



NARMADA PROJECT : CONTROLLED VOLUME CONCEPT

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ABSTRACT

The NARMADA project will be the largest irrigation project in the world. It will be situated in the state of Gujarat in Western India.

The water system will be supplied from a concrete gravity dam on the NARMADA river.

The conveyance system will include the main canal, branch canal and distributaries. It will include about 460 km of main canal, 3,500 km of branches/subbranches and 7,500 km of distributaries.

The canals and structures of the conveyance system with design flows over 8.5 m³/s will be operated according to the concept of "Controlled volume" which will notably reduce the response time of the system. This method will require the use of a remote monitoring and control system.

The first part of the paper is a general presentation of the project. The constraints are described and the main issues adopted on the project are presented.

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After describing the control logic of the control system, the paper presents the calculation principles and the control software organization. The regulation performances are presented on the main canal using a simulation model.

INTRODUCTION

The population in India, which is around 950 million at present, is expected to reach about 1 000 million by the turn of the century. The production of food grains which was around 50 million tons in the pre-plan period has reached about 195 million tons by now and will have to be raised to 220 million tons by the year 2000.

All these factors require an improvement in the performances of irrigation and this, in turn, requires that irrigation management be more flexible and better match the needs of users. This increased flexibility also increases the difficulties involved in canal control.

On most main canals there is a trend towards centralized automatic control systems, the aims of which are :

- to facilitate canal operation,
- to increase the operating flexibility of canals,
- to monitor canal operation in real-time,
- to ensure greater safety of the facilities.

This paper is an overview of the largest irrigation project in India. It presents :

- the main canal, branch canals and distributaries, summarizing the options adopted by Sardar Sarovar Narmada Nigam Limited (SSNNL) to control and manage the system,
- the constraints which the control system has to overcome,
- the principle of the controlled volume concept.

GENERAL PRESENTATION OF THE NARMADA PROJECT

General presentation

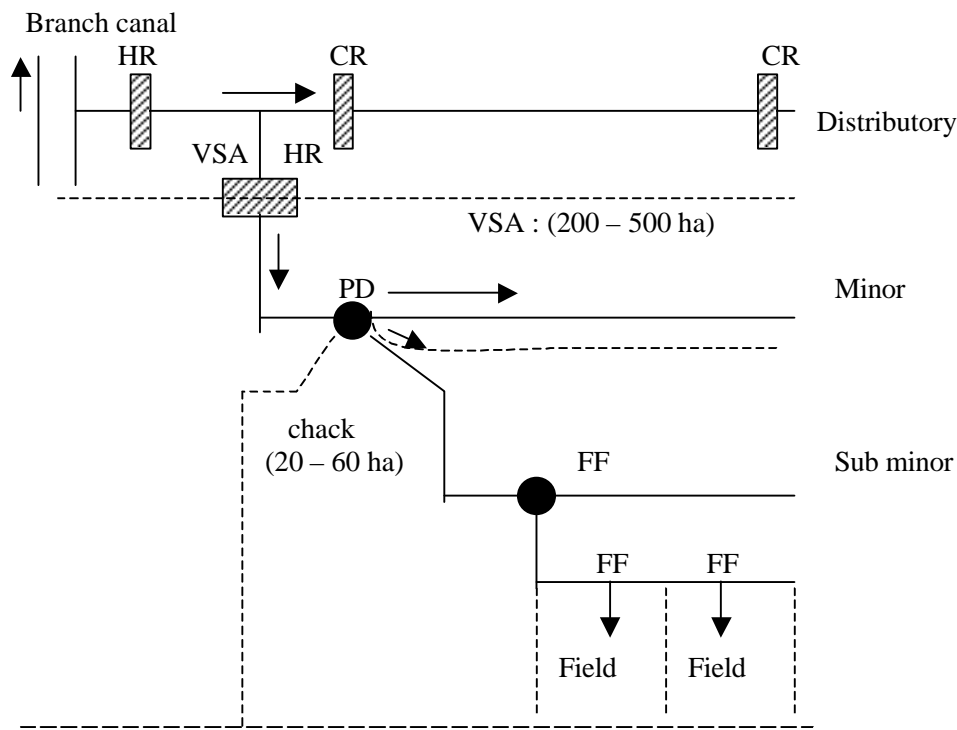
Sardar Sarovar (Narmada) Project, currently under construction, is one of the largest multipurpose water resources development projects in the state of Gujarat in Western India. It will consist of a large concrete gravity dam on the Narmada river, a hydropower complex and a vast network of canal systems to irrigate about 1,792 million hectares of land out of 3,428 million hectares of gross command area covering some 3,400 villages in Gujarat state. The project will also provide irrigation benefits to the neighboring state of Rajasthan.

