compensate for variability in the physical setting and to provide the ID with enough operational flexibility. Based on this design conveyance loss information, one can calculate that Gal Oya was intended to operate at an overall system water use efficiency of around 49 percent or an overall RWS of 2.04 at the tank, 1.54 at the headgates of distributaries (laterals), and 1.20 at the turnout. However, the ID shoots for an overall conveyance

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[14] Technical notes are Irrigation Department memoranda that are circulated to all engineers. These notes contain technical guidelines which are seen as being applicable to all irrigation schemes in the country. They were all revised in 1981. See Murray-Rust (1983).

efficiency of 70 percent or a system operating RWS of 1.4.

The technical guidelines for operating Gal Oya, contained in technical notes, originate from the national policy-making body. The most notable of the guidelines was the use of a nationally derived value of field water requirement for all irrigation schemes in the country despite the variability in soils and topography. As the Irrigation Department (ID) attempts to intensify water management, this rigidity constrains them from developing more appropriate operational guidelines for engineers. Consequently, both formal and informal operation rules are applied in Gal Oya. The formal rule reflects the nationally derived water requirements; in public the ID uses these rules consistently. The informal rule uses the experience from previous seasons to allocate water and land within the scheme.

Murray-Rust (1983) used the supply:demand ratio (SDR), a variant of RWS, to characterize dry-season water allocation of Senanayake Samudra storage and land authorization within the scheme service area. SDR is very similar to RWS and to the other specific water distribution indices mentioned elsewhere: it is water supply scaled by demands. For purposes of analyzing the allocation of tank storage to different parts of the scheme, SDR denotes the quotient between the estimated irrigation requirements, allowance for delivery losses included, and the estimated (actual) field water requirements. In equation form

$$SDR = (WR + L)/WR$$

where SDR = supply demand ratio;

WR = actual field water requirements, ft; and

L = water losses, ft.

Clearly, the SDR is the inverse of overall system water use efficiency and it is in fact a RWS.

Reservoir releases from Senanayake Samudra are regulated at a minimum operating SDR of 1.4 compatible with the target operating water use efficiency. This SDR level means that water in the tank is allocated 40 percent higher than the actual field water requirements. Tank storage is allocated on a season-by-season basis. Using generalized water requirements, the ID allots 5.0 ft of tank storage for an estimated seasonal actual field water requirement of 3.5 ft (8 mm/day for 135 days) for rice or a SDR of 1.4. For sugar cane, it allocates 4.0 ft of tank storage for meeting the estimated seasonal field water requirements of 2.8 ft.

Water and Land Allocation

In order to arrive at a stable water allocation policy, Murray-Rust (1983) analyzed the process of water and land allocation (authorization) in Gal Oya between 1969 to 1981. Enough emphasis was given to the relationship between the quantity of water stored in the tank and the corresponding amount of land authorized for cultivation using the SDR concept. Land authorization refers to the process of determining which areas within the irrigation scheme will be permitted to plant which crops in a season. Land authorization proceeds in three stages: (1) negotiations among government officials as to the areas that can probably be cultivated, (2) presentation of the negotiation decisions to farmers in cultivation meetings where minor adjustment can be made, or approval obtained, and (3) post cultivation meetings in which the Government Agent may respond to representations from farmers dissatisfied with Cultivation Meeting decisions.

The water shortage that occurred in the 1969 dry season highlighted the water allocation process in Gal Oya. In this season the ID was unwilling to allocate the stored water to areas that would result in a SDR lower than or equal to 2.0,[15] but was agreeable to allotting it to areas that would yield an SDR equal to 2.26. When reserves were low, the ID would reduce the extent of authorized land to maintain high SDR rather than spread water over large areas at low SDR in order to allow for operational uncertainties. One operational uncertainty is the planting of the encroached lands.

Prior to 1969, irrigation water in Gal Oya was delivered continuously in all main channels; if rotations were needed, they

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[15] This SDR value was based on sugar cane as it was the crop mandated by the government in this period. The value is calculated from available seasonal (supply) storage of 5.6 ft and seasonal actual field water requirement of 2.8 ft. For rice, it will follow that at this SDR level, 7.0 ft of stored water was allocated to 3.5 ft seasonal water requirement for rice.

were carried out at the distributary and field channel levels.[16] However, the 1969 water shortage necessitated a change in the continuous water distribution policy, and Gal Oya adopted a form of water rotation to conserve storage at Senanayake Samudra dam. Water release policies in Gal Oya were not formulated in the absence of participation (intervention) from national and local politicians. In one instance, the Prime Minister called a meeting with Minister of Agriculture in his house in Colombo to formulate water release policy during water-short periods. Irrigation engineers also were pressured by local politicians. Often these pressures were strong enough to override engineering and technical decisions.

Despite the constraints of both national policy and local pressures it is possible to predict with high precision the allotment to each major division of the available reservoir storage at Senanayake Samudra by 1 April. From 1969 to 1981 the dry-season tank storage has been consistently allocated among the three divisions of Gal Oya Scheme--Left Bank, Right Bank, and River Diversion--to about 60, 20, and 20 percent, respectively. It should be noted that this water allocation pattern remained consistent in spite of changes in the operating environment during the period: (1) the national policy of giving priority to sugar cane production over other crops in 1974-1975; (2)

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[16] Rotations at these levels might have been implemented with significant management inputs as the scheme during this period virtually did not possess adequate physical control facilities. Only the headworks of major canals had control gates.

fluctuations in water storage following the 1969 drought; and (3) the expansion of cultivated area in the Right Bank during the same period. This consistency made it possible to analyze and arrive at a better undertanding of the water allocation and land authorization process in Gal Oya. A series of significant regression relationships between net storage in Senanayake Samudra on 1 April and flow rates among major divisions were established. These relationships were used to predict allocations of the reservoir storage by 1 April to each of the major divisions.

The relationship between allocation of the stored water at Senanayake Samudra dam and the authorization of land for cultivation in the Left Bank is summarized in Figure 5. A minimum area of 5,200 ha. must be authorized for cultivation irrespective of net storage and SDR. The ID cannot base its storage allocation on technical considerations unless this minimum area can be authorized for cultivation; otherwise, it must bear the brunt of heavy political and social pressures. An equation describing the allocation-authorization relationship was established using regression analysis. The equation is

$$A = 2106 + 26.37\ S_n$$

where A = the extent of the area authorized, ha; and

Sn = net storage at Senanayake Samudra by 1 April.

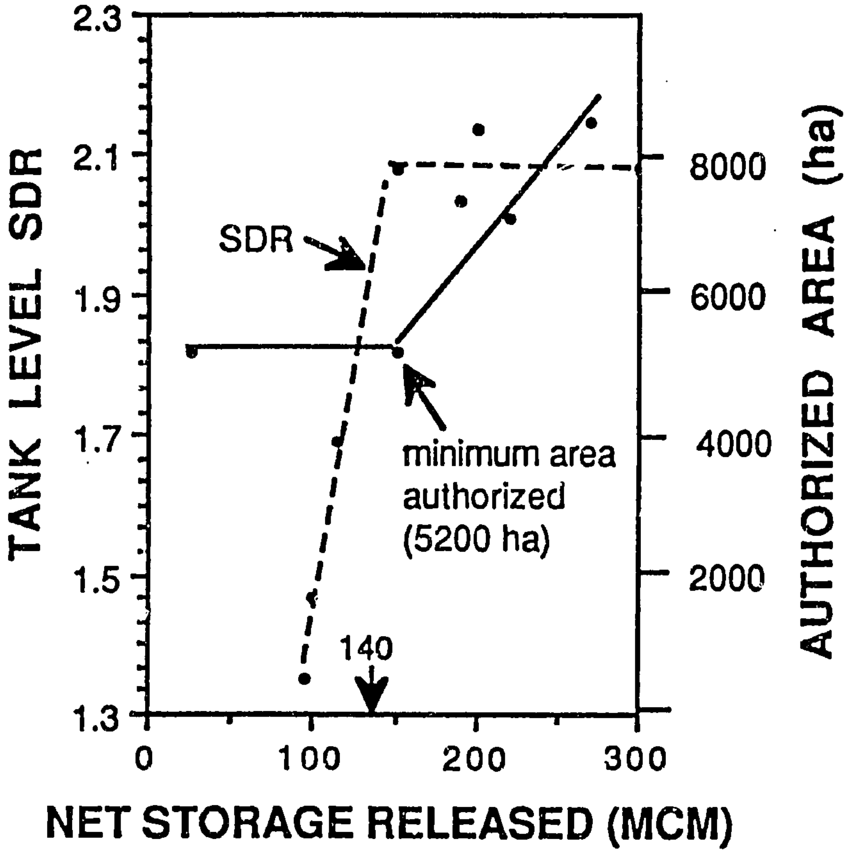

Figure 5: Storage allocation in relation to area authorization and tank supply demand ratio. Gal Oya Irrigation Scheme, Sri Lanka, 1969-1982.

