MODERNIZING SARDA SAHAYAK CANAL SYSTEM:
THE MASSCOTE APPROACH

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ABSTRACT

Mapping system and services of canal management, operation and maintenance aims (a) to enable decision makers, before engaging in investment plans, to ensure that diagnosis and solutions are investigated properly in irrigation modernization projects (through a rapid appraisal procedure); and (b) to suggest some specific strategies on how one should make the best use of the modernization investment made currently (mapping system and services for canal operation techniques).

On the basis of analysis carried out through a Food and Agriculture Organization (FAO) and Uttar Pradesh Irrigation Department (UPID) training workshop on 7–19 December 2007 for the Jaunpur Branch Canal (JBC) system of the Sarda Sahayak Irrigation Scheme, this paper describes what more needs to be done for modernizing irrigation management in JBC and in other command areas of the state. Some suggestions are: (i) recycling water through shallow wells in the area close to the canal to reduce waterlogging; (ii) formation of a federation of Water Users Associations (WUA) to reduce the cost of operation; (iii) installation of more cross-regulators in the branch canal to run the canal at the designed full supply level; (iv) installation of modular gates for distributaries and minors; (v) periodic calibration of measurement structures; and (vi) modernization of inner and outer cross-sections of the canal to attain their water-carrying capacity. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: canal operation; modernization; irrigation management; performance assessment

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RÉSUMÉ

La cartographie d’un système de canal et de sa gestion, exploitation et maintenance visent à (a) permettre aux décideurs, avant de s’engager dans des plans d’investissement, de veiller à ce que le diagnostic et les solutions soient bien étudiées en vue des projets de modernisation de l’irrigation (avec la procédure d’évaluation rapide), (b) proposer des stratégies spécifiques pour tirer le meilleur parti des investissements de modernisation réalisés (Techniques de cartographie et services pour la gestion de canal).

Sur la base de l’analyse effectuée au cours d’un atelier de formation mené par la FAO et le département irrigation d’Uttar Pradesh UPID du 7 au 19 décembre 2007 pour le canal Jaunpur (JBC) dans le système de Sarda Sahayak, cet article décrit ce qui doit être fait pour moderniser la gestion de l’irrigation à JBC et dans d’autres zones de l’État. Voici quelques-unes des suggestions: (i) le recyclage de l’eau par des puits dans la zone proche du canal d’eau afin de réduire l’engorgement, (ii) la création de la fédération des associations d’usagers pour réduire les coûts de fonctionnement, (iii) l’installation de régulateurs transversaux supplémentaires pour gérer le canal à son niveau de service maximum, (iv) l’installation de modules en tête des secondaires, (v) l’étalonnage périodique des structures

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1Modernisation du système du canal Sarda Sahayak avec l’approche MASSCOTE
SARDA SAHAYAK CANAL SYSTEM (SSCS)

Himalayan River Ghagbra (known as Karnali in Nepal) water was transferred by construction of the Girija Barrage downstream of the Indo-Nepal border at Girijapuri (Behraich) 9 km downstream Katraniaghat through a link canal, 28.70 km long and with a discharge capacity of 480 m$^3$s$^{-1}$. The Lower Sarda Barrage was constructed at Sardanagar (Lakhimpur-Kheri) on the Sarda River (known as Mahakali in Nepal) 180 km downstream of the Banbasa Barrage (constructed upstream on the Sarda River to divert water for the Sarda Canal system as far back as 1926) to receive Ghagbra water and transfer this water through the 680 m$^3$s$^{-1}$ capacity and 258.80 km long Sarda Sahayak Feeder Canal. A T-diagram of the feeder system is shown in Figure 1. Under the SSCS, a 1378 km long branch canal, 14 684 km long distributaries and minors were constructed (some of the old existing canal system of Sarda was modernized and became part of the SSCS) to provide irrigation water for 1.655 Mha of central and eastern Uttar Pradesh with irrigation intensity 115%. Construction of 17 752 km drains to mitigate waterlogging and lining of the feeder channel to reduce seepage was completed in various phases. The project was begun in 1968–1969 and completed by 2000. The cost of the project was Rs. 6629 ha$^{-1}$ (1 Rs. = US $0.0223, average over 2000) whereas the cash inflow was of the order Rs. 15 000 ha$^{-1}$ and internal rate of return (IRR) was 14% (Water and Land Management Institute (WALMI), 2005).

The following operational problems were encountered:

- Heavy siltation reduces the canal capacity. On average (2000–2004), a silt load of about 6.99 million cubic metres (MCM) enters the feeder channel downstream of the silt ejector.
- Actual irrigation never reached the design irrigation level of 1.93 Mha. Hardly half of the cultural command area (CCA) is being served. The highest irrigated area reported so far has been 0.892 Mha (1994–1995).
- Silt ejector: the Sarda Sahayak Feeder Canal is not a general canal flowing on the watershed. It crosses many small and large nalas (drainage streams)/rivers, 41 drains and rivers, of which 39 are siphoned and for the rest two aqueducts were constructed (on Gomti and Sai). Escapes at Ull and Chauka have been constructed to desilt the canal at head reaches.
- The bottom slope of the canal is 0.091 m km$^{-1}$, which reduces the silt-carrying capacity of the canal during the monsoon season. To reduce silt, silt excluders at Sarda Barrage bay nos. 19 and 20 and in the feeder canal at 0.3 km have been constructed. They are not functioning well, and fine silt remains in suspension.
- For efficient working of a silt ejector a differential head of 0.4–0.5 m is required, which is not always available. The regulation order of the Sarda Barrage advises closing the feeder canal when the Sarda River discharge reaches 4530 m$^3$s$^{-1}$ because above this discharge the silt ejector stops functioning. It has been reported that even if Sarda River flow is 1557 m$^3$s$^{-1}$, the silt ejector does not function. Perhaps due to shifting of the main stream to the left side of the river and to siltation on the right side, the river bed is raised (Irrigation Department, Uttar Pradesh, 2003).
- Due to closing of the ejector function, siltation tendency in the feeder canal increases and, owing to heavy silt, the feeder canal used to be closed during the monsoon.

