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USE OF A SIMULATION MODEL TO IMPROVE OPERATION OF DAM- RIVER SYSTEMS FOR IRRIGATION PURPOSE: ELEMENTS FOR A METHODOLOGY

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Abstract
In the Southwest of France, most of the hydraulic systems use natural rivers rather than canals for water conveyance and distribution to irrigated areas.

Water stored in dams during rainy period (autumn to spring) is released during the irrigation period with two main objectives:

- to satisfy farmers' requirements for irrigation water,
- to guarantee a minimal flow necessary for the ecological balance of the river.

Such rivers range from 20 to 150 kilometres long with flows during the irrigation period from 1 to 10 m3/s and storage dams capacity from 1 to 20 millions m3. Water extraction by irrigating farmers is on demand, i.e. free , and unpredictable though logically linked to irrigation practice and equipment constraints.

Classical operation of these hydraulic systems includes use of intermediate storage capacities at the pumping stations location, changes in the upstream flow once or twice a week, reaction to rainy events, etc.

The increasing demand for irrigation water and the limited available resource lead to a complexification of the hydraulic systems (construction of additional dams on affluents, increase in the number of extraction points,...) and to the development of improved operation methods, including sensors and remote data transmission as well as automatic control of the flow released from the dams, based on off-take predictions and analysis of differences between measured and targeted values.

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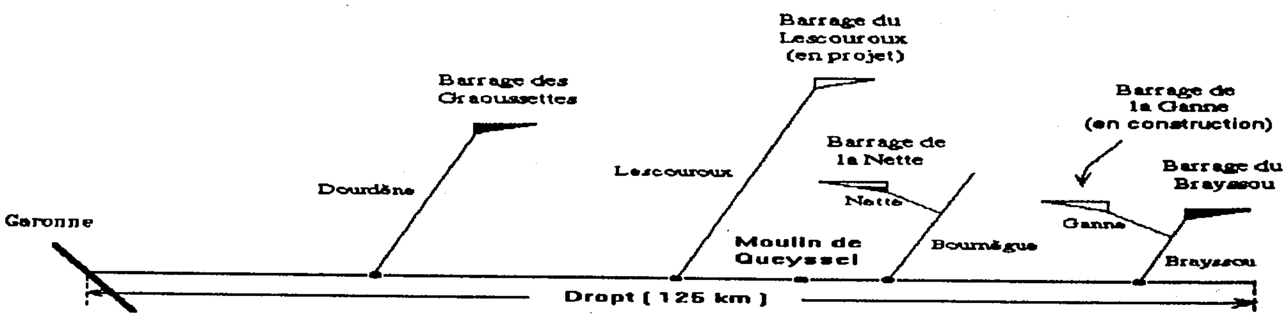
In the process of improving operation of hydraulic systems, simulation models can be used at three levels:

- analysis of collected data for different purpose: efficiency calculation, extraction identification, diagnosis of perturbations,...
- better understanding of the hydraulic phenomenon (time delays, effect of storage on upstream/downstream transformation of hydrographs, effect of different types of perturbations on the downstream flow, periodicity of some phenomenon.). This step can be of high importance regarding some decisions about extraction reglementation (river versus underground extraction, water storage and release for hydraulic mills,...),
- design, test and tuning of operation rules as well as automatic control algorithms,

This approach and its introduction in the management process, will be illustrated by a project lead by CARA[4] (Institution in charge of the Dropt management) and CEMAGREF[5] (a French research centre in agricultural and environmental engineering), studying the DROPT river (FRANCE) through the use of BAHIA simulation model.

1 Introduction

The Dropt river is a 125 km long, right side affluent of river Garonne in south-western France. The past ten years have seen a large development of irrigation in this region, mainly for corn production. The limited available water resource lead to a large project, planning the construction of 5 storage dam-reservoirs for a total capacity of 15 million m3 and the design of a global operation strategy. The CARA (Compagnie d'Aménagement Rural d'Aquitaine) is the institution responsible for the design and management of this project.



