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Rehabilitation of canal irrigation schemes in India: a qualitative analysis

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ABSTRACT

The article describes a brief history of canal irrigation development and rehabilitation measures taken up in the past. The processes leading to deterioration in the condition of canal irrigation systems, necessitating rehabilitation, have been described. Based on a survey of several irrigation commands in different agro-climatic zones, the problems in aged irrigation projects are presented. The purpose is to identify the technical and non-technical factors limiting the performance of canal irrigation systems. Regarding rehabilitation of canal irrigation systems, several policy issues have been raised and discussed. The importance of the issues raised pertaining to canal rehabilitation and the solutions have also been discussed in this article.

Key words: Canal, Canal operation, Irrigation, Rehabilitation, Soil properties

HIGHLIGHTS

- Canals have been an effective source of irrigation for several centuries in India, given its unique monsoon weather conditions.
- Old canal systems face several challenges due to poor design, technical defects, demand -supply mismatch, hydrological alterations, malfunctioning of flow control structures, and poor irrigation efficiencies.
- The pre-rehabilitation performance evaluation is necessary to obtain the current status of the under-performing canal irrigation systems.
- When there were physical constraints to improve the system performance, condition assessment was required.
- The condition assessment of irrigation schemes is helpful for identifying the factors which limit the performance of irrigation schemes.

1. INTRODUCTION

Geographically, the availability of land suitable for cultivation and the natural availability of water for watering crops in the mutual vicinity is not universally present in India (GOI, 1999). Therefore, in most instances, water has to be brought from distant localities to places that are agriculturally productive, and arable land is available in plenty. India has a long history of irrigated agriculture and canal irrigation has been an important form of irrigation from time immemorial. Also, it is cheaper. It is a well-established fact supported by the archeological evidence that irrigation in some form or other was in practice from the early civilization. The ancient Indian religious texts have mentioned that irrigation practices are followed from prehistoric times. The Harappan irrigation system was one of the architectural feats.

The Grand Anicut on the river Kavery constructed by Chola Kings nearly 2000 years ago, and the Vijaynagarum Canal system from Tungabhadra River, constructed about 500 years ago during the Vijayanagar Empire and renovated by the British Empire, are still in use.

Canals have been an effective source of irrigation in areas of low-level relief, deep fertile soils, a perennial source of water, and extensive command areas. After Independence, governments during various plan periods consistently focused on the development of large irrigation schemes for national food sovereignty. According to water and related statistics in 2021, there are 829 major and medium irrigation schemes. However, with the flux of time, the condition of the canal infrastructure deteriorated. The main factors behind the rapid decline in canal irrigation across India were the poor performance of surface irrigation systems, market failures, failure of participation of irrigation communities, and failure of public-sector agencies to deliver irrigation water (Bjornlund *et al*., 2020). The focus of irrigation development agencies changed to rehabilitation of existing old deteriorated projects rather than the development of new irrigation projects. The major international funding agencies like the World Bank, Asian Development Bank (ADB), etc., are now largely involved in financing programmes of rehabilitation of irrigation schemes (Kumar *et al*., 2022) rather than with new construction.

Large-scale investments worth several billions of dollars are made every year in many developing countries to rehabilitate irrigation schemes under donor-funded projects, with a large amount of the money actually spent on 'canal lining' with the assumption that a lot of freshwater would be saved through this action (Perry *et al*., 2017). The Tamil Nadu Irrigated Agriculture Modernization Project Phases I and II, both funded by the World Bank for a total amount of US$ 968.55 million (World Bank, n.d.); the Andhra Pradesh Water Sector Improvement Project funded by the World Bank for US$450 million (World Bank, 2010); the West Bengal Minor Irrigation & Flood Management Project funded by the World Bank for US$145 million (World Bank, 2020); and the ADB-Funded Madhya Pradesh Irrigation Efficiency Improvement project for US$375 million (Asian Development Bank, n.d.) are just a few examples.

Rehabilitation entails the reconstruction or restoration of irrigation and drainage facilities to their original design. It can also include the expansion of service areas and the provision of additional structures like flow control structures, drainage systems, on-farm facilities, and service roads (Sinha *et al*., 2019; Kumar, 2021). However, over a period of time, irrigation practices have evolved with rehabilitation measures taken up from time to time based on practical experiences and requirements.