The Uttar Pradesh Water Sector Restructuring Project (UPWSRP), financed with a loan of US $150 million by the International Development Association (IDA), envisages reforms in management of state water resources in general and irrigation, drainage and groundwater systems in particular. As a pilot project area the Haidergarh–

\[11\text{Rs. = 0.0223 US$ average over 2000.}\]
Jaunpur Branch Canal (HJBC) sub-basin has been selected to initiate reforms, which will then be replicated on the larger Ghaghra–Gomti basin, spread over 8 Mha. Project interventions are:

- creation of water institutional structures and building multi-sectoral water resources management capacity;
- irrigation department reform and capacity building;
- piloting reforms options for irrigation and drainage operations;
- piloting reforms options in water resources management.

Reliability and equity of public irrigation service is a critical issue as it is a basic service that is very important to food security. Therefore confidence in the system, feeling of ownership and concern for improved productivity of land and water require a lot more work and attention. This paper presents the investigation for the Jaunpur Branch Canal (JBC) system.
DESCRIPTION OF PILOT PROJECT AREA

The Haidergarh Branch, serving as carrier for the Jaunpur Branch System, takes off from the left bank of the main feeder canal at its 171.5 km. The head discharge capacity of the Haidergarh Branch is 163.5 m$^3$ s$^{-1}$ and is designed to run on a full supply level (FSL) of 3.0 m on head. Jaunpur Branch takes off from the Haidergarh Branch at 22.98 km and has been designed to run on FSL 3.5 m on head, having a discharge capacity of 123.2 m$^3$ s$^{-1}$. The salient features of the Haidergarh Branch Canal–Jaunpur Branch Canal (HBC-JBC) are given in Table I and a pictorial view is shown in Figure 2.

**Issues**

HBC-JBC never runs at the designed head of 3.0 m and 3.5 m, respectively, as can be seen in Figure 3 (State Water Resources Agency (SWaRA), 2009). Sedimentation load in HBC-JBC has been estimated at 1.66 MCM. Its disposal is a significant environmental concern. The development of a silt disposal policy is required, with full precautions to protect the natural drainage system and promotion of vegetation in the drainage basin, rather than merely dumping in lowland or wasteland areas.

Table I. Salient features of pilot project area of Uttar Pradesh Water Sector Restructuring Project (UPWSRP)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross command area (Mha)</td>
<td>0.585</td>
</tr>
<tr>
<td>Culturable command area (Mha)</td>
<td>0.323</td>
</tr>
<tr>
<td>Branch canal – HBC and JBC (no./length in km)</td>
<td>2/143</td>
</tr>
<tr>
<td>Distributaries (no./length in km)</td>
<td>31/857</td>
</tr>
<tr>
<td>Minors (no./length in km)</td>
<td>421/2462</td>
</tr>
<tr>
<td>Off-takes (outlets) on minors</td>
<td>4679</td>
</tr>
<tr>
<td>Direct outlets on branch and distributary</td>
<td>3665</td>
</tr>
<tr>
<td>Drainage system (no./length in km)</td>
<td>38/2502</td>
</tr>
</tbody>
</table>

Figure 2. HBC-JBC sub-basin pilot project area of Sarda Sahayak irrigation system, showing distributaries command area. This figure is available in colour online at www.interscience.wiley.com/journal/ird
TAHAL Consulting Engineers Ltd, Israel, redesigned the irrigation and drainage system of JBC (TAHAL Consulting Engineers Ltd, 2005). They proposed the construction of a silt ejector on the head of the HBC, cross-regulators at 44.2, 56.153, 67.00 and 97.43 km of JBC, 41 duckbill weirs in distributaries of JBC, check drops of 0.3–1 m depending on slope available and bed profile changes at 8558 places. About 480 gated structures on the head of minors, 8048 semi-modular outlets (off-takes), rehabilitation of internal and external canal sections involving earthworks in 2412 km were proposed at a cost of Rs. 1452 million. Similarly, for the construction of drains, earthworks of 2460 km, 421 Pucca works and 4,373 bed profiles at a cost of Rs. 477.8 million have been proposed. Modernization works were in progress at the time of the MASSCOTE training workshop, but pre modernization values are taken here so that this study may become a benchmark for the pre-project situation.

MASSCOTE TRAINING WORKSHOP

The objectives of the MASSCOTE training workshop were:

- to produce some insights into the management of JBC, to assess performance and suggest improvements;
- to increase skill regarding techniques, modern approaches to management and operation;
- to produce recommendations for follow-up irrigation modernization development plans.

Methodology

The evaluation of current processes and performance of irrigation systems and the development of a project for modernization of canal operation includes the activities of irrigation management: services to users; cost of producing the service; performance monitoring and evaluation; constraints and opportunities on water resources; constraints and opportunities of the physical systems. MASSCOTE has the following aims:
• mapping system characteristics in the water context;
• delineating manageable subunits;
• defining the strategy for service and operation of each unit;
• aggregating and consolidating canal operation strategy at the main system level.

MASSCOTE is an iterative process based on 10 successive steps (Renault et al., 2007).*

Step 1: Rapid Appraisal Procedure (RAP) in JBC

Objective. The objective was to identify the key factors related to water control, measurement and communications in the system as well as social organizations.