Aménagement hydroagricole
de la rivière Dropt

The first dam, the BRAYSSOU reservoir on the upstream part of the river, was finished in 1989 and started to deliver water in 1990 for an irrigated area of 1000 ha, with a weekly modification of released flow. In 1991 a remote data acquisition and control network was installed and allowed a daily modification of released flow on the basis of empirical analysis of data.
Results show that, due to complex behaviour of the hydraulic system, this type of operation gave poor results.

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It was then decided to improve the daily operation through a detailed study of the system, lead by CARA and CEMAGREF (Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts: a French research centre in agricultural and environmental engineering), using a simulation model. A three-steps approach was applied:

1. Analysis of the hydraulic system dynamic on the basis of recorded data.
2. Mathematical modelling of the hydraulic system, calibration of the model and use for diagnosis of bad functionning.
3. Design of an improved operation method and test using the model.

During this study various difficulties appeared: poor information from the farmers on the way they take water, unreliability of measurement devices, unavoidable disturbances on the system by various type of water users, delays in the infrastructure improvement ...

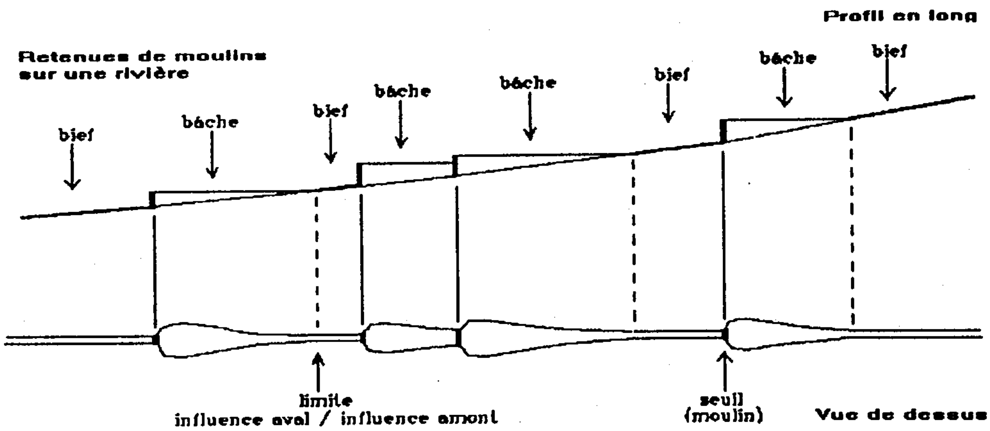
Though not yet concluded, this experience brings some valuable information on the type of methodology one can apply to solve his management problems on dam-rivers systems dedicated to irrigation areas.

2 Analysis of the Dropt River hydraulic system dynamic on the basis of recorded data

The upstream part of the Dropt river, from BRAYSSOU Reservoir to Queyssel, is a 39 km long succession of reaches separated by weirs and hydraulic devices.

In the past, hydraulic power of this river was used to activate mills. Every reach would, in turn, store water then release it to activate the mill during a few hours (2 or 3). The downstream mill would then store water and release it once its reach is filled.

Nowadays most of these mills have been abandoned, but hydraulic structures are still in place and are commonly used by farmers to store water for irrigation purpose, making the river a succession of pools (filled reaches).



Anyhow 2 or 3 mills are still in activity, using hydraulic power a few hours a day, in addition to electric or thermic power. Their functioning disturbs the hydraulic system, generating flow waves when they release water and flow shortages when they store water.

