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WATER DELIVERY PERFORMANCE

Johannes Makadho[a]

INTRODUCTION

Understanding and measuring performance is fundamental to the development of methodologies which can be used by researchers and by irrigation managers to find answers to specific problems. Work is needed in performance evaluation to identify both the appropriate dimensions and measures of these dimensions. Examples of these dimensions include:

- water delivery performance;
- agricultural production performance; and
- social performance in terms of achievement of the systems' social objectives.

In the process of manipulating resources, outcomes are generated which, when observed, can be expressed in a form of some level of performance. The level of performance has to be measured and quantified for it to be useful. This then calls for the determination of performance indicators and the determinants of performance that relate to a given activity through which a specific resource is manipulated.

Abernerthy (1986) discusses at length the issue of performance in water management. The basic question to be asked is: How should performance of an irrigation scheme be measured? What exactly do we mean when we refer to a particular system as "performing well" or "declining"? Can such qualitative statements be qualified through quantitative analysis? These questions call for a set of parameters that can be measured to quantify irrigation performance.

However, some difficulties are inevitably confronted in the process of assessing irrigation performance. Svendsen (1990) remarks that among the most basic and pervasive of these difficulties is confusion about the performance assessment; the physical extent of the "system" to be evaluated; the standards against which performance is to be judged; and the audience for the results. The effects of this confusion manifest themselves in making communication between performance evaluators difficult and clear resolutions difficult, if not impossible, to attain. Svendsen (1990) suggested five important perspective choices that must be faced explicitly in evaluating system performance. These are summarized below and form a basis for systematic approach to performance assessment:

- the purpose of the performance assessment;
- the objectives of the system to be analyzed, including a clear identification of those things which are to be evaluated;
- the activities of the irrigation system which are to be analyzed;

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- the measures to be used in conducting a performance assessment; and
- the standards which would be applied to evaluate the measured performance variables.

These choices provide an analytical framework through which data collection and analysis become simplified and the entire process of performance assessment is given some logical direction and focus (Svendsen, 1990). Through this analytical framework a shared approach will be established for performance assessment among researchers. This is currently missing (Small and Svendsen, 1990). It is observed here that this framework will enhance the thinking and convergence of opinion of researchers leading into some internationally acceptable classification of performance indicators.

However, it is suggested here that for the purpose of determining parameters to measure performance, the resource that is manipulated in the management process should be specified. For example, for the purpose of determining parameters to measure water delivery, it is appropriate to base them on the objectives of water management. The objective in the present case is: to ensure a reliable supply of the right amount of water at the right time where it could be effectively utilized for crop production.

ADEQUACY AND RELIABILITY OF WATER SUPPLY

This chapter will examine performance of irrigation water delivery systems from the dimensions of adequacy, reliability, and timeliness of water supply. In particular, simple indices for quantifying reliability and timeliness of water supply will be developed. The indices will be used to characterize the performance of the schemes under study. Adequacy is a measure for determining whether the total amount of water supplied met the crop water requirement. Reliability, on the other hand, refers to the degree to which the irrigation system and its water deliveries conform to the prior expectations of its users. The expectation of the user is presumed to be that water will always be delivered all the time in adequate quantities. The farmer should feel certain that he knows whether water will come to his field channel on a given day and in adequate quantities. Reliability thus includes the concept of predictability of flows as indicated by a water delivery schedule or operational plan.

If water delivery schedules exist and are implemented, there should be no difficulty in computing the reliability of supply with respect to both time and quantity of supply. If no measurements are made and no records kept, there is no way of knowing if operations are carried out according to the schedules. In the schemes under study, information on volumes of water delivered at various levels (tertiary or secondary) are not routinely collected. Again, there are no water delivery schedules or operational plans except that water is delivered on a rotational basis. In such cases, reliability can be defined as the percentage of time that a given percentage ratio is maintained or achieved. It can be argued further that the reliability dimension is intrinsically connected with allocation and distribution issues which naturally implies issues of adequacy.

Adequacy Levels Across Schemes Under Study

For the present study, irrigation water supply measurements were collected daily for summer 1990 and winter 1991 seasons covering twelve schemes. The irrigation water supply was computed for each scheme and expressed as an application depth in millimeters. Crops and irrigated hectares in all schemes under study were determined and were used to compute crop water requirement (CWR) using the Modified Penman Method. (For detailed cropping patterns see Chapter 5.) Table 4.1 gives the average cropping intensities per scheme type.