The 458 kilometer-long concrete-lined Narmada Main Canal will be one of the world's largest multipurpose water supply canal. It extends north from the dam site to the Gujarat – Rajasthan state border. Narmada Main Canal will have a design discharge capacity 1,134 m³/s at its head and it will taper down to 71 m³/s at the Gujarat – Rajasthan state border.

There will be 42 branches offtaking from the Narmada Main Canal with discharges varying from 320 m³/s to 3 m³/s. The system consists of 3,500 km of branches and subbranches, 7,500 km of distributaries and almost 30,000 km of minors and subminors.

Water management concept

The conveyance system includes the Main Canal and distributaries. It is operated by SSNNL (a wholly owned Government of Gujarat Undertaking) and supplies water to Village Service Area turnouts. Inside the Village Service Areas, the distribution system consists of minors and subminors and supplies water to chacks. All the chacks (nearly 40 hectares) within the service area will receive its allocated share of water depending on the size of chacks simultaneously during the period of supply (see figure 1).



Legende : HR : Head regulator
CR : Cross regulator

PD : Proportional divider

FF : On/Off gates

Fig. 1. Distribution system

The distribution system is operated by the Farmer's Association under the guidance of SSNNL. The following concepts of water management have been adopted by SSNNL.

Extensive Irrigation ⁴: Reasons for extensive irrigation proceed from the limited volume of water available for Gujarat, the size of the gross command area and the possibility of conjunctive use of ground water.

Supply-oriented irrigation system with downstream feedback : Considering the scarcity of water resources, the system will be operated according to supply priorities. As far as possible, requests from farmers to change the irrigation schedule in order to meet their individual agricultural constraints will be taken into consideration under certain conditions.

Volumetric and proportional flow rotational delivery system : The water distribution to each Village Service Area will be on a volumetric basis and, within each Village Service Area delivery of water will be on the basis of proportional flow to each chack. Within each chack the delivery of water will be on a rotation basis to each farmer.

Adaptation to climatic conditions: In order to save water, the automation of the operation of the main canal and distributaries is expected to increase the flexibility of the irrigation system, by allowing fast adaptation to unpredicted rainfall.

Equitable and reliable supply: Farmers, either upstream or downstream, will get equal chances to have timely water delivery according to predetermined and agreed schedules of irrigation.

Control system adopted by SSNNL

The canals and structures of the conveyance system with design flows over 8.5 m³/s will be operated according to the concept of controlled volume. The controlled volume concept consists in maintaining a constant volume in each

⁴ Extensive Irrigation is the term used to define an irrigation strategy that allows irrigation coverage of as large area as possible with a limited quantity of available water. In this type of irrigated agriculture, crop with less water consumption are preferred over water intensive crops.

reach of the same Branch canal. With the controlled volume concept, the water profile rotates around a pivot located approximately in the middle of the reach, according to the variation of discharge :

- for small discharge ($Q=0$) the water profile is horizontal,
- for a maximum discharge the water profile is parallel to the bed of the canal.

This method requires the use of a computerized remote monitoring and control system. The canal and structures of the conveyance system with design flows below $8.5 \text{ m}^3/\text{s}$ will be operated manually as directed by SSNNL in accordance with predetermined and computerized schedules.