From the equation, the net storage requirement for the minimum 5,200 hectares, is about 117 mcm. At this storage level, the corresponding SDR based on tank demand estimates of 5.0 ft (1.5 m) for rice is 1.5. Therefore, to operate at an SDR of 2.08, the net available storage at the tank for the minimum area should be about 140 mcm.

Only when storage exceeds this level can land authorization be based on technical guidelines. Below 140-mcm storage, social and political pressures override and place the ID in a tight managerial position. To counteract such pressures, the ID tries to restrict the area authorized for cultivation to maintain a high SDR consistent with its normal operational capability, or it inflates its tank demand estimates,[17] to keep operating under high SDR. But once the minimum 5,200-ha area has been authorized for cultivation the scheme operates under a roughly constant SDR of about 2.08, consistent with the designed tank RWS of 2.04.

To summarize, Gal Oya allocates the water stored in the dam 1.4 times the actual field water requirement or a minimum SDR of 1.4. This SDR is consistent with the target overall system water use efficiency of 70 percent. Without political and social pressures, the ID operates at a relative water supply of 2.08 which is slightly higher than the designed relative water supply of 2.04. In periods of low supply, the ID should first satisfy the water requirement for the minimum 5,200-ha service area.

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[17] Usually unauthorized cultivated lands are equal to about one-third of the authorized cultivated areas.

Other-wise political and social pressures override technical considerations in storage allocations.

To counteract these pressures and still maintain a high operating SDR consistent with its managerial capabilities, the ID has tried to reduce area allotments or double demand allocations at the tank. A somewhat rigid system, Gal Oya in the 1970s was not prepared to change operational rules of water allocation and land authorization prepared before the season in response to demand conditions within the season. Most short-term decisions about operations within the season are made in keeping with the stipulations of the water-allocation/land-authorization rule set before the season. The ID was contented with implementing a consistent policy of proportional storage allocation rather than respond to changes in demand partly due as a way of responding to a national effort to reduce operational wastes from perceived excessive water use by farmers. Allied to this is gradual reduction of land authorized over time to reduce demand, thus increasing SDR.

By fixing the SDR at Senanayake Samudra at a minimum of 1.4 before the dry season, the ID expresses its intent to operate within a certain management range compatible with its target operating water use efficiency or relative water supply of 1.4. If stored water is sufficient and political and social pressure are absent, the ID operates the system at a constant SDR of 2.08 which is higher than the designed relative water supply at the tank. This operation inputs included the use of nationally derived field soil water requirements to compute tank water demands, land authorization to curb system water demands, minimal water control and monitoring points, and water rotation when water supplies fall below the minimum SDR.

RELATIVE WATER SUPPLY AND WATER MANAGEMENT IN TWO INDONESIAN VILLAGE SYSTEMS[18]

Two Indonesian village irrigation systems, Tunggul and Blimbing in Central Java--were extensively studied in 1979-1980 crop seasons to characterize their management attributes and determine the influence of RWS on their operations decisions. These research sites were selected to cover a wide range of ecological settings. The topographic continuum includes Tunggul lying at the foothills of Mt. Lawu with a land slope of 3 to 7 percent and Blimbing on the flat plains with average land slope of less than 2 percent. Soils vary from sandy loam to loam in Blimbing and from sandy loams to clays in Tunggul. The Blimbing village irrigation system commands 158 ha, 32 ha of which are community lands compared to Tunggul's 413-ha command area, with 37 ha in community land.[19] Blimbing has a population density of 1272 persons/km^2, while Tunggul has 917 persons/km^2. Average

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[18] The discussion in this section draws mainly from the irrigation research conducted by Ramchand Oad in Central Java. See Oad (1982).

[19] Community lands receive special treatment in irrigation management; they are usually exempted from planting government mandated crops and seem to have priority for water, although the data are not conclusive on the latter point.

landholding size in Blimbing is 1.0 ha/farmer while that of Tunggul is 0.46 ha/farmer.

Technical Attributes of the Systems

Physical control capability varies between the systems. Blimbing derives its water supplies from three permanent masonry weirs that also supply water to seven other villages. It has primary up to quarternary channels, and the headworks from distributaries up to quarternaries are provided with gates that can be locked for security. The system distributes water to farmers' fields through on-farm channels with a density of 70 m/ha. Most quarternary channels are lined.

In constrast, Tunggul obtains water from two weirs, one of which has temporary intake structures. The other weir is permanent, but it does not have a gate. These two weirs serve three villages in addition to Tunggul. However, Tunggul has a higher on-farm channel density (80 m/ha) than Blimbing.

In contrast to the Gal Oya case, more detailed data have been collected for three seasons from these systems. Especially significant are the daily measurement of water supplies, seepage and percolation, rainfall, evaporation, and paddy water status from 10 out 13 *kelompoks* in Blimbing and 15 out 20 kelompoks in Tunggul.[20]

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[20] A kelompok is a group of farms receiving water from a single turnout. It is equivalent to a turnout service area or a water rotation area.

The Water Distribution Process

Three kinds of crop are grown: paddy rice, upland palawija crops (soybeans, corn, etc.), and mandated crops. By government order, Blimbing must grow 40 ha of tobacco each year, while Tunngul must grow approximately 100 ha of sugar cane. The location of these mandated crops within the villages is left to the discretion of the villagers. To grow paddy, the irrigation systems must supply about 1.4 lps /ha or about 12 mm/day, at the tertiary level.

A watermaster (ulu-ulu) is responsible for distribution of irrigation water and for upkeep of irrigation facilities and structures. The ulu-ulu is a village official supervised by the village headman. He is assisted by the water users' association, called Dharma Tirta in Central Java. He sees to it that water reaches the village channels from the diversion point or points. From these handover points (headgates of village channels), the Dharma Tirta distributes water among the village water users groups (kelompoks) under the supervision of the ulu-ulu. Each village system manages a community land.

The fundamental principle underlying water distribution in these systems is equity--sharing benefits from water supply among as many farmers as possible. A reasonable level of equity must be promoted for continued cooperation and involvement of farmers and for minimizing conflicts within the system. The following criteria were used in allocating water to achieve a reasonable degree of equity: (1) equal treatment for all private lands within systems' physical constraints, and (2) water allocation decisions that take into account the physical limitations of the systems during water shortages.

During the rainy season, when RWS exceeds 2.5, water in these systems is delivered continuously with farmers controlling the gates. Farmers can also fully control cropping decisions. However, in the dry season, the village institutions control water release and distribution because of low water supplies. Regardless of system hardware and software capabilities, system managers try to reduce demand for water to maintain a minimum working RWS of about 1.3 to 1.7 when confronted with water shortages (Figure 6).

Operating these systems below a RWS of 1.3 results in substantial yield reductions for rice, so mechanisms are adopted to keep RWS from falling below the minimum level. The primary mechanism to curtail system demands is to restrict the area authorized for rice cultivation. At RWS of about 0.9, some areas are left fallow or converted into palawija (upland) crops to reduce the demands for water.[21] Implicitly, both Irrigation Department field staff and villagers involved in system operations resort to system demand reduction to maintain a minimum operating RWS. They also try to maintain a certain set of management practices that do not entail extra efforts and costs. These practices range from continuous water distribution

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[21] Fallowing and planting upland crops are adopted to a minor extent in Philippine irrigation systems during dry periods. See Svendsen (1983).