2. CANAL IRRIGATION DEVELOPMENT: HISTORICAL PERSPECTIVE

In the history of canal irrigation, the first known ruler to introduce an irrigation canal system in India, as well as rehabilitation works, was Firoz Shah Tughlaq. He built the biggest network of the canal. During his reign, canals were constructed to supply water for the newly founded city of Hissar-i-Firoza, in 1355. He also renovated the Prithviraj Chauhan era's Western Yamuna Canal, to provide irrigation water. Emperor Shahjahan (1627–58 AD) constructed a new canal from Khizrabad to Safidon (from Karnal to Hissar) and also rehabilitated the canal built during the period of Akbar. However, the canal soon silted and stopped flowing. Ali Mardan Khan renovated the Western Yamuna Canal system to provide water to the royal palace. To have a dependable water supply, the Yamuna Canal system was integrated with another canal system from Sirmaur hills. It is presently located on the Delhi border near Najafgarh. The new canal system was given the name Ali Mardan canal system. The renovated canal system also received the diverted waters of the Sahibi river basin. During the British rule of India, canal irrigation was encouraged initially to find sources for more revenue. The British efforts to develop canal systems in India began in 1817. The efforts mainly included the rehabilitation of the older Mughal works as part of early construction activities. Vijayanagar channels which were constructed during the Vijayanagar Empire in South India were renovated by the British around this time. In 1830, the

Eastern Yamuna Canal was operationalized and monitored for the return on investment, by looking at the revenue flows. The observation indicated a gain of 23% on the capital invested in it (Whitcombe, 1971). Canal engineers were very hopeful about their motives at that time. Sir Proby Cautley, who visualized and supervised the construction of the Upper Ganga Canal, commented on the rehabilitation of Mughal canals and acknowledged that had the engineers of those days not been assured of the increase in the revenue they would never have built the canal systems (Cautley, 1860). Soon after the annexation of Punjab, the construction of a Canal irrigation system was begun. The perceived need to extend the agricultural settlements to less fertile lands compelled the people to contribute and co-operate among themselves for irrigation development. Subsequently, it led to the emergence of larger irrigation projects in the form of reservoirs for water storage and the construction of canals for supplying water to agricultural lands.

Nearly half of the 16.597 million ha of the land was irrigated by canals in India during 2008–09, out of which about half is located in the Northern plain. The statewise distribution of canal irrigated land is as follows: 91.72% irrigated area in Jammu and Kashmir, 66.24% in Chhattisgarh, 64.7% in Odisha, 44.28% in Haryana and 34.63% in Andhra Pradesh. The maximum irrigated area is in Uttar Pradesh, while other states accounting for considerable canal irrigation are Madhya Pradesh, Andhra Pradesh, Haryana, Punjab and Bihar (Josh, 2016). However, the total irrigated area came down to 157.2 lakh ha. in 2017–19.

3. PROBLEMS OF CANAL IRRIGATION SYSTEMS

Myriad technical and non-technical problems surface during the process of rehabilitation of irrigation canals. After the commissioning of an irrigation scheme, a number of problems and defects in the system appear during the short term as well as during the long term. A survey of irrigation system rehabilitation projects taken up in the states of Uttar Pradesh, Rajasthan, Punjab, Haryana, Madhya Pradesh, Odisha, Andhra Pradesh, and Karnataka, have led to the identification of the following problems.

3.1. Initial design shortcomings

Over-estimation of the catchment yield and over-design of the scheme is a major issue in many Indian irrigation projects. Examples are the schemes in the semi-arid and arid parts of the states such as Gujarat, Maharashtra, and Rajasthan. Based upon these estimations, the irrigation duty and culturable command area are decided. During actual operation, the design parameters do not synchronise with the irrigation demand of the crops grown in the command of the irrigation schemes. For the optimum control of water flow, timely delivery of irrigation water in the desired quantity, and necessity for ease of operation is felt for additional structures like cross regulators, etc. For shortcomings of initial technical design, the following may have to be considered: (a) the carrying capacity of the canals inadequate to deliver the required amount of water; (b) under-estimation of the seepage losses from the unlined canals system; (c) absence of cross drainage; (d) inadequate cross drainage; (e) mismatch in design discharge of different sections of the canals insufficient flow head for delivery of design discharge from the outlets; (f) absence of escape with sufficient capacity at proper locations; (g) absence of water measuring structures/devices; and (h) absence of control structures like Cross Regulator is also a problem.