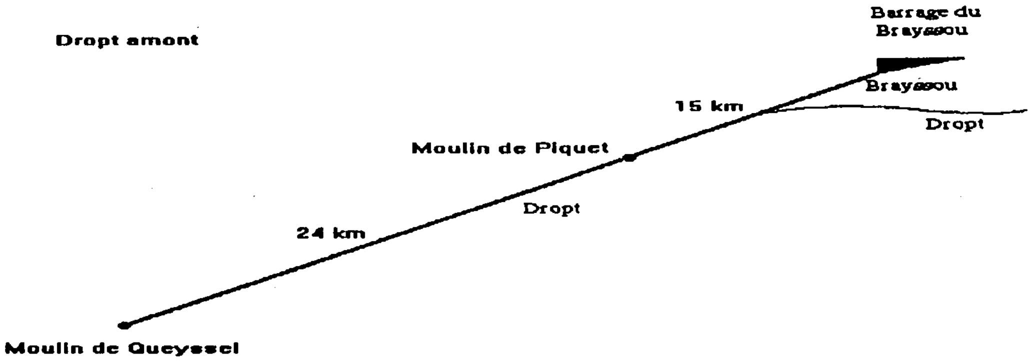
The main objective of the river regulation is to satisfy farmers' irrigation requirements and to guarantee a minimal flow downstream of the river.

One of the questions asked by managers was to know whether or not such activity should be prohibited to guarantee a correct operation of the whole system.

Analysis of field data measurements

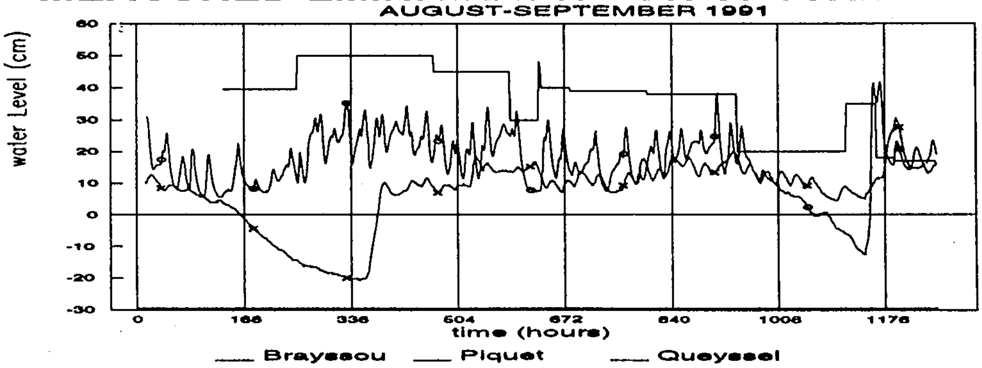
We shall present the way a mathematical model has been used to improve our understanding of the hydrauiic behaviour of the river. The first step was the analysis of existing data.

The upstream Dropt River is equipped with measurement points: one at the dam, one 15 km downstream at "Moulin de Piquet" intermediate reservoir, and the third one 24 km downstream (39 km from the dam) at "Moulin de Queyssel" intermediate reservoir.



The following figure illustrates the variation of water level observed at the measurement points during the months of august and September 1991.

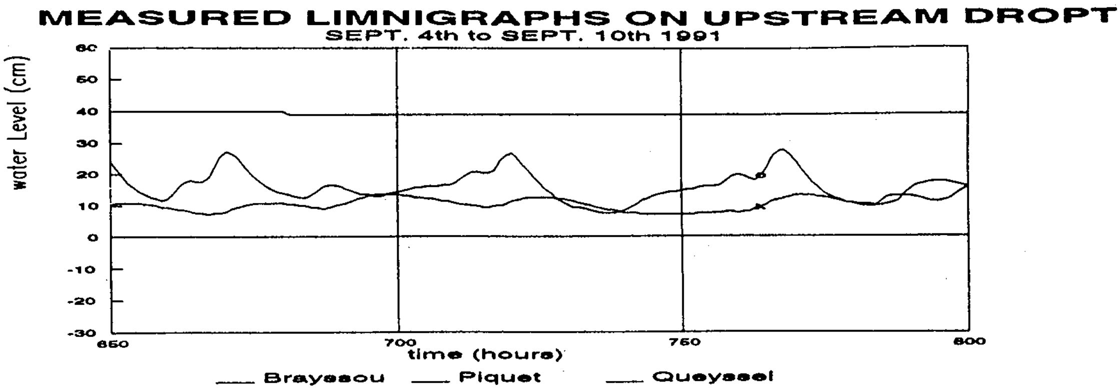
MEASURED LIMNIGRAPHS ON UPSTREAM DROPT
AUGUST-SEPTEMBER 1991



We can see that the water level in the corresponding intermediate reservoirs decreased under the weir level twice during the season: once in Queyssel at mid-august and once in Piquet at mid-September.
Each time the flow released from the dam was increased but with a slow reaction.

