# DYNAMIC REGULATION ON THE CANAL DE PROVENCE

Daniel Rogier* - Senior hydraulic and water supply engineer
Charles Coeuret* - Chief and Deputy, Dynamic Regulation
(Operation R & D)
Jean Brémond*- Chief and Deputy, Dynamic Regulation,
(Operation R & D)

## 1. DESCRIPTION AND SUMMARY

The present article is not a full and detailed description of dynamic regulation. This type of control has been the subject of many articles and, in this paper, we have restricted ourselves to one of the aims of this conference, that is to say highlighting the original and specific nature of various types of automatic control. We shall therefore quickly pass over some of the less original aspects, or those common to most modern control systems (such as local controllers or remote monitoring systems), to concentrate on certain more interesting features, and especially, communication of requirements by users, forecasting, the hydraulic aspects of a control system and safety.
The specific nature of the Canal de Provence and its control method, "dynamic regulation", may be summarized:

- as an entirely man-made water conveyance and distribution system comprising a branched network of various types of structure (canals, tunnels, feeders) mainly functioning by gravity flow. The system incorporates secondary, pump-operated conduits at its extremities the management of which is integrated into overall canal system management,

- as a system which supplies water to 40,000 ha of agricultural land, 70 towns and villages and a great many industries. It operates on an "on-request" basis (that is to say without rotational distribution or prior notification). Head flow is 40 $m^3/s$ and the length of just the main conveyance structures is some 230 km.

Dynamic regulation is a remote management, control and monitoring system which is entirely automated and ensures permanent closed-loop control of all water movements and safety devices.

Although the material features of this system have developed to reflect new equipment and techniques available on the market, its basic conceptual principles have remained unchanged. Major significance is accorded to calculation of consumption forecasts whereas actual control calculations (forecasts of canal flow and gate apertures) have been voluntarily simplified.

---

* Société du Canal de Provence - BP 100 - Le Tholonet -
13603 AIX EN PROVENCE CEDEX 1.

Experience has shown that abandoning calculation of transient regimes greatly reduces the burden of calculations and makes for substantial improvements in reaction time, which largely compensates for less precision.

Of course, the operator is not entirely absent. One of the centralized computer's functions is to call up the operator who takes over the controls when required and plays an active role in constantly improving the control program calculation modules.

## 2. OVERVIEW OF THE CANAL DE PROVENCE PROJECT - LOCATION AND SIZE

The Canal de Provence is the name given to a multi-purpose and complex hydraulic system for the conveyance and distribution of water in the south of France.

The area served is a vast region which is limited by:

- the Durance and Verdon rivers to the north, left bank tributaries of the lower Rhone,

- the Etang de Berre and the lower Durance valley to the west,

- the Mediterranean coast to the south,

- and the mountain ranges which receive adequate precipitation to the east.

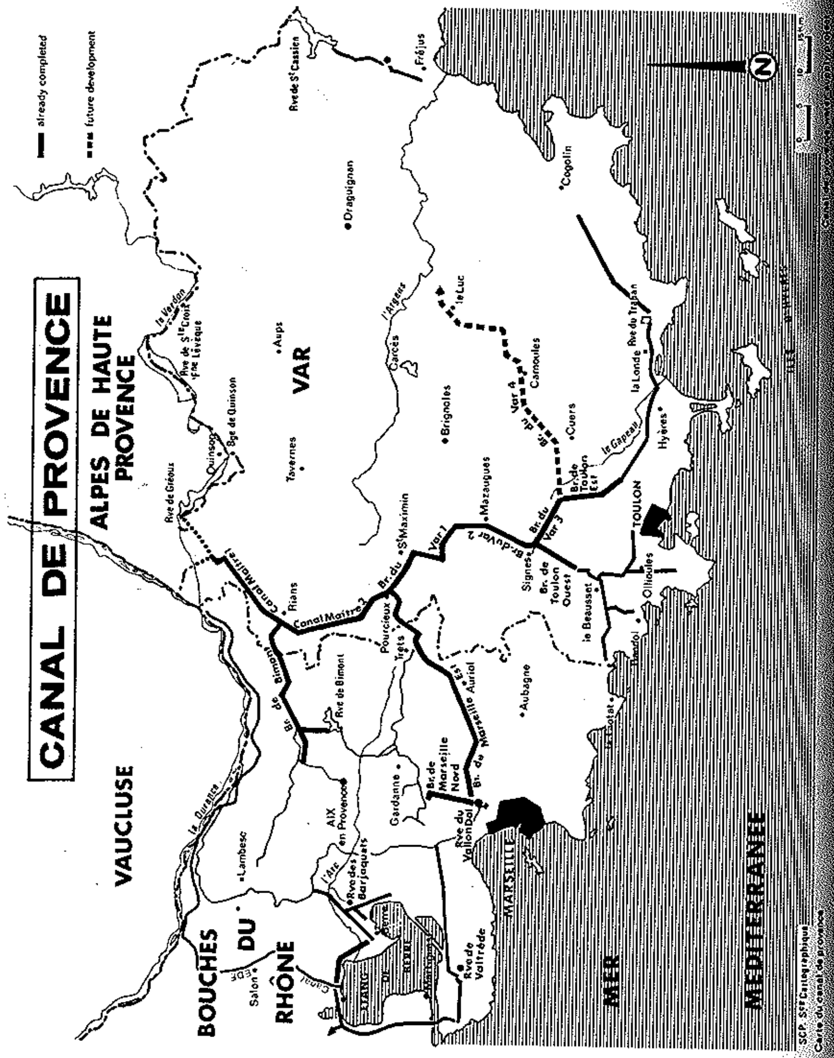
The total area covers some 110 km from east to west and 70 km from north to south.

