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WATER DELIVERY PERFORMANCE OF SECONDARY CANALS IN TERMS OF ADEQUACY AND WATER USE EFFICIENCY IN SINDH PAKISTAN

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ABSTRACT

This study determines the water delivery performance and evaluation of secondary canals of the Nara Canal, situated in southern province of Pakistan. Hydraulic data such as water levels and discharge measurements were collected for four consecutive seasons (02 Rabi and 02 Kharif seasons) during 2014 and 2015. The data was collected through gauge readings installed at head, middle and tail reaches on weekly basis. The gauge readings were converted to flow rates by time to time calibration of these gauges. Simultaneously, the primary hydraulic data was collected from Sindh Irrigation and Drainage Authority (SIDA) offices. Results show that Bareji, Belharo and Mirpur distributaries were providing averagely less discharge during six, four and four months round a year, respectively. However, in the remaining months the water supply either remained as per design or in excess. Water delivery performance was 'good' in August, 2014 and 'fair' in June and July, 2014, while for the rest of the months of 2014 and 2015 were rated as 'poor'. Study revealed that water use efficiency was higher at head reaches, equitable at middle reaches and inadequate at tail reaches during both the years. As a result of consistent over flows at head reaches the tail reaches always suffer especially when distributaries flow at a lesser rate than their designed discharges. In order to increase the performance of irrigation system, there is need to minimize system's conveyance losses and improve water application efficiency. This could be done through proper management and water distribution plans at tertiary canal levels. There is need to continuously monitor and measure the water diverted to the secondary canals and make sure that water approaches at middle and tail reaches.

Keywords: current metering, distributaries, equitable distributaries, gauge calibration

INTRODUCTION

About 60% of the total diverted fresh water is lost in the conveyance systems. It is not utilized by agriculture and does not contribute in crop production. This huge

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amount of water is lost in the system due to seepage, leakage, poor maintenance and control, inefficient irrigation management and distribution, pitiable application methods and on-farm water management practices, etc. However, in some cases, this lost water contributes the underground water resources and is recovered and reused for irrigation purposes in the downstream reaches. Agriculture consumes about 80% of freshwater in many under developed countries. These countries are considered as the utmost disorganized water users. According to Plusquellec (2009) the freshwater resources are shrinking and expansion of irrigation systems is declining, there is need to improve the performance of existing irrigation systems. The performance could be improved by removing paucities in the management systems in a holistic manner. Performance of irrigated agriculture is a very complex subject. Different sets of indicators are required to assess performance of the system at different levels depending on their objectives. For example, the operational performance of the system depends on the degree of contentment of a precise computed output target, indicated by indicators like yield, water use efficiency and cropping intensity, or a specific input target such as discharge, water level or timing of water deliveries. Hydraulic performance of an irrigation system refers that how much it is adequate to convey water to different locations? How efficiently it delivers and distributes irrigation water on spatial and temporal scales. Hydraulic performance of a system is measured against a set criterion, for which some indicators are established. These indicators include adequacy, operational efficiency, equity, reliability, timeliness; delivery performance ratio (DPR), as suggested by a large number of researchers (Molden *et al.,* 1998; Tariq *et al.,* 2004; Unal *et al.,* 2004). Information on discharge measurements can be used to calculate various performance indices, such as an efficiency; a term from which comparative evaluations can be made for different years and among other irrigation systems.

The performance assessment of irrigation systems must deal with operational assessment that provides required information to system managers and enable them to manage and operate the system (Bos *et al.,* 2005). The performance of an integrated irrigation system can be judged by several indicators such as water productivity, reliable supply and equity in water distribution within a canal command. Large irrigation command areas, mostly suffer from inequitable water distribution and mismanagement in canal operation (Guar *et al.,* 2008). Several other factors such as soil, climate, system design, institutional capacity, operation and maintenance also affect the irrigation performance (Bolaños *et al.,* 2011).

In this study two water delivery performance indicators, namely adequacy and efficiency were used. These indicators were evaluated for selected distributaries.

METHODOLOGY

Description of the study area

Study was conducted on three secondary canals (distributaries) i.e; Bareji, Mirpur, and Belharo distributaries. These distributaries were randomly selected on Nara Canal command in Mirpurkhas sub-division. Some important details of these distributaries are given in Table 1.