3.2. Defects due to aging of irrigation system

(a) The conveyance structures as well as regulatory structures of canal irrigation systems gradually lose their original functional capabilities as an aging effect. The problems are exaggerated due to poor maintenance of the canal irrigation system as a whole. Besides poor maintenance, the natural processes such as erosion of embankments, scouring, silting, and rusting of steel components like irrigation gates, etc. add to such problems. Defects arising from aging irrigation systems can be seen in (a) erosion of canal banks or embankment; (b) silting up of canals,

reducing the carrying capacity; (c) scouring of canals; (d) partial or complete damage of canal lining; (e) defective functioning of control gates; (f) changes in flow and depth characteristics of flow regime of the canal system; (g) loss of discharge carrying capacity; (h) longitudinal slope variations; (i) reduced water levels at the outlet points; (j) existence of undesirable head at flow control structures/locations; (k) expiry of the working life of the mechanical components of flow control devices; and (l) deteriorated condition of the water control structure.

3.3. Operational problems

The ease of operation of various components of the irrigation canal system and public convenience is an important factor after the completion of the construction and its operation. The social, political, or agricultural systems may be different from the assumed ones at the time of designing the system or may have changed since the time the irrigation infrastructure was built. During the rehabilitation of canals, several operational problems may arise such as (a) felt need for bridges; (b) requirement for cross drainage works; (c) faulty operation of water control structures; (d) lack of synchronization of the water demands with water release through canals; (e) the manner in which the water flow in a canal reaches a steady-state flow condition; and (f) lack of equitable distribution of water among the beneficiaries.

3.4. Problems of hydrological changes

During the operation of canal irrigation systems, some hydrological changes as listed below may take place. These changes generate new problems which were absent before the implementation of the canal irrigation system. In the wake of widespread rural electrification, availability of assured electric supply, and favourable hydrogeological conditions, exploitation of groundwater may take place on a large scale in canal command areas and such phenomena can reduce the water demand and canal water needs to be diverted to irrigate additional areas. The hydrological changes necessitate attention to: (a) Heavy seepage losses from canals causing an excessive rise in groundwater levels leading to salinity and waterlogging problems. (b) Increased conjunctive use of groundwater. (c) Effect of climate change on consumptive use of crops.

3.5. Demand and supply related problems

The canal network should be capable to supply irrigation water as crops demand every part of the command. The problem arises when due to economic considerations, or due to some other considerations, there is a shift in the crop rotation. Some of the demand and supply like: (a) Inefficient water conveyance and delivery of water during the crop-growing period. (b) Inequitable distribution of water. (c) Excess water uses for irrigating the crops. (d) Extensive problems of waterlogging and salt build-up. (e) Major changes in cropping pattern over time, resulting in changes in the aggregate water demand and demand pattern. (f) Growing concern for ‘equity’ and ‘adequacy’ in the water supply. (g) Shortcomings in timeliness, and reliability all over the command.

3.6. Malfunctioning of flow control structure

Continuous uses of the Flow Control Structure for long periods result in the loss of water flow control. The metal components are rusted and also lose their designed shapes. Depending upon the extent of damage these are to be repaired or replaced. The problems of malfunctioning of flow control structure may be related to: (a) Control of upstream water supply as well as constant downstream depth control. (b) Location-based variation of the differences of water levels between canal side and outside water level in the field channel. (c) Requirement of re-fixing and modifying the outlets for the canal system. (d) Absence of field channels. (e) Inappropriate method of on-farm water application such as flood irrigation, causing excessive runoff and lateral and vertical drainage problems in humid & high rainfall areas.

3.7. Manual interventions

The irrigation canal network systems sometimes is damaged by miscreants who want to draw water in an unauthorized manner. One of the main challenges facing large-scale irrigation schemes is infrastructure maintenance. When canal systems are maintained properly and used correctly, they can enhance farmers' access to water during different seasons in order to allow for several crops to be planted per year. Some of the problems caused due to manual interventions are: (a) Damage to the flow control structures by some farmers who indulge in the pilferage of water. (b) Poor maintenance of canal networks. (c) Unauthorized outlets for water withdrawal. (d) Inequity in the distribution of water among farmers under the same outlet and among outlets.

3.8. Low irrigation efficiencies

With reduced supply and increased demand for low water irrigation efficiencies cannot be afforded. Generally, there is not enough water to absorb the inefficiencies. The cost of inaction in rehabilitating or upgrading canal infrastructure to improve irrigation efficiencies may prove far higher in the long run than the cost of action. Problems to be addressed for low irrigation efficiencies are: (a) Low water conveyance, and distribution efficiency. (b) Development of land for improvement of irrigation efficiencies. (c) Need to provide new outlets or replacement of existing outlet points at changed locations.

