MANAGING A LARGE IRRIGATION SYSTEM UNDER EMERGENCY CONDITIONS: HIRAKUD PROJECT CASE STUDY, INDIA

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ABSTRACT

In Hirakud, a multi-purpose project, in India, rice is grown over an area of 160,000 ha during the monsoon season (June to October). Supplementary irrigation of 100 mm in September and 150 mm in October is needed. Often, due to erratic monsoon and lean rainfall in September/October, supplementary irrigation of 150 mm to 200 mm per month is needed. The crucial supplementation for crop maturity occurs during September 25 to October 25, after which the demand tapers off.

On October 5, 1984, a normal monsoon year, an emergency situation occurred due to the collapse of the left upstream river wingwall (of 15-m height). The command area of 85,000 ha below the aqueduct was consequently deprived of irrigation when 50 % of the command area was in dire need of 5 to 7 cm of supplemental irrigation during flowering stage of the rice crop.

After the collapse of the wingwall, an appropriate canal operation strategy was developed and implemented to ensure supply of water during the rehabilitation period to selective and needy areas on a priority basis. By innovative rehabilitation technique, the structure was put into commission by October 25, 1984, when partial water supply was resumed through the structure. By farmers' participation, appropriate production practice demonstration, and ensuring rotational water supply matching with crop water need (FAO 24, 1977), almost 75,000 ha received satisfactory irrigation. In spite of the reduced water supply, the crop yield in the project area was 20 % more than the normal yield.

INTRODUCTION

Mahanadi, the largest river in the state of Orissa has been harnessed by building a dam at Hirakud (1957), intercepting 83000 sq. km of basin area. The multipurpose objectives served by the dam are: to moderate large flood inflows of 2 M Cusec to 1 M Cusec, the safe carrying capacity of the river at the head of the delta, 300 km downstream from the dam; to generate hydropower with an installed capacity of 270 MW (later augmented to 307 MW); and to provide

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irrigation to 159,000 ha with an annual cropping intensity of 165 %. Two main canals, Bargarh Canal on the right (capacity 115 m^3/sec to serve 135,000 ha), and Sason Canal on the left (capacity 20 m^3/sec to serve 24,000 ha) provide irrigation water to the command area.

The perennial power release of a minimum of 300 m^3/sec has been harnessed by a new weir built at the head of the delta. This has brought an additional (1967) 130,000 ha under irrigation in the 100 year-old Mahanadi delta command. The overall command of 0.3 M ha in the Mahanadi delta now has a cropping intensity of 150%. By using a multiple cropping pattern, the delta has been transformed from a poverty-stricken, food-deficient region into a prosperous food-surplus region. There has been a dramatic increase in the productivity of rice crop. The yield has increased from 1 ton/ha over 0.1 M ha in 1957 to 3 to 4 tons/ha in the monsoon (June-October), and 5 to 6 tons/ha in the summer (January-April) of 1998 over an area of 0.25 M ha. The yield is comparable to Southeast Asian countries adopting modern farming practices. The average farm income has gone up from Rs 500/ha (US $80) in 1957 to Rs 12000/ha (US $300) in 1998, primarily due to the introduction of irrigation.

COMMAND AREA CHARACTERISTICS AND THE CANAL SYSTEM

In the above context, the Bargarh main canal, a contour canal of 85 km, conveying 115 m^3/sec at the head of the project functions as a lifeline to 70,000 farming families spread over a command area of 135,000 ha. The contour canal is aligned in moderately deep-cutting and filling (10 to 12 m), and is provided with a large number of cross-drainage structures over major and medium drains. The terrain slopes down (1 in 300) from the main canal to the Mahanadi and the Ong rivers which form the boundary of the command (Figure 1). The soil types in the command vary from clayey silt (25%) to medium textured (40%), and light textured (35%). There are highly pervious patches close to the main river covering 5% of the command, where light duty crops are grown.

Four large rivers with catchment areas of up to 500 square km cross the main canal through major aqueducts with ventage varying from 150 to 250 m. These rivers have pervious alluvial material on the banks at the crossing sites. The canal generally runs in heavy fillings of 15 to 20 m over a 200 to 300 m stretch at the approach and exit of each aqueduct, where earthen banks are constructed, conforming to a stable earth dam profile, retaining water with a potential head of 10 to 15 m. The earthen conveyance section is flumed (up to 60%) to a reinforced concrete trough through transitions which are supported on abutments and piers. All the aqueducts undergo periodic inspection in addition to a detailed annual inspection during the summer closure (May/June) through a Safety Assurance Program (SAP). The first aqueduct is at the 30th kilometer of the main canal over the river Danta, below which the command area is 85,000 ha.

