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IRRIGATION SYSTEM MANAGEMENT RESEARCH AND SELECTED METHODOLOGICAL ISSUES

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ABSTRACT

Recent field research findings indicate there is great potential to improve performance of existing irrigation systems in Asian rice growing regions. Crop yield, water use efficiency, irrigation efficiency, water adequacy, relative water supply, and water distribution equity criteria can be used to assess irrigation system performance. Requirements and relative merits and demerits for the use of these criteria are discussed. Methodological options available for evaluating field research on irrigation system management improvement are analyzed. Also discussed are applicability requirements and field considerations of practical alternatives for measuring critical hydrologic and hydraulic factors which enable the determination of water-related criteria for irrigation system performance evaluation.

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IRRIGATION SYSTEM MANAGEMENT RESEARCH AND SELECTED METHODOLOGICAL ISSUES

Irrigation development is accepted as the major vehicle for increasing agricultural food production in many countries in South and Southeast Asia, particularly those with large, expanding populations. Irrigation water enables use of modern high-yielding varieties of rice and other crops. It also makes a second and sometimes even a third crop possible in one year. Irrigation creates jobs in rural areas and can promote stability in society by creating a solid agrarian economy.

Concurrent with new irrigation facility development, substantial investments to upgrade existing systems and improve their performances are being made in several South and Southeast Asian countries. Two reasons for this have been identified.

- Performances of many existing irrigation systems have been unsatisfactory.
- New irrigation development costs are escalating rapidly because the most favorable lands for development are being exhausted (Small 1981). Investments to modernize existing irrigation systems are also being made because it is believed substantial performance improvements can be achieved cost effectively.

When water management became a key idea for improving irrigated crop environments in the late 1960s and early 1970s, many advocated the improvement of on-farm water management status as a primary means of increasing water use efficiency in irrigated systems. Symposia, conferences, and workshops were held to discuss on-farm water management issues. Numerous recommendations were made. Most recommendations assumed the greatest water management problem in irrigated systems was at the farm level.

Wickham and Takase (1976) refuted this notion. They argued that farm-level problems most often result from water allocation and distribution problems at the main system level. This level is beyond farmers' control. Unless main system management is organized and improved, on-farm water problems cannot be resolved. Recent experiences on part of the Command Area Development Program in Andhra Pradesh State, India, where "precision-developed lands and lined channels remained dry... for the simple reason that no one is (carefully) operating the canal system" (Ali 1976) exemplifies a similar situation. Other studies (Valera and Wickham 1976, Levine and Wickham 1977, Chambers 1980) suggest the farm level focus should not get priority over main system operation problems if major gains in irrigation system performance are to be achieved. Recently, Wade and Chambers (1980) analyzed the reasons why main system water management problems have not received adequate attention in the past.

Arguments favoring priority consideration of main-system problems over on-farm problems when trying to improve irrigation system performance are convincing. However, on-farm issues should not be completely separated from main-system issues because they are likely to be interrelated. Farms and farmers are as much a part of the irrigation system as are canals and canal tenders. Irrigation system management efforts should take a holistic view of problems existing at all levels of the system and try to analyze them.

A number of studies have established a consistent pattern of water distribution inequity in various types and sizes of rice irrigation systems in South and Southeast Asia (Tabbal and Wickham 1978, Islam 1978, Sumayao et al 1979, Valera and Wickham 1976, Early et al 1978). Recent field research in the Philippines (Tabbal and Wickham 1978, Early et al 1980), India (Ali and Hasan 1980, Hasan 1981), Sri Lanka (Shanmugarajah and Atukorale 1976), and Indonesia (Bottrall 1981) has also demonstrated that irrigation sytems can substantially benefit from improved water allocation and distribution methods at the main-system level. As interest in field research in irrigation system management expands, critical assessments of relevant criteria and analytical procedures useful in evaluating such research are needed.