There is no significant difference in cropping intensity between scheme types per given season.[1] However, cropping intensities are higher in summer for all system types than in winter. There is a tendency in summer to put more hectarage under irrigation than in winter. During summer, rainfall will be anticipated, hence a larger area is cultivated giving a higher cropping intensity. Since these schemes were developed mainly for supplementing food requirements in drought prone areas, there is a tendency to utilize as much land as possible in summer to grow food grain crops. The area put under irrigation in summer depends on the amount of water available in reservoirs and rivers as carryover from the previous winter's irrigation. Summer 1990 was not a particularly good season, receiving less than 75 percent normal rainfall. Thus 100 percent cropping intensity was not achieved in summer 1990.

During winter, there is a limited number of crops that can be grown. The choice is restricted to winter wheat and perishable horticultural crops. The price for winter wheat is not attractive and the crop is not popular among the schemes. Horticultural crops have marketing problems in terms of either flooding the market or lack of transport facilities to deliver produce on time to the market. Therefore, management and/or farmers deliberately reduce the area under winter irrigation in response to the above factors resulting in the relatively low cropping intensities shown in Table 4.1

Two quantities, water supply and water demand, are basic factors in irrigation design and operation. Total supply is the summation of the supplied irrigation water and rainfall. The demand is the summation of water requirements computed for all crops grown in a specific block of land. Individually, supply and demand are difficult to use in attempting to understand system performance. When combined as relative water supply (RWS), they provide an index with utility for both practical and theoretical application. Levine (1981) presents a detailed exposition of the relative water supply (RWS) concept and its use as an explanatory variable for irrigation systems. RWS is defined as the ratio of irrigation water and rainfall (supply) to the CWR (demand). RWS values were computed and results are presented in Table 4.2.

In interpreting RWS values, it is important to establish the critical RWS value below which water supply becomes inadequate. A RWS value of 1.0 means that the water supplied was equal to CWR. If RWS is equal to or greater than 1.0 then water supply is adequate to meet the theoretical minimum irrigation requirement. Therefore, adequacy can be assessed on the basis of satisfying the theoretical minimum requirement.

However, schemes can and do operate at RWS levels of less than 1.0, and may be economically more efficient than schemes which are operating at a higher RWS level. This is so because some small level of water stress may produce the highest output per unit volume of water. In cases where water is the scarce resource, this can be economically optimal.

Furthermore, crops react differently to sub-optimal water supply (Doorenbos and Kassam, 1979) but in general a supply of less than 80 percent of CWR gives rise to significant yield losses. In the analysis for adequacy of supply, it was decided to settle for the minimum adequacy level of RWS not less than 0.8

because it denotes the minimum requirements below which significant yield reduction occurs.

One conceptual issue to note here is that RWS is dependent not only on the systems' physical configuration, but also on decisions made by system managers and/or farmers on how much land to be irrigated in a given season. In this sense RWS measures not so much the raw supply available to the scheme but rather the choices that the system operators have made in deciding how much land to irrigate; and therefore what RWS to aim for in supplying some fraction of the demand. This is particularly so since only a few of the schemes operated anywhere near 100 percent cropping intensity during either season (Table 4.1). One of the more important questions that emerges from this concept is why cropping intensities are not higher in either or both seasons. It would be reasonable to expect system operators should be to lower the RWS by expanding irrigated area in order to increase the benefits stemming from the irrigation system.

The results on Table 4.2 reveals that all schemes got adequate water to meet the minimum demand of RWS = 0.8 during summer 1990. During the winter 1991 season, only one scheme, Bangure, did not get adequate water. Eleven schemes out of the twelve achieved RWS = 1.2, indicating that the supply exceeded the minimum requirement by 20 percent.

Table 4.3 summarises the weighted[2] adequacy levels of water supply per scheme type. The scheme types are based on management type (as discussed in Chapter 1), and conveyance system (pump or gravity).

