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Use of rivers for irrigation water conveyance

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Abstract
In the South West of France, irrigation and domestic water is generally supplied directly from rivers, whose upstream flow is regulated by a dam. These hydraulic systems are managed in order to satisfy water demands while complying the downstream flow orders and saving water.
Such a management can be optimised with existing simulation models as well as automatic control methods. Simulation models allow a correct modelisation of the hydraulic system operation, and therefore a better understanding of its overall dynamics and interactions between inflows, withdrawals and various perturbations. Based on such an understanding, automatic control techniques help to determine the optimal orders to be carried out a the dam, as well as to detect the perturbations and react to them. The regulation can be tested and improved through the simulation tools.

1 Introduction

Hydraulic systems, both for irrigation and domestic water supply, often use naturals rivers to convey water released from upstream dams to consumption places. These systems are widely spread in Europe, North Africa and South America. In France, they are generally encountered in the South West. Thus, CACG supplies more than 20 rivers, tributaries of Garonna and Adour rivers. The total length of these conveyance rivers reaches 2 000 km, the irrigated area amounts to 50 000 hectares and 200 000 people depend on them for their domestic water supply. Their flow is modified with the Neste canal and about 20 dams, whose volumes vary from 1 to 25 hm3. Figure 1 presents the CACG Hydraulic system.

In this paper, the main hydraulic characteristics of the supplied rivers are given. Then, the different *"tools"* we used are described. The latter range from the automatic system that gives in real time the flow at different points along the rivers and corresponding orders, to the models that simulate the hydraulic behaviour and automatically calculate the flow to be released at the upstream dam. Finally, we tried to estimate the benefits and limits of such a water management, thanks to our past ten years experience.

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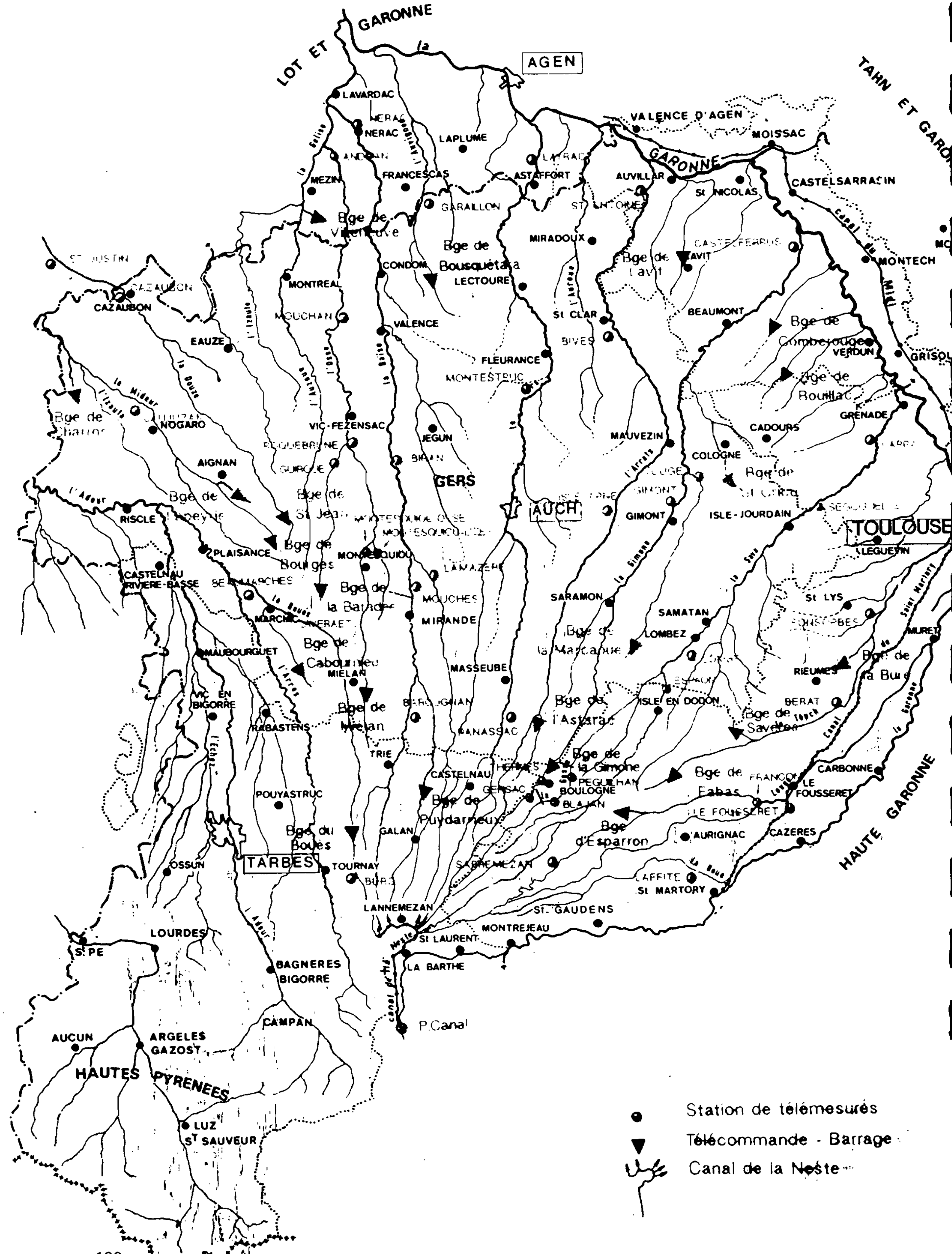
RESEAU DE TELEGESTION