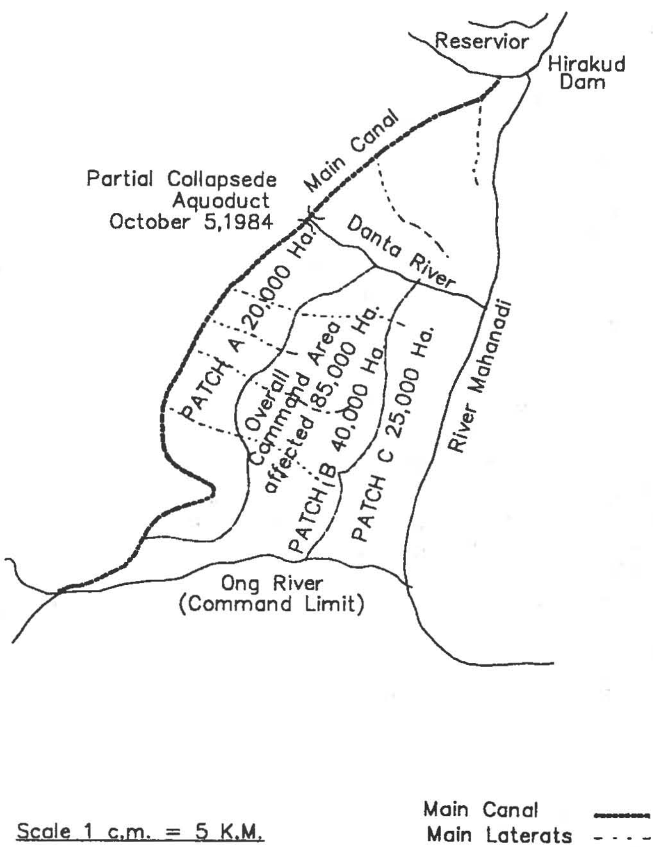

Figure 1. Index Map of Hirakud Canal System

STRUCTURAL DISTRESS/PARTIAL COLLAPSE OF THE DANTA AQUEDUCT

Structural Details

A normal trapezoidal channel with a bed width of 20 m is flumed to 12 m wide reinforced concrete boxed trough supported on end abutments and piers spanning 130 m of water way, corresponding to the bankful stage. The river spreads to 600 m during high flood that necessitates 200 m long, 15 m high earthen banks as approaches for entry and exit.

The river flows through the two 15 m high abutments of rubble masonry and each abutment is provided with two 50 m long training walls on the upstream and downstream. Each training wall slopes down from a height of 15 m at the junction of the abutment to 3 m at the toe of the canal bank at the river edge. The abutment and wing wall designed as retaining walls are supported on 12 m deep 3 m outer diameter wells with reinforced concrete steining. The wells were founded on firm incredible weathered rock/form clay. The well cap supporting the walls was only 2 to 3 m below the river bed which was erodable up to 8 m being of silt, fine sand to coarse sand. A 10-m wide and 1 m thick launching flexible rubble apron was provided against the wall to protect the foundation against scour.

Transition to the reinforced concrete trough was through canal wings of 20 m length on shallow foundation in firm ground that was rising slowly from the river edge. Essentially, the canal wings, river wings with well compacted earthen banks, which were lined with concrete on the canal section formed a seepage barrier against 15 m of hydraulic head (canal full supply level to river bed level). A creep length of 60 m was provided with the assumption that the river bed at the toe of abutment/wing wall will not erode dangerously (by provision of launching apron) to facilitate a piping path to develop. The river and canal wings were provided with 0.5 m thick filter backing with deep holes on the river wings for keeping the backfill unsaturated. A base width of only 0.3 to 0.4 height of the wall was considered adequate and was provided with the above assumption. Figure 2 details the aqueduct structure.