Water is distributed from a single intake on the Verdon reservoir, itself receiving upstream flows from a carryover storage reservoir (Sainte Croix). Control and diversion of Verdon flows have formed part of a vast hydraulic project for the Durance and Verdon catchment area. Man-made impounds enable significant volumes to be diverted to other river basins.

The hydraulic network downstream from the intake is used to convey and distribute water via a tree-structure canal system comprising four major branches connected to the main or master canal.

A compromise as to the distribution of water to the main utilizers (electricity authority, lower Durance valley irrigation, the Société du Canal de Provence) has attributed 760 million $m^3$ p.a. to the Canal de Provence out of an annual average available in the Verdon catchment area of 1100 million $m^3$ p.a.. The current annual diverted volume is 150 million $m^3$ with branches used to varying degrees.

Canal de Provence construction work has been carried out in successive stages since 1965. The last of the four branches referred to was inaugurated at the end of 1986. The fifth branch remains to be constructed at a date which has not yet been fixed.



## 3. BRIEF DESCRIPTION OF HYDRAULIC LAYOUT AND CHARACTERISTICS OF THE CANAL DE PROVENCE

### 3.1 MAIN CHARACTERISTICS OF HYDRAULIC STRUCTURES

A clear distinction must been made between:

- the main conveyance network comprising canals, tunnels, siphons and aquaducts,
- the downstream distribution networks, generally a fairly densily branched and pressurized network of conduits.

1/ The main conveyance network comprises the main or master canal and its four branches or secondary canals. It operates through gravity flow and has a head capacity of 40 m$^3$/s. Each one of the four secondary canals has a head intake flow approaching 10 m$^3$/s. Total length of the master canal and the secondary branches is 235 km and includes:

. 105 km open channels,
. 130 km pressure tunnel.

Various types of structures have been integrated in this network:

. 2 long siphons,
. 1 open channel aquaduct,
. 3 pressurized aquaducts,
. 2 small-hydros.

A seasonally operated reservoir (20 million m$^3$ capacity) and a back-up urban reservoir (3 million m$^3$) are supplied by canal branches.

The conveyance network integrates:

- main pressurized conduit conveyances with offtakes on the canal sections. Certain conduits being supplied by pumping stations or booster stations,
- a 56 km-long old canal system (head flow 7 m$^3$/s) has been integrated into the new conveyance system and connected to the Canal de Provence during construction of the latter.

2/ The distribution networks, always pressurized, are operated through gravity flow or pumping stations depending on topography (38 pumping stations or booster stations). Water is allocated as follows:

. irrigation: 1/3 of distributed volumes - 35,000 pressurized distribution points (4 to 9 bars guaranteed pressure) supplying around 40,000 ha,

. urban: 1/3 of distributed volumes - generally untreated water supplied to 70 towns or villages,

. industrial: 1/3 of distributed volumes - major flows supplied to limited number of users, mainly in the petro-chemical industry.

### 3.2 Specific hydraulic nature of system operation:

Hydraulic operation and system control is dependent on:

- physical constraints inherent in the distribution and conveyance network,
- constraints due to the guarantees given to users,
- constraints due to optimized operation.

1/ Physical constraints:

- practically no reservoir has been designed as a regulation structure, however, daily storage reservoir which are integrated into overall regulation and on whose availability regulation is based in addition to the usable capacity of reaches at each flow regime,
- restricted possibility of spillage due to the limited number and small size of water courses restricting outflows to values which are greatly below branch nominal flows,
- gravity flow operation. All releases at the head of the system must be capable of propagation down to the user. The average propagation time for water through the system is three to eight hours depending on the branch involved.

2/ Constraints due to delivery guarantees given to users:

The principle adopted is to have a system which operates "on request". The client, whether farmer, urban or industrial user, has total freedom to request or refuse water at any time within the limits of the guaranteed flow in his supply contract.

In practice, forecasting is relatively easy for urban and industrial consumption. However, it is much more delicate for irrigation where meteorological factors play a significant role. Storms (no irrigation) and, particularly, ends of periods of strong wind (irrigation) are typical characteristics of the region's climate which lead to sudden changes in irrigation requirements. The suddenness with which these changes occur (which may be aggravated by daily or weekly variations) and the relative slowness of hydraulic reaction time are the source of the main difficulties encountered in canal control.