External indicators. The external indicators compare input and output of an irrigation system to describe overall performance. These indicators are expressions of various forms of efficiency, for example water use efficiency, crop yield and budget. However, they do not provide any detail on what internal processes lead to these outputs and what needs to be done to improve performance. However, they could be used for comparing the performance of different irrigation schemes. Once these external indicators are computed, they are used as a benchmark for monitoring the impacts of modernization on improvements in overall performance.

A first estimate of the external indicators is US $770 ha\(^{-1}\), while productivity of water amounts to US $0.077 m\(^3\). Both external indicators are low, which is more the consequence of recorded low yields than a low productive cropping pattern. The RAP in JBC can be used as a reference diagnosis to monitor the impact of the ongoing modernization project.

Internal performance indicators. Internal performance indicators are related to operational procedures, management and institutional set-up, hardware of the system, water delivery service, etc. These indicators are necessary in order to have a comprehensive understanding of the processes that influence water delivery service and overall performance of a system. Thus they provide insight into what could or must be done to improve water delivery service and overall performance (the external indicators). The values of the primary internal indicators reflect an evaluation of the key factors related to water control and service throughout the command area. The internal indicators and their sub-indicators at each level of the system are assigned values from 0 to 4 (0 indicating least desirable and 4 indicating most desirable).

RESULTS AND DISCUSSION (FINDINGS)

The completed results of the RAP including for the main canal, secondary and tertiary canals and final deliveries, the status of social order (Table II), service to farmers (Table III), service by main canal (Table IV), effectiveness of Water Users Associations (WUAs) (Table V) and control structures on main, secondary and tertiary canal systems (Table VI) are tabulated.

Table II. Social order

| Social order in the canal system operated by paid employees | 1.3 |
| Degree to which deliveries are not taken when not allowed, or at flow rates greater than allowed | 1.8 |
| Noticeable non-existence of unauthorized turnouts from canals | 1.2 |
| Lack of vandalism of structures | 0.4 |

*Two steps which have been excluded from this study are a) Management Unit and b) Integrating SOM (Service Oriented Management).
Service by main canal

There is a large gap between what the managers think they are doing in terms of delivery services and the actual estimation on the ground. The largest differences are obtained for reliability and control of flow rate. The quality of operation is assessed through averaging indicators on cross-regulators, turnouts, general communication conditions and operation (Table VI). The resulting indicator shows that the overall quality of canal operation declines downwards: 2.1, 1.9 and 1.6 for main, secondary and tertiary canals, respectively.

Table III. Service to farmers (canal)

| Actual water delivery service to individual ownership units (e.g., field or farm) | 1.2 |
| Measurement of volumes | 0.2 |
| Flexibility | 1.2 |
| Reliability | 1.2 |
| Apparent equity | 1.4 |

Table IV. Service by main canal

| Actual water delivery service by main canal to second-level canals | Actual | Stated |
| Water delivery service at head of field channel | 0.8 | 1.2 |
| Number of fields downstream of this point | 0 | 0 |
| Measurement of volumes | 0.8 | 2 |
| Flexibility | 1.4 | 2 |
| Reliability | 1.4 | 1 |

Table V. Water User Associations: the ranking for WUA is low (1.4)

| Percentage of all project users who have a functional, formal unit that participates in water distribution | 1 |
| Actual ability of strong WUAs to influence real-time water deliveries to the WUA | 2.4 |
| Ability of WUA to rely on effective outside help for enforcement of its rules | 1.2 |
| Legal basis for the WUAs | 2 |
| Financial strength of WUAs | 1 |

Service by main canal

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MAIN FEATURES OF JBC REPORTED FROM FIELD VISIT

Beyond the indicators of RAP the main features reported by the groups are as follows:

- Design discharge at JBC head is 1644 MCM yearly and canal roster is designed for 115% irrigation intensity. Owing to heavy siltation in the canals, only 60–70% of water is available, which caters for 50% of CCA.
Diversification and agriculture efficiency are inversely proportional to canal water supply: the less canal water you get, the more diversified and efficient you are.

Absence of water control (level or discharge) below distributary headworks. Off-take gates to minors are non-existent or damaged.

Inaccurate or improper measuring structures at all levels.

Highly sensitive off-takes along distributaries and minors leading to chaos in the water distribution.

Limited conveyance capacity: encroached free board upstream of the canal reaches.

Siltation is a serious constraint for maintenance and operation.

High density of illegal direct outlets along the main canal.

Waterlogging in upstream reaches.

Escapes are insufficient and not easy to operate.

**Step 2: System capacity and sensitivity**

**Objectives.**

- assessing the physical capacity of irrigation structures to perform their function of transport, control, measurement, etc.;
- assessing the sensitivity of irrigation structures (off-takes and regulators), identification of singular points;
- mapping the sensitivity.

**Regulating capacity at head**

The entire irrigation system is a run-off of the river type and neither head nor intermediate reservoirs can help management in smoothing the fluctuations between demand and supply. Normally these fluctuations depend