EVALUATION CRITERIA

Criteria for evaluating field research to improve irrigation system performance must be adequate for the purpose and must be measurable quantitatively, or at least, qualitatively. Returns to investment is one criterion for evaluating any plan to improve irrigation system performance. For various reasons, however, research efforts often cannot be fully evaluated by economic analysis alone. Because most physical changes initiated by field research to improve irrigation performance are water related, it is imperative that water and its benefits to people be the central focus of evaluation.

Present information about criteria used to evaluate field research in irrigation system improvement is inadequate. Physical evaluation criteria or indices that have been used or seem useful in studying the impact of irrigation system management research include crop yield, cropped area, water use efficiency, irrigation efficiency, relative water supply, water adequacy, and water distribution equity. A better perspective of field situations can be obtained by using multiple criteria than by employing a single criterion. Usefulness and limitations of these

criteria are discussed in the following sections. Some limitations are inherent in the definitions of the indices; some are associated with methods by which they are determined.

Crop yield. Crop yield is a function of various inputs including water, which is critically important. Inputs can be classified into natural and managed. Natural inputs are environmental variables such as solar radiation, rainfall, temperature and humidity, and insect and disease incidence. Managed inputs are supplied by deliberate human action. They include irrigation water, variety and fertilizers used, and insect, disease, and weed control measures.

For yield to be a meaningful criterion for evaluating irrigation system performance, information is needed about factors that are likely to affect yield. Multidisciplinary teamwork is necessary to understand the contributions of these factors. Socioinstitutional situations that influence use or nonuse of managed inputs in the irrigation system must also be understood. To study water as the sole key explaining yield differences may be difficult and risky because planners and decision makers often base judgments on crop yield alone. Pilot research may not show substantial yield benefit due to improved water management because other unrecorded natural or managed factors reduced production. Conclusions based on inadequate research information may lead to undesirable decisions.

Cropped area. In many areas, improved irrigation systems management should save irrigation water and make it available to expand farming area. If expansion cannot take place near the system this may not be the case. In some cases improvement may be from savings in energy expenditure only (as in a pump or tube well system). In others, the result may be in preventing or improving a waterlogging problem in the system. A combination of improvements is also possible. Research planning should consider these possibilities and the data base should be broad enough to satisfactorily analyze relevant factors.

Water use efficiency. Agronomists have defined water use efficiency by crop yield alone, i.e. units of harvest per amount of water applied (De Datta 1981). Although this concept is useful for comparing productive efficiency of crops in water use terms, it is not a satisfactory index for evaluating irrigation system performance. Water use efficiency (WUE), as defined below, has been used as an index of field water utilization efficiency in rice irrigation systems (IRRI 1974).

$$\text{WUE (\%)} = \left(\frac{ET + S\&P}{IR + RF}\right) \times 100$$

where ET is the evapotranspirational requirement, S&P is the seepage and percolation requirement, IR is irrigation water supply, and RF is the rainfall amount.

This equation provides a simple way of examining water use relative to total water supply from irrigation and rainfall sources. It serves as a useful indicator of the system performance when rainfall is negligible. A problem arises when there is substantial rainfall. Because rainfall is unpredictable and because rainwater, beyond a certain amount, is uncontrollable at field level, excess rainfall drains from the command area of an irrigation system. A reservoir or a pump system operation is usually adjusted by cutting back or stopping water supply (suspension schedule) when excessive rainfall occurs.

The WUE equation does not adequately reflect such a management action because it cannot separate controllable from uncontrollable. For example, a system using two different control levels and different amounts of irrigation water during two different seasons may have the same WUE because rainfall varies during the two periods. Similarly, despite good irrigation water control in a system, WUE may be low if there is high rainfall that is not controllable by the system. This equation is limited because it cannot adequately evaluate irrigation water as a manageable factor in the system operation procedure.

Irrigation efficiency. Irrigation efficiency (IE) is a theoretically sound approach for measuring system performance in terms of irrigation water delivery. It compares net irrigation requirement with irrigation supply. The ratio of the two parameters is defined as:

$$\text{IE (\%)} = \frac{(ET + S\&P) - RF_e}{IR} \times 100$$

where RF_e is the effective rainfall. The advantage of using IE as an index of irrigation system performance is that it can determine the efficiency with which water from any irrigation source (reservoirs, pumps, diversions, etc.) has been supplied in response to net irrigation requirement (the numerator in the equation). Because the equation only considers effective rainfall, it is sensitive to operational decisions for supply of water from the irrigation source. IE provides an objective comparison of the performance of two or more systems, in irrigation water terms, regardless of rainfall pattern (Greenland and Bhuiyan 1980).