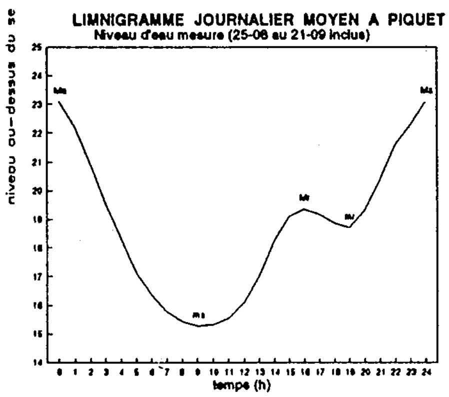
The dam flow has been changed 10 times during these two month, i.e. once a week. The operation was clearly deficient, not achieving its "minimal flow" objective.

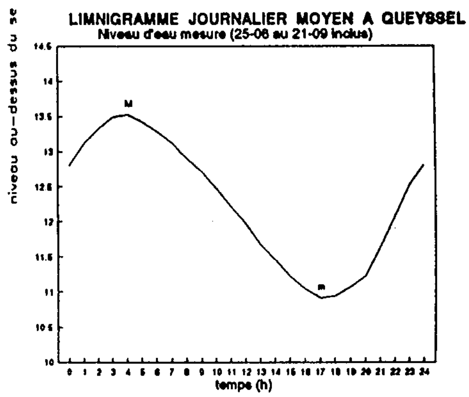
The detailed analysis of these hydrographs can give us more insight on the hydraulic system behaviour. The next figure illustrates a detail of the previous figure during a six day period in the beginning of September.



Daily water level oscillations are obvious. They result from daily oscillations in the irrigation off takes, farmers using their pumping equipment mainly during the day, as well as from storage-release cycles from the mills.

An even more detailed analysis of daily hydrographs in Piquet and Queyssel show the following structures:





Minimal flow values are observed in Piquet at 10 am, while they are observed in Queyssel around 5 p.m. This is probably due to irrigation practice and time delays in hydrographs propagation.

An additional minimal value is seen at Piquet around 8 p.m., but it is not observed in Queyssel. This is probably due to storage-release cycles from mills in the upstream part of the river. The phenomenon is quite negligible when compared with daily cycles due to irrigation practice. The main effect should be experienced straight downstream the hydraulic mill.

These interpretations of the measured hydrographs have to be confirmed by model simulation.

3 Mathematical modelling of the hydraulic system, calibration of the model and use for diagnosis of bad functioning

In order to confirm these interpretations of the field data, the hydraulic system behaviour has been simulated using BAHIA model, developed by CEMAGREF, that is dedicated to Dam-River-Pumping Station systems.

3.1 Technical Characteristic of BAHIA Model

This model allows the representation of any river network, with dams, intermediate reservoirs, extraction points, hydraulic structures ,... by mean of a user-friendly interface. Only simple geometrical dimensions are required (reach length, reservoir surface, weir length,...)

The hydrographs transfer is represented by the Hayami Equation (linear), or by the Diffusive Wave Equation (non-linear), depending on field data available and on the required accuracy.

The Hayami equation depends on two constant parameters: the delay parameter and the diffusion parameter. It is solved by use of the Laplace Transform.