The telemetry and control system will include three levels :

- The Remote Terminal Units located at measurement and control structures along the main and branch canals. These units will collect and transmit the measurements and receive instructions including set points.
- The Divisional Operation Centers located along the branch canals. These centers will receive the measurements and generate the desired gate positions. There will be 15 Divisional Operation Centers, each one controlling one or several branch canals. Each Divisional Operation Center is independently in charge of 50 to 100 Remote Terminal Units.
- The Main Control Center will be located on the main canal near Ahmedabad. It will receive the measurements and generate the instructions and gate position for Remote Terminal Units on the main canal. There will be 111 Remote Terminal Units. The Main Control Center also has direct communications with the 15 Divisional Operation Centers.

For the remote transmission network connecting Main Control Center, Divisional Operation Centers and Remote Terminal Units, SSNNL envisages using fiber optic.

Management system adopted by SSNNL

In parallel with the telemetry and control system, and according to the hierarchical organization of SSNNL, an « Irrigation Management System » will support the organization and the supervision of the water distribution as well as project management. It comprises four operating levels:

- The Village Service Area where raw agricultural data (irrigated area, actual cropping pattern, etc...) are collected. These areas send to or receive irrigation requests and irrigation schedules from Data Collection Centers.
- The Data Collection Centers will be located on the branch canals at certain Remote Terminal Units. The total number will be around 132.
They receive data from the Village Service Area and after checking for consistence will transmit them to Divisional Operation Centers. They will

receive instructions from Divisional Operation Centers (Irrigation schedule and gates operation) and will pass them on to Village Service Area and SSNNL field staff.

- The Divisional Operation Centers are in charge of 8 Data Collection Centers. All data concerning irrigation management are processed in Divisional Operation Centers (e.g. irrigation schedule, gates operation schedule, billing, accounting, etc...). They will receive instructions from the Main Control Center as regards water allocation and will report the actual status of operation, water consumption, etc...
- The Main Control Center located near Gandhinagar is the main decision center for the operation. It determines the general water balance of the whole area and fixes the water allocation of the various agro-climatic areas. It supervises the overall operation of Narmada and validates irrigation schedules prepared by Divisional Operation Centers.

The connection between villages and Divisional Control Centers will be by VHF radio communication.

The transmission network between the Divisional Operation Centers and Main Control Center for the water requirements will use the same communication hardware as the telemetry and control system.

MAIN CONSTRAINTS FOR THE CONTROL SOFTWARE

The control software which will be used to automate the conveyance system with flows above 8.5 cubic meters per second will comply with the following constraints:

- Size and complexity of the system: even if the controlled volume concept considerably reduces the system response time, decisions have to be made in a reliable and coordinated manner. The decisions made on the branches have an impact on Main Canal operation which will have to be accounted automatically.
- Safety: Because of the huge dimension of the main canal and some of the branch canals, significant risks are associated with overflowing or failure of the banks. To alleviate these risks, fast information and reactions are necessary. For some low probability faults, opening of spillways can be envisaged but for other more frequent events, wastage of water must be avoided and more efficient safety conditions must be provided. This is the case for the Saurashtra branch (discharge 400 m³/s) canal where pumping stations or hydropower plants can stop suddenly on power outage will result in an immediate large variation of flow.

- Flexibility: The method adopted for the water distribution has the following consequences on the possible variation of flow along the various types of canals:
 - *Minor*: constant discharge. ON/OFF operation
 - *Delivery canals*: constant discharge during one week or so, except in case of changes requested by farmers and accepted by SSNNL. During the year, the flow can vary according to the water requirements and be very small when only Municipal and Industrial supply is concerned.
 - *Branch canals and main canal*: Same conditions of flow variation as for distributaries. In addition, the main canal and some branch canals are subject to sudden variation of flow.