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2 South West Rivers and Water Management

2.1 Hydraulic and hydrological background

CACG supplied rivers have common characteristics :

- their total length does not exceed 150 km, so the conveyance delay from the dam (or canal) to the downstream end does not exceed four days.
- the natural flows are negligible in comparison with pumping flows, therefore river flows are similar to canal ones.
- the only control point is upstream at the dam flood-gate : good management of the *"dam-river-pumping stations"* system is only based on the dam out-flow management. For example, they are no intermediate flood-gate dividing the river in reaches, which would allow the use of upstream reach storage to supply downstream reaches.
- the river supply season begins on July 1st and ends long after the irrigation season, generally in December and even in January or February.

Furthermore, the water supply follows an on-demand schedule, i.e. each user takes water whenever he needs it.

Finally, the water needs and resources are hardly balanced : water wasted earlier in the season could be used at the end of the irrigation season.

2.2 Management purposes

Management aims to :

- supply each user with the water he needs (in time and quantity),
- keep all along the river a sufficient flow in order to preserve the water quality. Generally, this second objective is achieved if the downstream flow exceeds a minimal value. This minimum value, theoretically constant, is translated into a target value that changes during the season, generally every week, and depends on reservoirs water level, water consumption forecasts .... Dynamic programmation is required to simulate these modifications and calculate the optimal target. This constitutes the basis of a *"strategic management"* of supplied rivers.

The water balance being hardly reached, the downstream flow targets have to be closely followed in order to spare water. Therefore, the water needs and corresponding flow releases have to be forecasted. Furthermore, perturbations have to be taken into account (rain, unexpected pumping stations starting ...). Thus, in order to be performant, a regulation system requires :

- real-time information data (dam outflows, river flows),
- a good understanding of the hydraulic system (delay duration, lag times, water taking),
- and an accurate dam outflow calculation method, taking into account forecasting and sensitive to observed perturbations.

3 Tools for a good regulation

The approach developed both by CACG and CEMAGREF consists of three parts:

- the set up of hardware and software to receive information and transmit orders in real time.
- the use of a simplified simulation model with short calculation duration. Simulation models lead to a better understanding of the hydraulic system. They make possible the test of traditional and new management methods before their real operational implementation.
- application of automatic control techniques on water system management. These techniques allow the optimisation of dam outflow control by taking into account downstream flow target and measurements through real time information. Thus, water can be saved and operators may give up routine works for supervision tasks and contacts with users.

3.1 Hardware and software to receive information and send orders in real time

They consist of :

- a network station and three linked computers. One of them is dedicated to data acquisition and automatic command calculation and transmission. The remaining two computers are used for data visualisation, analysis and treatment.

- 200 field data acquisition stations (river flow measurements, dam water levels, river oxygen rate, temperature ...). The measuring devices are either traditional sensors (pressure, temperature) or optoelectronic sensors used for liminometry.

- 30 canal off-take structures and dam flood-gates motorised and remote-controlled.

PC and measurement stations are linked through "France-Telecom", using modem cards. Remote sensing and command transmission may be done whenever using one of the PC or a common Minitel station. This is generally done automatically and periodically by PC, depending on a program that manages the amount of information necessary for decision making. Dam river flows in different locations are analysed every one to three hours.

3.2 Simplified simulation model

. The hydraulic phenomenon to be simulated seems complex :

- discharge changes and therefore unsteady flows are considered,

- discharge flows are greatly perturbed on one hand by uneasily estimated natural flows and on th other hand by irrigation pumping stations. The latter can only be evaluated globally an approximately (even if the number of pumps is known, the number of which are actually working very difficult to define precisely).