The difficulty of measuring effective rainfall in the field is a practical limitation of the use of IE as a performance index of irrigation systems. Effective rainfall is difficult to measure because it is dependent not only on intensity, duration, and distribution of rainfall but also on farmers' field-level water management practices, especially

bund spillway management. Effective rainfall measured at various fields in the system can vary considerably for the same amount of rain. To obtain a good representative value of effective rainfall, many fields should be monitored, which requires substantial resources.

Comparative studies in the Philippines by Acoba (1981), however, show that the water use-rainfall ratio method of estimating effective rainfall (Dastane 1974), gives reasonable values for some rainfall patterns. It is easy to use and much less resource-consuming than any of the field-monitoring procedures. This method is limited because it does not use the farmer's field-level water management practice as a variable in estimating effective rainfall. However, values obtained by field monitoring or by using the water use-rainfall ratio method are generally satisfactory to provide information for comparing a system's performance over time because differences in effective rainfall values caused by farmer practice will probably be small.

Relative water supply (RWS). Relative water supply is the ratio of total water supply from rainfall and irrigation sources to total evapotranspiration need and seepage and percolation losses (Moya 1979):

$$RWS = \frac{IR + RF}{ET + S\&P}$$

Thus,

$$RWS = \frac{1}{WUE}$$

when WUE is expressed in absolute values of those terms. RWS values for short periods, e.g. weekly, when compared with rainfall amounts for that period, indicate how much water delivery control has been exercised at the irrigation source. When the concept is applied at the field or small area-level and over short periods it is a useful indicator of water adequacy (or inadequacy), but it does not adequately indicate the performance efficiency in a system for the same reasons as explained for WUE.

Water adequacy. A good estimate of water adequacy status can be obtained from weekly or every-10-day RWS values. Use for longer periods is difficult because if substantial rainfall occurs during a short time span, most of it will leave the system, but the RWS value will give an erroneous impression of high water adequacy for the whole period. However, field estimates of water adequacy for rice are not difficult to make. Water supply for rice is adequate as long as fields are not below the saturation moisture content level. Therefore, visual observations of sample fields in different parts of the command area can be usefully applied. Visual observation records enable count of the number of days during crop growth period when water in the field is less than saturation level. From this count, stress days (number of consecutive days during a growing season without standing water in a sample field, excluding the first three during each occurrence) can be calculated to reflect the degree of water inadequacy to the crop (Wickham 1971).

Stress days, particularly during the reproductive stage of the rice crop, significantly reduce rice yield. If a functional relationship between different inputs, including water, and rice yield has been established, the number of stress days, used as a measure of water adequacy, can estimate how much yield loss took place at any site because of water stress.

Stress days are a simple and easy-to-measure criterion used to determine degree of water inadequacy in rice irrigation systems. However, the criterion does not recognize differences among soil types for moisture-holding capacities or depths to water level below soil surface for root system proximity. Sometimes rice plants may not be under stress because roots are adequately supplied with water although there is no standing water in the field. The stress day concept can be misleading in this situation. To avoid this confusion, De Datta (IRRI, 1982, pers. comm.) suggested that nonflooded days may be a better description of the water status than stress days. Small (1981) developed a water shortage index that can be calculated from pan evaporation rate data and depth to the perched water table below soil surface. Analysis of data from the Philippines explaining rice yield reduction caused by water stress shows the water shortage index gives better results than stress day index (Small 1981).

Water distribution equity. The ability to distribute water equitably to all farmers within the command area is essential to good irrigation system management. If there is adequate water for all farmers to grow any crop, the objective of equity may be to provide all farmers with enough water. Often, and especially in the dry season, available water is not adequate for all farmers to grow any crop, especially rice which is most water-demanding. In this case crop planning (zoning) becomes important and equity questions become complicated. Equity criteria for areas with crop zoning should consider net returns for all farmers, as well as soil suitability. Equity issues may be complicated by water rights questions, in which case equity may not mean equality.

