Chapter 4

Control Philosophy

There are many methods for Canal Control Operation for distribution of water since long. Generally the system deployed so far used supply based rather than demand based operation, leading to uneven distribution of water. Tail end WUAs used to get less or sometimes no water, as upstream end WUAs collected water immediately available. Travel time is another constraint. It takes more than four days to reach the tail end for about 100 Km canal. Thus if water requirement is generated now at tail end, it might take more than four days, during which time, the crop may be lost.

In order to deliver water as when required without much delay and to improve the canal efficiency, demand based supply is found more efficient. Water is made available at right place, in right quantity, at right time improving the yield thus improving can efficiency. One of the methods for calculation of canal efficiency is yield (Crop) to water delivery (volume of water) ratio.

We will discuss mainly the following control philosophies, now adapted in the recent times. Some of them can be used with Manual control, but some of them are essentially using SCADA system.

1. Downstream Level Control
2. Upstream Level Control.
3. Constant Volume Control
4. Controlled Volume Control (Dynamic Regulation)

The method of operation is based on the location of the water surface pivot point in the canal pool. The pivot point is the location within the canal pool at which the level or depth remains constant while the water surface slope varies.

- Constant Down Stream Level: The pivot point is located at the downstream end of the canal pool, (Fig 4.1A)
- Constant Upstream Level : The pivot point is located at the upstream end of the canal pool, (Fig 4.1B)
• Constant Volume: The pivot point is located generally near the midpoint of the canal pool, depending upon the canal configuration (Fig 4.1C)
• Controlled Volume: The pivot point can move within the canal pool, depending upon demand and supply requirements (Fig 4.1D)

The location of the pivot point is particularly important when selecting a control method, i.e. local manual, local automatic or supervisory control.

4.1 Downstream Level Control:

Most canal systems use the constant downstream depth method of operation in which the water level at the downstream end of the each canal pool remains relatively constant. There are two primary reasons why this method is so prevalent. Firstly the canal can be sized to convey the maximum flow under steady conditions, with steady state water levels will never exceed the normal level at that design flow rate. The size of the canal prism and the lined free board can be kept a minimum, reducing construction costs initially and safe during modernization. Secondly, this method of operation is very compatible with local manual control, which is the prevalent method of control with the most of the existing canals.

Generally major turnouts are usually located near the downstream end of the canal pool, i.e. in the upstream of check structure. With a constant downstream level allows turnouts to be designed for a maximum and relatively constant depth in a canal pool preventing problems in water delivery to users caused by low or fluctuating water levels. Escapes gates are also located at the downstream end of the pools, useful for releasing water during emergency in case water levels at increase beyond available free board.

When a constant level is maintained at the downstream end of the canal pools, the water surface profile will essentially pivot about this point as the Canal flow changes. (Fig. 4.1 A) A storage wedge between different steady-state flow profiles is generated. When the flow increases, the water surface gradient and storage volume must increase. Conversely, storage volume must decrease for reduction in steady-state flow.
Constant downstream level method of control is particularly effective when combined with the upstream operational concept having supply oriented operation due to storage consideration.

A flow change which originates at the upstream end of a canal pool will tend to create the changes in the storage which accompany this method. When pool inflow increases, the water surface gradient must become stepper, thus additional water quantum is required to achieve higher surface elevation in the upstream of the pool. When the pool inflow decreases, the water surface gradient must become flatter, thus water in excess will be required to be depleted to lower the surface gradient in the upstream of the pool, thereby making the water surface gradient flatter.

Any control method can be used to implement the constant downstream level method of operation. Local manual control method has been traditionally used but automatic or supervisory control can be successfully implemented for constant downstream depth control operation. Constant depth in the downstream can be controlled with the use of either upstream or downstream canal control gate. The upstream gate would be controlled to satisfy a downstream operational concept and the downstream gate would be operated to satisfy an upstream an upstream control concept. However controlling upstream gates to satisfy downstream level will need the communication means to know the downstream level. This is now possible with modern SCADA systems.