Table 4.3 shows that:

- During the summer 1990 season water inadequacy occurred only in pump schemes with RWS value of 0.69. On average in the winter 1991 season, all scheme types got adequate water;

- For each scheme type, the summer season received a lower RWS than the winter season. The seasonal difference in RWS was significant at 1 percent significance level;

- During the summer 1990 season, RWS for pump and gravity schemes average of 0.69 and 1.62, respectively. Thus, the gravity schemes got relatively more water compared with pump schemes;

- During the winter 1991 season, both pump and gravity schemes got adequate water but the gravity systems averaged a higher RWS (2.26) than pump schemes (1.51);

- The pump schemes on average achieved a RWS value of less than 0.8, indicating inadequacy of water supply in summer. During winter, all scheme types achieved RWS > 0.8;

- When comparing Agritex schemes (RWS = 1.36) and community schemes (RWS = 0.85) during summer 1990, it is clear that community schemes performed better by taking a decision to irrigate the maximum area possible with the water available thereby achieving the minimum acceptable RWS limit under similar cropping intensity level to Agritex schemes; and

- Pump schemes are more susceptible to receiving inadequate water than gravity scheme. The difference between pump and gravity schemes was significant at the 1 percent significance level.

Reliability of Water Supply

If daily measurements of irrigation water and rainfall are available, then RWS can be calculated for specific periods during the season. For the purpose of estimating reliability levels, RWS indices were computed for every 10-day period throughout the two seasons under study. The reliability index is defined as the number of 10 day periods (decades) when RWS is equal to or greater than 0.8 divided by the number of decades in the season, expressed as a percentage. Table 4.3 gives the reliability estimates per scheme type. The nature of water supplies for scheme types under study can be more clearly defined with this type of analysis. A RWS value simply indicates some level of adequacy for the season, but a high RWS does not necessarily go together with a high reliability estimate. This indicates that the reliability estimate gives additional information to the RWS index regarding the nature of water supply. Adequate supply for the season does not necessarily imply high reliability levels.

The reliability estimates given in Table 4.3 show that the winter season 1991 had more reliable water supply than summer 1990. This seasonal difference was significant at the 5 percent significance level. The difference between community and Agritex schemes was not statistically significant even though the former scheme type had a slightly higher reliability level than the latter. Gravity schemes had more reliable supply than pump schemes and this difference was significant at the 5 percent significance level. This is a result of pump breakdowns reported by farmers and the manner in which the pumps were operated. The pumps were run by the Department of Water Development and yet the schemes are managed by Agritex. This division of responsibilities caused problems whereby the pump attendant would not appreciate the need to supply the right amount of water at the right time. Water delivery schedules were not always adhered to because the pump attendant, for example, would go to town to get his salary. This has changed now because the Department of Water Development is now under Agritex.

It has been demonstrated that RWS alone does not give a full picture of water supply performance. Likewise, reliability estimates give only part of the story regarding the "timing" of water deliveries. There was therefore a need to develop other indices that would provide more information on other aspects regarding timing of water deliveries. This brings us into the concept of timeliness, for which indices were developed.

TIMELINESS OF WATER SUPPLY

Timeliness means correspondence of water deliveries to crop needs. It can be considered on the basis of accuracy of fit between two time history curves (Rao, 1993). One curve represents the evapotranspiration needs of the crop throughout the season, while the other represents the actual deliveries of water. Researchers have not quite come up with a way to quantify this "accuracy of fit between the two time history curves." An attempt is made in this chapter to develop indices that quantify timeliness as defined above.

Timeliness Indices

The development of timeliness indices for water supply should consider certain important aspects. Firstly, what is it the index should express or measure? Should the main issue be how well the CWR was met or should attention also be given to the extent the supplied water was utilized by the crop? For instance, is a RWS of 0.7 and no decade receiving more than CWR a timely situation because no water was wasted under conditions of scarcity? Should the cases of over-supply of water be considered as poor timing and therefore be expressed in the timeliness indices?

The following indices were therefore developed with the above questions as guidelines:

$$t_1 = \frac{\sum_{i-1}^{n} U_i}{\sum_{i=1}^{n} C_i}$$

where:

S_i = water supply in decade i;
C_i = CWR in decade i;
$U_i = \text{Min}(S_i, C_i)$ or $U_i = C_i$ if $S_i > C_i$
or $U_i = S_i$ if $S_i < C_i$

The numerator ΣU_i in the above equation represents the amount of water which the crop received and utilized for all the decades in question. If supply is equal to or greater than demand in a particular decade, the crop would utilize only what it can consume -- that is c_i. In this case the supply will have been delivered on time. On the other hand, if supply is less than demand, then the crop uses what it will have received, which is the supply S_i. In this case the supply will not have been delivered on time to meet the demand.