3/ Constraints due to optimized operation: the aim is to make best use of reach storage capacities at a specific point in time to reduce energy expenditure or increase income from power production. This constraint is therefore imposed on the control system.

## 4. BASIC PRINCIPLES OF DYNAMIC REGULATION

### 4.1 GENERAL COMMENTS

The general theory underlying this method of control is to obtain overall automated remote management; this means that actuation of each control device (gate, pump, etc.) is computed and controlled automatically, and not in accordance with parameters (flows, levels, volumes, etc.) recorded in the vicinity of the device, but based on the overall status of the hydraulic system from the head of the canal system right down to the areas where water is distributed to users.

This general theory of control is not intended to be all encompassing. It cannot be separated from those specific factors which historically led to the Canal de Provence being progressively studied and then constructed (considerations which will be described in section 4.3). Generally speaking, the following paragraphs will explain the reasoning which give dynamic regulation a specific nature.

Firstly, the basic aims of this type of control are:

- to satisfy the requirements of different users with no other restrictions apart from the maximum flow provided for in each individual contract. The users must never receive notification of their allocation or requests for observance of water rotational distribution or for a specific delivery time slot. Explained in other terms, availability must be comparable with that applied to an electricity supply,
- to incorporate remote monitoring, remote control, optimum cost/benefits and automatic management of safety devices in a single system,
- to execute all these functions in a closed loop with no need for operator intervention; the latter only being required to intervene in the control system on emergencies and, routinely, to trace the source of computer-detected defects.

Secondly, the following main methods are used to implement these aims:

- the calculation methods and especially hydraulic calculations used to forecast flows and controlled instructions are kept simple and are broken down in time and space. Inevitable approximations are compensated for by the frequency of computation updates,
- overall system safety resides not only in the operational quality of each individual component but, to a large extent, on the highly flexible architecture both of the equipment and the operating software which generally guarantees greater reliability than that which would have been obtained by simply doubling or tripling equipment,
- one of the specificities of dynamic regulation software is the priority given to volume control relative to flow control.

> Monitoring flows is only used as a method of reach volume management in which an attempt is made to permanently guarantee the presence of the so-called reference volume, itself variable in time, and calculated so as to optimize the requirements which result from consumption forecasts. The most direct evidence of this policy is that there is no longer any direct connection between the water level elevations in the reaches and the transitting flow rate.

The total absence of restrictions on water usage makes consumption forecasts a fundamental aspect of control.

## 4.2 DYNAMIC REGULATION EQUIPMENT AND OPERATING PROCEDURES

Dynamic regulation makes use of operating procedures and associated equipment and apparatus which is widely available in process automated control and, especially:

- data acquisition,
- data transmission,
- data processing and remote control.

* Data acquisition:

The data required consists of measurements of physical parameters (levels, discharges, pressures, gate positions) and indications of status (on/off, alarm).

Water levels are measured by means of float sensors and electro-magnetic, ultrasonic or Venturi-type meters are used to measure discharge.

Pressure measurements are taken by means of mechanical or electrical differential pressure gages.

Volume is measured by integrating water level and flow measurement.

* Data transmission:

Due to the physical characteristics of the hydraulic network, the statutory requirements and reliability, an all-cable transmission system has been adopted.

A dual network is used which comprises transmission cables laid alongside the hydraulic installations and links via the public telecommunications network.

The control center can contact any outlying station along two separate routes; should there be a break on one channel, the link will be ensured by the other.

A voice communication network is used only for every day operating purposes or on emergencies. This network is not used for usual real time control.

Data processing and remote control:

The functions of acquisition and processing data and gates and pumping control are carried out in real-time by means of a series of programs which constitutes the software of the dynamic regulation process. These programs use precalculated data and results from hydraulic computations.

The system operates by a multiprogramming real-time monitor routine.

Two computers ensure real-time process control and supervision of the hydraulic operation of the system by means of two graphic color display consoles and an alphanumeric console. In normal operation one computer handles the computation required by the process control; the other computer monitors the display consoles. The second computer is able to take over the role of the first on its failure to ensure regulation.

The system operates day and night. Outside normal working hours at the Remote Control Center, certain warning signals are automatically re-transmitted to the local operation centers.

## 4.3 BASIC PRINCIPLES OF DYNAMIC REGULATION

In this section the general principles referred to earlier (section 4.1) will be expanded on. Firstly, it has to be stated that the principles of dynamic regulation are indissociable from the project for which they were first studied (Canal de Provence) and the conditions in which the research, study and execution of this project took place.

### Brief historical background to Canal de Provence study and execution:

The first upstream sections of the Canal de Provence were commissioned in 1969 and had been designed to operate on the downstream control principle, that is to say, each reach was controlled at its head by a Neyrtec gate which maintained a constant level immediately downstream. It was during the preliminary studies of the downstream structures, which constitute the main elements of the Canal de Provence, that a system of automatic centralized remote control came into being. This idea was significant insofar as it enabled the same equipment to be used (measurements, transmission, data processing) both for remote control and remote monitoring. In fact, the great distances between the structures and the difficulties of access made remote monitoring almost mandatory as there was insufficient reason to provide permanent operating staff on most of the structures.