In conclusion, it can be noted that all remote controlled canals must be able to carry any flow from 0 to the design discharge. The main canal and some branches can face important and unpredictable variation of flow.
- Inaccuracies of adjustments: The cross regulators consist of several gates in parallel. Satisfactory operation of the canal requires that flows through these structures be correctly adjusted. Close to the maximum flow, many cross regulators of the Main Canal will have only a 7 to 8 cm of head loss. Under these conditions, the inaccuracy of flow adjustment may easily reach 10 to 20%. These inaccuracies due to the laws governing the flow through a gate are compounded by the problem of harmonizing gate movements. A change in a gate opening can disturb the flow on the neighboring gates. The performances of an automatic control system depends on the quality of controls. Depending on the reach status, the inaccuracy of the adjustments can be considerable and this lack of accuracy will have to be compensated by the feedback of the control software.
- Drawdown conditions: To avoid uplift pressure under the concrete slabs on the canal during unsteady flow conditions, the rate of level change in the canal must be limited. In the table hereafter, the drawdown conditions imposed by SSNNL are presented.

Table 1 : Drawdown conditions

Time step	Cumulative variation
0 h – 1 h	15 cm
1 h – 2 h	30 cm
2 h – 4 h	30 cm
4 h – 24 h	65 cm

CONTROL CONCEPT PRESENTATION

Presentation

All the canals with above 8.5 m³/s discharge will be controlled using the controlled volume concept. The control software receives information from the telemetry network, permanent databases and if necessary operators and generates instructions which will be sent to the Remote Terminal Units. The general organization of canal control in cruise mode is shown in the following figure.

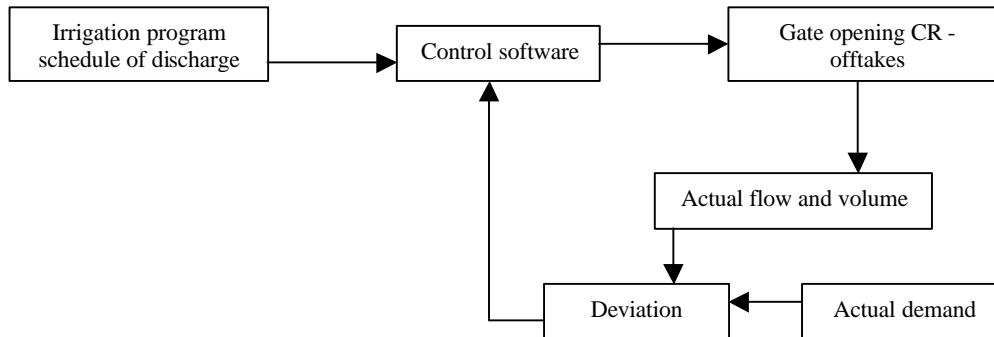


Fig. 2. General Organization

At the start of the system, the irrigation program computes the schedule of discharges at each point of control and at each instant over a 24-hour period. The function of control software is to implement this program of flows in compliance with the forecast using the control facilities (CR, offtakes) which are remotely controlled. For each structure and each regulation time step, the software calculates gate openings, and dispatches the required instructions to the control facilities and checks that the facilities have operated properly. As a general rule, the actual demand and the condition of the canals will not exactly conform to forecasts. There are two reasons for this :

- i) It would be illusory to think that all the variations in demand required by farmers and carried out by gate keepers are integrally carried over onto the control centers.
- ii) The physical limitations inherent in such a system, such as : minor incidents, inaccuracy of measurements, inaccuracy of hydraulic formula, inaccuracy of calibration coefficients, variations in time of the hydraulic coefficients, etc..., will not enable a total match between the forecast flows and real flows.

The control software will have to take into account these discrepancies in order to correctly adjust the control regulators and the offtake gates.

It should be noted that these discrepancies are not known in detail. It will be through the consequences they have on the volume of pools that will be determined and monitored through the measurement of levels transmitted by the telemetry network. These are therefore volume deviations which trip corrective actions.