However, from a research methodology point of view, measuring or assessing water distribution equity is not a problem once equity criteria have been established. Equality of water delivery can be judged by flow measurement and water adequacy data. Net returns can be determined by benefit and cost analysis, and water delivery and adequacy measurements can be made at appropriate points in the system if crop zoning criterion is applicable.

ANALYTICAL PROCEDURE

To evaluate the impact or benefits of an irrigation system improvement effort in the field,

comparative measures should be used. Comparative procedures used to analyze directly measured or estimated values of the chosen criteria are: the before and after comparison, and the with and without comparison. Data collection requirements for using these methods are comparable to those adopted for benefit-cost ratio or internal rate of return economic analysis.

The before and after comparison. This method requires that the chosen criteria be measured or estimated at the treatment site over time. A benchmark period represents the before situation and the treatment application period represents the after (more appropriately, during for system improvement research undertakings) situation. Differences in the output or the criteria values under scrutiny are attributed to the treatment.

Unless each period is stretched to a long duration, it is hard to gather representative data using this method. If the benchmark is for 1 year (2 crop seasons), which is often the case, chances are high that that year is not a representative year. The same holds true for the treatment application period. Because most usable criteria are related to weather, which varies from year to year, the question of representativeness of the period of study becomes important in research. Biological factors such as insect and disease incidence, which affect crop yield, are also related to weather. Changes in institutional factors such as government subsidies or input distribution mechanism over the study period may also affect farmers' agronomic practices and crop yield.

Using production functions to estimate yields for the cropped area rather than using actual yield data may eliminate, or reduce, some problems associated with year-to-year variability in crop yields caused by weather-related or biological events. However, one must be careful when using production functions because they are useful only if the relationship of output to inputs has been accurately established. Establishing sound production function relationships also requires representative data.

Some of the data required for the chosen evaluation criteria can be obtained by conducting a recall survey of sample farmers instead of making field measurements. However, because the length of effective memory recall of most farmers for detailed quantitative figures is usually limited (Taylor 1980), and because farmer biases can be undesirably high for some data, such as water adequacy, this method is often not the best.

The with and without comparison. This method eliminates some disadvantages of before and after comparison by using spatial comparison, instead of temporal comparison. It can also be used to evaluate broad questions such as the distribution of irrigation benefits among various groups of users (Herdt 1980) due to irrigation system management efforts.

One limitation of this comparison method is that similar areas outside the treatment site to represent the without situation are hard to find (Taylor 1980, Small 1981). The difficulty is greater if the treatment area is large, which is usually the case with irrigation field research. If sites are not comparable, bias of unknown magnitude and direction can be introduced to the evaluation. Therefore, site selection must be given special emphasis. Homogeneity of soil type, hydraulic and hydrologic status (irrigation inflow, seepage contribution from canals, water table level, rainfall, evaporation rate, soil percolation rate, etc.), type and variety of crops grown, crop management practices, and farmers' socioeconomic background are desirable in compared sites.

When field research to improve irrigation system management is evaluated, benefits are obvious if the imposed treatment alleviates water shortage and/or expands the service area. Sometimes, however, improvement is in water savings at the source and there may not be adjacent land available to benefit from water savings which accrue from reduction in water overuse or wastage. Improvements may also give longer-term benefits by alleviating existing or potential waterlogging problems. Such situations require special analyses to determine the values of water saved and land drainage improved.

MEASURING HYDROLOGIC AND HYDRAULIC FACTORS

Several hydraulic and hydrologic factors play key roles in treatment choice and implementation in field research to improve irrigation system management. Hydrologic variables are related to water availability and use. Hydraulic variables relate to water flow. For practical measurement, these two types of variables are considered in the following section in terms of water requirement and water delivery. Relevant issues in methodologies used to measure/estimate them and related practical limitations are discussed.