Therefore,
t_1 is bounded by $0 < t_1 <= \min\{1, RWS\}$; and $t_1 = RWS$, if and only if, $S_i <= C_i$ for all decades.

Similarly,
$t_1 = 1$, if and only if, $S_i >= C_i$ for all decades.

This index is simply the fraction of the total demand that is satisfied by the water supply during the season under consideration in a timely fashion. For example, a value of $t_1 = 0.8$ explains that 80 percent of the demand was met on time by the supply delivered.

Another index that expresses the water utilized as a fraction of the total water supplied could be useful in supplying extra information regarding timeliness. This index t_3 can be expressed thus:

$$t_3 = \frac{\sum_{i=1}^{n} U_i}{\sum_{i=1}^{n} S_i}$$

Index t_3 could be defined as the water use efficiency (WUE). It expresses the water utilized as a fraction of the water supplied. Some levels of water wastage can be established whereby the supply exceeds the demand. For instance, a low value of t_3 would indicate some poor timeliness of supply whereby the water deliveries exceed the amount utilized by the crop. This denotes some level of water wastage in the system.

In developing the above indices by relating water supply to CWR for every 10-day period, it is assumed that soil moisture storage does not change from one 10-day period to the next. The hydrologic data collected in this study were limited to water supply in relation to CWR. The study covered 12 schemes and with such a big sample it was not logistically possible to monitor changes in soil moisture storage.

However, a case study approach could be used to look into such detail whereby the soil moisture regime is also monitored and timeliness indices determined in view of the level of moisture available in the soil. This would fine tune the indices developed here.

Comparative Analysis on Timeliness of Supply

The computations for the above indices t_1 and t_3 were carried out for all schemes under study. Table 4.4 shows the average timeliness indices obtained for each type of scheme per specific season.

The results on Table 4.4 reveal the following:

- The timeliness of supply as estimated by t_1 values was approximately the same in both community and Agritex schemes for each season in question. The seasonal difference was not statistically significant;

- A greater proportion of the water supplied to community schemes was utilized than in Agritex schemes for both summer 1990 and winter 1991 seasons. In other words, more water was wasted in Agritex than in community schemes as a result of poor timeliness. The seasonal differences were significant at the 5 percent significance levels in both seasons.

Table 4.5 summarizes the results on the comparative analysis for pump and gravity systems.

Results given in Table 4.5 reveal the following:

- The levels of timeliness of water supply as indicated by t_1 was slightly higher in gravity than in pump schemes during summer 1990. In winter 1991, the reverse occurred. In both seasons the difference between pump and gravity schemes was not statistically significant; and

- More water was wasted in gravity schemes than in pump schemes as a result of poor timeliness in both summer 1990 and winter 1991 seasons.

It is important to establish threshold levels of the index t_1. This can be done by collecting data for a long period of time and estimating threshold t_1 values by establishing some relationship between the indices and crop yields. Index $t_1 = 1.00$ denotes perfect timeliness of supply, in which supply is greater than or equal to CWR in all 10-day periods. Index $t_1 < 1.00$ denotes that timeliness of supply was not perfect. Therefore, decreasing values of t_1 from the reference point of 1.00 are indicative of worsening situations of timeliness of supply.

Furthermore, interpretation of t_1 should be done together with t_3. Index $t_1 = 1.00$ is not necessarily portraying the best usage of the water supplied. Index t_3 expresses the water utilized by the crop as a percentage of the supply. Therefore, the ideal situation is where both t_1 and t_3 are equal to 1.00. This situation denotes perfect timeliness and no water wastage.

From the foregoing discussion it should be noted that none of the schemes achieved the ideal situation of both t_1 and $t_3 = 1.00$. In fact, in a few individual cases where timeliness was perfect ($t_1 = 1.00$), the t_3 value was quite low. This denotes that perfect timeliness of supply was achieved at the expense of high water wastage.

The indices presented quantify adequacy and reliability of water supply, timeliness of supply and water wastage based on hydrologic measurements. To get a reasonably balanced picture regarding overall performance of the schemes, the observations made by both farmers and management will be considered.