4.2 Upstream Level Control:

In the case of constant upstream level control method, upstream level of the canal pool is maintained constant. This method is also sometimes called ‘Level Bank operation”, since the canal bank must be horizontal to accommodate the zero-flow profile, as Fig.4.1. The construction of a level bank canal at downstream is the main drawback of this method. It can increase the cost of the construction considerably and may be very difficult during modernization, making it difficult to adapt during the use of SCADA system.

The constant upstream level control method of operation is most effective when combined with the downstream operational concept. Flow changes originating at the
downstream of the pool cause canal water levels to change in the direction needed to achieve new steady state profile.

Downstream level rises during reduction in pool outflow causing the water surface gradient to become flatter, thus additional water quantum is required to achieve higher surface elevation in the downstream of the pool. An increase in the outflow causes downstream level to fall, thereby the water surface gradient becomes steeper, and thus water in excess gets depleted to lower the surface elevation in the downstream of the pool.

Any manual or automatic control method can be implemented for constant upstream level control of operation. Control can be based upon maintaining the target level at the upstream pivot point thus allows the target to be located immediately downstream of the check gate structure being controlled. Automatic control can be used with level control set point at each pool’s upstream end. Local automatic control can be used for a demand based system without requiring long distance communication between depth sensor and the control structure. Automatic float actuated gates use this principle to react to downstream demand.

In the case of Manual or semi-automatic operation, it takes some time to have level effect at upstream that of the releases at the downstream, making the control system sluggish. However this is not the case in the use of SCADA system,

4.3 Constant Volume Control

This control technique shifts the control from Supply based system to demand based system. It is rather the beginning of better control system not requiring sophisticated control algorithms, and expensive SCADA system, but a control system with good communication facility. The pivot point in each pool should be determined to have successful operation. The pivot point may not be exactly at the center of the canal pool, but may vary depending upon the physical dimensions of the pool.

Constant volume operational method is based on maintaining a relatively constant volume of water in each canal pool at all the times. This will cause the water surface to pivot about a point near to mid-pool as the flow changes form one steady-state to another. This method is sometimes called “simultaneous operation” because the
simultaneous gate operating technique must be used to keep the pool volume constant. The main advantage of the constant volume method of operation is the ability to quickly change the flow conditions in the entire canal system. One disadvantage of simultaneous operation is the additional canal bank and lining required at the downstream end of each pool, as compared to normal conventional canal bank. However, this additional height to accommodate the zero-flow water surface, is only about half as that is required for level bank operation. Another potential drawback to constant volume operation is the requirement of simultaneous adjustment of all the control structures. Local manual control could only be used if a gate operator is stationed at each check structure, which is usually not feasible. Supervisory control is the primary control method used for constant volume operation. Using Supervisory control, all of the control structures can be adjusted simultaneously from control location, either manually or automatically.

4.4 Controlled Volume Control (Dynamic Operation)

With controlled volume control operation a canal system can be operated by managing the defined volume of water contained in each pool. The volume can be made to change to satisfy the control criteria, allowing the pivot point to move within the pool. Since the operation is based on volume, either flow or level (quite often flow) is used as the measured quantity. The location of the pivot point assumes much less importance than with the other method of operations. In fact, the water surface may sometimes rise or fall without the pivot point, like reservoir.

This type of control method is applied to control canal system rather than canal pool in the total canal system as discussed in the three earlier operational methods. It offers most flexibility of any one of the methods, allowing adapt to normal, abnormal and emergency conditions, but excessive depth fluctuations must be prevented. This method can be adapted to any of the above system very easily.

Fig 4.2 illustrates the typical example of control volume control operation. In this example there is a rapid outflow reduction at the downstream end of the canal. The check gates upstream are all simultaneously adjusted to reduce the canal flow, but the amount of flow reduction is smaller at each successive check. Therefore the flow into each canal pool at the upstream gates is greater than the outflow, increasing the
volume of water in each pool. After the volume has increased by the desired amount additional gate movements balances inflow and outflow to prevent excessive depths.

There could be several reasons for creating the operations in this example. The level fluctuations can be managed to minimize the rapid draw down at the upstream end of the pools without wasting water or exceeding the maximum levels allowed at the downstream end. This can save lining damages which might have otherwise resulted from the flow change. Another reason might be to transform the rapid flow change at the downstream end into a gradual flow change in the upstream canal pool, by pool storage as a buffer.