<table>
<thead>
<tr>
<th>Main canal</th>
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<tbody>
<tr>
<td>Cross-regulator hardware (main canal)</td>
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<tr>
<td>Travel time of a flow rate change throughout this canal level</td>
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<tr>
<td>Turnouts from the main canal</td>
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<tr>
<td>Regulating reservoirs in the main canal</td>
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<tr>
<td>Communications for the main canal</td>
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<tr>
<td>Existence and frequency of remote monitoring (either automatic or manual) at key spill points, including the end of the canal</td>
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<tr>
<td>General conditions for the main canal</td>
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<tr>
<td>Operation of the Main Canal</td>
</tr>
<tr>
<td>Clarity and correctness of instructions to operators</td>
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<tr>
<th>Second-level canals</th>
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<tbody>
<tr>
<td>Cross-regulator hardware (second-level canals)</td>
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<tr>
<td>Turnouts from the second-level canals</td>
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<tr>
<td>Regulating reservoirs in the second-level canals</td>
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<tr>
<td>Communications for second-level canals</td>
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<tr>
<td>Existence and frequency of remote monitoring (either automatic or manual) at key spill points, including the end of the canal</td>
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<tr>
<td>General conditions</td>
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<tr>
<td>Operation of second-level canals</td>
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<th>Tertiary-level canals</th>
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<tr>
<td>Cross-regulator hardware (third-level canals)</td>
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<tr>
<td>Turnouts from third-level canals</td>
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<tr>
<td>Regulating reservoirs in third-level canals</td>
</tr>
<tr>
<td>Communications for third-level canals</td>
</tr>
<tr>
<td>General conditions for third-level canals</td>
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<tr>
<td>Operation of third-level canals</td>
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</table>

Table VI. Control structures on canal system

largely on the flexibility allowed to the users. At present, flexibility of the service is low and experienced fluctuations (see Step 3) are mainly generated by uncontrolled outlets along the main canal. In the future the fluctuations will thus depend on how far the uncontrolled outlets have been reincorporated into the management and how flexible the future service will be. Once the needs for regulating fluctuations have been properly investigated, the capacity to accommodate some flexibility in the running discharge would have to be explored in two ways: online buffer storage or using volume control along the main canal.

Carrying capacity of the main system

The carrying capacity along the main system is reduced due to severe siltation (Figure 4), which is a result of the heavy sediment load from the river. The silt is inherent in the system. Another aggravating factor is the flat topography; canal slope is too low to allow high velocity, particularly at the tail reaches, causing siltation. The vegetation and weed growth and scour of the sides (Figure 5) add to the problem of reduction in capacity of the canal apart from the irregular section of the canal causing changes in the characteristics of the canal, such as roughness coefficient and shape of the canal section.

Discharge measurements at the border between management units

Along the main canal, there are 12 measurement points upstream of cross-regulators (near major distributaries) which are also locations of change of jurisdiction of management units (seven divisions). Rated section and staff...
gauges are used for flow measurements. However, no periodic calibration is carried out to maintain accuracy of measurement and some gauges are in poor condition (Figure 6). The gauge registers have been maintained properly, with readings taken at 12 h intervals.

**Functioning of cross-regulators**

There are 12 cross-regulators along the Jaunpur Branch Canal (Figure 7). In the absence of proper maintenance, difficulty in their operation is often experienced (Figure 8). Typical variation of water level upstream of the cross-regulator (km 22–120) is between 20 and 30 cm. The cross-regulators are really used here for water-level control, i.e. upstream control. With this typical variation in water level (tolerance on control) the major distributaries, having low-sensitive off-takes at head, are not greatly affected. Only direct minors with medium to high sensitivity experience significant discharge variation as a result of water-level fluctuations (Figure 9).

**Remote monitoring of canal roster**

The weekly roster is based mainly on crop water requirement and cropped area. The appropriate strategy for management of the surplus canal water entering the command area during rainfall would be by diverting the flow to areas of lower rainfall, groundwater recharge, fish ponds and irrigation tanks for optimizing utilization. This requires the introduction of supervisory control and data acquisition (SCADA) for real-time information monitoring.
Escape capacity and measurements

There are four escapes along the Haidergarh Jaunpur Branch Canal from 0 to 143 km. There are no measurement devices in these escapes. Excess water coming into the branch canal is meant to go to the nalis through these escapes. However, in reality, the escapes are not functioning properly because of choking of drains, poor maintenance and flat topography, making evacuation of surplus flows extremely difficult. In case of emergencies, the number of escapes is found to be insufficient in the canal. The escapes are seldom operated, and hence silt remains in the water carrier system.

Seepage quantification

The issue of seepage quantification is critical with regard to several aspects of water management and system operation. Some studies taken up by the project authorities reveal that the estimated seepage loss is of the order of 13.94 m³ s⁻¹ along the entire length of the Haidergarh and Jaunpur canal for a peak discharge of 165.5 m³ s⁻¹, which is about 9% (TAHAL Consulting Engineers Ltd, 2006). Waterlogging is high in the upstream reaches of JBC due to over-irrigation and loss of canal discharge (through direct outlets on main canal) reduces availability of flow to tail end.
Cost and energy input: seepage water is usually recovered at a financial cost/energy input. Clearly, reducing seepage can reduce energy spending and cost of pumping in the upstream command areas (SMEC International Pty Ltd, 2007).

SECONDARY SYSTEM: DISTRIBUTARIES

Water level control in JBC

There are 10 major distributaries in JBC and there exist 51 direct minors off-taking from the main branch canal. Total length of distributaries is 465 km. Density of cross-regulators on the secondary system is too low to perform the required water-level control.

Sensitivity of off-takes

The secondary system consists of a large network of approx. 825 km serving about 500 off-takes. Field observations during December 2007 show that, contrary to the situation found along the branch canal, the off-takes along the distributaries are much more sensitive. In the absence of off-take gates, the sensitivity tends be very high (4 and above). For example, in Figure 9 the discharge withdrawn at this point is likely to be highly fluctuating when the water level in the distributary fluctuates.

TERTIARY SYSTEM: MINORS AND QUATERNARY SYSTEM

Field channel operation

The off-takes on minors (kulabas) are ungated and the absence of water-level control structures along minors results in chaotic management (Figure 10). The farmers put up temporary earthen bunds to divert the flows and to get their share of water.