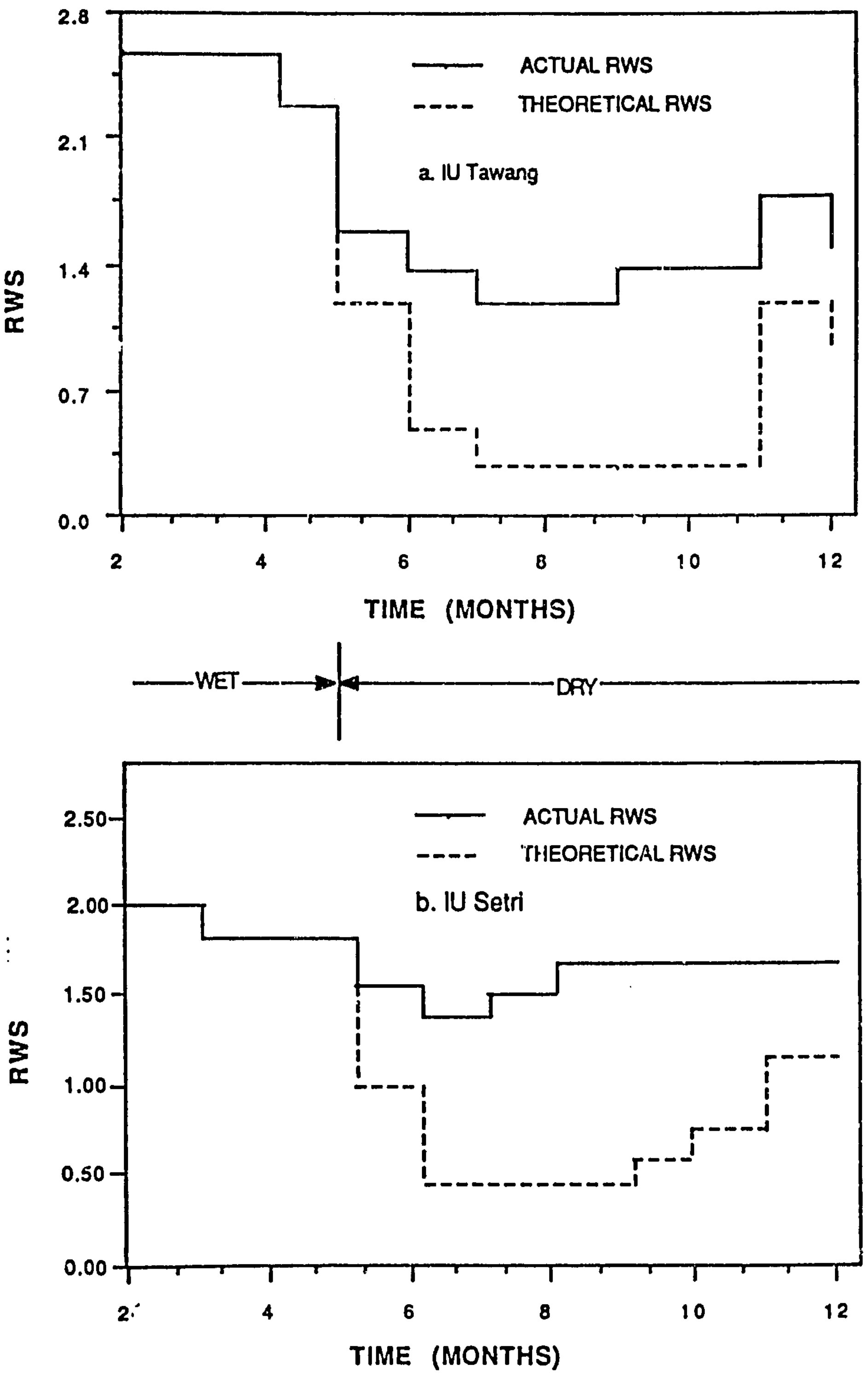

Figure 6: Temporal distribution of relative water supply in sample units in the Tunggul Irrigation System, Central Java, Indonesia, 1979-1980.

when water supplies are plentiful to ad hoc water rotation, planting palawija crops, and putting land in fallow when supplies are scarce. With this management trend, farmer inputs have increased greatly in comparison to those of the Irrigation Department.

IRRIGATION SYSTEM MANAGEMENT INTENSITY STUDIES IN THE PHILIPPINES

Both scale and type dictate the level of managerial inputs needed to run an irrigation system. The size of the command area often denotes scale of irrigation system, but the number of important decision points in regard to water allocation and distribution also indicates scale. In some instances, the number of participants in the irrigation process--both farmers and irrigation field personnel per unit of service area--also indicate the complexity of a system from a managerial view.

The character of water supply and the kind of organization for handling operations, on the other hand, indicate the type of an irrigation system. The nature of the water supply relates specifically to the technology of acquisition. Common acquistion technologies include run-of-the-river (diversion), storage (reservoir), and pump systems. An irrigation system can be either government, communally, or privately operated, depending on whether it is run by a government agency, a farmer group or association, or by a private group or individuals.

The scale and type of irrigation system affect the cost of water, and cost eventually influences management intensity. The total cost to deliver water to farmers consists of capital investment costs and operation and maintenance costs. A 1976 economic analysis of 690 Malaysian irrigation systems showed the existence of economies of scale in constructing small- and medium-size (less than 10,000-ha service areas) diversion irrigation systems (Taylor and Tantigate, 1985). The per hectare operation and maintenance cost of larger systems also tends to be lower than that of smaller ones. With regard to technology of acquisition, pump systems are the highest cost systems followed by diversion and controlled drainage systems.

P. Moya (1985) reported similar observations from her economic analysis of twelve irrigation systems in Central Luzon. The annualized total cost of delivering water for diversion systems, both national and communal, was $100 per hectare compared with $185 per hectare and $392 per hectare for surface and deepwell pumps, respectively. Again, the pump systems are costlier than the diversion systems.

The authors of both studies, however, suggest that readers interpret the results cautiously, because they are specific to the environmental conditions and contexts of the sample systems. Yet even with these limitations, the results indicate to irrigation managers the variability and magnitude of costs of handling water in different types of irrigation systems.

Scale and Type of Philippine Irrigation Systems

Philippine irrigation systems fall into three broad categories reflecting both scale and type (P. Moya, 1985). These are

1. National irrigation systems maintained and operated by the National Irrigation Administration (NIA), a semiautonomous government agency, or self-liquidating corporation in charge of irrigation system maintenance and operations in the Philippines. Usually, national systems are either diversion systems with low barrages or reservoir systems with large, high dams. Two large national reservoir systems, the Upper Pampanga River Integrated Irrigation System (UPRIIS) and the Magat River Irrigation Project (MRIP) in central and northern Luzon, respectively, command over 100,000 hectares. In comparison, some national diversion system service areas range from a few hundred to several thousand hectares. Recently, however, the NIA began turning over to farmer organizations diversion systems with service areas less than 1,000 hectares. Thus, national systems will soon have minimum service areas of 1,000 hectares.

2. Communal or village irrigation systems owned, maintained and operated by farmers. Characteristically, these systems are small, widely dispersed, and often found in marginal areas. Typically, these systems tap small creeks, rivers, and springs by temporary diversion structures and serve areas of less than 10 hectares to several hundred hectares. A few communal systems have service areas over a thousand hectares. Since the late 1970s, many of these village systems have either been "learning laboratories," "models," or "recipients" of technical and social assistance from the NIA participatory program.

3. Surface or deepwell pump systems Surface pumps lift water from creeks, canals, or other sources at or near the surface. Deepwell pumps draw water from depths exceeding 10 m. Until the government reduced subsidies for system operation and maintenance, the NIA was responsible for most pump systems (except the private shallow pumps). Today these pump systems, particularly the deepwell systems, are in transition from government to private control. They are being turned over to farmer organizations for maintenance and operations. Thus, communal or village pump irrigation systems also exist now.