- the rivers may be very long (more than one hundred kilometres). Therefore, transfer ((conveyance) delays are very important in regards to perturbation duration.

Solving this type of problem requires both a lot of data and long simulation duration, which is n consistent with our purposes of fast calculations and simplicity in application.

. BAHIA model, developed by CEMAGREF avoids such disadvantages. The hydraulic system description is quick. Indeed, only the most important hydraulic points are defined. Furthermore, the management simulation is based on a representation of hydrograph transfer by Hayami equation. The latter describes the river dynamic through two parameters: delay time and diffusion parameter. A calibration module included in BAHIA allows the determination of these two parameters based on field measurements.

This system representation allows the simulation of any type of hydraulic situation : changes in a dam out-flow, pumping, rain, changes in irrigation practice, and storage in intermediate reservoirs. The required elements of a given situation are defined in a user-friendly way.

One of the most evident application of BAHIA is its use as a teaching tool : operators can test their reactions in some simple and typical cases. The use of the software to interpret and understand reai, observed phenomena is much more difficult due to the various sources of the perturbations. The user needs a good experience and hydraulic understanding. Finally, this software is very useful to test and improve the efficiency of new automatic regulation algorithms.

3.3 Automatic control of hydraulic systems

Automatic techniques, or system analysis, are commonly used to study the dynamic and control of hydraulic systems.

3.3.a Linear simulation

The system is represented by a "black box" that receives inputs (upstream flows, pumping ...) and creates outputs (results of the previous inputs : downstream flows, water levels ...). The black box itself is represented by a simple, linear dynamic model that links inputs and outputs. The information is measured with a given time step T (half-hour, hour ...) and a linear model is chosen to describe the relation between

- the downstream flow of the river at times t, t-T, t-2T ,
- the upstream inflows originating from dams at times t-rT, t-(r+1)T, t-(r+2)T,
- the offtake flow (pumping) at times t-rhT, t-(rh+1)T, t-(rh+2)T,

where T is the measurement period, rT and rhT are the various time delays of the system ($0<h<1$).

Figure 2 shows the reliability of this type of equations in relation to Hayami model.

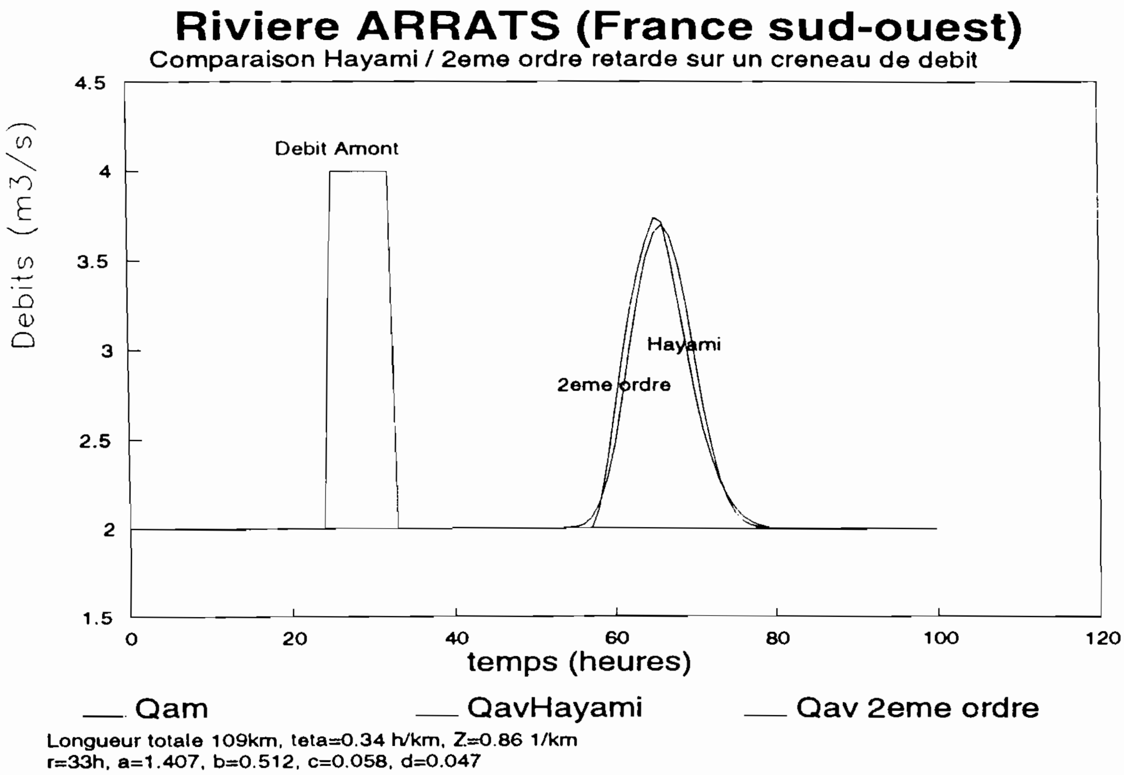

Figure 2 : Dynamic representation by a second order simplied system

Two types of methods may be used to calibrate the linear model :(commonly called "second order" model) :

- a direct adjustment of the linear model on field data,
- an analytical calculation of the linear model coefficients as function of the Hayami parameters, these parameters being calibrated on field data.