Control logic

Three different actions at each cross regulator and at each regulation time step are associated:

- **anticipatory action** (feed forward) which determines the discharge to be adjusted according to the predetermined irrigation schedule and the foreseen consequences of recorded events such as a pumping station outage.
- **corrective action** (feedback) which determines the discharge correction in order to maintain the volume stored in the pools at a constant target volume. This action is computed according to level measurements on the canal.
- **a coordinating action** which consists in adding a part of the corrective action made on the downstream CRs (cumulative carry forward).

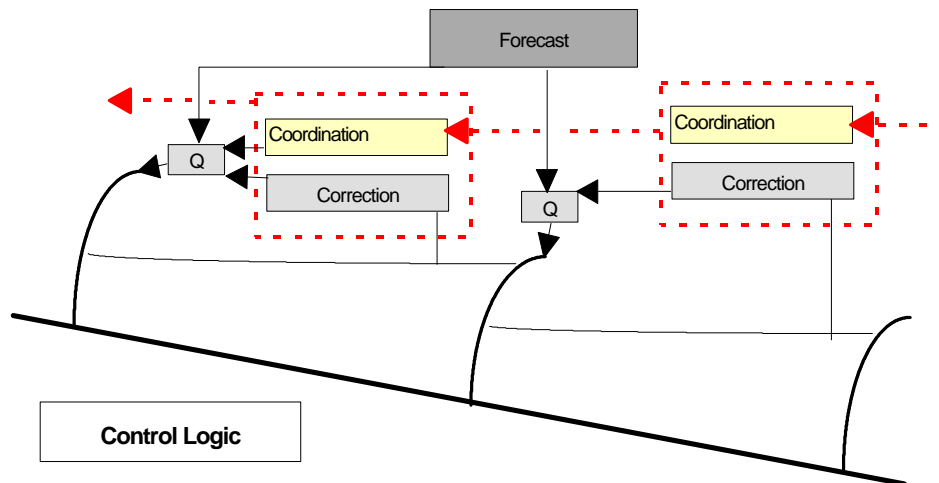


Fig. 3. Control Logic

Finally, the discharge to be adjusted at each regulation time step is given by the following formula :

$$Q = Q_{\text{Forecast}} + Q_{\text{Correction}} + Q_{\text{Coordination}}$$

Calculation methods used in the software

- **Anticipatory action**
The flow forecast is obtained directly from a pre-established irrigation programs taking into account the hydraulic delay.
- **Corrective action**
The role of the correction flow is to keep the pool volume equal to its target volume. The correction flow is the result of feedback between the deviation,

the target volume and the estimated volume, and the discharge set upstream.
This control feedback loop is presented hereafter:

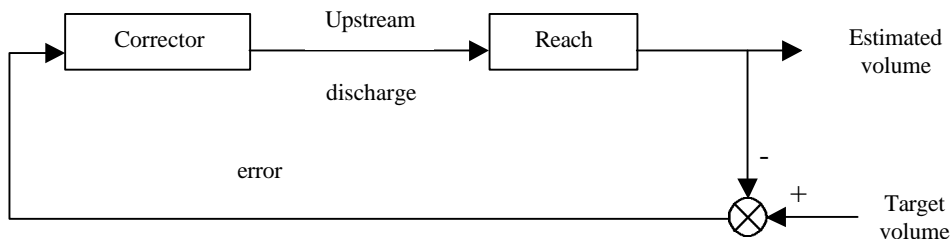


Fig. 4. Control system feedback loop

In order to determine all the parameters of this control loop, it is necessary to:

- estimate the volume present in the pool at the given control time step,
- know the algorithm which calculates the correction flow based on the error.

- Estimate of the reach volume

The volume present in a reach can only be estimated. The volume estimation method proposed is currently applied on the Canal de Provence in southern France. This method uses predefined tables in steady flow conditions to supply the volume stored in the pool based on the operating flow and the level downstream of the reach (Deltour-1995, Strelkoff et al-1998). At each time step, the program reads the tables and gives the pool volume based on the downstream level and the operational discharge.

- Calculation algorithm of correction flow

On irrigation canals, the coefficients of proportional integral correctors are difficult to set and finding the best set of coefficients to optimize coordination of adjustments between the reaches is a delicate, long and fastidious operation.