4. ANALYSIS AND FINDINGS

Most of the canal irrigation projects in India are decades and in some cases centuries old. Canal irrigation schemes developed with mammoth expenditure deteriorate with time and slowly fail to provide and distribute the irrigation water as per requirements. These issues brought about the necessity of canal rehabilitation. There can be exploratory studies to find the possibility of improving the performance of canal irrigation systems without rehabilitation such as shifting to groundwater exploitation through tube well irrigation. In the past, irrigation systems were designed for a much lower level of irrigation requirements than the increased demand of the present day. When the condition of the canal system deteriorates to the extent that it is unable to serve its basic purpose and also loses its economic advantages envisaged at the time of construction, then rehabilitation of such canal systems becomes mandatory (Cornish & Skutsch, 1997). In addition to the changes in circumstances over time, the original design standards may no longer be appropriate. Rehabilitation provides the opportunity to review original assumptions and make changes as necessary. During such reviews, both technical and non-technical factors are given due weightage. The technical factor covers all engineering aspects related to the infrastructure of the canal system and non-technical factors cover mainly operational aspects of the system. The reduction in hydrological performance is considered the ostensible cause of declining agricultural outputs from the irrigated area. High crop yields and an increase in area coverage indicate that the system is performing satisfactorily (Kumar, 2021).

However, lower values of performance do not necessarily indicate that the hydraulic performance is unsatisfactory and that the infrastructure, therefore, needs to be restored. This is because reliable figures on the cropped area are difficult to obtain, and water from the source which the scheme taps are being diverted to other uses (urban water supply, rural water supply, industrial water supply) (Kumar *et al.*, 2022). Quoted areas are often the nominal commands and therefore show no variation between years. Lands that theoretically lie outside the project may benefit from the project water supply, while areas within the project, particularly in the tail regions, may be inadequately served. Many other factors may reduce yield and irrigated area, including, for example, a reduction in the water supply at source; crop losses due to pests and diseases; diminished soil fertility; erratic weather conditions; alternative uses of the land, etc. It is therefore difficult to make meaningful correlations between water supply and yield within localized areas.

Investments in modernizing aged irrigation infrastructure are key to enhancing water security for irrigated agriculture. However, the outcomes of such investments are insufficiently understood, potentially limiting the future planning of interventions (Sinha *et al*., 2019). The basic issue with the rehabilitation of any existing irrigation canal is related to the question 'when should any system be considered for rehabilitation work?' The answer is not straightforward because irrigation schemes are complex systems. Besides technical factors and engineering considerations, the performance of a canal irrigation system is influenced by many other factors such as canal operations, socio-economic factors, environmental factors, and agronomic factors (Perry, 2007). Factors are often interlinked, so causes and effects may not be explained easily.

To produce the anticipated improvement in the performance of canal irrigation systems, the effect of a few factors is such that they also affect the performance in multiple manners while for others it can be in an isolation manner. It is not possible to establish that all components of the canal irrigation system required to produce an expected improvement in performance can be ranked together. According to the prevailing circumstances the institutional, social, and economic factors influencing the performance of a canal irrigation scheme may play a greater role in affecting the scheme output than the technical factors. Investment in the professional development of project managers, systems operators, farmers, and contractors through training programmes will also be very effective for the benefits of the irrigation scheme. But still, such examples of intensive managerial training for canal operations are the exception, rather than the rule. Lack of operational experience among staff running large-scale surface irrigation systems results in weakening the efficiency of canal irrigation due to poor data collection and ineffective management of the systems. Unfortunately, the relative importance of the various constraints may not be readily apparent. For large irrigation projects, if one is able to identify a factor that acts as a major factor limiting the scheme's performance significantly, then depending upon nature and approximate magnitude of the resulting problem, the scheme can be short-listed for rehabilitation, and in this situation it should be ensured that the economic returns to rehabilitation investments are largely favourable. When the need for any specific component of the canal irrigation system is established then it should be selected for a programme of rehabilitation. However, when the canal had poor water flow and high levels of water loss as a result of the varying width and height of accumulated earth banks in the canal bed, coupled with a porous and seeping bed and embankment in several parts of the canal, then it should be considered for a rehabilitation works. The priority among projects is also considered according to their strategic importance and the area served. Depending on available funding, such works can be considered for inclusion under a rehabilitation programme.