This second method gives a better physical understanding of the dynamic. For instance, it explains the value of the linear model time delay coefficient as a function of the corresponding delay parameter in Hayami representation.

3.3.b Control calculation

Different automatic regulation methods are available for calculation of the dam releases (dam outflows) as a function of forecasts, measured and targeted flow values. Whatever the regulation method, the control is defined as the sum of two terms :

- a first term called "open loop", function only of the downstream target flows and irrigation outflow forecast,
- a second term called "closed loop", that adjusts the open loop results, according to the differences observed between the theoretical calculations of the open loop and the system measurements.

Likewise, different types of regulation exist. Either they reverse the transfer function (open loop calculation) or they take into account the observed differences.

The CACG regulation method uses a "time anticipation" open loop and a pole placement closed loop ensuring stability and precision for the regulated system.

Stability and fast reactivity are the fundamental advantages of automatically regulated systems. It prevents the gates from widely opening to shutting down from one release to the next one. Let us consider a recurrent perturbation with a short return period (non predicted taking for example) happening upstream of a measurement location. If the transfer (or conveyance) duration is higher than the perturbation recurrence period, the discharges adjustment will generally be useless. In fact, such an adjustment could even increase the phenomenon. In order to avoid this problem, perturbations are taken into account in a progressive manner. While the perturbation is confirmed from one control time step to the other, its effect is progressively taken into account. The stability is therefore ensured by a smooth reaction to observed perturbations.

This smoothing must not change the average of the dam discharged volumes. This condition also applies to the open loop calculations, where the discharged water volumes must equal the required volumes. This ensures the system precision.

The "real time management" consists of two complementary parts :

- real time data acquisition and remote control,
- automatic calculation of dam releases.

CACG has always aimed to develop an automatic control system for all the Gascogne rivers. The data acquisition and transmission network were part of this strategy.

The efficiency of the present "real time management" can be compared to the efficiency of previous management based on daily readings of limnigraphs and manual adjustment of dam flood gates, which needed a lot of time spent on the roads, rivers and fields.

4 Real time management - A ten years experience

4.1 Unquestionable benefits

These benefits can be summed up in the formula :

"Efficiency improvement without affecting the water supply reliability"

But how is defined *"efficiency"*? In fact, there are 2 possible mathematical formulations :

- $e1 = 1 - \Sigma$ (Qmeasured -Qtarget) / Qreleased
  where Q is the flow (m3/s).

The efficiency value equals 1 if the target flow has been achieved. This equation is useful when considering the balance between needs and resources in water volumes.

- $e2 = 1 - \Sigma$ | Qmeasured -Qtarget | / Qreleased

This formulation is used when the performance of the regulation system is considered. e2 is then called performance index.

Currently, for Arrats and Baïse rivers, released water volumes are respectively 10 and 15 million m3, water losses are limited to 20 %, so the efficiency (e1) reaches 80 %, while efficiency (e2) equals approximately 75 %. With traditional management methods, these values are around 50 to 60 %. Therefore, a real time management allows a saving of 20 % of the total amount of water. Figure 3 shows that the efficiency improvement has not increased the risks in water shortages in the downstream portion.