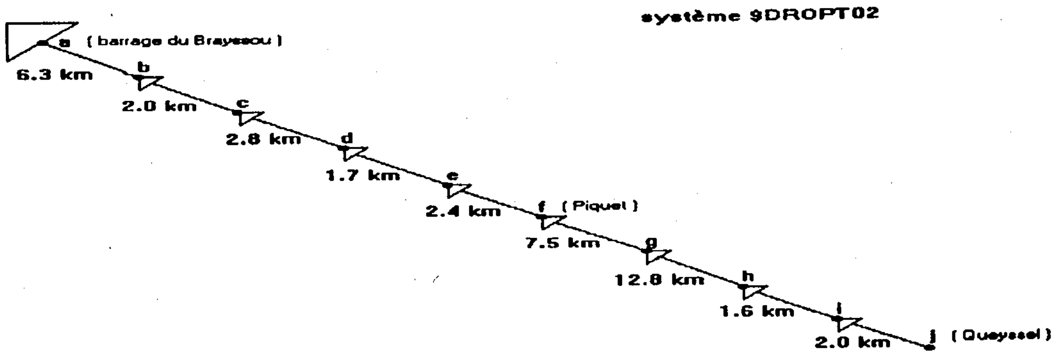
The Diffusive Wave equation also depends on two parameters whose values can vary with the flow value. It is solved by use of accurate numerical discretisation schemes. Though more time-consuming than the Hayami equation, this equation allows the representation of variable delays in the hydrographs transfer, an important phenomenon when considering automatic control.

A calibration module, included in the software, allows the determination of the equation parameters through treatment of field data.

The hydrographs transfer through intermediate reservoirs with hydraulic release structures (weir, pipe, siphon.) is calculated solving the "reservoir equation" by use of Runge-Kutta method.

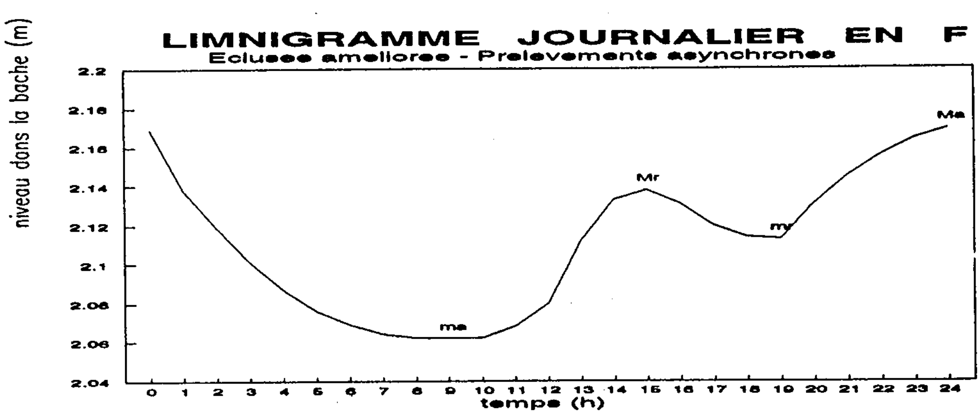
3.2 Application of BAHIA model for the simulation of the Dropt River dynamic

The system has been represented by the following scheme:



Points F and J are equipped with sensors that measure the water level in intermediate reservoirs. Lengths of the different reaches are introduced as well as reservoir characteristics: surface and discharge structures dimensions.

The first application of the model was the simulation of storage-release cycles at the grinding mill, and daily irrigation off-takes at the other intermediate reservoirs. The next figure illustrates results of these simulations.



As one can see, by comparison with previous figures, the simulation confirms our hypothesis that daily oscillations are due to daily irrigation off-takes and additional fluctuations are due to storage-release cycles at hydraulic mills.

3.3 Model Calibration

In order to improve the validity of the simulation results, model calibration is indispensable. While geometrical data are reliable, the main difficulty lies in the calibration of hydraulic parameters on river reaches and hydraulic coefficients of the weirs.

Due to bad initial calibration of hydraulic measurement devices at the equipped points the real calibration had to be postponed.

Though frustrating, this point is very important: Accurate use of a simulation model cannot be realised without reliable field data.