Water requirement

For irrigation systems, water requirement equals all water needed for land preparation requirements, environmental demands on the cropped area (evapotranspirational requirement), and unavoidable losses in the system, including seepage and percolation losses in canals and fields. Canal losses can be minimized by lining, but because lining is usually expensive, some canal losses are generally considered unavoidable. Good canal maintenance can reduce water losses.

Evapotranspirational and seepage and percolation requirements. For rice which is mostly grown in flooded soil, the water requirement in the field is the sum of the crop evapotranspiration (ET) and seepage and percolation (S&P) requirement. Methods of measuring ET are numerous and many studies have evaluated their relative advantages and accuracies. Reasonably accurate estimation of potential

ET for rice can be made using pan evaporation data. Tomar and O'Toole (1980) recommended a pan (US Class A) factor of 1.2 for calculating ET in rice for the tropical regions of Asia. Variation in the ET rates for different rice growth stages is controversial. These are of minor practical importance for irrigation systems because water losses are likely to be much larger than these variations would normally account for.

ET is an environment-dependent phenomenon and does not vary significantly across sites within a system area. S&P is extremely site-specific because it depends on factors that may vary substantially across sites. These factors include soil texture, water table depth, drainage outlet proximity, and farmers' field bund and water management status. Therefore, laboratory measurements of S&P using soil samples are likely to give unreliable results. The field level S&P measurement technique for rice irrigation systems developed by Giron and Wickham (1976) directly measures daily water level subsidence using an inclined graduated scale installed in a field. S&P is calculated by accounting for the corresponding ET value and any rainfall that may have occurred. The method is simple and inexpensive.

The main advantage of field level S&P calculation is that measurements can be done in situ in undisturbed soil. However, the following precautions are necessary to get reliable data from a sample field: the instrument must be installed with legs deep enough into the hard pan so it does not move in the soil with the expected disturbance in the field; water inflow from and outflow to surrounding fields must be checked frequently because if these flows are not recorded, large errors will be introduced in the measurement; field bunds must be managed at normal levels and unusual cracks or holes in the bund plugged; and measurements should be made at a large number of sites or fields so an average value for the whole area will include diversity of soil type and other physical factors mentioned earlier. The fulfillment of these conditions in the field requires substantial effort.

Canal losses. Canal losses include seepage and deep percolation losses occurring in the canals in the course of water conveyance. Measuring canal losses can take substantial efforts, especially if accuracy is necessary. Two methods are commonly used: inflow-outflow and ponding.

In the inflow-outflow method, canal loss between two points in a canal is the difference between the flow measured at the head location and the flow at the end location plus the flows into channels between the two locations. This method estimates losses for actual canal operating conditions without disturbing the regular irrigation schedule. It will provide accurate results only if flow measurements are made reliably and precisely. Difficulties and uncertainties arise because canal losses are usually small when compared to canal discharges. The error involved in measuring canal flows can be comparable to the canal losses. If skilled people operate a relatively accurate measuring device, such as a current meter, over a long observation reach this method can yield a more reliable estimate of actual canal loss than other alternatives, especially for high-capacity canals.

In the ponding method, water is impounded between two points in a canal and total water lost to seepage, percolation, and evaporation is measured. This method is convenient for small canals that can be easily ponded. However, results from such small-canal measurements may be misleading if extrapolated for larger canals. Ponding large-capacity canals and leak-proofing every water entry or exit point in the pond is difficult, especially when water levels in connecting canals maintain a differential head. Ponding also disturbs canal operation. The method can also provide erroneous information because the hydraulic head at different points in the canal under the ponded condition is not what it would be under normal flowing condition. Because ponding causes silt in water to settle, the soil pores in the canal bed and side slopes may become clogged and seepage and percolation rates will be reduced. Despite these limitations, ponding is often used primarily because it is simple and measurements are easy.

Water and Power Consultancy Services Ltd. (1981) of India recently published an excellent review of the applicability of different methods for measuring seepage losses in irrigation channels.