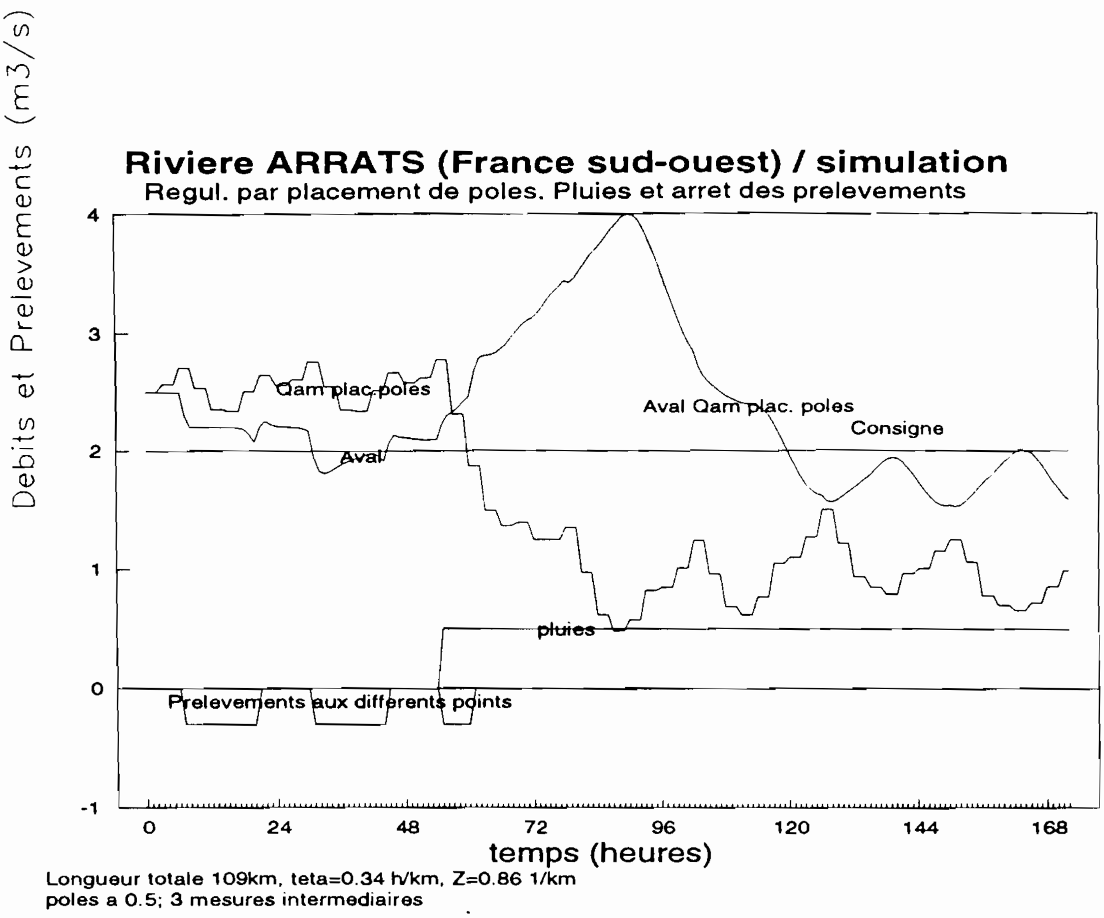

Figure 3 : Regulation by "placement des poles" in the case of unexpected rainfalls causing the irrigation to stop

4.2 Future improvements

Improvement in the model would solve problems encountered today and that will be considered progressively in the future. These problems concern both the theory and the operation.

On the theoretical point of view, even though Hayami's model can easily be linearised and leads to short calculation duration, its approximations are too rough. One of the worst approximations is the constant flow transfer delay. Year long measurement campaigns confirm that flow transfer delay is decreasing with increasing river flow. In theory, the calibration of these transfer delays would have to be done for each individual situation and flow value.

In order to compensate this delay variability, the closed loop reactions have to be smoothed to consider all possible situations. CACG and CEMAGREF are presently studying ways to take into account the variation of the transfer delay time without using too complicated models, which would lead to simulation duration prohibitive for real time management.

On the operational point of view, the best way to use the *"automatic"* software has to be defined. In practice, operators still change directly the dam released flow through the open loop, by changing the forecasted values. Any irrigation forecast increase is immediately converted in an equivalent increase of the open loop and thus of the dam released flow. This situation where operators "by-pass" the automatic control is encountered at the beginning of the irrigation season when flow discharges and pumping are very low but a quick pumping increase is forecasted for the following days. The need in water is very sudden and has to be forecasted to prevent rivers from drying. An equivalent situation is encountered after a rainfall, irrigation events being stopped for several days. Reducing immediately the water discharges by the open loop is much quicker, and consequently much more effective, than letting the closed loop progressively operate. Between these obvious and extreme cases, intermediate situations exist when operators' reactions are added to the present closed loop ones, leading to water losses.

To sum up, due to their characteristics, Gascony rivers supplied by CACG can not be completely automatically controlled. A *"half-automatic"* management is possible, but difficult. On the other hand, in the case of rivers less similar to canals, (with natural flows), the management may be completely automatic, considering the fact that the downstream flows must oscillate around the targeted value.

5 Conclusion

Rivers are obviously the cheapest way of conveying and delivering water, when possible. Lately, thanks to the development of real time information and control systems and to hydraulic models improvement, water delivery through rivers has become a very interesting means of saving ... water.