SEQUENCE OF EVENTS LEADING TO DISTRESS ON OCTOBER 5, 1998

Following 150 mm of rainfall between October 1, 1984 and October 5, 1984, a medium flood of 5 m depth occurred at the aqueduct, which led to 1 m subsidence of the apron over a 5-m diameter patch, protecting the left upstream wingwall. Some boiling was noticed. The distress that occurred from the evening of October 5, 1984, is detailed below:

- muddy water exited on the river bed at the boil area around 6 P.M., which within half an hour became a turbulent boil (about 10 m upstream from the junction of the wing wall and abutment)

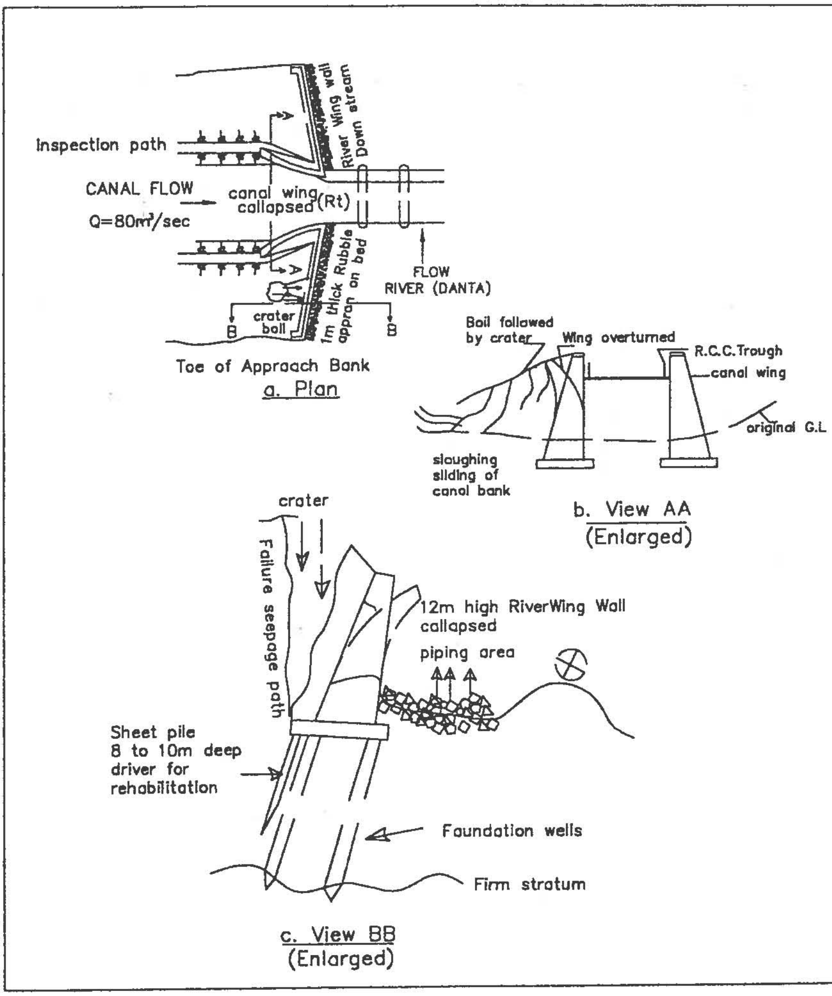

Figure 2. Partial Collapse of Danta Aquaduct

- sudden collapse of the earth slope between the right upstream canal wing and left upstream wing occurred over a 5 m diameter patch leading to a crater, through which water from the canal was flowing.

- a 10 m stretch of canal wingwall collapsed against the crater and 50 m^3/sec out of the canal discharge of 80 m^3/sec flowed out under and over the collapsed canal wing and exited under the river wing causing the protective rubble apron to move out over almost a 10 m stretch, with violent noise; the residual head at the boil location was almost 5 m.

- a large mass of saturated earth flowed from the crater adjacent to the canal wing and literally pushed a 20 m stretch of 10 m high river wing wall to overturn into the river, about 2 m above the well cap; all of this resulted in a substantial collapse of the right protective transition upstream of the trough, which remained firmly seated on the abutment. Figure 2 details the damages that occurred.

- the supply at the head of the main canal was closed by 7 P.M., following evidence of piping on the river bed, but the volume of water in the 30 km reach of main canal of 3 m depth continued to flow into the river, substantially aggravating the damage until 7 A.M. on October 6.

With 85,000 ha of command area below the aqueduct where crop needed supplementation of 5 cm to 10 cm for maturity, two crucial issues had to be addressed following this sudden disaster:

- managing water distribution below the aqueduct.
- rehabilitating the collapsed right upstream appurtenances at the earliest opportunity to resume supply.