In light of new developments in the NIA approach to managing irrigation systems, rarely does a system fall under one category. The NIA has embarked upon an intensive program to organize farmers to become partners in managing many of these systems; therefore, many hybrid systems will come to the fore. An example of a hybrid could be a bureaucratic-communal reservoir system, where farmers and the irrigation bureaucracy jointly manage specific portions of a reservoir system.

Philippine Irrigation Management Studies: An Historical Account

Irrigation system management studies have been carried out in the Philippines since the early 1970s following identification of many farm-level irrigation problems attributable to the low performance of the main system. The first classical irrigation management investigation was jointly conducted by the NIA and the International Rice Research Institute (IRRI) from 1973 to 1975 on Lateral C of the Penaranda River Irrigation System (PenRIS) a run-of-the-river system in Central Luzon (Tabbal 1975). The study aimed to improve the productivity and equity of access to water in the system by increasing the predictability of delivery among sections of the lateral.

Modest innovations in existing system operational procedures were introduced, but there was essentially no structural upgrading. Allocation and distribution rules were stringently enforced through systematic checking and sequencing of measured flows into four sections of the lateral. These innovations resulted in a 39 percent overall increase in production. A 3600 ton increase in rice production from the same water supply was achieved at a cost of 20 pesos/ton (Early et al., 1978). The increase in production accrued mostly from increased area planted and improved unit yield at the tail of the system. Equally significant, predictability of water delivery to all parts of the system increased, notably the chronically water-short tail parts. The gross water distribution inequity that had prevailed in the system for some years before the research was rectified. Water use efficiency at the head parts of the system also improved. Therefore, farmers put more trust in irrigation field personnel as a consequence of more predictable water distribution.

The benefits shown by the PenRIS study paved the way for a more intensified management research. For the second time, IRRI and NIA conducted a high input management study at the Lower Talavera River Irrigation System (LTRIS), the UPRIIS show window (Early et al., 1978). During the period of the high intensity management study, total system water supplies were adequate to satisfy system water demands. The problems in LTRIS were both inequitable water distribution among parts of the system and the attendant low water use efficiency in some portions of the system. The high input management study was expected to address this twin problem of low water use efficiency and water distribution inequity.

The high-intensity managerial inputs included measurement, control, monitoring and communication of relevant water-related variables from all decision points starting at the headgate of the main canal all the way down to the turnouts. In addition, researchers and field personnel regularly touched base with selected farmers within the turnout areas to gather feedback on system performance. System operations were adjusted on the basis of this feedback. Despite the high operational requirements, only minor modifications in irrigation facilities and structures were made. Although not structurally perfect, LTRIS was probably one of the irrigation systems in the Philippines best-equipped to implement water distribution at the farm level during the period of the study. Nothing, however, was modified or altered in the operational setup. Water allocation and distribution rules for UPRIIS were implemented as originally designed.

This management investigation duplicated the success of the PenRIS study. Production in the area rose by 2500 tons annually at a cost of 10 pesos per ton (Early, 1981a; Small et al., 1981). System water use efficiency went from a pre-project level of 43 percent to 70 percent during the study period. Measured water flows among sections of the system during the period indicated improvement in water distribution equity. As a result, farmers were more satisfied with the day-to-day operations of the system, and they interfered less in the management.

The PenRIS and the LTRIS studies yielded significant productivity, equity, and efficiency benefits despite non-participation of formal farmer groups or farmer associations in the operations of the system. These studies did not include as a component of operational design and innovation a water user institution such as the farmer association. These action-research undertakings indicate that technically well-performing systems can be successfully operated even when formally organized farmer participation is absent. Farmers are unlikely to want to invest time to manage any part of an irrigation system if it is managed appropriately by the Irrigation Department (Castillo, 1981).

Questions were raised about the practicability and implementability of the methodology used and the utility of results generated because of the pilot nature of the two action research studies. To address these questions, three management investigations of varying inputs were designed and implemented simultaneously in three UPRIIS subsystems from the 1979 dry season to 1983 dry season (Moya et al., 1983). These studies also aimed to come up with a management model or model tradeoffs that irrigation managers could feasibly internalize as parts of their standard operating procedures.

Management inputs varied in terms of intensity of decision points being monitored and controlled and in terms of the amount of information being collected and used. The scale of the irrigation subsystems studied also differed from 2,500 hectares to 25,000 hectares, but the nature of water supplies was held constant by conducting all of these studies within the UPRIIS service area. The management continuum was defined at the least intensive end as the extensive model treatment with inputs increasing to the intermediate model treatment and the maximum to the intensive model treatment.

Preliminary analysis of data from this set of management studies indicated some degree of tradeoffs among levels, costs, and applicability of some management intervention inputs. Conclusive statements and findings, however, are unavailable because more rigorous and comprehensive analyses must still be done.

Study Sites

The following discussion on applications of RWS and operational intensity of irrigation system management derives principally from the results of two sets of studies, but will also draw relevant observations and conclusions from other investigations to shed more light and understanding on the points emphasized. The first set of studies were conducted by Svendsen (1983) on three types of Philippine irrigation systems from the 1979 wet season to the 1980 dry season. The study focused on farmers' individual and collective irrigation behavior as affected by the nature of system water supplies. The behavior of irrigation operational staff was observed. The study was carried out in (1) six turnout areas of PenRIS in UPRIIS and two communal systems, (2) the Talaksan Pump Irrigation System, and (3) the Salapungan River Irrigation System.

The second study was conducted by Valera (1985) in selected UPRIIS subsystems from 1980 to 1983. In the same period and in the same sites that the three management intensity studies were carried out, Valera selected three subsystems for comparative assessment. These subsystems were (1) the Lower Talavera River Irrigation System (LTRIS); (2) Lateral F extension, Talavera River Irrigation System, lower section, (lower TRIS lat F); and (3) Lateral C-1, Pampanga River Irrigation System (PRIS C-1).

Valera (1985) covered the 1983 dry season when UPRIIS encountered a serious water shortage. The 1982 monsoon did not bring enough rains and, hence, did not produce sufficient surface runoff and inflows to fill the reservoir up to its normal operating level. As a consequence, at the planning stage in October, only about 68 percent of the total UPRIIS command area could be expected to receive water from the impoundment.

Site Descriptions

UPRIIS. A site for most of these studies, UPRIIS will be discussed in detail. UPRIIS is the first large reservoir irrigation system built in the Philippines and is designed to serve about 106,000 hectares. More than half of this command area consists of the service areas of rehabilitated subsystems; the is rest new area. It is operated and maintained by the NIA.

It was anticipated that the upgrading and improvement works done on UPRIIS would bring the system physical control capacity to regulate and measure flow rates from the headgate of the main canal up to the turnout serving five 10-hectare rotation units. The tasks and responsibilities of field irrigation personnel from the district chief down to the ditchtenders were keyed to this type of design. Also, farmers were expected to join water user associations in their rotational area and to be partners in internal water distribution.

Operational procedures to match this intended system physical control level were formulated. System water demands were aggregated from the measurement of water requirements in the field based on crop growth stage and phase of farming activities allowing for some losses at the main and lateral or sublateral canals. Irrigation supplies were measured corresponding to system water demands and issued uninterruptedly in the primary and secondary canals, while five 10-hectare rotation units distributed them by turn. Irrigation field personnel delivered water to the turnouts, after which the farmer association took over distribution among rotation units. These intended allocation and distribution rules were implemented only during the first two-year settling period of the system. After this period, substantial modification and alteration in the planned physical and institutional infrastructures were observed.

Due to design and construction flaws, operations could not be carried out smoothly. Farmers modified, altered and, even worse, destroyed many of these physical facilities. This resulted in less than the intended level of control. Where the system design fail to deliver, any one or a combination of the following changes in the physical components of the system--temporary checks, broken irrigation facilities and structures, unauthorized turnouts, and missing farm ditches--could result in a corresponding failure in the institutional infrastructure. For this reason, the planned rotational distribution was not successful. These circumstances put NIA personnel back to square one; they had to begin again devising operations rules to match altered physical and institutional infrastructures.