Controlled volume control operation requires the use of the supervisory control method. Supervisory computer-directed control is the most essential, because without computer assistance, the complexities of controlled volume operations would require frequent intervention by operational personnel. Computer directed control would use specially developed software to automatically control the check gates to maintain the desired volumes, requiring infrequent operator intervention.

This type of system was first tried at Pilot Project for Dynamic Regulation (PPDR) at Mazalgaon; however was not fully successful as already mentioned earlier. We must be really careful in implementing such a system in developing countries in general and India in particular.

This system is being implemented now at Narayanpur Canal Irrigation Scheme of Krishna Bhagya Jal Nigam (KBJNL) now, but the results are yet awaited.

Since the Controlled volume control (Dynamic Regulation) will be the philosophy adapted in future as it is going to improve the canal efficiency by delivering water as and when required, increasing the yield. The system is basically a demand based operation rather than supply based operation.

We will discuss on this type of control system in more details.
Fig. 4.1 CANAL CONTROL PHILOSOPHY
At the start of the system, the irrigation program will compute the schedule of discharges at each control point for a 24 hour period. We assume that the rotation cycle is of 24 hour (one day)

According to this forecast schedule of flow, the regulation software calculates the gate opening for each structure and for each time step and dispatches the corresponding instructions to the control facilities for implementation and then checks that all instructions have been properly executed. This completion of execution is confirmed by the real time data collection of all the parameters.

With the concept of controlled volume, the response time of canals being suppressed, this principle of operation can be achieved immediately without waiting for the propagation of water from the headwork. It is assumed here that sufficient amount of volume is kept in all the reaches of the canal.

However, the extreme flexibility of this concept must not conceal the fact that the actual demand of water and the precise conditions of canals are not exactly known and assessed due to:

- The extreme complexity of the whole system with a very large number of irrigation off takes where problems can arise at any time failure, rain, social
constraints, etc. making it difficult to get all necessary information in real time. The physical limitations inherent in such a system such as inaccuracy of measurements, inaccuracy of hydraulic formulas and calibration coefficients, slow variation of roughness coefficients, etc. do not enable a total match between the computed flows and depths and the actual ones.

- All unexpected small events which can happen all along the canal which will affect the normal operation of the control system.

The regulation software has to take account of these discrepancies in order to adjust the control regulators and the off take gates. It has to be noted that these discrepancies are not known in detail, but through the consequences they have on the volume of pools which themselves are known precisely through the measurement of levels transmitted by the telemetry network. These corrective actions are therefore based on volume deviations.

The basic model must simulate the canal operation, considering all the as-built dimensions. With this canal model, the maximum values of these discrepancies have to be determined, with all causes being considered. These values are those which can be taken into account by the control system without any consequences on canal operation (stability and accuracy).

### 4.4.1 General Control Concepts

In general the closed loop control of a physical system is represented by the Fig 4.3.

The command determined by the corrector acts on the system in order to suppress the deviation between measured and target valves.

For canal control, the closed loop action is represented by the same diagram where:

- Perturbations are unforeseen outflow,
- Measurement is the volume in the reach,
- Target is the target volume in the reach.
In such a system the corrector must comply with three criteria of performance:

- **Accuracy**: the range of the deviation must be as small as possible and particularly after a correction of a perturbation, the volume of the reach has to become again close to the target volume.

- **Speed**: the correction must be performed quickly and the steady condition has to be reached after a short period.

- **Stability**: the correction must not create oscillations of the water level with a risk of amplification affecting the canal safety.

Most of the time, it is not possible to satisfy perfectly all these three criteria and generally the corrector performances are a compromise between these conditions.

This type of control exercise is used in selection of the best-suited corrector by using the conceptual, theoretical and mathematical development and then tested simulation.

In modern Design Control System, especially in computer control design, extensive use of process and controller modelling is performed. This avoids undertaking the old lengthy, laborious and hazardous trial and error parameter tuning. One of the most efficient modern design methods is pole placement method. Generally implementation of the P+PR controller is proposed for Dynamic control of canal system. This controller will need the tuning of at least two parameters per pool, with no modelling of the process as in the modern System Control Design, and in a trial and error approach.
4.4.2 Control Logic

The control logic is directly deduced from the general control concept chosen, i.e. controlled volume.