A senior management group was assembled in the early morning of October 6, 1984, to work out a strategy to be implemented on war footing so that the aqueduct would become operational within 15 days to carry at least half of the original design supply.

WATER MANAGEMENT DOWNSTREAM FOLLOWING FAILURE

A management strategy was formulated with the objectives of:

- Increasing the chances of survival of the crop over as much of the command area of 85,000 ha as possible.
- assessing the crop water need realistically and ensuring supply for obtaining good yield at least over 80% of the command area.

Crop Survival

By noon on October 6, all regulating shutters on the main canal and laterals were fully closed to conserve and store water by forming a reservoir covering 1400 km of major and minor channels of varying width of 1 m to 20 m and depth of 0.5 m to 3 m. The stored water was assessed as 200 ha-m.

The cropped area needing irrigation, 80,000 ha as non-paddy, and early paddy over 5,000 ha, was maturing by October 10. The cropped area could be realistically delineated into three distinct patches as shown in Figure 1. Patch A: covering the head 30 % of the command, Patch B: covering the central 45% of the command, and Patch C: covering the tail 25% of the command. The crop condition over any patch was essentially the same, because of the transplanting dates that were staggered by 10 days from patch to patch.

In Patch A, a medium duration paddy (June 25 through October 10) was grown with better water availability, to enable growing a second pulse/oil seed crop (November-January) and a third summer paddy crop from January through May. In the central Patch B, 50% of the area (20,000 ha) was covered with medium paddy maturing by October 25 and the rest with long duration variety maturing between October 31 to November 5. A second crop of summer paddy (January—May) was grown over half of the command area along with pulses, oil seeds, and vegetables. Over Patch C, only 20% was covered with medium duration paddy maturing by November 10 and the rest by November 15 to 20.

Essentially, the irrigation need over the tail patch (where 30 to 40% is low clayey soil, supporting long duration), is felt up to October 31 in good and average years (monsoon rainfall 1000 to 1200 mm), and to November 7 in bad years (monsoon rainfall 800 to 900 mm). It is the erratic nature of the rainfall, particularly when the monsoon does not become active until the middle of July (transplantation need of 150 to 200 mm is substantially wet from monsoon) and when the monsoon recedes in early September when the balance crop water need is at least 200 mm (gross). Such situations call for extremely careful, rotational management by active participation of farmers.

WATER MANAGEMENT STRATEGY

The first task was to assess the realistic consumptive use for the paddy at/prior to maturity stage in each patch. The background information that was gathered revealed the following:

- 3 to 5 cm of water was ponded over 20,000 ha of Patch A.
- 1 to 2 cm of ponded water was available over 20,000 ha of Patch B (tail half) and the upper half of 20,000 ha had 2 o 3 cm ponded water.

- Patch C of 20,000 ha was just moist at field capacity and most of the pervious patches needed immediate watering.

The flowering and milk ripe stage of maturity has the highest ET need of 3 to 5 cm and any reduction of water would cause disproportionately large reduction in crop yield. Based upon the crop stage, the soil-water depletion, consumptive use and irrigation application quantity were decided as shown in Figures 3a, b, and c.