1992 Measurement campaign with improved calibrated devices on the river will provide reliable data for the model calibration.

3.4 Conclusion and diagnosis

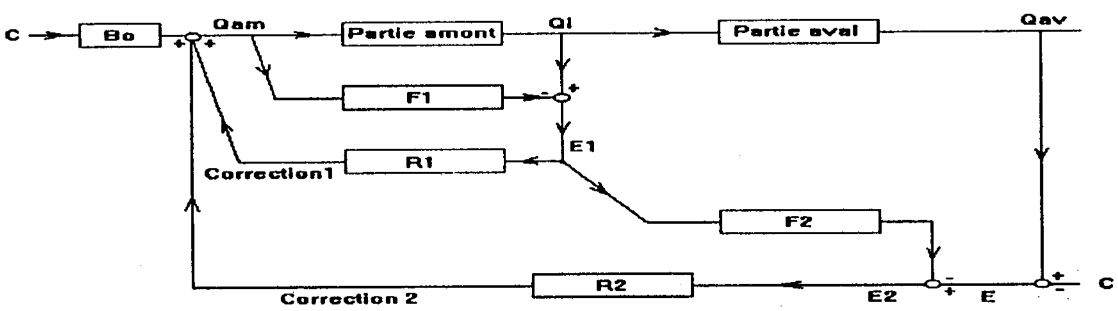
The first conclusions on the present system operation, on the basis of field data analysis and model simulations are:

- The present operation shows very poor results with shortage periods. This is due to infrequent dam discharge adjustments and lack of reliable discharge calculation method.
- Daily oscillations of hydrographs are natural, due to irrigation practice. Operation rules should not compete to match these oscillations as the storage capacity of the system is sufficient to handle them. Any operation rule should consider "24 hours-smoothed" hydrographs at the measuring points to calculate upstream dam-discharge.
- Storage-release cycles at the hydraulic mills simply create an additional perturbation, that is totally smoothed when arriving at the downstream end of the hydraulic system. Hence it should not be considered as a problem for the current system management. However detailed analysis of these releases effects on irrigation users just downstream of these mills is necessary.

4 Design of an improved operation method and test using the model.

The regulation control structure adopted to regulate the Dropt system using 2 measurement points has been represented on the figure below.

Schéma de régulation prenant en compte
une mesure intermédiaire



F1 and F2 are Transfer functions (Linear Dynamic Models) relating upstream and downstream flows respectively for the first and second part of the river.

The Open-Loop calculation is done by anticipation of predicted off-takes, using the hydraulic time-delay calculated by the model calibration.

The Closed-Loop calculation requires a more complex method:

R1 and R2 are PID (Proportional, Integral, Derivative) regulators aimed at regulating errors observed on the system at the measurement points.

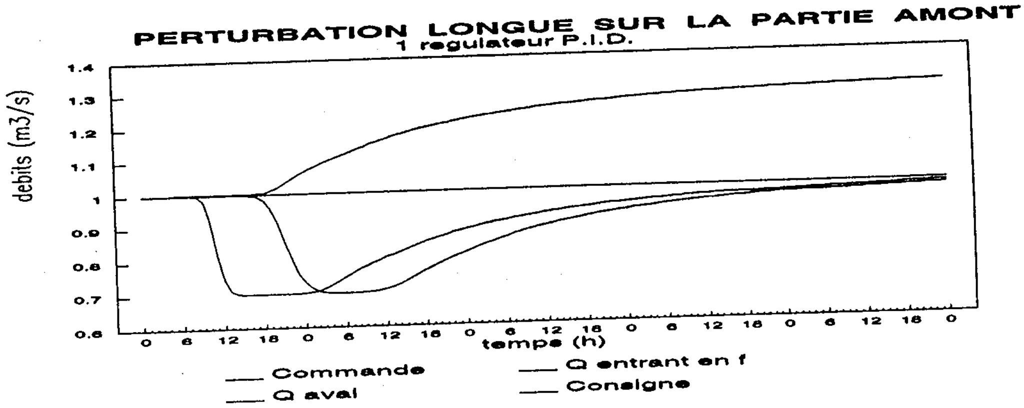
At the first measurement point the error is defined as the difference between predicted and measured flow values. The predicted flow value depends on upstream hydrographs transfer by F1, minus predicted off takes.