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.
- 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.
- Coordinating action which consists in adding the corrective action made on the downstream CRs (cumulative carry forward).

Finally, the discharge to be adjusted at each regulation time step is:

\[ Q = Q_{\text{Forecast}} + Q_{\text{Correction}} + Q_{\text{Coordination}} \]  

(4.1)

4.4.3 Flow Correction

As described above, the adjustment of flow for each cross regulator and at each step of time is obtained by adding three actions:

- The anticipatory action (Open loop) determines the discharge to be adjusted in order to comply with the schedule of irrigation and the consequences of the detected perturbations (for example the outage of a pumping station).

With the controlled volume concept this action is very easy to implement, as no propagation delay is to be taken into account. In this way the open loop consists in
applying directly the schedule of flow with the corrections deduced from the detected perturbations.

- The corrective action (closed loop) determines the correction of flow adjusted at the upstream CR in order to maintain the target volume of the reach.

Finally, the most difficult part of the control system is corrective action. It is to be noted that the choice of a particular controller does not change the general strategy as above. Practically one has simply to modify the module in the regulation software devoted to this task. This action requires a long development and the utilization of automation concepts and methods.

![Diagram](diagram.png)

**Fig. 4.5 Closed loop action**

### 4.4.4 Pole Placement Controller Design

In this study, the corrector and the reach are represented by transfer functions which, can be expressed as below:

- Time domain
- Frequency domain
- Discrete domain

Generally the control software utilises the formula derived from the time domain mathematical expression.

The formula of the corrector is obtained by using the pole placement methodology:

- Identification of the transfer function of the reach (reach volume function of flow);
- Selection of the best suited transfer function for performing the required canal control;
- Determination of the closed loop transfer function along with appropriate control coefficients;
The results are to be validated by simulation at each step.

There are two characteristics of this approach:

- One parameter only has to be tuned for a pool: the correction time $T_c$.
- This correction time is closely related to physical features of the pool. As all the physical parameters are available before the start of the system, it is an advantage of the method.

4.4.5 The P+PR (Proportional + Preoperational Reset) Controller Design

P+PR controller needs two parameters for each pool, as described. This approach is not based on a modelling of the physical system for control purpose. As a consequence, the tuning of the parameters is performed by a lengthy and hazardous trial and error procedure, since the parameters have not physical meaning. This constitutes a major drawback for the method. Moreover, since the pool controllers are in fact coupled, tuning of one set have an influence on the other controllers.

4.4.6. Regulation Software Formulas

Formulas for computation of volumes and of correction discharges are expressed as:

4.4.6.1 Volume Assessment

Different solutions can be utilised to assess the volume of a reach. It is a pseudo steady flow condition method, where the volume is computed by back water profile with the following conditions:

- Downstream depth of the reach corresponding to the water level measurement,
- Discharge obtained by averaging the measured flow at the upstream CR.

4.4.6.2 Volume Calculations

The regulation database contains a two dimensional array as shown in Table 4.1 for regulation for each reach, as shown, giving the volume of water in the canal according to the transiting discharge and to the water level downstream. All the values have been predetermined by a steady flow condition calculation.
Table 4.1 Volume per reach of the Canal

<table>
<thead>
<tr>
<th>Level</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>V(Q1,L1)</td>
<td>V(Q2,L1)</td>
<td>V(Q3,L1)</td>
<td>V(Q4,L1)</td>
<td>V(Q5,L1)</td>
</tr>
<tr>
<td>L2</td>
<td>V(Q1,L2)</td>
<td>V(Q2,L2)</td>
<td>V(Q3,L2)</td>
<td>V(Q4,L2)</td>
<td>V(Q5,L2)</td>
</tr>
<tr>
<td>L3</td>
<td>V(Q1,L3)</td>
<td>V(Q2,L3)</td>
<td>V(Q3,L3)</td>
<td>V(Q4,L3)</td>
<td>V(Q5,L3)</td>
</tr>
<tr>
<td>L4</td>
<td>V(Q1,L4)</td>
<td>V(Q2,L4)</td>
<td>V(Q3,L4)</td>
<td>V(Q4,L4)</td>
<td>V(Q5,L4)</td>
</tr>
<tr>
<td>L5</td>
<td>V(Q1,L5)</td>
<td>V(Q2,L5)</td>
<td>V(Q3,L5)</td>
<td>V(Q4,L5)</td>
<td>V(Q5,L5)</td>
</tr>
<tr>
<td>L6</td>
<td>V(Q1,L6)</td>
<td>V(Q2,L6)</td>
<td>V(Q3,L6)</td>
<td>V(Q4,L6)</td>
<td>V(Q5,L6)</td>
</tr>
</tbody>
</table>