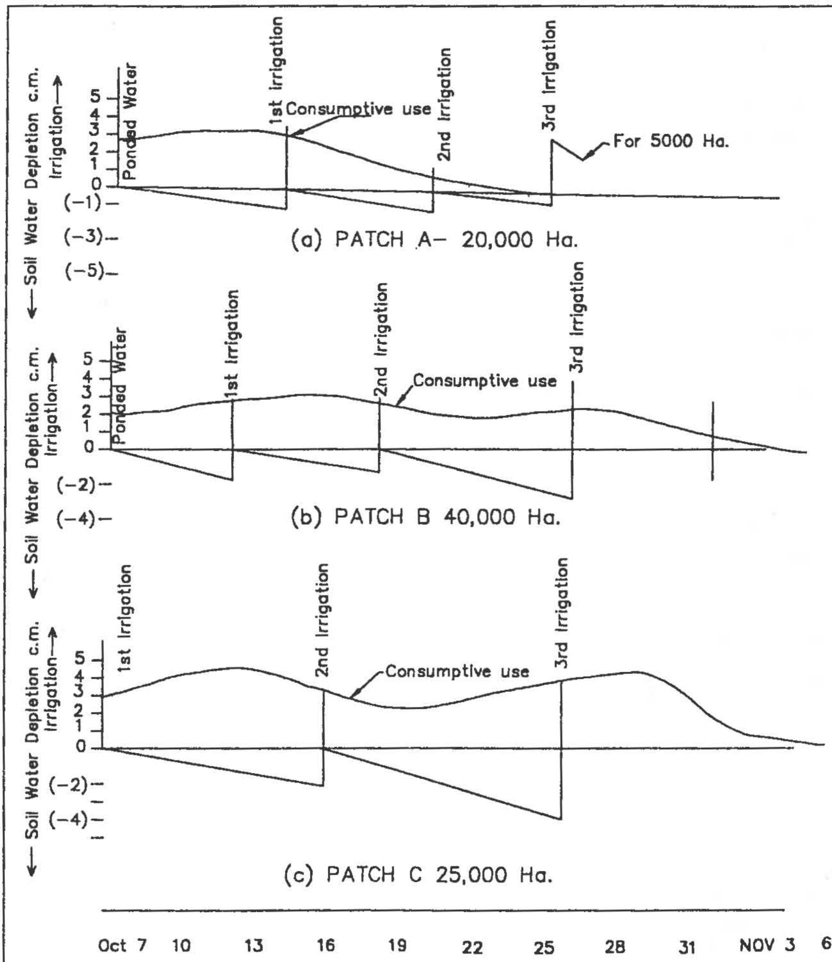

Figure 3. Schematic Description Between Soil-Water Depletion, Actual Irrigation and Crop Consumptive Use (Paddy)-October 7th through November 6

Water Management From October 7 Through 13

Because of availability of 4 cm of ponded water in Patch A, water supply was totally stopped to 20,000 ha. In Patch B, over the upper 20,000 ha with a minimum of 2 cm of ponded water, supply was shut off for 4 days (October 7 through 11). The lower 20,000 ha was provided with 2 cm between October 7 through 11).

In Patch C, the entire 20,000 ha was given 5 cm between October 7 through 13, with the objective of making the crop survive, but it became clear that over the absolute tail area of 5000 ha, the flowering just did not occur. Rainfall of 2 to 3 cm occurred over Patches B and C between October 10 through 15, helping irrigation management significantly.

Water Management From October 13 Through 20

By October 11th, almost the entire Patch A had no ponded water, but the root zone being at field capacity, 2 cm was supplemented to the upper and middle areas of 10,000 ha and only 1 cm was allowed to the lower 10,000 ha, starting from October 13.

For Patch B, in a staggered fashion, 2 cm was given to the upper 20,000 ha from October 13. For the lower 20,000 ha of Patch B and about 15,000 ha of Patch C water was allowed just to keep the surface wet, to prevent development of shrinking cracks. By October 20, the entire reservoir over the canal network dried up, but with the rainfall almost 40,000 ha in Patches A and B had minimal need (less than 1 cm as milk ripe stage was reached).

It was anticipated that by October 20, the partial rehabilitation would enable resumption of supply through the aqueduct, but another 5 days were needed for starting half supply. Even pushing 20 m^3/sec through the canal on October 21 did not succeed.

Between October 21 and 25, almost 5,000 ha out of the paddy coverage of 80,000 ha had totally withered, but the remaining 75,000 ha had healthy crop, of which the tail 30,000 ha was in immediate need of watering (flowering starting over 15,000 ha and the rest in milking stage).

Through an innovative rehabilitation strategy, the aqueduct became operational on the night of October 25 and almost 40 m^3/sec was pushed downstream on the morning of October 26. Between October 26 and November 10, a gross supplement of 150 mm was given to 40,000 ha in the tail and 50 mm to needy patches, which successfully met the crop water need of 75,000 ha of paddy crop by and large. The key favorable factors were:

- cloudy skies reduced evaporation loss
- no water was allowed to spill to the draining channels, which normally carry 10 to 15% of the overall discharge.
- farmers were constantly guided by agriculture extension service officials on application of fertilizers (before flowering) and not to pond up more than 1 centimeter or so to reduce deep percolation loss.
- the assurance that was given that this structure would be rehabilitated in 10 to 15 days did materialize.