Irrigation scheduling

Implementation of the water distribution schedule called warbandi or osrabandi, which gives water directly to farmers with date and time schedule of irrigation water in proportion to the cropped area, is being attempted by system authorities. However, this requires tight regulation of canal water to ensure water at the promised date and time. In case of a gap in supplies, warbandi is followed in the next rotation of water supply. For the success of warbandi adequacy of water, discipline amongst users and equity have to prevail. Participatory irrigation management has to play a greater role in operation and maintenance of the canal system. The Participatory

Figure 10. Lack of control structure at tail end of Shivgadh minor of Jaunpur distributary. This figure is available in colour online at www.interscience.wiley.com/journal/ird

Irrigation Management (PIM) Act 2009 has been recently enacted by the Government of Uttar Pradesh. Its rules, although prepared, are still under process of finalization.

Overuse on head reaches and shortages in tail end

Due probably to the unreliable services of canal water, upstream farmers are usually practising over-irrigation whenever they get access to water. The excess of water (more than the crop water requirement) gets deep underground and it is noticed that the groundwater table is high. Inversely, the tail-enders of the field irrigation channels (FIC) are suffering from shortages of water and are practising conjunctive use of surface and groundwater.

SENSITIVITY OF IRRIGATION STRUCTURES

Variable sensitivity along main canal

The sensitivity of irrigation structures along the main canal is quite variable, as one can see in Figure 3. The sensitivity of the cross-regulators is low to medium, and there is no substantial head difference between upstream and downstream of the cross-regulator. Cross-regulator sensitivity expresses the ratio of the variation of water level and the variation of the main discharge. For instance, the cross-regulator referred to as no. 13 has a sensitivity indicator of 0.6, i.e. for a variation of 5% of the discharge in the main canal, the water level will vary at the cross-regulator by 0.03 m (3 cm), which is very low (Figure 11).

The sensitivity of major distributary off-takes ranges from low to very high (Figure 12). Out of 22, three are low-sensitive ($S < 0.5$), while 12 are medium ($S$ between $0.5$ and $1.5$) and 7 are high to very high ($S > 1.5$).

Table VII examines the sensitivity indicators estimated at the off-taking structure along the canal and the resulting variation of discharge for two levels of water control: when the water level is controlled at 20 cm and when it is controlled at 10 cm. It is clear that the current control exercised along the main canal, which has been reported as characterized by a variation of 20 cm of water level, is insufficient to keep a steady discharge at the off-takes. Only three off-takes are below 15% of discharge variation. An increased control of water depth at 10 cm would put most of the off-takes lower than 12.5% variation of discharge. Still off-takes 1, 2, 17 and 21 need some more specific interventions, basically to reinstall a slide gate in order to allow enough head between the main canal and the distributaries to reduce the sensitivity.

Very high sensitivity along distributary canals and minors

There is no water control structure along the secondary canals; therefore the water level is dictated by the ongoing discharge. The sensitivity indicator for the water level in a non-regulated section of a canal is given by following equation:

$$S = \frac{H}{(1.66)}$$

where $H$ is the water depth at the considered point.
For a water depth of 0.83 m, $S$ is equal to 0.5; this means that a variation in the discharge of 20% will be reflected by a variation of water depth of 0.1 m (10 cm).

Table VII. Off-take sensitivity along JBC and resulting discharge variation for a typical variation of head

<table>
<thead>
<tr>
<th>Off-taking structure ranking as in Figure 13</th>
<th>1</th>
<th>2</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>9</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>15</th>
<th>17</th>
<th>19</th>
<th>21</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity indicator</td>
<td>3.5</td>
<td>3.5</td>
<td>0.45</td>
<td>0.85</td>
<td>1.2</td>
<td>1.67</td>
<td>1</td>
<td>1.25</td>
<td>1</td>
<td>0.56</td>
<td>2.5</td>
<td>0.5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Discharge variation in distributary for a $\Delta H$ of 20 cm (percentage)</td>
<td>70</td>
<td>70</td>
<td>9</td>
<td>17</td>
<td>25</td>
<td>33</td>
<td>20</td>
<td>25</td>
<td>20</td>
<td>11</td>
<td>50</td>
<td>10</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>... and for $\Delta H$ of 10 cm (%)</td>
<td>35</td>
<td>35</td>
<td>5</td>
<td>8</td>
<td>12.5</td>
<td>16</td>
<td>10</td>
<td>12.5</td>
<td>10</td>
<td>5</td>
<td>25</td>
<td>5</td>
<td>50</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 12. Sensitivity of cross-regulator and off-takes along JBC. This figure is available in colour online at www.interscience.wiley.com/journal/ird

Table VIII. Off-take sensitivity along JBC and resulting discharge variation for a typical variation of head

Step 3: The perturbations

Objective. Identifying and characterizing positive and negative perturbations, their dimensions, origin, frequency and timing, location, size and amplitude and options for coping.

Figure 13. Typical off-take along a minor serving a field channel highly sensitive to variation of water level, $S = 6$. This figure is available in colour online at www.interscience.wiley.com/journal/ird

For a water depth of 0.83 m, $S$ is equal to 0.5; this means that a variation in the discharge of 20% will be reflected by a variation of water depth of 0.1 m (10 cm).

Sensitivity of the structure off-taking from the distributary and minor is extremely high (5 or more). Sensitivity assessment of a minor off-take serving a field channel (shown in Figure 13) is given in Table VIII. Thus it is evident that canals are not water depth regulated and off-takes are ungated. Management of flows is impossible and chaos prevails.

Step 3: The perturbations

Objective. Identifying and characterizing positive and negative perturbations, their dimensions, origin, frequency and timing, location, size and amplitude and options for coping.