Water delivery

Water delivery or flow measurements are usually an essential component of irrigation system management research. Knowing how much water is going where is the first step toward understanding a system's management improvement needs and for evaluating the impact of an improvement. Many ways of measuring water flow in canals are available but not all are equally useful for field research.

Flumes are the most widely used devices for measuring water flow in irrigation canals. The Parshall flume is most commonly used. It was developed by Ralph Parshall (1926), and combines many attributes necessary for water management research use. It is accurate, causes minimum head loss, and is self-cleaning. However, it is hard to build. Throat section configuration and the sloping floor make construction and field installation difficult and skill demanding. It is also expensive to build.

The development of the cut-throat flume (Skogerboe et al 1967) improved upon limitations of the Parshall flume but did not sacrifice accuracy. Cut-throat flumes are relatively easier to construct and install in the field because there is no throat section and the floor is flat. Cut-throat flumes are also more economical; they can be constructed for the same flow capacity for about 60% the cost of Parshall flumes (Early et al 1980).

Since 1977, vane-type flow-measuring devices have been used for some research in the Philippines, particularly for measuring small flows. The device was developed by Gilles and Wickham (1977) for rectangular and trapezoidal cross-sections. Later it was adapted to circular cross sections (Butlig and Svendsen 1980). It is a low-cost device and requires almost no head loss to measure flow. In the field, cost can be further reduced if the same portable vane plate is used for several units of the same size and shape. The vane device has created mixed reactions among users. Measuring the deflection of the vane plate is not as easy as reading a fixed gauge. Because the plate is sensitive to force, strong wind or high velocity water flow causes fluctuation and makes it difficult to read the gauge. The plate can also be easily tampered with.

Another flow-measuring device often used for irrigation system operation and research is the staff gauge. It is an inexpensive, easy-to-install, and easy-to-read device but the cost of a current meter, which must be used to establish the head-discharge relationship for the measurement point, is high. However, because one meter can be used for multiple sites, cost per site can be reduced. This method is better suited for large flows that would need very expensive flume devices. Using a staff gauge requires that the point of measurement has a stable channel cross-section (free from scouring, erosion, or sedimentation), that flow is not turbulent, and that there is never a back water effect. Avoiding this effect is critical because staff gauges will grossly overestimate flow when back water effect has taken place. Such effect can happen if the canal is checked or downstream flow is restricted. For accurate results, flow calibration in the canal using a current meter and canal cross-section measurement should be made frequently and at least once a season.

To obtain accurate water flow data, the frequency of readings of the chosen flow-measuring device must be determined by observing flow fluctuations in the canal. If daily flow is highly variable more frequent readings are desirable. For relatively stable flows, two to three daily readings is generally adequate. Taking infrequent readings for a fluctuating flow can cause more error in the flow estimation than could be caused by the inherent inaccuracy in a commonly used equipment. Using continuous water-stage recorders can eliminate this problem, but they are expensive.

When choosing a water flow measurement device for research use, one must be aware of practical field limitations. They are sometimes more important than relative accuracies and relative costs. Farmers are often wary of new measuring devices, particularly if they block easy passage of water. Without good farmer acceptance and cooperation, it is difficult to achieve consistent uninterrupted measurements. Farmers are likely to remove measurement devices if they think they are impeding their water supply. Staff gauges are the best from this consideration. Flumes are the most difficult. Vane-type devices do not obstruct water flow.

CONCLUDING REMARKS

Criteria for satisfactorily evaluating an irrigation system's performance status and for measuring the impact of improvement efforts are not clearly understood. More in-depth research is needed to develop evaluative criteria for various types of irrigation systems and practical ways of measuring and analyzing them.

When undertaking field research concerning irrigation system improvement, we should scrutinize not only the appropriate treatments to be applied but also how data will be analyzed. It is also helpful to consider relative advantages and disadvantages of available evaluation and data collection methods.

Lack of sufficient benchmark information is a major constraint to applied research for improving irrigation system performance. Agencies responsible for or concerned with such improvement should consider establishing benchmark data collection programs for as many irrigation systems as possible. Uniform methodologies should be applied for collecting data for various systems in a country or region to enable useful cross-site analyses.

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