Table 1. Salient features of distributaries and minors

Patent channel	Distributary/ minor	Off-take (RD)	Design discharge (cfs)	CCA (acres)
Jamrao canal	Mirpurkhas	343	64.0	16815
East branch	Barejo distry	408	41.50	14032
West branch	Belharo minor	143	54.78	17124

Collection of hydraulic data

Hydraulic data on water levels and discharge measurements were collected for four seasons (i.e. 02 Rabi and 02 Kharif seasons) during 2014 and 2015. The data on water levels were collected using gauge readings installed at head, middle and tail reaches on weekly basis. The gauges were calibrated periodically and gauge readings were converted into flows rates. Synchronized primary hydraulic data was also collected from Sindh Irrigation and Drainage Authority (SIDA) / Area Water Board offices.

Installation and calibration of gauges

Iron gauges were installed on permanent cemented structures located at head; middle and tail reaches of the distributaries. The gauges were calibrated after each de-silting activity if occurs else after every six monthly season. Flow measurements were taken using a current meter near each calibrated gauge section in the distributary.

Calibration of a gauge structure determines the relationship between water depths versus corresponding flow rates measured in a selected section. An empirical equation for the different depths and corresponding flow rates could then be developed as described by Molden and Gates (1990) in equation (i).

$$Q = KD^{n} \qquad \text{(i)}$$

Where,
Q = total discharge, cfs.
K = constant (varied with the difference of gauge bottom and average bed elevation of that section of the canal), and
D = the average flow depth and n is exponent (feet)
Water delivery performance indicators

A time period of four seasons (02 Rabi and 02 Kharif seasons) was fixed for two consecutively years i.e., 2014 and 2015. It is mathematically described by Molden and Gates (1990) equation (ii):

$$P_A = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum RP_A\right) \qquad \text{(ii)}$$

Where,
P_A = suitability indicator aggregated over a region R and time T,
P_a = a ratio of delivered to required (designed) flows at a point (reach).

Efficiency indicator of an irrigation system implies how a system efficiently utilizes water and in fact it is contrary to adequacy indicator (relative delivery).

$$P_F = \frac{1}{T}\sum_T\left(\frac{1}{A}\sum AP_F\right) \quad \text{(iii).}$$

Where,
P_F, are efficiency, indicators,
P_f is a ratio of required (designed) to delivered flows at an off take, T is time, and A is Area.

Table 2. Performance standards for water delivery performance indicators suggested by Molden and Gates (1990)

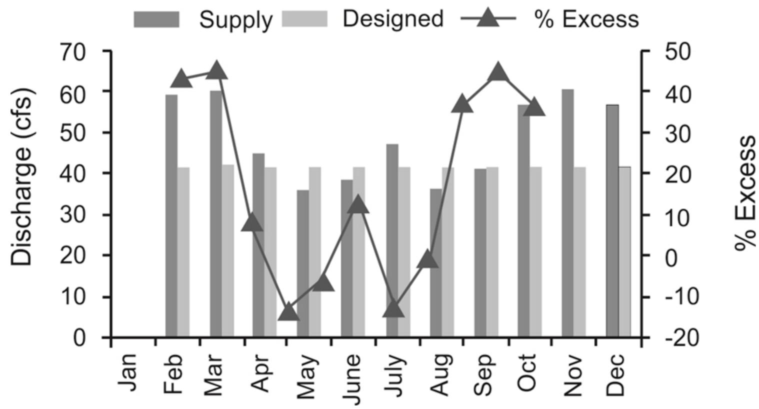
Indicator	Good	Fair	Poor
P_F	< 0.80	0.80-0.89	≥ 0.90
P_f	< 0.70	0.70-0.84	≥ 0.85