The volume in the reach at a given time is calculated in real time by linear interpolation in the table 4.1.

By knowing level measured downstream of the reach Ly and the transiting discharges Qx; the volume is obtained through the following calculation:

\[
V(Q2, LY) = \frac{V(Q2,L3) - V(Q2,L2)}{L3 - L2} (LY - L2) + V(Q2, L2) \tag{4.2}
\]

\[
V(Q3, LY) = \frac{V(Q3,L3) - V(Q3,L2)}{L3 - L2} (LY - L2) + V(Q3, L2) \tag{4.3}
\]

\[
V(Qx, LY) = \frac{V(Q3,LY) - V(Q2,LY)}{Q3 - Q2} (Qx - Q2) + V(Q2, LY) \tag{4.4}
\]

### 4.4.6.3 Transiting Discharge

This discharge corresponds to the average discharge adjusted by the cross regulator situated upstream of the reach, but which has not yet propagated down to the downstream CR. It can be estimated in real time.

The propagation time to establish the discharge from upstream to downstream of the reach is:

\[
\text{Delay} = \frac{\Delta V}{\Delta Q} \tag{4.5}
\]

V: Volume of water calculated in steady state
According to Table 4.1, the reach delay is calculated, in real time, for the operating point defined by the downstream water level and the transiting discharge at the previous regulation time step \((Q_x, LY)\). The reach delay is equal to the rate of variation of the volume over the discharge for a constant downstream water level.

If the transiting discharge at the previous regulation time step \((Q_x)\) is between the discharges \(Q_i\) and \(Q_{i+1}\) of the database table, the following is obtained:

\[
\text{Delay} = \frac{V(Q_{i+1} - Q_i)}{Q_{i+1} - Q_i}
\]  

Finally, the transiting discharge is equal to the average released discharge upstream of the reach during the delay.

This discharge is calculated on each regulation time step by converting the delay into a number of regulation cycles \((N_b = \text{Delay} / \text{Regulation time step})\).

\[
Q_{\text{transit}} = \frac{1}{N_b} \sum_{i=1}^{N_b} Q(t - i)
\]  

\(Q(t-i)\) is the discharge measured at the cross regulator upstream of the reach at time \(t-i\). The transiting discharge is used to estimate the volume in the canal.

### 4.4.6.4 Determination of Correction Discharge

Pole Placement Method

The transfer function of the corrector gives the value of the correction discharge. The coefficients of the transfer function are obtained using the pole placement method.

The mathematical expression of the function is:

\[
Q(t)K_p[\text{Error}(t) + (N_1 - 2D_{1c})\text{Error}(t - 1) + (D_{1c}^2 - 2N_1D_{1c})\text{Error}(t - 2) + N_1D_{1c}^2 \text{Error}(t - 3)] - (D_{1c} - 1)Q(t - 1) - (D_{2c} - D_{1c})Q(t - 2) + D_{2c}Q(t - 3)
\]

Where:

- \(\text{error}(\cdot)\) are the volume deviations at instants \((t), (t-Te), (t-2Te)\) and \((t-3Te)\)
• Q( ) are the flow corrections already done at instants (t-Te), (t-2Te) and (t-3Te).