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DOI: 10.1002/ird
Water-level perturbations along the Branch Canal

One source of perturbations is related to inaccuracies of the process, which lead to increasing fluctuations downstream of the network (Figure 14). The absence of proper measuring devices, water control devices and data acquisition lead to complexities in canal operation.

Discharge perturbations

As the system is a “run-of-the river system”, it is subjected to greater variability in inflow, causing perturbations as reported in Figure 3. Actual gauge at HBC head is often below the threshold value and for JBC FSL is never maintained and is far below 2.5 m, as against 3.5 m.

Excess and illegal withdrawals

Fluctuations of the flow occurring along the branch canal are due to illegal off-takes. Along the secondary and tertiary canals, however, it is not only due to illegal withdrawals (Figure 15) but also to temporary earthen bunds (Figure 16) to raise the water level in the absence of a proper water control device, causing extremely high perturbations for downstream users.

Table VIII. Sensitivity assessment for the off-take shown in Figure 12

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minor</th>
<th>Field channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water depth $H$</td>
<td>$H = 0.75$</td>
<td>$H = 0.25$</td>
</tr>
<tr>
<td>Sensitivity for water depth in minor</td>
<td>$S = \Delta H/\Delta Q/Q$</td>
<td>$S = [\Delta q/q]/(\Delta H)$</td>
</tr>
<tr>
<td>Sensitivity for water withdrawal of field channel</td>
<td>$S = H/a$</td>
<td>$S = a/HS = 1.66/0.25 = 6.64$</td>
</tr>
<tr>
<td>Exponent $\alpha$ of the discharge head relationship</td>
<td>1.66</td>
<td>1.66</td>
</tr>
<tr>
<td>Estimation of sensitivity</td>
<td>$S = 0.75/1.66 = 0.45$</td>
<td>$S = 0.25$</td>
</tr>
<tr>
<td>Assuming an INPUT variation of discharge of</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Resulting water depth change</td>
<td>$\Delta H = S \cdot [\Delta Q/Q]$</td>
<td>$\Delta H = 0.45 \times 0.1 = 0.045$</td>
</tr>
<tr>
<td>Resulting variation of discharge at field channel</td>
<td>$\Delta q/q = S \cdot \Delta H$</td>
<td>$\Delta q/q = 6.64 \times 0.045 = 0.3$</td>
</tr>
</tbody>
</table>

For a discharge change of 10% in the parent canal, the change in the field channel is 30%

Water-level perturbations along the Branch Canal

Figure 14. Jaunpur Branch Canal, 72 km. This figure is available in colour online at www.interscience.wiley.com/journal/ird

Options to cope with perturbations are as follows:

- One option is to absorb the positive perturbations in the branch canal itself by raising the canal banks and storing the water temporarily. This would require careful monitoring of the water levels by the operators.
- Another option would be to divide the flow proportionately into the off-takes.
- The timely and synchronized operation of series of cross-regulators with real-time data of water levels, and by reducing the operation time of the cross-regulators by mechanizing the operation.

**Step 4: Mapping water networks and water balance/accounting**

*Objective.* The objective here is to map the nature and structure of all the streams and flows that are affected and influenced by the command area. It includes assessing the hierarchical structure and the main features of the irrigation and drainage networks, natural surface streams and groundwater, and the mapping of the opportunities and constraints including drainage and recycling facilities.

*Physical boundaries of the project.* By limiting the hydraulic boundaries between HJBC headworks and the two river basins Gomti in the north and Sai in the south, the water balance is accounted for.

*Water balance at different scales: Gross Command Area (GCA) and subunits.* Water balance is important for the entire gross command area. It is also important for any sub-management unit that may be decided...
as part of the improvement programme, considering the situation of each subunit is different with regard to water inflows and outflows.

**Canal water application.** The discharges into the canal system are known. The quantity of water entering into the system can be assessed. The canal runs for about 9 months of the year (i.e., with 2-month and 1-month closures, respectively, during Kharif and Rabi), irrigating Kharif, Rabi and Zaid crops. An actual cropping pattern of 89% Kharif (rice, jawar, bajra, maize, urd, arhar and other crops), 98% Rabi (wheat, gram, pea, oil seeds, potato and other crops) and 1% Zaid (cereals, pulses and sugarcane). The cropping intensity works out to 188% during 2004–2005 whereas the design irrigation intensity is 115% only, 67% in Kharif and 38% in Rabi. Against this, actual irrigation is about 46% of CCA, with 60% of water availability.

**Water resources.** For farmers in the command area there are three major sources of water resources: canal surface water, groundwater and direct rainfall. Where these three sources of water can be combined, basically in the irrigation gross command area, the water supply to agriculture is not limited. Shallow groundwater of good quality is available in most places, although the sodic problem occurs in some areas, particularly in the eastern part of the commandable area (CA).

**Inputs and outputs of the water balance in JBC.** Water balance with regard to water input and output for surface and subsurface water is given in Table IX.