Today, system water supplies are allocated according to generalized estimates of 1.5 liters per second per hectare during land preparation period and 1.2 liters per second per hectare during the crop growth. Water is continuously distributed to all parts of the system during plentiful water supplies and rotated when scarce. All the study sites within the UPRIIS essentially have the same characteristics and operations rules. The differences among them, if any exist, can be attributed to the extent of modification and alteration done on the physical and institutional infrastructures to meet varied field realities.

Talaksan Pump Irrigation System. The NIA constructed and operated this low-lift pump system for sometime, but it is now commnunally owned and operated. The farmer association accepted the system when the NIA turned it over to them for management. The system lifts water from Angat River in Central Luzon. It covers about 38 hectares of rice fields at the foot of the Sierra Madre Mountains. In addition to the physical control facilities at the system level, the farmers constructed about 80 meters of field channels per hectare of service area, creating a capability of serving essentially every farmer individually.

Salapungan Irrigation System. This is a (diversion) run-of-the-river irrigation system that captures the flow of San Miguel River, Central Luzon behind a low, 35-m concrete dam. River flows fluctuate widely and decrease after the rains stop. The farmers constructed this system with aid from the government in the late 1960s. Before the study period, this system was operated and maintained by a farmer association. During the study period, however, the management of the system was in a transition state. The NIA took over its operations when it was integrated with UPRIIS.

The system covers about 515 hectares in the wet season and 412 in the dry season. Compared to the Talaksan Commmunal Pump Irrigation System, the Salapungan Irrigation System has low physical control facilities. Farmers built about only 14 meters of farm ditches per hectare of service area.

Irrigation Behavior and the Nature of Water Supplies

Results from these management studies on Philippine irrigation systems show a relationship between the nature of water supplies and the decision-making behavior of water users and irrigation personnel. One telling water supply-farmer behavior relationship that was verified by early irrigation studies was diversion of excess water to fields when water was available as a direct response to uncertain water supply deliveries (Wickham and Wickham, 1974). Slack or complacent management behavior on the part of irrigation personnel is attributed to abundant water supply in those areas that received water.

Where Water Supplies are Adequate and Reliable. Previous studies describe as "adequate" the water supplies of systems with a RWSA greater than 2.0 (Valera, 1985; Svendsen, 1983; Moya et al., 1983).[22] In parts of the system well supplied with irrigation water, farmers would divert water quantities three times greater than their requirements (e.g., RWSA = 3.4) and allot to management two-thirds of the diversion.

1. Farmer irrigation behavior. Farmers who anticipate and enjoy reliable and adequate water supplies by virtue of either a stable water supply at the source, or an advantageous location in the system, generally depend on system water deliveries rather than on rainwater for most of their water requirements.[23] Svendsen (1983) reported that about 60 percent of the sample farmers, mostly head-end farmers and pump users, depended solely on system irrigation deliveries rather than on rain for their seedbed and land preparation water requirements. In contrast, the remaining 40 percent, mostly tail-end farmers, delayed their seedbed and land preparation activities to be in phase with the monsoon season rather than with the irrigation delivery schedule.

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[22] These RWSA values represent the ratios of the water supply at the lateral headgates to the actual water demand in the fields.

[23] The practice or behavior of using irrigation before rainwater departs from the traditional concept of irrigation as complementary to rainfall.

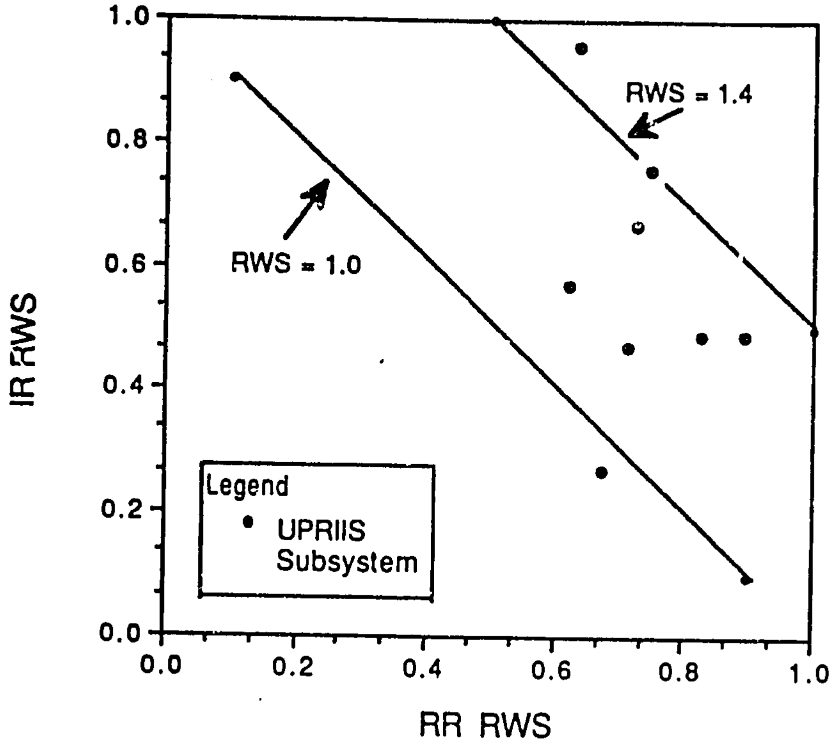

Figure 7: Rainfall utilization and design relative water supply for some UPRIIS subsystems. Nueva Ecija, Philippines, 1982 wet season.

To meet crop and soil water requirements during the growing period, farmers and irrigation field personnel even in the national reservoir systems, where rainfall utilization should have high payoff, used only about 5 percent of the total rainfall. Valera (1985) made the same observation: effective use of rainfall was low in two UPRIIS subsystems that he studied. At LTRIS, the ratio of the total irrigation supplied (IR) to total rainfall received (RR) in the 1982 wet season was 1.26 and that of PRIS C-1 was 1.01. These ratios indicate that LTRIS and PRIS C-1 used about 50 percent of the total rainfall in order to maintain a RWS (Figure 7). The nominal total amounts of rainfall were already more than sufficient to meet the total system environmental demands; still, quantities of irrigation equal to rainfall amounts were supplied to compensate for rainfall uncertainties and physical system control deficiencies.

The management intensity studies documented system rainfall utilization (Moya et al., 1983). In this analysis, both the total rainfall amounts and the total irrigation supplied during the 1982 wet season were each scaled by the total environmental water demands (ET plus S&P) to delineate the conjunctive irrigation-rainfall use. The scaled rainfall was plotted on the horizontal axis and the scaled irrigation on the vertical axis (Figure 7). With perfect information about the timing and distribution of rainfall and the environmental demands for water, any technically and operationally well-performing irrigation system ideally should fall along the RWS=1.0 line. Along this iso-RWS, irrigation releases are assumed to complement rainfall. Moving to a higher iso-RWS denotes decreasing water use efficiencies.

To compensate for a lack of complete and accurate water information, most of these systems operate at higher iso-RWS (Figure 7). Moving to higher iso-RWS denotes greater water supplied than demanded and, therefore, indicates lower water use efficiency. Except for LTRIS and PRIS C-1, most of the UPRIIS subsystems supplied irrigation to bring rainfall RWS to the overall RWS level closer to the designed level of 1.4. Higher yield productivity can also be expected at this RWS level.

Handling water allocation and distribution to account for rainfall will complicate irrigation system operations that are already complex without accounting for rainfall. Rainfall stochasticity creates uncertainty that irrigation personnel must deal with. Hence, only when accurate means to forecast rainfall are at their beck and call, will irrigation field personnnel utilize rainfall more effectively.

From the foregoing, it would seem that reliability as well as amount of water supply will bring forth a clear pattern of irrigation response behavior. A simple estimate of reliability of supply is established as the proportion of time (number of weeks) when water supplies equal or exceed water demands by 50

Table 4. Water supply and demand situations, simple reliability estimates, 3 UPRIIS subsystems, Center Luzon Philippines, 1983 Season.