The decision was taken to study and construct a small-scale control system based on these principles for upgrading an old supply canal with the following characteristics: length: 56 km
head flow: 7 $m^3/s$

The actual civil and electro-mechanical works involved in implementing dynamic regulation consisted in:
- motorizing the existing control gates,

- building two additional cross regulators equipped with actuated gates,
- installing the measurement and teletransmission equipment and fitting out the main remote control center at Le Tholonet near Aix-en-Provence.

On commissioning in 1970-1971, the system operated without hitches.

As a result, dynamic regulation was adopted for new stretches on the Canal de Provence.

Furthermore, those stretches already constructed but which operated with downstream control were upgraded to dynamic regulation using the teletransmission infrastructure which had been set up for remote supervision.

The general principles of dynamic regulation were finalized at this time but the methods of application (detailed logic and equipment used) have been greatly developed under the influence of two fundamental factors:

- feedback from full-scale operation since commissioning the longest sections of Canal de Provence in 1975 up to commissioning the latest major section at the end of 1986,
- rapid development of the characteristics and performances of all types of equipment used for this type of control.

Having established the historical background, the basic principles of dynamic regulation can now be enumerated:

1/ Dynamic regulation has an all-encompassing role in time and space. Thus, the operation of a gate depends not only on one or two measurements of levels but on a group of measurements, on a series of checks on consumption at the outlets, on the positions of the other gates, on the water level of reservoirs fed by upstream and downstream reaches because - and this is the main feature of the system - all reaches take part in meeting a peak demand or in absorbing scheduled or unscheduled non-acceptance of water. The system of canals acts as a large reservoir controlled by an industrial computer which receives the various data mentioned above, verifies, compares and interprets them, works out orders for the gates, starts or stops the pumps or the hydroelectric power units and directly controls and optimizes the necessary operations.

2/ From the outset, it was proposed, and confirmed by experience, that dynamic regulation system management was to be carried out automatically in a closed loop without operator intervention. The central computer executes both routine operation and emergency management. Any warnings are generated at the control center or the home of an operator indicating extreme circumstances have arisen when the system is no longer capable of automatic management and/or when an operator should take over control.

In addition, operator control with manual intervention is routine in two configurations:

- commissioning of new installations,
- repairs making certain structures or equipment unavailable or modifying operating constraints.

3/ Control associated with dynamic regulation is the discontinuous type with adjustment of gates and control structures at regular intervals except on emergency operations.

4/ Particular importance is attached to the quality of forecasts for several reasons:
- 100% availability precludes prior knowledge of flows to users and therefore certitude as to flow data;
- to optimize water consumption and avoid any spillage due to poor management of conveyed volumes (spillways being reserved for particularly serious physical incidents);
- transit time may reach 8 hours whereas storage capacity en-route or at the ends of sections is extremely small.

5/ The calculation method used for controls, based on flow forecasting and the canal status, is extremely simplified, particularly with regard to flow simulations. All long hydraulic computations (due to the number of parameters) have been executed off-line. The results of these calculations, of necessity approximate, are used to execute on-line calculations. The imprecision which results is compensated for by the frequency of updating overall computations (as often as equipment instructions). In particular, no calculations of transient flows using Barré de Saint Venant equations are executed in real-time.

6/ The general logic in dynamic regulation remains very close to regulation carried out by a human operator. The control tasks may be broken down into simple tasks whose logic can be easily understood by a trained operator. This offers two major advantages:
- operators may be allocated one or several elementary tasks;
- easy improvement of the control computation program by modifications to the contents of one or several control elementary modules. This latter aspect introduces flexible, openended features into dynamic regulation design so that it might be easily updated as a result of operational feedback.

7/ If dynamic regulation is to be situated relative to other types of regulation, its partial analogies with other types of control should be noted:

- upstream control: control with dynamic regulation depending partly on an estimated forecast of needs,
- downstream control: measurement and taking into account the canal flow status, automatic reaction to variations between real and desired levels.

It must also be noted that dynamic regulation is basically proportional with only a small integral component to avoid hunting.