In order to facilitate the calibration of the control parameters, the corrector proposed is obtained by using a proven and conventional automatic method : the pole placement methodology (Deltour (1995), Sanfilippo (1997), Sanfilippo (1998)).

The coefficients of the corrector proposed are obtained from a single parameter (the correction time). This parameter establishes the targets which the corrector has to achieve, i.e. the time at the end of which an error has to be corrected.

Control software flow chart

At each control time step, the calculations described in the following flow chart are executed.

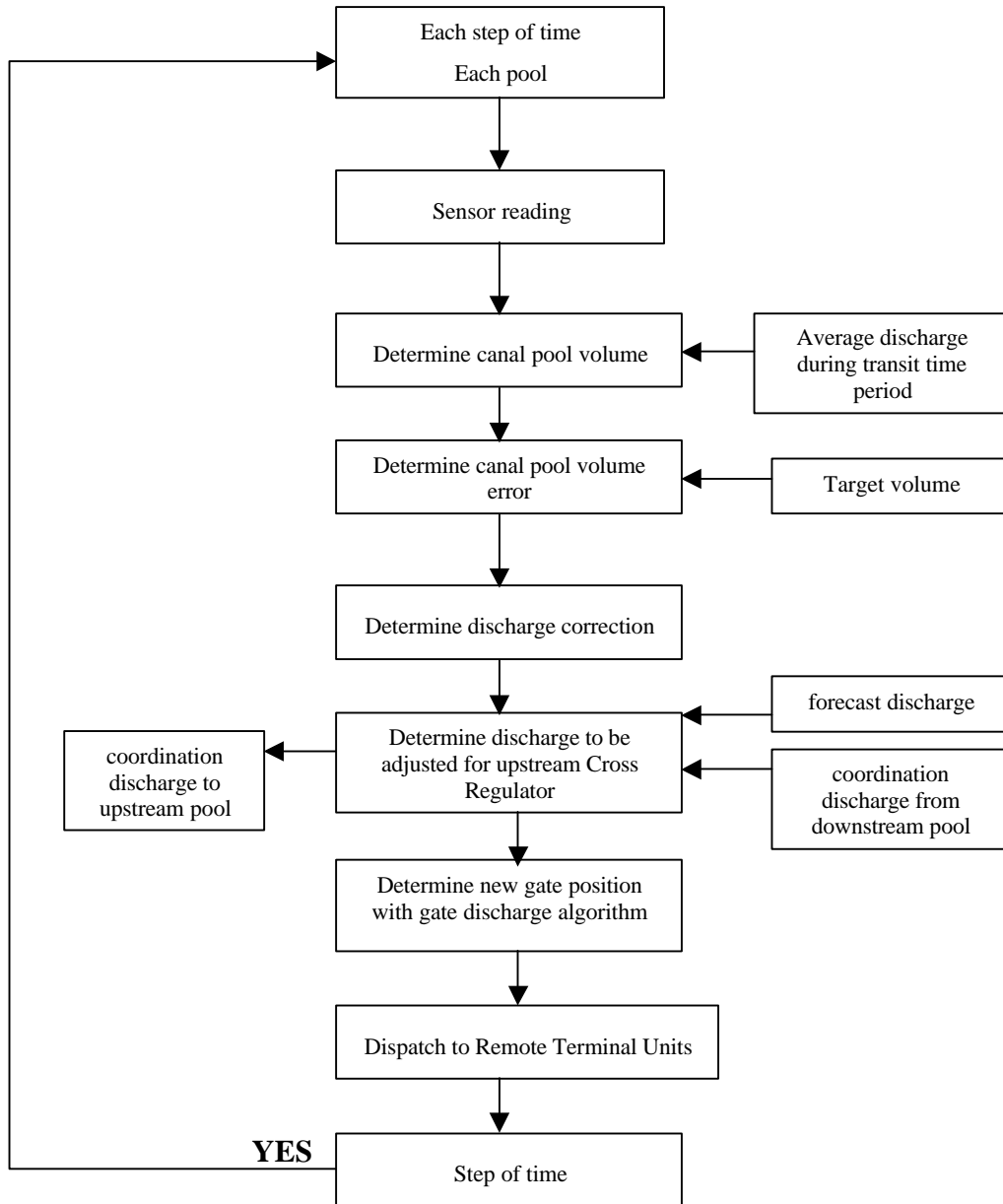


Fig. 5. Control Software Flow Chart

CONTROL SYSTEM SETTING AND TESTING

Final setting of the canal control system requires the definition of the following for each pool:

- The control time step.
- The correction speed of the controllers (correction time).
- The coefficient of correction carried over to the upstream reaches (for coordination between reaches).

Use of a simulation software

The control system parameters cannot be calibrated directly on the site. For safety reasons and to optimize the performance of the control software, it is essential to have available simulation software. This simulation software enables :

- analysis of the system hydraulic constraints,
- better knowledge of canal hydraulic behavior,
- canal simulation in automatic control,
- calibration of the control parameters.

At the start of the 1990s and in collaboration with the Indiana Institute of Technology in Bombay, SSNNL began the research work which has enabled it to develop :

- a simulation model in steady flow conditions (Acharya (1994)),