Subsystems	Average RWSA	Percent of Irrigation Weeks			
		RWSA < 1.5	1.5 ≤ RWSA ≤ 2.0	RWSA > 2.0	Reliability RWSA ≥ 1.5
LTRIS	2.1 (79)	33%	29	38	67
PRIS C-1	1.4 (27)	63	25	12	37
Lower TRIS lat F	2.1 (26)	0	60	40	100

( ) Figure inside parenthesis represents coefficient of variation percent, or RWSA equals or exceeds 1.5, to the total number of irrigation weeks within a season.[24]

Reliability (R) = No. weeks RWSA =>1.5/Total No. of weeks

The nature of water supplies in LTRIS, PRIS C-1, and lower TRIS lat F during the 1983 dry season can be more clearly defined with this type of analysis. The lower TRIS lat F site was the mosthighly reliable (100 percent) system with a mean RWSA of 2.1,[25] followed by LTRIS (67 percent) with a mean RWSA of 2.1, and by PRIS C-1 (37 percent) with a mean RWSA of 1.4 (Table 4).

Despite equal seasonal average RWSAs of 2.1, the irrigation behavior of lower TRIS lat F farmers differed from that of LTRIS farmers (Table 5). Because the water supplies were reliably higher in lower TRIS lat F, farmers tended to use input levels higher than either those of LTRIS, or PRIS C-1 farmers. As a result, they obtained the highest yield. Also, more lower TRIS lat F farmers were satisfied with the irrigation service. However, they participated in operations more than the farmers in either LTRIS or PRIS C-1 by checking the main canal. They could participate in operations rather easily because the irrigation

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[24] Based on design water allocation and distribution of 1.5 lps/ha --13 mm/day-- and field water demands of 10 mm/day; the minimum operating RWSA should be 1.3 for UPRIIS.

[25] Two perennial creeks augmented the water supplied from the UPRIIS reservoir to lower TRIS lat F.

Table 5. Estimated means of yield, nitrogen fertilizer, herbicide, and pesticide expenditures at the study sites, dry season, 1983.

Site	n	Yield (t/ha) (%C.V.)	Nitrogen (Kg/ha) (%C.V.)	Herbicide (P/ha) (%C.V.)	Pesticide (P/ha) (%C.V.)
LTRIS	45	4.69^{ab} (29)	91^{a} (36)	54^{a} (89)	161^{a} (56)
PRIS C-1	52	4.22^{b} (34)	87^{a} (35)	22^{b} (138)	132^{a} (78)
lower TRIS Lat F	62	5.06^{a} (26)	93^{a} (47)	67^{a} (78)	135^{a} (86)

Column means followed by the same letter are not significantly different at 5% level.

(n)	Number of samples
(% C.V.)	coefficient of variation in percent
(P/ha)	Philippine Pesos/hectare (P 7.9 = $1)

officials were least visible in this site. Probably, the greater part of heir satisfaction with irrigation service accrued from the "liberty to participate in management" that they enjoyed precisely because irrigation personnel were rarely around the site. They also had the lowest fee payments. In part, low fee payments could also be accounted for by the higher labor contributions that farmers made to keep their individual water supply reliably high. Water distribution was most inequitable in this system as a result of the virtually "laissez-faire" conditions. Equity was probably not a concern of those who received water in the lower TRIS lat F since everyone received supplies 1.5 times greater than demand and reaped high yields.

2. Irrigation personnel behavior. What about the behavior of irrigation personnel under reliable and adequate water supplies? The minimum management behavior exhibited by lower TRIS lat F staff is understandable. The water supply in this system was 1.5 or greater times the demand for the entire irrigation calendar. This reliably adequate water supply condition gave the irrigation field personnel much management leeway to permit farmers the full opportunity to participate in system operations and substitute for their management inertness. Water is distributed continuously throughout the system with less supervision.

LTRIS had the same seasonal average RWSA of 2.1 as the lower TRIS lat F. But in contrast to the seasonal 100-percent reliability of water supplies at lower TRIS lat F, water supplies at LTRIS were only 67 percent reliable throughout the season (Table 4). Ad hoc water rotation was enforced to minimize the variation. To compensate for further unreliability, both farmers and irrigation field personnel intensified their management activities by night irrigation or night canal patrol as the needs dictate.

Where Water Suppies are Scarce and Unreliable. Water scarcity manifests itself in the system when RWSA falls below 1.4 (Oad 1982; Valera 1985; Svendsen 1983). This RWSA level alerts both farmers and irrigation personnel to be prepared for higher management inputs to distribute water effectively. Further reduction of RWSA to 1.0 or less will require complementary measures to promote productivity and equity. And the decision-making behavior of farmers and irrigation personnel will be affected.

1. Farmer irrigation behavior. The RWSA at Salapungan River Irrigation System (SIS) averaged about 1.74, with a range of 0.62 at the tail to 2.86 at the head of the system. Under constraints of undependable water supplies (due to stochastic river flows) such as the case in SIS, farmers direct their management activities towards squeezing two rice crops within the period of dependable river hydrograph. The SIS tail-end farmers accomplished this objective by adopting combinations of risk-averting and season-shortening practices, including direct seeding, planting short-duration rice varieties, and mechanizing land preparation to shorten the duration of the cropping season (Agua et al., 1980; Acoba, 1981; Svendsen, 1983). To complement these measures, they also intensified communication with fellow farmers and adopted ad hoc water scheduling. The head-enders, in contrast, enjoyed water supplies 2.86 times their water demands. Their decision-making behavior conforms to that of farmers under adequate water supplies.

Communal pump users experience chronic water scarcity as a result of high maintenance and operations costs. They operate with RWSA less than 1.0 no matter how reliable and abundant the water supplies are at the source (Svendsen, 1983; Moya and Murray-Rust, 1985). Communal pump users would try to minimize their operational costs by either cutting down their pumpage (pumping times) or spreading water to a greater number of users who in turn would help defray operational costs. Thus, the high operations and maintenance costs intrinsic to pump irrigation systems constrained communal users to apply water both more efficiently and equitably.

This water use behavior parallels that in the hill irrigation systems of Nepal (Martin et al., 1986) where floods spawned by heavy monsoon rains repeatedly destroy water-capture and conveyance systems within a single cropping season. As a result, substantial labor must be mobilized to fix the damages, and headenders need labor contributions from the tailenders to repair the damaged water-acquisition facilities. This forces operations personnel to allocate and distribute the available water more equitably.

When farmers do not have a full hand in controlling water deliveries, as in the national irrigation systems, they concentrate their efforts on supply-augmenting measures when confronted with scarce water supplies. PenRIS farmers closely monitor the adequacy levels of their water supplies at the turnouts and when the levels are assessed to be lower than their needs, they check the parent sublaterals or laterals. Checking is the principal mechanism used by farmers to increasing their turnout water supplies. Few conflicts arise from checking because farmers do it during the night when the resistance from

Table 6. Management indications and farmer participation under different water supply behavior. WPRIIS Subsystems, Central Philippines, 1982 wet season and 1983 dry season.

Subsystem	RWS		1983 Wet Season Management Indicators			RWS		1983 Dry Season Management Indicators		
				Observed Presence %					Observed Presence %	
	Avg	CV%	No. of checks	AWMT	DT	Avg	CV%	No. of checks	AWMT	DT
LTRIS	3.0	76	1^{a}	25^{a}	11^{a}	2.1^{a}	79	5^{a}	31^{a}	19^{a}
PRIS C-1	4.3	155	5^{b}	40^{b}	23^{a}	1.4^{b}	28	5^{a}	30^{a}	19^{a}
Lower TRIS lat F	1.9[a]	--	2^{a}	25^{a}	25^{a}	2.1^{a}	26	9^{b}	22^{a}	17^{a}

In a column, means followed by a common letter are statistically insignificant at 5% probability level.

[a] Unmeasured flows not accounted

their fellow farmers is least. In addition, they only resort to this practice after having sent "feelers in the air" that they would check because their request for more water from fellow farmers and irrigation field personnel had failed.