## 5. DYNAMIC REGULATION LOGIC

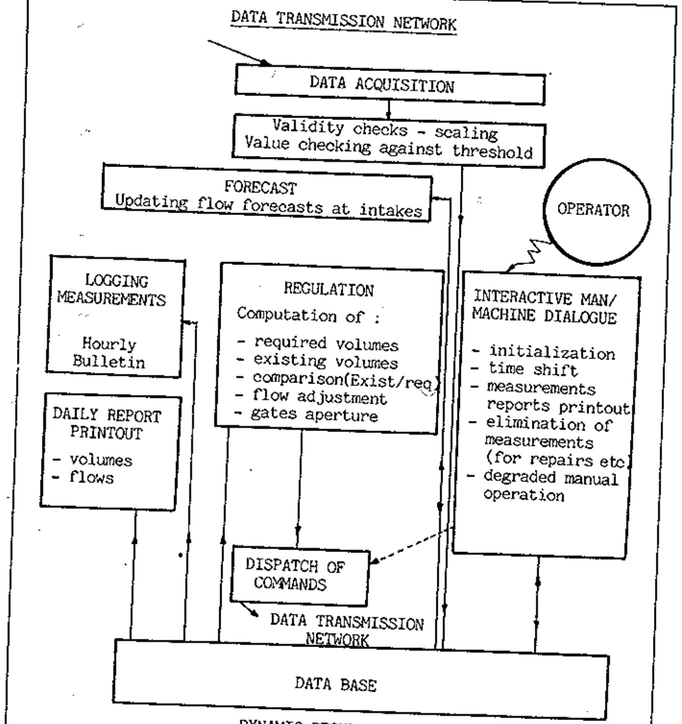
### 5.1 GENERAL REMARKS

This section will cover the most significant aspects of dynamic regulation logic, that is to say those which play a vital role in the regulation process and/or those whose originality makes them most typical of this type of regulation. As this consists of "logic", most of these aspects will deal with the software used by the main computer and local micro-computers. However, the man/machine relationship for program improvements and emergency operation is also of importance.

### 5.2 DESCRIPTION OF TASKS AND MAIN CALCULATIONS CARRIED OUT BY THE CONTROL SOFTWARE

#### 5.2.1. Control software architecture. Description of main computation modules

The main program structure may be shown by the following diagram:



DYNAMIC REGULATION
TASK ORGANIZATION FOR PROCESS CONTROL COMPUTER
MAIN COMPUTATION MODULES

Additional details as to the contents of modules:

- data acquisition: the central data transmission unit ("front end") manages data exchanges between the computer and external data sources. This unit controls exchanges which are received by the computer passively. Data acquisition is a continuous function (updating at intervals varying from 4 to 40 seconds depending on the section of network involved).

- monitoring of measured data and alarms: this module monitors incoming data. Its basic functions are:
  . validity test (measurement defect, transmission defect),
  . high/low threshold test function,
  . coherence test function (general measurement logic relative to all data to check measurement validity),
  . averaging,
  . extrapolation to give value based on other values (in time or space) in the absence of available data,
  . issue any warnings.

  This conventional module is executed every fifteen minutes.

- consumption forecasts: a conventional module which generates forecasts at ten predetermined times daily.

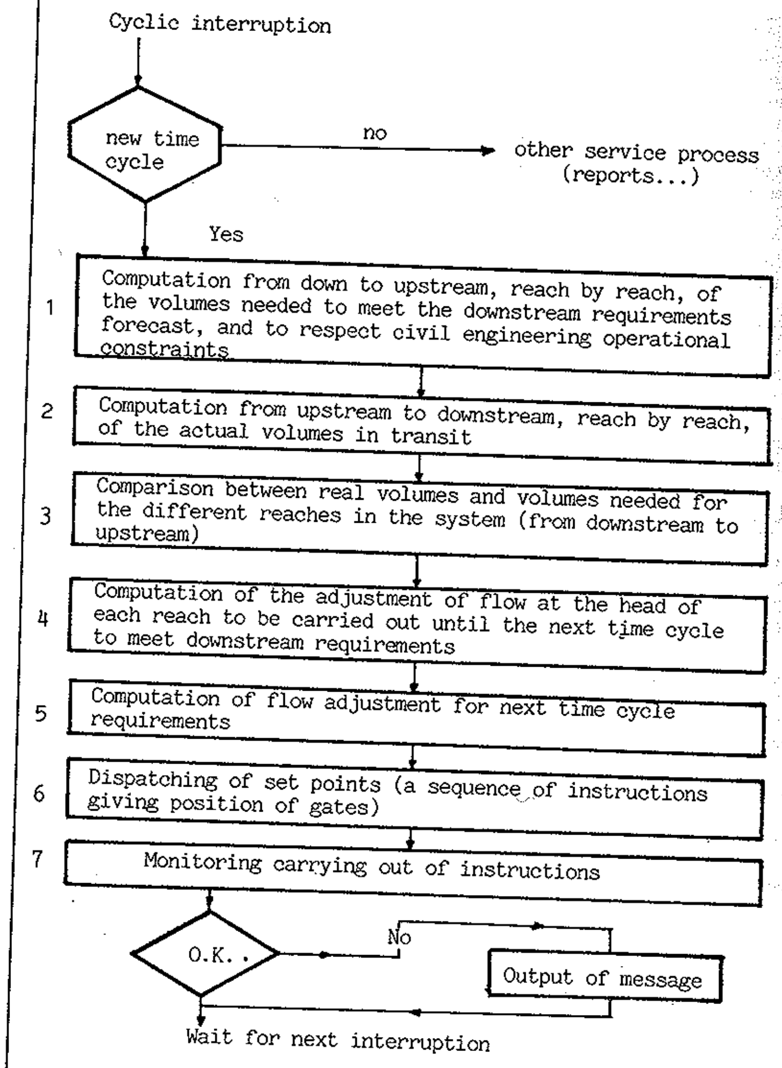
- control: this module provides the core of the regulation program. Its contents are given in greater detail in sections 5.2.2. to 5.2.5. It supplies the set point for check gates and operates safety gates. It also provides set points for start-up and shut-down of pumping stations operated from the control centre. This module executes every 15 minutes.