FARMER ASSERTIONS ON WATER SUPPLY PERFORMANCE

Monitoring the perception of water users and managers on adequacy, reliability, and timeliness of water supply is another practical approach to assessing performance. The percentage of farmers satisfied with the service can give valuable insights into water supply performance. Farmers were asked to give their opinion on whether the water supply in summer 1990 season was good or poor. Some 71 percent of the farmers asserted that the season was bad; and 29 percent asserted that the season was good. Table 4.6 gives a breakdown of the farmers' views per scheme type.

Table 4.6 shows that in all scheme types the majority of farmers interviewed indicated that water supply during summer 1990 was poor. The 71 percent of the sample farmers who reported a poor 1990 summer season were asked to give reasons for the poor water supply. The reasons given fell into 3 categories namely: drought; poor infrastructure; and poor farmer organization. Drought was mentioned by 40 percent of the sample respondents. Poor infrastructure was blamed by 25 percent of the sample farmers. Examples of poor infrastructure were given as pump breakdown (9 percent); unlined canals (10 percent); siltation (6 percent). Poor farmer organization was cited by 5 percent of the sample farmers.

With respect to reliability of water supply, farmers were asked whether there were times when they could not get water when they needed it. The results are summarized in Table 4.7.

In all scheme types, more than 80 percent of the respondents indicated that there were times when water was not available when they needed it. This is indicative of some level of poor reliability of supply across all scheme types. This assertion by farmers reinforces the results obtained in the water requirement analysis (Table 4.3) where reliability estimates ranged from 20 to 64 percent of the time during summer 1990. Furthermore, the asserted poor reliability of supply disrupts the rotational system of water distribution among farmers, leading to poor timeliness. The t_i values were less than 1.00 in all scheme types (Tables 4.4 and 4.5) in both summer and winter seasons.

In a postal survey covering all Agritex irrigation personnel, respondents were also asked to give the main causes of poor water supply during the past two seasons (1988/89). They responded as indicated in Table 4.8.

The majority of respondents (53) attributed poor water supply to non-availability of water at the source due to poor rains. This was compounded by reduced storage capacity and water losses due to siltation and poor irrigation infrastructure, respectively. This indicates that even though the water might have been available at source, there was a range of factors which contributed to inadequate water deliveries to farmers' fields.

When asked to give three reasons in order of priority, drought scored the second highest frequency as the top reason. Poor infrastructure scored the highest frequency as a reason for poor water supply; and reduced storage capacity due to siltation scored the third highest frequency as a reason.

The reasons for poor water supply given by Agritex personnel seem to be the same as those given by the farmers. Poor rains and poor infrastructure have been mentioned by both farmers and management as major contributory factors to poor water supply.

The farmers were also probed to give their views on whether immediate action was taken to solve water shortages caused by poor infrastructure and poor farmer managerial ability. A total of 155 observations were recorded and 63 percent of these reported that no immediate action was taken to solve the problem. Again, the majority of Agritex personnel (69 respondents out of 107) confirmed that no immediate action is taken to address the water management problems encountered in the schemes. This is an indication that slow reaction to the water shortage problem did contribute to poor water supply reliability. When asked what the responsible authorities say regarding poor water supply, 77 percent of the respondents indicated that no response was forthcoming from the authorities. Therefore, with no immediate action taken to address causes of poor water supply, coupled with no response from responsible authorities, a situation of very low level of water supply reliability prevailed even though water might have been available at source.

CONCLUSIONS

RWS as a measure of water supply adequacy provides information about levels of system physical and operation control and perhaps operational effort expended. RWS also reveals much about the operational decisions taken by both farmers and management regarding the area to be irrigated for the season under consideration. This is the most significant contribution of the RWS concept.

The explanatory power of RWS can be enhanced by interpreting it in conjunction with reliability estimates. The reliability estimates improve performance assessment by estimating the percentage of the season during which water was adequate. The addition of the timeliness index further improve performance assessment by estimating the percentage of CWR that was promptly satisfied by the water supply during the season under consideration. Therefore, water supply delivery performance levels can be quantified on the basis of the indices presented in this chapter. Both the indices, and farmer and system managers' perceptions of supply patterns have been used as indicators of performance. However, the two types of indicators can be used in such a way that the operators' knowledge of system constraints reinforces the results from water measurement in explaining performance.

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ENDNOTES

1. All significance tests reported in this chapter were carried out using the Analysis of Variance (ANOVA) Statistic.

2. The adequacy levels were weighted by the number of schemes in each scheme category.