Performance assessment of irrigation and drainage infrastructure involves systematic observation, documentation, and interpretation of the management of an irrigation and drainage system, with the objective of ensuring that the infrastructure provides for the basic needs of irrigation (Jameel & Qureshi, 2012). When there are prima facie observations for any canal irrigation scheme about the felt needs of rehabilitation then its pre-rehabilitation performance evaluation will be helpful to confirm further actions. A checklist has been presented describing the factors which potentially may limit the canal irrigation scheme performance. Besides the proposed checklist, the opinion of the farm beneficiaries regarding system constraints and priority needs is also important. This will be helpful for identifying the underlying causes of apparent constraints. The decision as to whether to renovate or improve can be taken only when the reasons for declining performance have been clearly identified. External indications of underperformance or perceived defects are due to a number of interlinked causes. From the perceived defects the causes can be grouped into six broad categories, viz., agriculture, economics, system design operation, system deterioration, and head works and supply. Guidelines for the performance evaluation of irrigation projects have been prepared by the Central Water Commission of India (CWC, 2002). These guidelines suggested by the Central Water Commission consist of an evaluation of project hydrology and project performance on the five attributes, viz., physical performance of the irrigation scheme,

economic performance, management performance, environmental and ecological performance, and socio-economic and agro-economic performance (CWC, 2002).

Several forms of inefficiencies in irrigation projects are observed with the passage of time. In several cases, the deterioration in the physical components of the canal irrigation system occurs to such an extent that they fail to perform their intended function. In such situations, large investments become inevitable to bring them back to a stage where they can perform normal day-to-day functions. Subsequent to pre-rehabilitation performance evaluation (after it is confirmed that there were physical constraints to improving the irrigation system performance), a condition assessment is required to be undertaken (Mateos *et al*., 2010). Assessing the condition of irrigation schemes is helpful for identifying the factors that limit the performance of the schemes. The procedure can help determine whether rehabilitation could improve scheme output and/or what other measures may be required such as promoting conjunctive use of groundwater and surface water, or promotion of micro irrigation systems, or use of underground pipelines, etc. if the proposed project continues. The objectivity and consistency of condition assessment can be improved by: (1) identifying the factors which lead to schemes performing below expectations; (2) determining the condition and fitness of scheme components; and (3) establishing priorities for improvement. The condition assessment procedure provides a consistent basis for determining the fitness of an asset to perform its function. Two types of condition assessment of canal irrigation schemes are necessary. (1) The condition of individual scheme elements and their fitness for the safe intended function. This mainly concerns the physical condition of irrigation structures and their stability. It is very easy to identify the physical defects, but their removal may not necessarily solve problems of underperformance. The condition of eroded canal banks is such an example. (2) Function-based condition assessment is performed to know the capacity of the structures or elements required to perform their intended functions properly. The condition assessment allows a selected set of assets, identified on the basis of priority of need, to be included in a programme of rehabilitation. The priority projects can be assessed and updated through detailed investigations of their compatibility with local conditions Alternative design options can also be identified and assessed if required.

Before the implementation of rehabilitation works, some technical investigations are essential. These investigations might include soil investigations, topographic surveys, and hydrological & hydrogeological investigations. In addition to these investigations, the design statements of the existing canal system are required for preparing the technical plans for rehabilitation. In the past, many irrigation systems were designed for a much lower level of irrigation requirements than the demand of the present day, and further, their performance over time might have diminished. A good example is the Vijaya Nagara Channels, some of which are several centuries old, irrigating vast tracts of land in four districts of Karnataka. The farmers in the command area are currently growing water-intensive paddy, sugarcane, and banana replacing the traditional low-water-intensive cereals, leading to a water scarcity situation in many tail-end areas. The system is now under modernization. Rehabilitation and modernization activities of the irrigation system are planned (1) to make required corrections in deficient physical infrastructure in order to set it to the original design, (2) to modify the water distribution and delivery infrastructure for meeting the increased demand and better services, (3) to ensure timely, and equitable use of water, and (4) to improve the efficiency of the water conveyance. The canal rehabilitation works consume massive investments and there is a need for some fresh thinking to control and minimize the investment. The soil properties of canal command play an important role in re-engineering to be carried out for canal rehabilitation and modernization activities. The canal rehabilitation projects are more susceptible because of the high variability of soil properties. For such projects, as a matter of policy, the rehabilitation works, their locations, and their scale must be decided based on intensive soil investigations. The lining of canal reaches can be implemented in the stretches where the hydraulic conductivity of the underlying soil is high or the canal is running in embankments. The canal stretches in cutting or passing through impervious rocks need not be lined. The selection of

borrow pit should be made carefully where the moisture content is not more than the optimum moisture content. Due to poor erodibility, the steep slope should be treated for soil erosion. For all these measures intensive soil investigation must be adopted to decide on the appropriate rehabilitation activities so as to optimize the massive investment in canal rehabilitation projects.