RESULTS

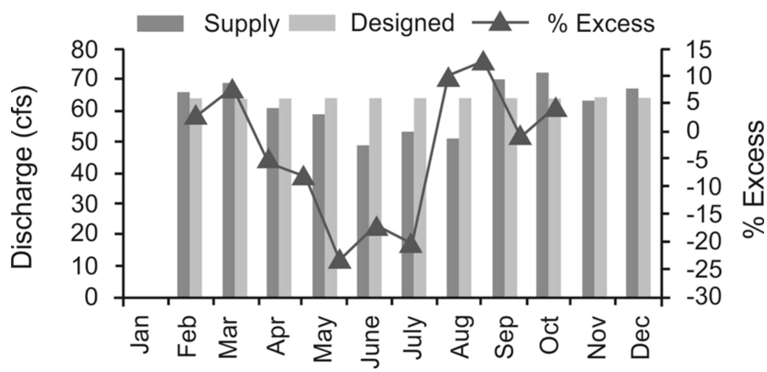
Irrigation supply and demand

Irrigation supplies were measured on weekly basis using a graduated staff gauge (Q-h). The measurements were taken at fixed locations of the bank, at the head, middle and tail reaches of the distributaries. Based on weekly observations, monthly average discharges for 4 seasons of 2 consecutive years are illustrated in Figure 1. Water deliveries in the irrigation systems remain closed for about 21 days each year during the month of January for annual maintenance. Also, there are rotational closures as well, which are not fixed. However, these are scheduled on irrigation water availability at the head of main canal. Figure 1 shows monthly irrigation supply, designed discharge along with excess supply on all the distributaries. Results show that out of eleven months Bareji distributary received less supply of water during May, June and August as compared to its designed discharge while, during rest of the months water supply remained as per design or in excess. Almost similar trends were observed at Mirpur and Belharo distributaries. Mirpur distributary was under supplied during the months of April, May, June, July and August, while during rest of the months of the year water supply remained as per design or in excess. Similarly, Belharo distributary received less supply during May, June, July and August whereas, it received supplies as per design or in excess during rest of the months of the year. The data reveals that cotton is grown during May to October; hence water supply may not meet its water requirements. Ultimately its production might be affected due to fewer water supplies in these distributaries.

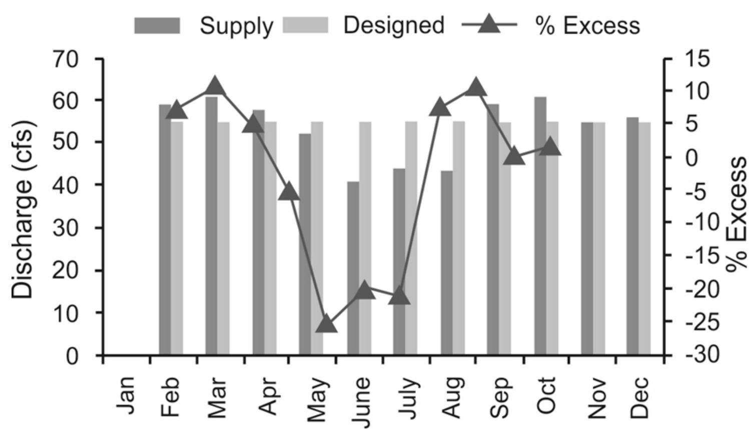
Spatial and temporal scales were used to determine the water delivery performance. The spatial indicators determine the water delivery performance at head, middle and tail reaches of the distributaries in its command area (A), while the temporal indicators are used to determine water delivery performance in time (T).



(a) Bareji distributary



(b) Mirpur distributary



(c) Belharo distributary

Figure 1. Monthly irrigation supply, demand and excess at all distributaries water delivery performance

Spatial performance indicators

To determine spatial performance, the indicators such as relative delivery, efficiency and equity were taken into account. The data in Figure 2 suggest that the average relative delivery values ranged between 0.79 and 1.25. The value of relative delivery below 1.0 indicates that distributaries were under supplied by about 24% while they were over supplied by 46%. During June, July and August all three distributaries received less supply. It was noted that the less supply was attributed to lower stage in the main canal as well. A continuous rotation policy was noticed in almost all distributaries during these months but the rotation was not judicially implemented. It could thus be adequately presumed that the delivery performance during these three months will define the lowest possible acceptability and hence will address the entire year. The observed delivery performances were compared to classification standards suggested by Molden and Gates (1990). It was observed that only August, 2014 was rated as 'good', June, July, 2014 were rated as 'fair' while rest of the months of 2014 and 2015 were rated as 'poor'. The monthly variations in relative delivery were significant, and can be attributed to mismanaged systems at distributaries level.