- remote control: this module executes immediately after the control module in normal operation (closed-loop operation). It transmits gate instructions to the teletransmission system and checks their execution.

#### 5.2.2. Control module logic:

As previously stated, this module executes every fifteen minutes.

The basic operations are shown in the diagram on the following page:



Regulation module block diagram

The 7 main procedures shown in this diagram are:

1/ Calculation of volumes required:

The aim is to provide continuous optimum volume in each reach practically independently from the backwater curve and incoming and outgoing flows. This volume has the following characteristics:

- it is optimized so as to satisfy physical constraints (canal lining maintained under water, reduction of underpressures) and, above all, forecasts (incorporating probable flows or refusal of flows to users, whether normal of exceptional);

- it is therefore basically dependent on forecasts and varies throughout the day and year.

- it is the volume, defined on the adjustment to be executed, which is transitting through the reach to meet forecast downstream requirements and complying with the aforesaid physical constraints.

The required volumes are calculated at each adjustment cycle based on forecast flows or scheduled offtakes from downstream to upstream. The basic calculation takes place for a section of reach (from 500 m to 2 km long) and considers that the flow is in the form of series of permanent regimes without taking into account the discontinuous profile which this supposes for the backwater curve.

The conversion from transitting flows to required volumes uses:

- precalculated and tabulated laws (conventional relationship between $V = f(Q,H)$), which integrate any level constraints already mentioned,

- criteria of choice between the different possible values for the required volume between a minimum value and a maximum value which would cause spillage. In this respect, optimization of pumping and turbining leads to the volumes required being calculated as a function of the time of day.

2/ Calculation of real volumes

Real volumes are also calculated for sections, from upstream to downstream. These calculations are carried out using:

- stored previous adjustments for upstream sections and measurements transmitted as to the downstream section,

- $V = f(Q,H)$ charts already mentioned,

- the actual average transitting flows (flows measured at reach intakes or calculated based on laws of height, opening and flow at the level regulators).

3/ Comparison of volumes required and real volumes. Quality of forecasting:

This comparison is made for each stretch on the canal, then for each reach using the previous calculations, and is executed from downstream to upstream.

Certain general figures regarding transitting volumes, forecasts and discrepencies are given below:

- average volume transitting through the main conveyance structures (i.e. excluding distribution conduits):

  350,000 $m^3$ open channel
  1,000,000 $m^3$ in galleries.

- volume variations in a reach (e.g. 6 km reach – nominal flow 11 $m^3/s$):

. minimum required volume = 55,000 $m^3$
. maximum required volume = 100,000 $m^3$
. average current operation discrepency between volume required and real volume: 5,000 $m^3$.

- accuracy of forecasting: forecasts cover the following 24-hour period. They are updated ten times per day. Maximum error over a 24-hour period is around 15% and, in view of the total average transit time of around eight hours, maximum real error between volumes required and volumes released at the canal head are largely below $15 \times \frac{8}{24} = 5\%$, the discrepency being proportionally smaller for a shorter period.

4/ Calculation of adjustment flow at reach head

5/ Calculation of gate opening: adjustment flow is assessed so as to ensure a required V minus real V as close as possible to 0. Gate aperture is calculated using conventional methods based on the relationship between flow, water levels and gate opening.

6/ Transmission of command itself: In the normal automatic control option, the computer dispatches set points to local gate controllers via the teletransmission network. It is to be noted that if the discrepency relative to a former position is less than a predetermined threshold, no command is dispatched (neutral zone).

7/ Execution report: This report is a very detailed printout with, if necessary, alarm dispatch to the duty operator's home when occurring outside normal working hours.

## 5.3 SAFETY OF DYNAMIC REGULATION

Of course, in the present case, the question arises as to the levels of safety for system which is managed in a closed loop without operator intervention.

- priority is given to safe supply to the various users,

- followed by safety of third parties (adjoining owners, in particular) on incorrect operation or accident to a structure (particularly spillage), finally, the safety of structures and maintenance equipment, detection of failures and repairs.

Project authorities have, in fact, been basically concerned with safety of structures and equipment. Due to the distances between structures and the isolated nature of most of them, remote monitoring was the first aim sought after. Remote control came into being subsequently based on the idea of using the infrastructures, particularly the teletransmission system provided for the remote monitoring function.