### Table IX. Field water balance: all units in MCM (million cubic metres)

<table>
<thead>
<tr>
<th>Component</th>
<th>Kharif</th>
<th>Rabi</th>
<th>Zaid</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Av %</td>
<td>Av %</td>
<td>Av %</td>
<td>Av %</td>
</tr>
<tr>
<td><strong>Input</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>2995</td>
<td>87</td>
<td>208</td>
<td>18</td>
</tr>
<tr>
<td>Groundwater supply</td>
<td>105</td>
<td>3</td>
<td>531</td>
<td>48</td>
</tr>
<tr>
<td>Canal and drainage</td>
<td>334</td>
<td>10</td>
<td>371</td>
<td>34</td>
</tr>
<tr>
<td>Total</td>
<td>3434</td>
<td>100</td>
<td>1110</td>
<td>100</td>
</tr>
<tr>
<td><strong>Outputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>1762</td>
<td>54</td>
<td>1248</td>
<td>85</td>
</tr>
<tr>
<td>Seepage</td>
<td>1002</td>
<td>31</td>
<td>148</td>
<td>10</td>
</tr>
<tr>
<td>Runoff</td>
<td>476</td>
<td>15</td>
<td>75</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>3240</td>
<td>100</td>
<td>1471</td>
<td>100</td>
</tr>
<tr>
<td>Increase in subsurface storage</td>
<td>194</td>
<td>—</td>
<td>—361</td>
<td>51</td>
</tr>
<tr>
<td><strong>Groundwater balance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Input</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seepage from canals</td>
<td>58</td>
<td>5</td>
<td>91</td>
<td>38</td>
</tr>
<tr>
<td>Seepage from field</td>
<td>1002</td>
<td>95</td>
<td>148</td>
<td>62</td>
</tr>
<tr>
<td>Total</td>
<td>1060</td>
<td>100</td>
<td>239</td>
<td>100</td>
</tr>
<tr>
<td><strong>Extraction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>105</td>
<td>33</td>
<td>532</td>
<td>72</td>
</tr>
<tr>
<td>Domestic and industrial use</td>
<td>40</td>
<td>12</td>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td>Flow to drains/river</td>
<td>173</td>
<td>55</td>
<td>172</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>318</td>
<td>100</td>
<td>744</td>
<td>100</td>
</tr>
<tr>
<td>Increase in subsurface storage</td>
<td>742</td>
<td>—</td>
<td>—505</td>
<td>164</td>
</tr>
</tbody>
</table>

AV = Average.
Groundwater table fluctuation. Available studies show that the level of groundwater throughout the CA is related to the canal water system and management. High recharge of groundwater occurs as a result of losses through canal seepages and at the head end of the minor, which is often over-irrigated. Inversely, at the tail end of minors the water level is much lower due to lower water surface supply and better drainage conditions (Figure 17).

COST OF MANAGEMENT, OPERATION AND MAINTENANCE

Annual working expenses on canal in HJBC

Step 5: Mapping the cost of operation

Objective. The objective is to gather as many elements of costs as possible entering into the operation of the system in order to identify where possible gains should be sought for with the current service and operational set-up, and what would be the cost of implementing an improved service. This step thus focuses on mapping the cost for current operation techniques and services, disaggregating the elements entering into the cost, costing options for various levels of services with current techniques and with improved techniques. The breakdown of the budget for management, operation and maintenance in HJBC is shown in Figure 18. Canal irrigation cost comes to Rs. 1294 ha$^{-1}$ in HJBC, while revenue is only Rs. 267 ha$^{-1}$ at the present irrigation rate. Thus only 20% of annual working expenses are being recovered. Actual irrigated area is about 46% of the command due to lack of proper maintenance and reduced water availability due to siltation. Groundwater irrigation cost (from diesel pumping sets) is about Rs. 2000 ha$^{-1}$ for each irrigation. Hence canal and groundwater need to be used conjunctively to cater for the whole command and encounter the bad effects of each of the other irrigation systems (waterlogging and salinity in surface irrigation and water table decline in groundwater irrigation system).

Step 6: Service to users

Objective. The objective is to map existing and potential options for services to users with consideration to farmers and crops as well as to other users of water.
Urgent need for Federation of Associations

It is critical to develop an intermediate level of competence (technician) responsible to front the associations and to interface with the main service provider (Irrigation Department). To achieve that it is advisable to create rapidly a Federation of Water Users Associations (FWUA), grouping nearby WUAs, leading to a size that allows the federation to have sufficient financial resources and means for operating the system and organizing the development of the association. The mission of the FWUAs will be manifold: to organize an effective operation and maintenance interface with Uttar Pradesh Irrigation Department (UP-ID) on the whole range of issues of management and to develop the capacity of WUA members. To carry out these tasks a technician would have to be recruited by the federation on a long-term basis (5 years) and trained appropriately by project authorities.

Depending on the average number of WUAs grouped in a federation, we can anticipate between 50 and 100 FWUAs in the Jaunpur Branch Command Area. The former corresponds to eight WUAs per federation and the latter to four.

Cadastral information system and use of geographic information system value-added WUA maps. WUAs can be assisted by providing a cadastral information system and geographic information system value-added WUA maps generated for planning of cropping pattern and water distribution according to their needs and circumstances.

Step 7: Mapping the demand for canal operation

Objective. Assessing means, opportunity and demand for canal operation, a spatial analysis of the entire command areas, with preliminary identification of sub-command areas (management, service).
The mapping of the demand for operation is based on three main criteria: service, perturbations and sensitivity. Conceptually the demand can be seized through the following formula:

\[
\text{Demand for operation} = \text{Service} \times \text{Perturbations} \times \text{Sensitivity}
\]

The higher the service, the higher the demand; the greater the perturbations, the higher the demand; and the higher the structure sensitivity, the higher the demand for operation.

Demand expresses the requirements to achieve given targets with due consideration to the constraints; it also reflects the efforts needed to operate the system to perform as targeted. In some areas little effort is sufficient, whereas in others more effort is needed to achieve the same objective.

**MAIN CRITERIA FOR PARTITIONING THE COMMAND AREA FOR CANAL OPERATION DEMAND**

*The level of service*

The demand for operation will depend on the definition of service agreed upon at main system level as well as at subunit levels.

*The perturbations*

The main perturbation along the main canal is related to the runoff during Kharif, as this affects the entire system with a similar intensity; a priori there is no differentiation of the demand with respect to this criterion.