- a simulation model in unsteady flow conditions (Acharya (1994)).

The performances of the simulation software was compared with other simulation models. Thanks to this research work by Dr K.D. Acharya, SSNNL has the reliable and high-performance tools needed to undertake hydraulic studies of this size.

Creation of a simulation platform

In order to analyze the performances of the system, the control software has been linked to the SIC simulation software (CEMAGREF 1992) used for the study. Collaboration with SSNNL will enable this platform to be integrated in the model developed by Dr K.D.Acharya.

Calibration of the control parameters

Different simulations on the first ten pools of Narmada Main Canal have provided the following results:

- Control time step : a first analysis carried out with a control time step equal to 1 hour was not conclusive. This choice limits the flexibility of the canal.

Other simulations were carried out with a control time step of 30 minutes and 15 minutes. Comparison of results has led a time step of 15 minutes. This choice optimizes performance without using the gates too often.

- Correction time : The correction time which defines the correction rate has been set at 8 hours.
- Coordination coefficient : So that control remains stable and uniform, an identical coordination coefficient has been chosen for all the reaches equal to 80%.

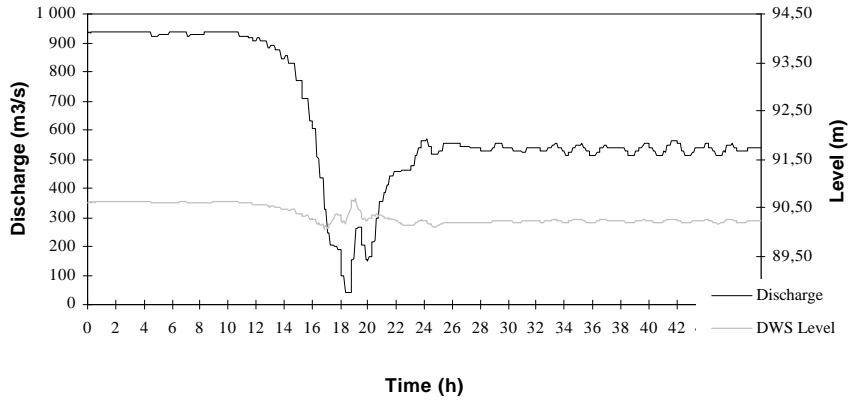
Regulation testing on Narmada Main Canal

The purpose of the simulations is to analyze the balance between the control system proposed and the actual behavior of the canal. Three types of situations have been analyzed :