We shall not give a detailed description of the principles adopted to ensure the system operates safely on failure of equipment or sets of equipment used in the data collection channels – data processing, dispatch of commands. Many of these facilities and arrangements are conventional to control and monitoring systems and, insofar the safety inherent in the main equipment (failure rates, etc.) is concerned, they will be delt with in the other paper presented to this conference (Instrumentation: Canal de Provence).

We shall simply summarize the more typical safety aspects of dynamic regulation:

- most of the structures are unattended and there is generally no alternative to remote detection and control. Any accident (spillage, bank failure, fire, vendalism, etc.) noted by personnel is too late for effective telecontrol or human intervention,

- the reliability of the various components is very important, particularly regarding transmissions (MTBF and MTTR-related considerations are referred to in the other paper) and architecture of the system plays a greater role due to the possibility of built-in compensations for equipment weaknesses,

- in these conditions, the main safety system is the central computer software as it not only offsets any deficiencies in transmission or control measurements, but also detects local variations in the regulation process and analyzes failures or incidents based on various logged data. This system warns the operator by giving the reasons for his required intervention,

- operators may be called up as follows: during the working day (8h-17h), an operator is always present near the control room for an activity which is generally without immediate connection with the regulation in progress.

Outside these hours, a portable interactive terminal is permanently installed in the operator's home. This terminal is connected to the remote control center via a commuted telephone network. The operator is warned of his need to take action by an individual call-up device (portable Eurosignal system) which invites him to make contact with the central computer. However, it has to be noted that manual control, whether from the control center or from the partial terminal may only take place as a form of degraded dynamic regulation as the latter takes into account adjustment instructions issued during propagation,

- safety, like the central program, is open-ended and based on operational experience. Particularly, commissioning a new branch always takes place manually and it is as a result of the information regarding this commissioning that specific safety-related instructions are defined,
- in view of the essential role of the central computer regarding safety, it is duplicated as was explained earlier. On computer process control failures or defects, the screen monitoring computer takes over regulation calculation.
- as we indicated earlier, the modular structure of the software makes it possible to easily transfer onto manual control. Detection of defects in calculation zones or systems is carried out simply and the lack of any complex analytic methods enables analogic software to be provided for automatic and manual regulation,
- based on the same principle, there are very few safety devices to be automatically tripped locally. The principle is that a system or a safety procedure will not function correctly in case of need unless frequently operated and preferably as part of the normal regulation process. The only passive safety systems are the canal spillage systems or surge tanks which are calibrated for flows which remain below nominal canal flows.

### 5.4 DYNAMIC REGULATION LOGIC - THE TEST OF EXPERIENCE

Since the first experimental tests, the design of dynamic regulation, and above all its method of implementation have been adapted to developments of equipment and feedback from actual operation. Nevertheless, on balance, this feedback confirms that the major options taken on design of the system (simplicity of calculation program, closed loop control, compliance with flow calls) would be maintained if the project were started up today.

Of course, progressive start-up of regulation software modules has been made easier by the gradual growth in flows to users. This generally occurs on all major artificial hydraulic systems, particularly regarding irrigation.

However, if the Canal de Provence project were redesigned today, we feel that the main modification would involve civil work. In fact, before the decision was finally taken to adapt the canals to dynamic regulation, the first section of the Canal de Provence had been constructed with, on certain sections of the canals, horizontal banks which, at that time, were intended to accomodate conventional downstream or constant volume control.

On the existing sections, dynamic regulation was adopted as soon as completely finalized and a larger freeboard became unnecessary.

It is to be noted that, even today, at project design stage, a dynamic regulation simulation program enables the freeboard to be established: these studies lead to predictions of a 15% maximum reach length with horizontal banks.

The last Canal de Provence branch commissioned in 1986 (Marseilles East) has been constructed with constant depth reaches.

The present trend is towards decentralization of functions and decision making, particularly with the introduction onto the market of software permitting very simple decentralized control. However, there is a mandatory limit to the extent of decentralization due to the overall character of dynamic regulation.

To summarize, we feel that the difference between the initial project for dynamic regulation and an analogeous project studied today would be the ease and speed of design. In fact, over the last ten years, hydraulic projects involving automated regulation have multiplied and there are now many comparable projects. However, no fundamental changes have taken place in the basic logic of regulation.

## 6. BRIEF OVERVIEW OF OTHER SPECIFIC CASES OF DYNAMIC REGULATION INSTALLATIONS ON IRRIGATION PROJECTS

### 6.1 GENERAL COMMENTS

The term "dynamic regulation" precisely describes the system of regulation which was developed by the Société du Canal de Provence and applied to its own structures. In particular, it uses the principle of volume regulation as part of an automated management system. This system makes use of specific methods for real-time data processing. When describing other systems, we shall limit ourselves to these type of installations which were developed with extensive participation of the Société du Canal de Provence engineering and operating departments.

The largest of these systems will not be described in details here as it is installed on the new water supply to Athens (Greece) from Mornos dam (220 km conveyance with 23 $m^3/s$ flow) and therefore has no irrigation function. In addition to this project, we shall refer to three irrigation projects, two of which use or will use dynamic regulation and one which involves centralized remote control for subsequent conversion to closed-loop dynamic regulation.