All the coefficients are known when the correction time Tc is fixed:

\[ D_{1v} = e^{-2\pi} \]
\[ K_p = (1 - D_{1v})^2 T e \]
\[ P_1 = 0.1 \]
\[ P_2 = e^{-2\pi T e/Tc} \]
\[ D_{2c} = P_1^2 P_2^2 \]
\[ D_{1c} = 2D_{2c} - 2P_1 P_2^2 - 2P_2 P_1^2 \]
\[ K_D = \frac{2 - D_{1c} - P_1 - 2P_2}{K_p} \]
\[ N_1 = \frac{P_1^2 + P_2^2 + 4P_1 P_2 - P_1^2 P_2^2 - 1 + 2D_{1c}}{K_p K_D} \]

P+PR (Proportional + Proportional Reset) controller

The correction discharge is the sum of two terms:

A proporationnel term : \[ P(t) = K_p \text{error}(t) \]

A proportionnel reset term : \[ PR(t) = K_I T_e \frac{\text{error}(t-1) + \text{error}(t)}{2} + PR(t-1) \]

This gives for the correction discharge the following expression:

\[ Q(t) = \left( K_p - \frac{K_I T_e}{2} \right) [\text{error}(t) - \text{error}(t-1)] + K_I T_e \text{error}(t) + Q(t-1) \quad (4.9) \]

This approach is not based on a modelling of the system for control purpose.

Therefore, for each pool, the parameters \( K_p, K_i \) are to be tuned by a lengthy trial and error procedure.

### 4.4.7 Regulation Software

The regulation software is the heart of the whole system. All the relevant canal as-built parameters for any particular site should be programmed to give appropriate results. Initially the model should run for some time, and should be fined tuned using on-line working parameters.

The regulation software ensures automatic control of the main canal and all check structures, including Cross Regulators and Head Regulators of Distributaries.
The control software performs three different actions simultaneously:

- **Anticipatory action** (demand forecasting and open-loop control): The software receives the pre-established discharge program at off-takes from the Water Allocation Management System. Discharges forecast at check structures are then calculated from these programs according to hydraulic characteristics of canals.

- **Corrective action** (feedback): Pool inflow and outflow cannot be perfectly balanced in practice, resulting in volume variations in each pool which have to be counterbalanced by a corrective action. The volume of water contained in the canal is calculated in real-time from field sensors (level, discharge, gate opening) and canal modelling. This volume is compared to the target volume in order to compute corrective action through a controller.

- **Coordination action**: The corrective action can be different for two adjacent pools, causing discrepancies between inflow and outflow in the pools. This imbalance is mitigated by carrying forward the corrective action from one pool to the other upstream pools. However, this action, referred to as co-ordination action, is not mandatory, as any imbalance can be corrected by another corrective action. Coordination actions speed up the control process and help maintain pool volumes closer to their targets.

### 4.4.7.1 Software System

The software should develop using open operating system making it immune to operating system. This is object-oriented software, organized into several classes of objects. Each class defines on one hand the data or “members” required to describe the object, and on the other hand the collection of “methods” which can be used to carry out treatments. “Dynamic Regulation” is composed of classes which can be divided into 3 main packages

- **Topology package** related to the physical elements of the system
- **Control package** related to functional elements that define the operation rules and control logic of the system
- **Utilities package** for data acquisition and user interface.
The general structure of the software should be easy to maintain and adapt to particular canal sites. The advantages of the structure can be seen on at least two levels:

- It is structured from general classes to specialized
- It is possible to adapt the behaviour of a class and create new classes, limiting the modifications to what is strictly required and taking advantage of the parent class over the time. This may be useful to add new functions or to adapt the existing ones to different operational conditions.

The software also should take care of all the possible problems which can occur in due course of time in real world as below

- Discrepancy between forecast and actual demand
- Failure of communication links
- Failure of sensors
- Operation of the canal in specific conditions for maintenance works, etc.

### 4.4.8 Regulation Interface

Through the operating interface, the operator monitors the performance of the regulation software and makes all the changes required during operation. This may be, for example, modifications of set points, scheduling at off takes, and operational mode in the software.

This interface also offers tools based on the canal hydraulic models and designed to assist operators in their work. As an example the following tools are available:

- Calculation of water propagation times
- Verification of coherence of measurements
- Calculation of the discharge at one structure depending on conditions fixed by the operator

The customisation interface is used to adapt the software to system changes in terms of either physical characteristics or changes on measuring and control equipment in the field.