At PRIS C-1, where RWSA averaged about 1.4 and was below the target RWSA of 1.5 more than two-thirds of the irrigation calendar, farmers were wary of using ancillary inputs. The PRIS C-1 famers applied low levels of nitrogen fertilizer and other inputs; they obtained very low yields. To improve individual water supplies, they participated in operation of the main canals. But they participated nearly at the same level under both adequate and scarce water supply situations; the observed number of checks per week that they made along the main canal was almost the same for both wet and dry season (Table 6).

2. Irrigation field personnel behavior. When faced with short water supplies, irrigation field personnel would try to cut water demands to be within the designed RSWA operating range. For example, the UPRIIS operations staff decided to spread the shortage proportionally among their four irrigation districts when the water level at the reservoir subsided to an elevation that could irrigate only 68 percent of the normal dry-season service area. This way, they could operate at the minimum range of the designed water allocation and distribution scheme. This range appears to be within RWSA of 1.5 to 2.1 (Oad, 1982; Murray-Rust, 1983; Svendsen, 1983; Valera, 1985).

It seems that field personnel operate irrigation systems within a constant RWSA range and adhere to design requirements for water allocation and distribution. Management indicators such as observed presence in their places of work of the UPRIIS assistant water management technicians (AWMT) and ditch tenders (DT) did not differ much between the 1982 wet season and the 1983 dry season (Table 6). This parallels the observed nearly equal participation in system operations of farmers in both wet and dry seasons. The three management intensity studies yield the same result; the number of hours worked by field personnel during the 1983 dry season remain the same as those for the 1982 wet season. This partly explains why Valera (1985) concluded that these management indicators were insignificant for differentiating system performance. The management level or range may, in fact, be truly uniform among the subsystems.

Even when confronted in the middle of a season with situations as occurred in PRIS C-1 in the 1983 dry season, operations staff still tended to oversee according to the designed management setup. When RWSA was below the designed 1.5 for more than two-thirds of the irrigation calendar, Valera (1985) observed decreased daytime presence of both AWMTs and DTs, but increased farmer participation (checking along the main canal) in their work areas. With supplies too little and ureliable to handle, irrigation field personnel were harassed by irate farmers. They showed up in their work areas only in times they were sure that water would arrive in order to avoid direct confrontations with farmers. Operations staff, by being less visible in their work area, indirectly permitted farmers to participate in water allocation and distribution to compensate for their absence. A PenRIS AWMT who performed very well during water shortage crisis was the one who coordinated and facilitated negotiations about water sharing among the users (Svendsen, 1983). At the end of the 1983 dry season, both PRIS C-1 farmers and irrigation personnel realized that under such tight RWSA of 1.4 and unreliability of 63 percent, even the intensified management efforts of night irrigation and canal patrol would not pay off in terms of productivity and equity. Despite their efforts, water was still distributed and allocated inequitably among users and production was low. The situations in PRIS C-1 appeared to indicate the lower limit to management intensification.

From the context of the foregoing, the observation that operations staff reduced water demands by cutting down the service area in order to escape culpability in case management meets disaster could not be altogether true. All indications are that they would like to operate within the designed limit of the systems and guarantee quality accountability to the users. To a certain extent, the greater part of their management inertia may be due to lack of appropriate incentives to work extra hours to distribute water. They were not paid overtime fees or extra remunerations for extra work. Martyrdom has long been doomed in irrigation system operations.

GENERALIZATIONS

This paper concentrated on three problems: (1) identifying a more all-embracing index for describing operational behavior of irrigation systems, (2) employing this index to characterize operational intensity of some Asian irrigation systems, and (3) oulining other issues relevant to improving the index to characterize operational response behavior more sharply.

An All-embracing Indicator

To be useful and meaningful, an index must capture and reflect the intricacies deriving from the "behavioral" nature of irrigation system operations. The index must be able to reflect both the fundamental objectives and the socio-technical characteristics of irrigation systems. This paper attempted to identify which of the existing irrigation performance criteria and indicators can meet the essential requirements of this index desired.

The three criteria most commonly used to rate irrigation system performance are the same as the objectives of investments in irrigation systems: productivity, equity, and efficiency. Often they are incompatible, if not in opposition. An irrigation system can hardly score high according to all three criteria.

Meanwhile, a few recent irrigation studies have used indices to specifically describe outcomes of water distribution in terms of the relationship between water supply and water demand. These are the Pasten number, TWFAI, and RWS. These indices are generically linked to one another in that all reflect water supplies scaled (normalized) by water demands. Moreover, one can also argue that they also mirror the "behavior" of the irrigation systems as they reflect the behavior of the people involved in operating irrigation systems. Insofar as the performance of any irrigation system is directly tied to the behavior and attitudes of both farmers and irrigation field personnel, the response behavior of both farmers and irrigation field personnel dictates the performance of irrigation system. The trite, but necessary converse to this is that the response behavior of both farmers and irrigation field personnel is shaped by the amount of water appearing or expected to appear. Thus, the relationship between

Table 7. A comparison between common irrigation system performance indices and specific water distribution indicators.

Common irrigation system performance indicators	Specific Water Distribution Indices RWS	 TWFAI	 Pasten
Productivity	X	X	
Equity	X	X	X
Efficiency	X	X	

Note: A blank cell indicates that a specific water distribution index does not consider a priority the corresponding system performance indicator.

water supply, irrigation behavior, and system performance constitutes a series of feedback loops or a spiral of cumulative causation.

Provided system operational rules are implemented, the Pasten number, TWFAI, and RWS will mirror the fundamental objectives of irrigation investments (Table 7). Delivering quantities of water to meet water demands will promote productivity and efficiency of water use. Furthermore, since water demands are to be calculated based on crop and land water requirements, TWFAI and RWS also reflect equity in utility of water use. While the Pasten number may reflect productivity and efficiency of water use, it has as a priority the attainment of equity. In practice, the Pasten number is used to uphold equity principles in operating some Indonesian village systems.

From the foregoing we see that TWFAI and RWS can be used to sort out differential response behavior of irrigation systems and therefore operational intensity and mode of managing irrigation sytems. Although RWS and TWFAI are equal, RWS was used as a scaler for operational intensity and response behavior of the irrigation systems in this paper.

RWS: A Sorting Index

RWS gives a general indication of water regimes of most irrigation systems. RWS exceeds 2.0 in well-watered systems and it falls below 1.5 in water-short systems. A noteworthy RWS range is 1.5 to 2.0. The lower end of the range represents the design RWS; the design RWS increases to 2.0 on the upper end according to the degree of variance of the existing system from the designed one. RWS also suggests levels of system physical and operational control, and perhaps operational inputs intensity. It was also anticipated that these water-demand-scaled indices reveal operational response behavior of both farmers and irrigation personnel.

In this analysis, RWS by itself could not sort out the operational response behaviors of irrigation systems. Even such simple estimates as reliability of water supplies (as introduced in this paper), when coupled with RWS levels, sharpen the differentiating utility of the index. Combining RWS levels and reliability estimates, four types of flow supplies were identified as important in characterizing irrigation system response behavior: (1) reliable and adequate, (2) unreliable but adequate, (3) unreliable and inadequate, and (4) unreliable because expensive.[26] A fifth category that was not observed in any of the studies is (5) reliable, but inadequate.

<u>Reliable and adequate supply</u>. RWS for this type of flow equals or exceeds the target RWS of 1.5 about 90 percent of the irrigation period. When a supply condition such as this occurs, farmers apply higher levels of production inputs. This results in higher yields (e.g., more than 5 tons/ha in lat F TRIS lower

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[26] One flow category that others may look for in this classification is excessive water conditions, but it is not considered in this paper as all the systems considered in this study did not report any incidence of overflowing water supplies.

in the 1983 dry season). Farmers can participate more in the operations of the system because the irrigation field staff are not in their area of assignment. As a whole, they are satisfied with the operation of the system.