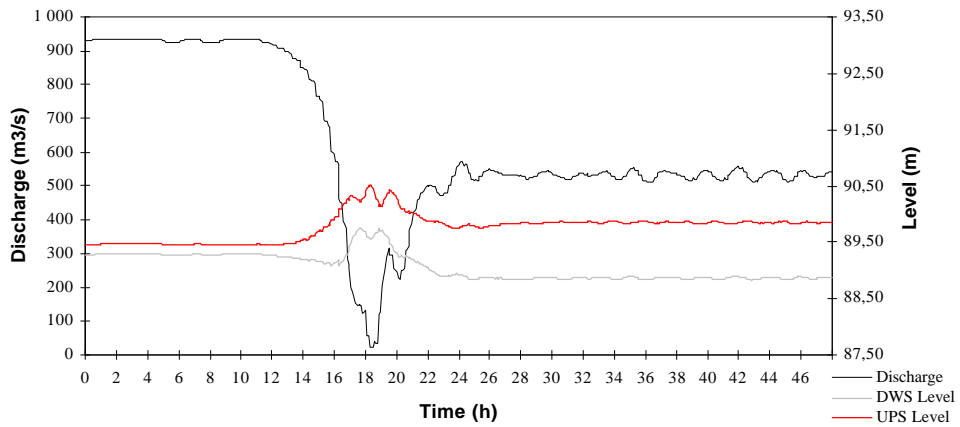
- normal operation with demand variations,
- abnormal operation corresponding to the shutdown of the Saurashtra branch canal ($400 \text{ m}^3/\text{s}$),
- emergency situation with a total closure of the Main Canal.

All the simulations were executed for the most critical operating configurations (close to maximum flow). The graphs in figure 6 hereafter show the results of the simulation in case of sudden shutdown of the Saurashtra branch canal due to the electric supply outage. These results, which correspond to a control response after an instantaneous refusal of $400 \text{ m}^3/\text{s}$, are visible on CR0, CR1, CR2 of the Main Canal. They show uniform and stable behavior of the canal which confirms the constraints imposed by SSNNL. This validates the accuracy and the reliability of control software.

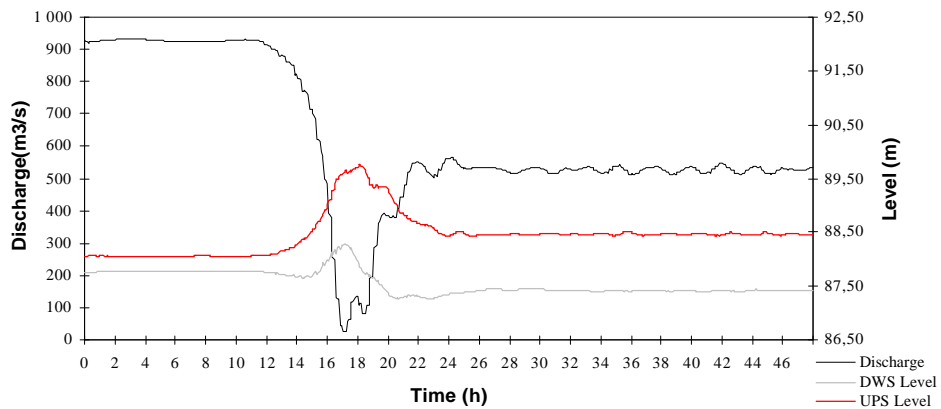
CR 0



CR 1



CR 2



DWS : downstream

UPS : upstream

Fig. 6. Simulation Results

CONCLUSION

This paper is a summary of the Narmada Project which describes :

- the overall organization of the Sardar Sarovar (Narmada) project,
- the choices made by SSNNL to control the canals which convey more than 8.5 cubic meters per second,
- the main principles characterizing the control software proposed.

Even if at this stage of the project nothing has been definitively adopted, the studies carried out on the pilot project have demonstrated that :

- the controlled volume concept is well-suited to the project. The control process adapts to the system dimensions by reducing the transit time on the conveyor,
- the control logic proposed enables :
 - known events to be anticipated,
 - volume in the reaches to be maintained equal to the target volume,
 - all the settings to be coordinated.
- the control system proposed ensures stable and uniform behavior of the canals.

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