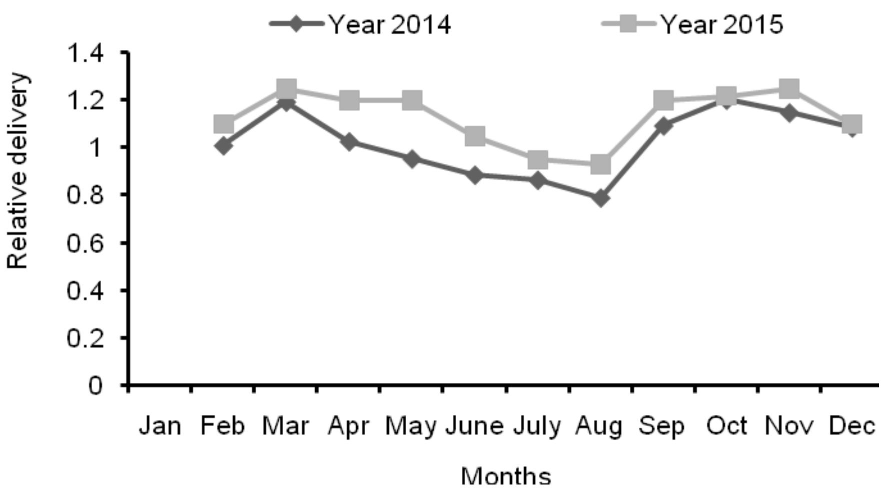


Figure 2. Spatially relative delivery indicator

The average relative deliveries at three reaches i.e. head, middle and tail are depicted in Figure 3 for the years 2014 and 2015. The water delivery reduces from head to tail reaches. The observed value of relative delivery indicates that the water delivery at the head reach was almost as per design for three to four months while it was higher for about seven to eight months. Whereas, at middle reach it progressively decreased to 0.8 and at tail reach it becomes 0.60. An increase in supply at head would improve water deliveries at the middle and the tail reaches.

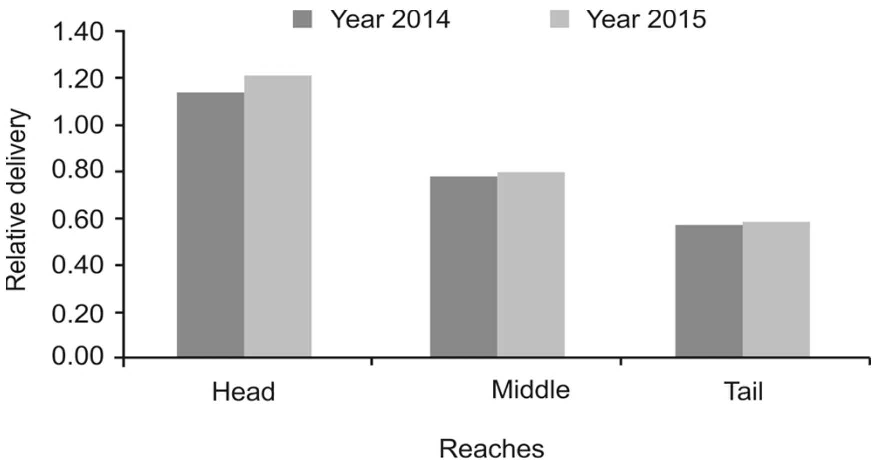
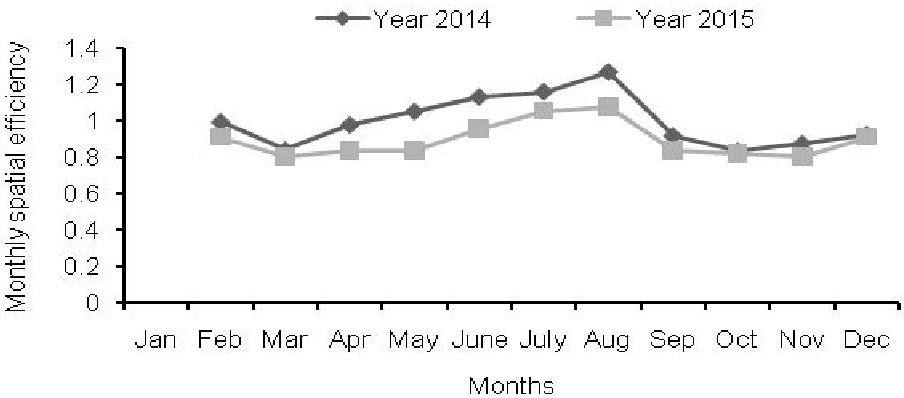
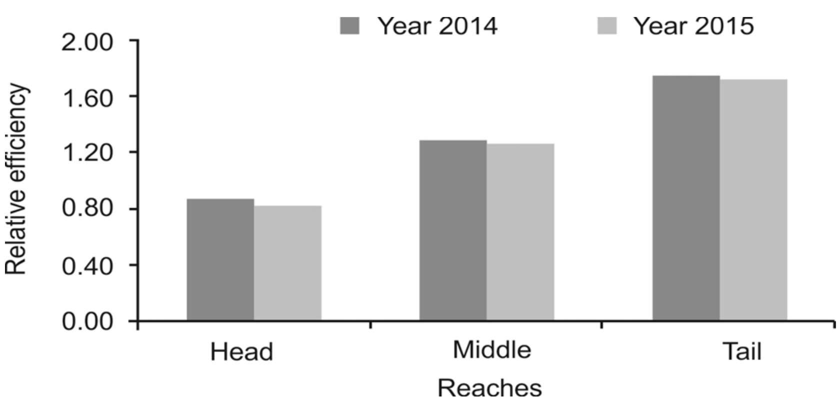