Along the secondary system the intensity of perturbation is related to the number of upstream nodes (partition of flows) given the lack of control which characterizes the secondary network. This is why the length of the secondary networks would have to be taken as a criterion of differentiation of the demand for operation.

*Length of secondary canals*

As seen in the initials steps (RAP), the problem of distribution is plaguing the secondary system and below. Therefore, the longer the secondary canal, the more effort is required to properly manage the water flows and ensure in particular that the tail-enders are receiving a fair share.

*Recycling*

Recycling is needed in some sub-command areas, whereas it is non-existent elsewhere. This criterion is therefore a critical one in allocating efforts for operating the secondary system. Wherever drainage is recycled, fewer efforts are needed for operation and, where there are no recycling facilities, high efforts to control water deliveries on the upstream side.

*Step 8: Canal operation improvements*

*Objective.* Identifying improvement options (service and economic feasibility) for each management unit for (i) water management, (ii) water control and (iii) canal operation.

*Water management strategy*

At the moment the designed objective of water management is to provide canal water to all users at a maximum rate of 0.3 L s\(^{-1}\) ha\(^{-1}\) corresponding to the traditional concept of the Gangetic irrigation system. The concept of equity is based on a fair share of canal water deliveries. There are clear indications, though, that these achievements in terms of equity are low both along the main system and along the minors.
Drainage management

The issue of drainage is also central in the command area. Various patches of waterlogged area can be seen in the CA. Studies made by SMEC International Pty Ltd (SMEC, 2007) and International Resource Group, USA (IRG, 2008) consultants show that waterlogging is to a large extent due to the raising of groundwater table as a consequence of over-irrigation and canal seepage in the head end of canals and minors.

A strategy of drainage for the whole command area needs to be designed within the project considering the natural drainage conditions within the landscape, as well as the improvements one can expect by improving water management and more specifically decreasing over-irrigation in some key places.

Water resource monitoring: water balance on subunits

The ongoing modernization project (Uttar Pradesh Water Sector Restructuring Project, UP-WSRP) is making valuable efforts to generate a network of measurement points for the three resources contributing to water supply to crops: canal water, rainfall and groundwater. The project has proceeded to the installation of a network of 500 measurements points for groundwater monitoring, for rainfall, together with an improvement of the measurement made on the surface supply.

The initial phase of installation of the monitoring network was achieved in 2005, and it is time now to consolidate or further strengthen the operation of the network. Efforts that have been put into the installation and the initial stage of data collection should be refocused now on the production of water balance studies at various scales of the GCA, to help develop an effective and sustainable water management.

According to the TAHAL hydrogeology study (TAHAL Consulting Engineers Ltd, 2005) water conditions are significantly variable, and one should contemplate revising the equity concept by ensuring that the areas that are in less favourable conditions for groundwater access receive more canal water. In other words, the equity should be set on the “access to any source of water” and not limited to canal water.

What strategy?

The water management strategy within the command needs some further clarification in terms of management options for canal and groundwater. Simply replicating what was there before to spread water and fight against famines does not seem to correspond to today’s demand for water services in support of crop diversification.

On water management issues, the policy of developing conjunctive use and improved surface water management to avoid waterlogging needs to be spelled out more clearly and with indications on how this would have to be put into practice; for instance, how to favour groundwater pumping in head ends of minors to reduce waterlogging.

The previous concept of “pushing water” would have to lead the way to a concept of serving user groups with more flexibility, an increased reliability, to cope with the demand from users dictated by local water conditions and/or by their willingness to pay for a good service would have to be as far as possible taken on board.

Irrigation modernization strategy within UP-WSRP

However, during the MASSCOTE exercise two problems have been identified as far as the modernization project is concerned:

- The water management strategy is unclear, at least in the documents of the project, as discussed previously in this section.
- New concepts of operation, discharge and water-level control techniques, and introduction of new type of structures, are not known or mastered by local irrigation staff.

The appropriation of the modernization management strategy by irrigation staff needs to be increased through appropriate training.
Regaining control of level and discharge

The MASSCOTE has clearly pointed out that the control exercised along the network of canals on the flows are far too low to avoid chaos prevailing. This situation leads to various problems (water scarcity and waterlogging). The modernization project would have to aim at:

- regaining water-level control along the main canal by diminishing the tolerance on water depth variation to 10 cm;
- installation of effective control structures along the distributaries;
- equipping all withdrawing structures with appropriate gates.

RECOMMENDATIONS

The following recommendations were formulated:

1. Introduction of SCADA for real-time information monitoring. A real-time information system would have to be put in place to allow making quick decisions on the basis of a reliable in-time assessment of the situation.
2. Recycling water through shallow wells in the area close to the canals. This is an option that attempts to reduce waterlogging upstream of the command area; it has to accompany a better control of water deliveries in the same areas.
3. Installation of measurement devices at all levels. Flumes are being installed in some distributaries. Periodic calibration of measuring devices is required.
4. Automation of cross-regulators. To regain control of the water level along canals four cross regulators have to be installed; it is recommended to use automatic structures whenever possible to reduce staff requirements for operation.
5. Remodelling the canal to increase the conveyance capacity. Transport capacity is reduced by high sediment deposits; therefore a modernization programme needs to include restoration of the transport capacity.
6. Federation of WUAs. Formation of federations of WUAs would have to be included in the PIM Act 2009 of the Government of Uttar Pradesh (GOUP) and rules for its regulation need to be framed for its implementation.
7. Water balance studies at local levels. Water balance for each sub-canal and further each federation of associations will have to be carried out in order to develop for each management unit an appropriate water management strategy.

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REFERENCES

Irrigation Department, Uttar Pradesh. 2003. Concept paper on various operational problems in Sarda Sahayak Project.