The canal System is operated under the controlled volume concept of canal control which practically suppresses the canal response times and enables fast adaptation for the water demand variations. However other control concepts can be chosen, like
controlled level concept in the due course of time if needed. This will help the system to convert from demand based operation to supply based operation, during draught times, where there is water shortage, and must be controlled critically.

This control system requires the installation of a remote transmission network (telemetry and control system) consisting of:

- The remote terminal units (RTUs) located along canals. They collect / transmit measurements, and receive instructions and set points.
- The Control Centre, receiving the measurements from the RTUs and generating instructions and set points dispatched to the RTUs.

Control Centre controls the canal using a hydraulic Regulation Software which constitutes the active core of the system. Regulation Software comprises a large number of calculation modules, each ensuring an elementary operation. These modules receive information from the telemetry network, permanent databases and, if necessary, operators and generate instructions which are sent to the RTUs or displayed on the screens of the operators.

![Diagram of Canal Control](image)

**Fig. 4.6 Canal Control for normal operation**

The general organisation of canal control for normal operation is shown in the Fig.4.6
4.4.9 Exceptional Operation

The regulation software has also to cope with some possible accidents and malfunction of the system while it is running normal operation. These instances can arise separately or simultaneously, affecting a point or a large part of the canal.

The result is an extremely large number of possibilities. It is possible to define an overall strategy, taking into account progressive deterioration of automatic reaction and also accompanied by progressive decentralisation of the decision.

The accidents and malfunction of the system can be classified as:

- Control system operation failure (transmission line break and/or failures of computers and peripherals)
- Hydraulic system failure and/or control structures (blockage of a gate, massive inflow of run-off water as a result of heavy rainfall etc.).
- Measurement inaccuracies or unexpected changes in demand.

As a solution to these types of failures, various degraded operating levels can be proposed, depending upon the seriousness of the incident and the operating status of the control system. The actions should be taken can be fully automatic, by means of the regulation software, or must include manual operator actions depending on these elements.

The regulation software can determine and execute the correct action as:

- Communication system is working.
- Diagnosis of the incident is possible.
- The flow variations are acceptable due to the incident.

The result of the above has the effect as:

- Conditions apply to the whole system,
- The conditions apply upstream of the point where an incident has occurred. In this case the canals situated downstream are subject to deteriorated operation.
The regulation software cannot correct the consequences of the incident

This occurs in the case of a too important corrective action or an impossible automatic diagnosis which makes the corrections risky. In this case it is assumed that the remote communication is operating correctly.

In this context, the control centre operator takes over control manually, either on the whole system or simply downstream of the incident. He decides the corrections to be made and transmits the instructions to the RTUs which execute them automatically.

The regulation software cannot correct the consequences of the incident and the RTUs cannot execute the instructions

This is a variation of the earlier case, when the remote communication of orders is not possible.

In this case the central operator takes the decisions and transmits them to the local operator who executes them manually.

The incident occurs when the remote transmissions no longer operate

The decisions are then taken and executed locally by an operator at the RTU site. In all cases, staff on duty must warn the Control Centre via the communication network or by any other means, and he applies the following local safety rules, depending on the current problem:

- Loss of communication means with the Control Centre. An audible alarm warns regulator site personnel of a loss of communications with the Control Centre. The operating mode is set to "manual" and the gates are operated to maintain the level upstream the cross regulator at its value before loss of communications. When the communications return, an audible alarm indicates that automatic remote operation can be resumed.

- Overrunning the level thresholds (high-high or low-low). Regulator site personnel are informed of the threshold overrun by an audible alarm. The operating mode is then set as "manual" and the regulator site personnel operates the gates so as to
maintain the level upstream of the CR at its limit value (high-high or low-low). This manual operation is maintained until the Control Centre informs site personnel that remote automatic mode operation can be resumed. The same procedure is applied for manual operation of escapes when the "high-high" level is overrun.

In order to highlight the emergency strategy for different types of problems, the decision flow charts are presented hereafter. A first flowchart provides the general framework of emergency operation. Three additional flowcharts describe in more detail the mechanism for decision for each of the three categories of incidents presented above.

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