## 6.2 STRETZEVO IRRIGATION SYSTEM, MACEDONIA REPUBLIC (YUGOSLAVIA)

### 6.2.1. Basic characteristics

The irrigation area covers some 20,000 ha and is supplied from a reservoir (100 million $m^3$) and conveyance canal (44 km long, head flow 12.5 $m^3/s$). The irrigation networks are pressurized and the main canal comprises 10 reaches.

Canal equipment and instrumentation includes:

- number of remote control structures: 10
- number of remote control units: 12
- canal offtakes: 10
- number of measurement points: 39
- number of signals: 150
- type of regulation: real-time computer-operated centralized automation.

### 6.2.2. Specific nature of regulation system:

The general principles of this system were defined by the Société du Canal de Provence which acted as consultant for the main project hydraulic features (conveyance and distribution of water). Detailed development of regulation software was executed by Institute Mihailo Pupin in Belgrade.

Control uses a more strictly controlled forecasting method than on the Canal de Provence due to the presence of large areas of collective land in the irrigated areas. The distribution of water on this land is subject to a relatively strict rotational schedule.

In addition, calculation of consumption forecasts leaves the operator with a selection margin. The computer supplies the operator with the data required for past consumption and the operator himself decides on the method for best integrating this data into forecasting procedures.

Finally, designers of detailed regulation software considered using dynamic programming as an option to optimize main canal reach volumes. If the tests which are programmed to be carried out in the near future are satisfactory, it will be worthwhile comparing this method of calculation to that used by the Canal de Provence on which the partially arbitrary nature of certain calculation decisions (required volumes for example) ,is compensated for by regular improvement of calculation modules by operators.

## 6.3 ROCADE CANAL AND ASSOCIATED IRRIGATION SYSTEM (HAOUZ - MARRAKECH - MOROCCO)

### 6.3.1. Basic characteristics

- 50,000 ha irrigated area supplied from 2 reservoirs:

  - Aït - Chouarit (350 million $m^3$)
  - Lalla - Takerkoust (85 million $m^3$)

  which supply, respectively:

  - a newly constructed main canal, Rocade canal (127 km long, 20 $m^3/s$ head flow),
  - a former canal, the N'FIS canal (8 $m^3/s$) the management of which is to be upgraded to take into account developments in unpressurized water distribution.

- number of remote controlled in-line regulation structures: 6 on Rocade canal and 1 (the head structure) on N'Fis canal,

- two water intake structures on the canal together with a certain number of safety gate are also remote controlled,

- total number of remote control units: 15

- number of measurement points: 40

- number of signals: 150

- Unpressurized irrigation network without pumping (first phase) and with pumping (second phase). The project also supplies a traditional gravity flow network and the town of Marrakech.

- Type of regulation: automatic dynamic regulation has been adopted which groups together canal regulation and control of reservoir supplies to the canals. The system is operated from a computer installed in the main remote control center office at Marrakech. An extension is planned to control a hydroelectric plant which will be constructed on the Sidi Driss reservoir which supplies the Rocade canal with water from the Ait Chouarit reservoir.

### 6.3.2. Specific nature of regulation system

On this project, the Société du Canal de Provence acted as consultant for all hydraulic and regulation questions specific to the Rocade canal. The essential principles of regulation software were established and are very similar to those used on the Canal de Provence.

The detailed software is currently being designed, the SCP will supply the regulation software, training and assistance for system commissioning.

The fundamental difference relative to the Canal de Provence will be forecasting which will involve more strictly controlled water distribution to ensure a partial water rotational policy between the various irrigation networks supplied by the canal. The reason for this policy is the shortage of water in this region.

## 6.4 EL NASR CANAL AND ASSOCIATED IRRIGATION NETWORKS (WEST NILE DELTA – EGYPT)

### 6.4.1. Basic characteristics

In the present case, this consists in modernizing the control system on an existing canal which takes waters from the Nile to the west via a series of pumping stations. Project characteristics are:

- irrigated area: 120,000 ha
- canal length: currently 55 km, to be extended to 85 km in the near future,
- head flow: 120 $m^3/s$
- canal supplied by 5 main in-line pumping stations with total 125 mW capacity,
- 4 canal-supplied secondary stations and 9 intakes,
- centralized remote control and monitoring:
  82 remote control units,
  67 data measurement points,
  385 signals or alarm items,
- micro-computer controlled system.

### 6.4.2. Specific nature of regulation system

Operation currently planned and studied by the Société du Canal de Provence consists in a centralized remote monitoring and control system for all the main canal pumping stations. Operation must function in an open-loop system (computer-aided control). However, on the request of the Egyptian Ministry of Irrigation, the basic principle of control, and of the equipment installed, has been designed for later development to closed-loop dynamic regulation, integrating behaviour and forecasting of flows to irrigation networks supplied by the canal.