The assumption that operational field staff substitute water for management appears tenuous. What is apparent is that irrigation field staff tend to run irrigation systems within or close to a RWS range compatible with the designed operating RWS. Irrigation releases are controlled to be within the minimum operating RWS. Parenthetically, most irrigation systems are apparently operated to achieve targets specified by design parameters. The results of water distribution in UPRIIS and the water allocation-land authorization process in Gal Oya illustrate this phenomenon. The practices in the Indonesian village systems further corroborate that design relative to water supply limits operational intensification by irrigation staff.

The average RWS due to irrigation alone[27] was 1.43 for LTRIS and 1.23 for PRIS C-1 despite the heavy rains during the 1982 wet season. These values are comparable to those observed in normal dry seasons. Actual RWS is higher if rainfall is included, but including rainfall in RWS calculations creates an excessive management burden for operational staff. So, rather than increase their management efforts to use rainfall more effectively,

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[27] This is the ratio of the quantities of water supplied through irrigation (IR) alone to the quantities of environmental water demands (ET + S&P).

irrigation field staff opt to maintain their efforts within a designed management range compatible with RWS of 1.5 to 2.0.

Given this type of water supply, water control is minimal and distribution is continuous. Allocation and distribution are inequitable, but biased towards the adequate side. Consequently, equity is of little concern to the users. Productivity is high; water use efficiency is low.

<u>Unreliable but adequate supply</u>. This type of flow occurred when RWS exceeds 1.5 only in one-third of the entire season. Under these conditions, both farmers and field irrigation staff intensify their vigilance and management efforts to minimize flow uncertainties. Ad hoc water rotation and night patrol of canals are practiced. Farmers use lower level of inputs; thus, yield levels are lower. Water distribution outcomes are more equitable and efficient.

<u>Unreliable and inadequate supply</u>. This extreme situation occurs when RWS is equal to or greater than 1.5 only in one-third of the season. With such flow uncertainties, productivity, equity, and efficiency cannot be improved even though management efforts are intensified. When PRIS C-1 experienced this type of flow in the 1983 dry season, productivity, equity and efficiency were low despite the intensive water rotation, the day and night canal patrol and strong farmer participation in the operations. This type of flow sets the lower limit to increasing operational intensities of irrigation management.

Reliable but expensive supply. This type of flow occurs when the RWS is less than 1.0, but when supplies at the source are reliable. This occurs specifically in the communal pump irrigation systems where farmers operate at RWS just equal to or less than 1.0 to minimize water costs. Water is distributed on a quasi-demand basis. Generally, farmers use lower input levels and thus attain low yields. Ceteris paribus, yield loss may be offset by the high market price for produce they get when planting is appropriately timed. The time of planting is fully controlled by the farmers.

Implications and Further Issues

The explanatory power of RWS can be enhanced by incorporating reliability estimates of water supplies. Even the simple reliability estimates presented in this paper, when integrated with RWS, were better predictors of response behavior of both the farmers and irrigation field staff. Perhaps the addition of a few more dimensions, such as estimates of risk and uncertainties, would highly improve the applicability of this index.

Evidence from irrigation management research suggests that irrigation systems are operated at a constant level of management intensity. Field staff respond to water information collected, but they respond towards keeping the design management level associated with the designed RWS (Figure 8). The Gal Oya in Sri Lanka, two Indonesian village systems and the Philippine irrigation systems mentioned in this study, all cut system water

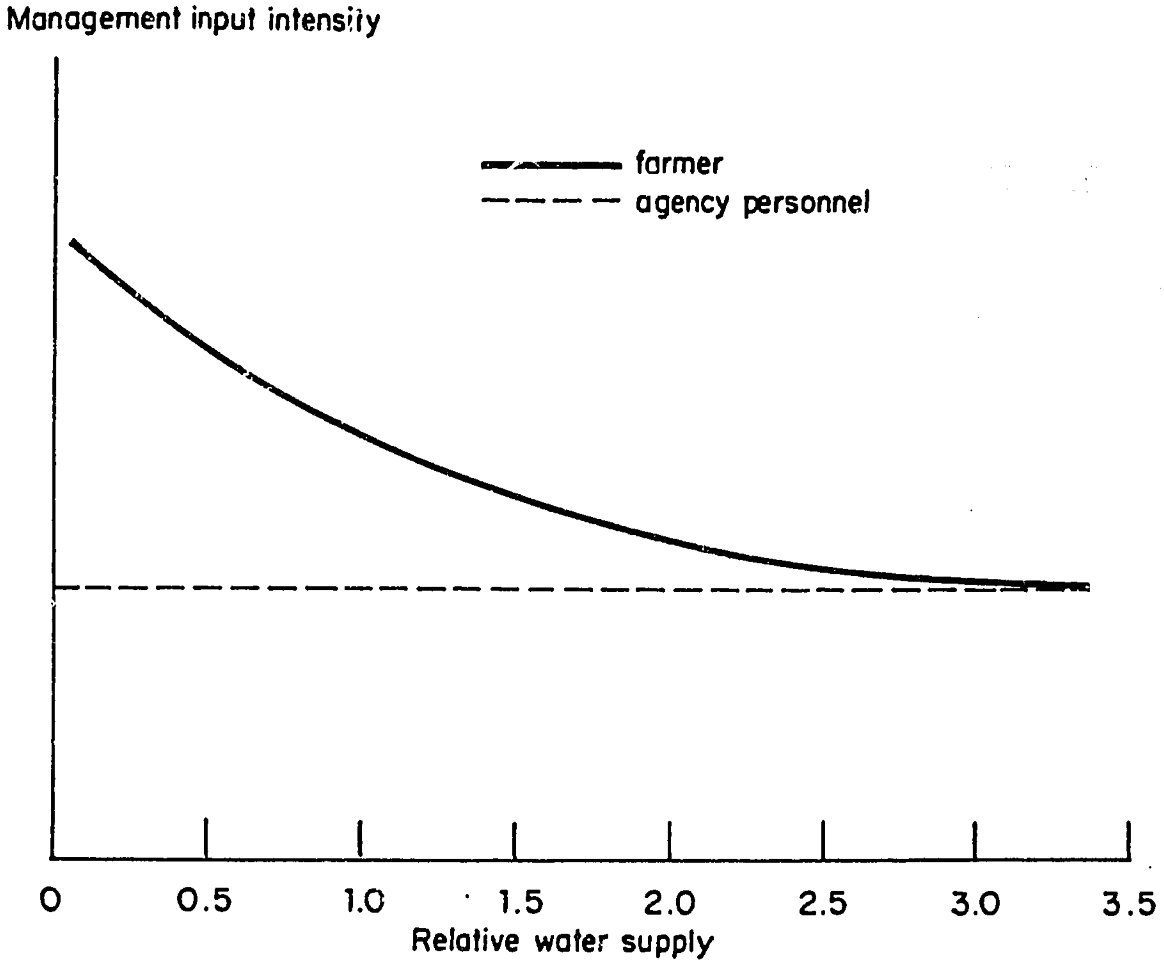

Figure 8: Apparent relationship between irrigation operations and relative water supply.

demands by reducing area under cultivation to be within the minimum operating RWS of about 1.5 at the distributaries. Or, to hold agency management inputs constant, irrigation field staff permit farmers to participate in the operations of the system and to provide the extra inputs needed to run the system.

The findings from this study have important implications for the design and construction of new systems or the rehabilitation of existing ones. These activities should focus on providing means to ensure reliable water supplies. One possibility is to build intermediate storage facilities to buffer short-term failure (deviation from the target RWS of 1.5) in water delivery performance. Inasmuch as the amount and the reliability of water supply dictate the limit of new construction and rehabilitation, particularly if it involves expansion of area coverage, the assessment of reliable water (safe water yield) is very important. Irrigation personnel are amenable to intensifying operational intensity only within the range compatible with RWS of 1.5 to 2.0. This does not in any way suggest or insinuate that irrigation systems can not be operated with higher water use efficiencies or RWS lower than these values. But what is apparent is that both farmers and field staff run irrigation systems according to targets or the operation inputs specified by the range of the design relative to water supply. This has been integrated or even institutionalized into the system operating environment--physical, social, cultural--and requires time and money to modify.

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