Following the rehabilitation of a canal irrigation system, the management and operation of the system also become important and are to be considered for efficient water distribution and utilization (Kularam *et al.*, 2016). Inadequate operational practices may limit the water supply improvements expected from improved infrastructure. Poor operational control and on-farm water management could lead to excessive water wastage. Farmers must be able to exploit a better supply from the rehabilitated scheme. They may need training in irrigation water management and system maintenance. A formal or informal water users' group must exist to control and monitor the canal operations. The costs of a rehabilitation project must be justified either in the form of increased output through expansion in the cultivated area, in the form of improved yields on the existing command area, or both. In certain circumstances, rehabilitation must be able to sustain the additional demand created after the commissioning of the original irrigation scheme by maintaining the current levels of agricultural output. The gross irrigated area, crop yields (kg/ha), cropping intensity (gross cropped area/net sown area), and overall net income per unit cropped area (INR/ha) are widely seen as primary measures of system performance (Jagadeesan & Kumar, 2015). The water delivery in an irrigation command is an interplay of several factors including the operation of flow control structures as per the demand for irrigation water. In addition to irrigation other demands for water such as water for industrial use, and urban water supply requirements including water for drinking purposes, water for livestock, forestry, and wild animals are to be taken care of.

5. CONCLUSIONS

Current global debates on water security suggest that countries facing water security challenges should invest in physical infrastructure as well as institutions for water management to reduce water-related risks (Grey & Sadoff, 2007; Sadoff *et al.*, 2015). Along with new water sector investment, investments in modernizing aged irrigation infrastructure are key to enhancing water security for irrigated agriculture (Sinha *et al.*, 2019). Historically, the development of canal irrigation systems and their deterioration after serving for a limited period is a natural happening. Over the period of time, irrigation practices evolved with rehabilitation measures taken time-to-time based upon practical experiences. The main objective of rehabilitation remains taking corrective measures for the prime causes of scheme underperformance, rather than a complete overhaul of the system. This objective is achieved by planning canal rehabilitation activities. (1) to make required corrections in deficient physical canal infrastructure in order to set it to the original design, (2) to modify the canal infrastructure for increased demand and better services, (3) to ensure timely proper, and equitable use of water and (4) to improve the efficiency of the water used for irrigation. Regarding rehabilitation of canal irrigation systems, some major policy issues appear. The first major issue is regarding the necessity of canal rehabilitation. The possibility of improving the performance of canal irrigation systems without rehabilitation can also be explored. In a few cases, it is possible by shifting to groundwater use when hydrogeological conditions are favorable for tube well installations. When the condition of the canal system deteriorates and its economic advantages are lost, the rehabilitation of such canal systems becomes mandatory. Due to changed circumstances of water supply and additional water demand generated, the original design standards may no longer be relevant. Rehabilitation provides the opportunity to review original assumptions and make changes as necessary. An issue is also faced when prioritizing canal irrigation schemes for rehabilitation. Priority ranking is suggested on the basis of three factors: the condition of a component, the function of the area served, and a measure of the functional importance of the component. The pre-rehabilitation performance evaluation is also an issue to be considered to obtain the current

status of the under-performing canal irrigation systems. Once it is confirmed that there were physical constraints to improving the system performance, condition assessment is required. The condition assessment of irrigation schemes is helpful for identifying the factors which limit the performance of irrigation schemes.

The technical investigations for rehabilitation activities are other issues that need to be addressed properly. The canal rehabilitation projects are more susceptible because of the high variability of soil properties. For such projects as a policy the rehabilitation works, their locations and magnitude must be decided based upon the intensive soil investigations Lining of canal reaches can be implemented in local patches of length where the hydraulic conductivity of soil is high or the canal is running in embankments. The canal rehabilitation works consume massive investments and there is a need for judicious thinking to optimize the investments. The investments are made in components that give the highest returns with minimum negative (social and environmental) effects. Rational physical rehabilitation depends on the diagnosis of the condition of the infrastructure to determine its impact on the physical performance of the scheme. After identification of the key constraints on scheme performance, those constraints can be removed selectively. The costs of a rehabilitation project must be justified either by increasing output by expanding the cultivated area, or by raising the yield on the existing command area. In some circumstances, rehabilitation will be necessary to safeguard current levels of output.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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