Figure 3. Reach wise relative delivery indicator



(a) Spatial efficiency indicator



(B) Reach wise efficiency indicator

Figure 4. Monthly spatial and reach wise efficiency indicators for 2014 and 2015.

The monthly spatial efficiency indicator was determined for two years and is illustrated in Figure 4 (a and b). The values show that the spatial efficiency of water application increases from April and reaches to maximum during August 2014, while it increases from June, attains maximum value during August 2015. However, it remained lower for all the remaining months of 2014 and 2015. The lowest efficiency of 0.80 was observed during months of March and November for 2014 and 2015. However, aggregated efficiency at head was about 0.80, while at middle reach it was 1.20 and at tail reaches its value was higher than 1.60. It could be concluded that the efficiency of water use at higher at head reach, whereas near to reasonable at middle reach and inadequate at tail reach during both the years.

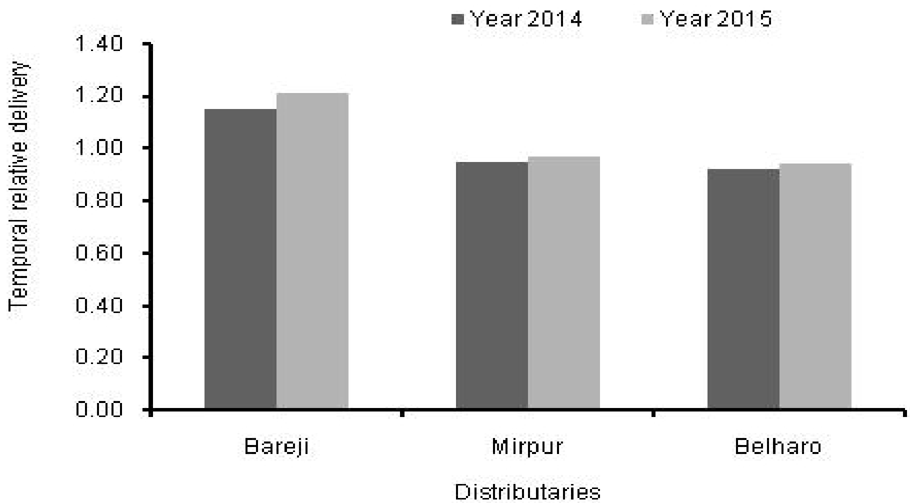


Figure 5. Temporal relative delivery

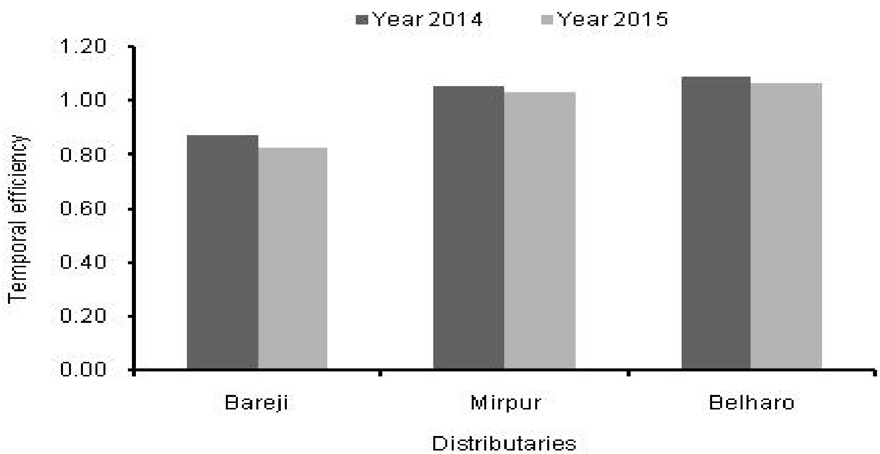


Figure 6. Temporal efficiency indicator

Temporal performance indicators

The temporal relative deliveries for individual distributary have been illustrated in Figure 6. A steady decrease in relative delivery values could be noted between head and tail reaches. The traditional postulation suggests that the gravity irrigation systems are more favorable to head reaches. This hypothesis for water delivery seems applicable in the cases of these three distributaries.

Temporally aggregated efficiency indicator for individual distributary is shown in Figure 6. The temporal efficiency indicators steadily increase in the downstream direction along the secondary canal.

Overall water delivery indicators

The overall water delivery indicators for the years 2014 and 2015 are shown in Table 3. Data reveal that the relative deliveries averaged over the year, the overall efficiency and PF is poor. This shows that the water supplied to each distributary was in excess but it is not distributed judicially among the end users. All these delivery indicators suggest that system is not functioning properly and need proper attention so that its efficacy could be improved.

Table 3. Overall water delivery indicators at three distributaries

Year	PA	PF
2014	1.02	0.99
2015	1.131	0.89

DISCUSSION