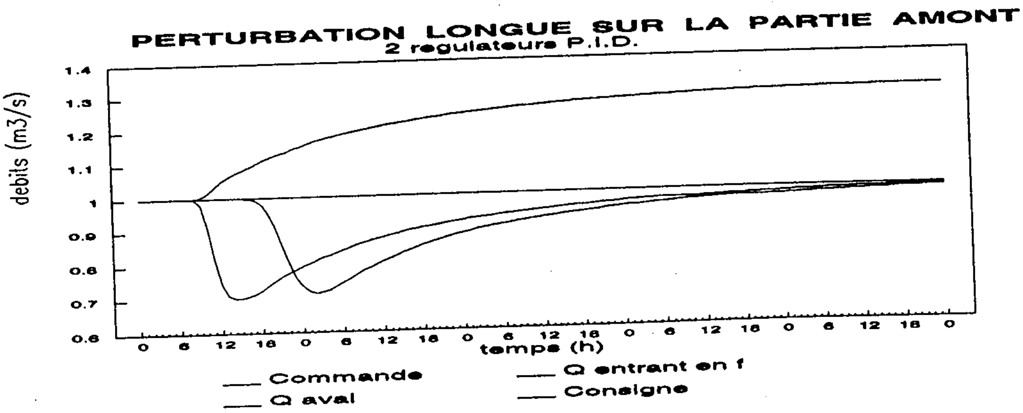
At the second (downstream) measurement point the error is defined as the difference between targeted and measured discharge, minus the transfer by F2 of the error at the first measurement point (in order to avoid a double correction of the first error).

Regulators R1 and R2 are calibrated to guarantee the stability and precision of the global control system.
In a first step acceptable values of PID coefficients are determined using an analytical method (Nyquist method). Then the simulation model is used to tune these coefficients in order to get desired performances.

Experience shows that PI regulators, without any Derivative term, are sufficient.

The next figures illustrate the Regulation response to an unpredicted perturbation (constant off-take) on the upstream part of the river:





The first figure illustrates the case when only one measurement point is available, downstream of the system.

The second figure illustrates the case when two measurement points are available.

This comparison shows that introducing an intermediate measurement point allows faster response to perturbations that occur in the first part of the system, as these perturbations are detected earlier. This induces a valuable water saving.

Further developments of this regulation technique will be achieved in the future. This algorithm should be implemented on the Dropt River for the 1993 irrigation campaign.

5 Conclusion

This study of the Dropt River Regulation for irrigation water conveyance using a simulation model (BAHIA) illustrates some of the important methodological steps that have to be followed.

A. Reliable field data are the basis for any accurate analysis of any Hydraulic System Operation. Data acquisition and transmission should be one of the major concern of Managers.

B. The detailed analysis of these data is a preliminary step to the use of a simulation model. The **simulation model is just a tool** that can help solving some problems if these problems are clearly identified.

C. Once a problem is identified (interpretation of measured data, analysis of operation rules,...) the use of a simulation model gives a deeper insight on the dynamic of the hydraulic system. Carefully selected scenarios will help solving the identified problems.

D. The model calibration can be considered as a two steps phase.
- To get insight of the hydraulic system behaviour a rough calibration is sufficient.
- To test and improve operation rules a detailed calibration is indispensable.

Whatever the case, the model calibration is a very important phase that needs some basic hydraulic knowledge. This should not be underestimated.

E. The improvement of operation rules and the design of regulation algorithms (automatic or other) have to be tested on a large variety of scenarios, covering different hydraulic situations that can be encountered in reality. This analysis can only be done through a close collaboration between the model user and the system manager (in case it is not the same person).

References

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