REHABILITATION TECHNIQUE: IMMEDIATE AND LONG-TERM

Immediate Remedial Works

As the canal wingwalls and the river training walls with rubble apron at the river bed were the main barriers against uncontrolled seepage, their restoration above the firm broken surface was considered emergent. But a trial barrier just upstream of the river wing by steel sheet piles driven to clay with a capping beam was considered an essential appurtenance. The sequence of activities were:

- de-watering and drying the scoured bed over 50 m x 70 m of 10 to 12 m depth to rebuild the walls and retaining bank; excavating and banking the slushy material (5000 m^3)—October 7 through 11.

- re-building the collapsed stretches of canal wingwall (20 m long) and upstream river training wall (15 m long) with reinforced concrete wall by buttressed support; prosper keys were introduced into the old edges—October 9 through 20.

- driving 8 to 10 m deep steel sheet pile over 20 m length just upstream of the well cap to cover the broken zone of river wingwall; large pieces of rubble masonry from the broken canal wingwall moved 30 m and were blocking the pile path; the pile line was, however, taken to rest on hard clay/weathered rock to prevent any possibility of soil movement in between the foundation wells; the sheet piles were capped by a reinforced concrete beam which was tied to the well cap—October 10 through 15·

- clayey soil was compacted below optimum moisture content in 0.15 m thick layers between the reconstructed canal and river wingwalls, pneumatically tamped in 0.05-m thick layers (foundation of canal and river wing junction of sheet pile)—October 10 through 23.

- a well-designed 1 m thick filter layer was laid at the back of the river wing along with weep hole to safely drain any seepage water—October 20 through 24.

- the displaced rubble apron on the river bed was thoroughly cleared and a 5 m wide, 1 m thick graded rubble apron was added to ensure safe exit gradient to seepage and also safety against scour during high floods—October 20 to 24.

All these activities were carried out continuously over three shifts a day for 18 days, supervised by 10 senior executives.

Long-Term Remedial Works

A critical analysis of the failure revealed that uncontrolled piping led to the failure, but the failure of both canal and river wings were due to inadequate section to retain the over-saturated soil mass as a gravity structure. The base width of 0.3 to 0.4 of height of surcharge was certainly inadequate. The basic assumption of dry backfill, assuming satisfactory functioning of this filter backfill provided was deficient. Further, in order to ensure a safe seepage path for the large head difference between the canal full supply level and the river bed level. It was decided to extend the reinforced concrete trough section by 70 m upstream, where the canal bank is only 5 m in height. The extension of the reinforced concrete trough supported on piles was carried by underwater technique, deploying barges on the running canal. The canal supplied irrigation, industrial and drinking water throughout the year. The short-term remedial works (October 1984) cost Rs 4 M, and the long-term (1985-1986) cost Rs 15 M, against the original structure cost of Rs 1 M (1955-1957).

WATER USE AND YIELD

Against a normal supplementation of 0.40 to 0.45 m (400-450 mm) in average and bad years, the overall supplementation in 1984 was only 0.34 m over the command area of 75,000 ha below the aqueduct.

To assess the impact of deficit irrigation supply (anxiety was shown by the farmers), detailed crop yield data was collected over 189 villages. It came as a surprise that, over 150 villages (65,000 ha), the yield on the average was 3.2 T/ha against 2.5 to 2.7 T/ha recorded between 1960 to 1983. The reason attributed by the Directorate of Agriculture, Orissa, was that better aeration of the crop root zone (due to drying of soil) resulted in full filling of the grain and reduced the chaff to a minimum.

LESSON LEARNED AND CONCLUSION

Danta Aqueduct, a major hydraulic structure, on an 80 m^3/sec canal collapsed due to scour, subsidence, and failure of masonry wingwalls protecting the high approach bank, and functioning as transition from earthen trapezoidal section to reinforced concrete trough section. Uncontrolled seepage occurred from a high hydraulic head of 15 m between the canal full supply level and the river bed level.

Analysis and investigation revealed the need for a longer approach transition and stronger section against overturning and tension for the retaining walls. River bed scour at the abutment and wingwall toe needed critical attention and treatment as well as constant surveillance for sustainable safety of such hydraulic structures.

Careful and participatory water management resulted in near optimal crop yield even for the emergent situation that resulted in 18 days of canal closure. For the command area that receives year round irrigation and with watertable 4 to 5 m below, 15% less supplementation did not affect crop yield.

Note: The first author functioned as a superintendent engineer in-charge of operation of the system (1981-1987) and was directly responsible for the restoration work. The second author is an International Training Consultant for the World Bank assisted Water Resources Consolidation Project in the State of Orissa.