Water shortage is main limitation to agricultural production thus there is a need to improve overall performance of irrigation schemes. Proper and sensible use of available water in a system is need of time to resolve the issue of water shortages. This study determines the hydraulic performance and evaluation of secondary canal levels of the Nara Canal, situated in southern province of Pakistan. Results show that Bareji, Belharo and Mirpur distributaries were under supplied for four to six months during a year. However, in the remaining months the supply remains in according to design or in excess. According to classification of Molden and Gates (1990) only Aug, 2014 was rated as ‘good’, June and July, 2014 were rated as ‘fair’ while, the remaining months of the years 2014 and 2015 were rated as ‘poor’. Efficiency of water use was high at head reach, whereas it was near to reasonable at middle reach and inadequate at tail reach during both years. As a result of consistent over flow than the designed at head and middle reaches, tail reaches suffers specially during months with minimum flows.The relative deliveries averaged over the year, the overall efficiency and PF was poor. This shows that the water supplied to each distributary was in excess but it was not distributed wisely among the end users. Likewise, the equity of water supplied in the system was rated as ‘poor’ so that the reliability was also rated as ‘poor’. Almost similar results were reported by Mangrio *et al.* (2013); they suggested that in Jamrao sub-division, there is a serious need to improve the system’s performance and water supplying agencies should pay attention to provide designed share to each distributary and minor. In a previous study conducted at Kalpani distributary Murray Rust and Halsema (1998) observed similar results through a performance evaluation study. According to them, the outlets located at the upper reaches along the distributaries were drawing more share as compared to proportional share than those located at lower ends, regardless of the inflow conditions.

CONCLUSION

The existing irrigation water management at Bareji, Belharo and Mirpur distributaries is poor. For their long term sustainability, water distribution, equity, adequacy, water use efficiency and water saving, continuous monitoring and mantenance of distributries is required. There are times during the year, when water supply is in surplus and much portion of that is used at head reach that ultimately increases waterlogging and salinity. The relative deliveries averaged over the year, the overall efficiency and PF was poor. The water supplied to each distributary was in excess but it was not distributed wisely among the end users. Multi-sectoral water demands in the area are intensifying and putting more pressure on water demands. The increasing water demands dictate large scale development of irrigation systems to meet rising domestic and industrial water needs.

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