An Intelligent Decision Support System for Irrigation System Management

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ABSTRACT

In this communication is considered the design of a decision support system for the short term water resource management of an irrigation system. The operations of similar systems are often impaired by different stochastic events like device failure, heavy rains or dry periods and new long term goals. To be effective, such a decision support system which is based on knowledge techniques (state identification) and adaptive optimization (short term plans), requires the development of an information system based on water resource demand and supply. This information system gathers data from different fields (hydrology, meteorology and agriculture) so that accurate predictions about available reserves and demand levels can be performed.

So, this communication presents the structure of the decision support system and focuses on tactical management information needs.

The case study considered deals with a three-reach irrigation system.

Keywords: Decision Support Systems, Information Systems, Irrigation Systems.

1. INTRODUCTION

Agriculture has, throughout History, played a major role in human societies endeavours to be self-sufficient in food. However, irregular floods and droughts cycles have seriously impeded the attainment of such an objective. This is why, for Mankind, agricultural land irrigation has increasingly become a challenge and water resource control a priority.

During the last century, decisive civil engineering technique improvements as well as digital control developments provided human societies with new means of better controlling water resources, so a lot of effort is made in this direction.

In canal control significant progresses are obtained and General Predictive Control has been considered to achieve successfully this task [7] [8]. However, for short term water resource management, since canal operation improvement requires good information on the system status and good knowledge of the system behavior, empirical or hierarchical solutions have been developed [9].

Today, irrigation systems performance have increasingly hindered by the evolution of new demands of water and adverse environmental issues. In this context, new approaches are needed for more insight into ways of achieving greater efficiency at decision-taking stages involved in water resource management, in order to optimize the available water resources and to help decision making for canal management.

So this study presents a global approach of an intelligent decision support system for the short term water resource management of an irrigation system.

2. THE BASIC IRRIGATION SYSTEM

The global objective for irrigation systems is to meet, regardless of uncertainties, water demand for agricultural, industrial and domestic uses at each discharge point while maintaining an acceptable level of water along the reaches and in the reservoirs during any given period [6].

To ensure effective water resource management, a basic irrigation system is considered for illustration in this study. It consists of the following elements (figure 1): an upstream reservoir with control gates, a sequence of interconnected reaches with downstream control gates and off-take discharge devices, a final exit section with a flow metering device.

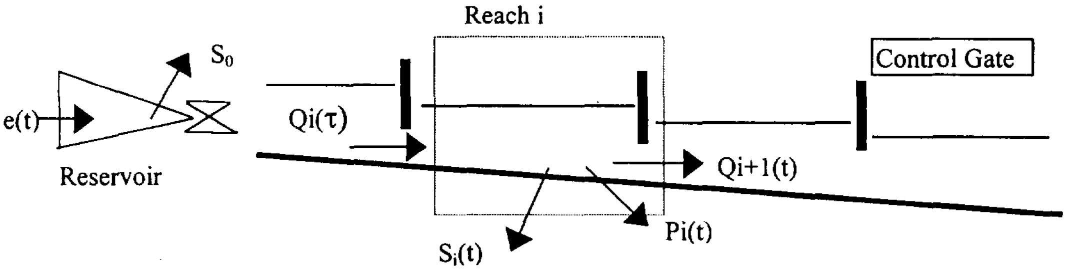

Figure 1: The Basic Irrigation System

It appears that to cope with short run water resource management, the operations of an irrigation system must be described in two ways:

1) In terms of continuous transfer relations relating inflows to outflows in each reach and following non-linear dynamics such as:

$$\dot{Z}_i(t) = f(Z_i(t), Q_i(\tau), Q_{i+1}(t), P_i(t), S_i(t)) \qquad \tau < t \quad i = 1 \text{ to } N \tag{1}$$

where N is the number of reaches,
$Z_i(t)$ is the downstream water level in reach i at time t,
$Q_i(\tau)$ is the upstream inflow to reach i at time τ,
$Q_{i+1}(t)$ is the downstream outflow to reach i at time t,
$S_i(t)$ is the spilled outflow at time t,
$P_i(t)$ is the downstream pumped flow at reach i.
These equations can be discretized and linearized with a good approximation leading to relations such as:

$$Z_i(t+1) = Z_i(t) + [\sum_{\tau<t}(h_{t\tau}.Q_i(\tau)) - Q_{i+1}(t) - P_i(t) - S_i(t)]\Delta t/\sigma_i \tag{2}$$

where $h_{t\,\tau}$ are the transfer coefficients associated to the linearized model and σ_i is a reference area for each reach i [7]. In this case, the upstream water reserve evolves following relation:

$$V_{t+1} = V_t + (e_t - Q_{1t} - S_{0t}).\Delta t \tag{3}$$

where e_t is the water input rate to the reservoir and Q_{1t} the upstream inflow of reach 1 at time t.

2) In terms of qualitative or logical terms related with the degree of saturation of water levels, the intensity of perturbations (rains or dry periods) and the operational state of downstream control gates, pumps and off-take discharge devices.

This description is concerned with :

- physical constraints such as:

$$\begin{cases} Z_i^{min} \le Z_i(t) \le Z_i^{max} \\ 0 \le Q_i(t) \le \tilde{Q}_i(t) \le Q_i^{max} \\ 0 \le P_i(t) \le \tilde{P}_i(t) \le P_i^{max} \\ 0 \le S_i(t) \le S_i^{max}(Z_i(t)) \\ V_{min}^t \le V(t) \le V_{max}^t \\ 0 \le S_{0t} \le S_0^{max}(V(t)) \end{cases} \qquad i = 1 \text{ to } N$$

where Q_i^{max} and P_i^{max} are nominal flow capacities, $\tilde{Q}_i(t)$ and $\tilde{P}_i(t)$ are actual capacities. For instance, when the pumping devices of reach i are down, $\tilde{P}_i(t) = 0$.

- qualitative evaluations of actual water demands in view of past deliveries and current meteorology. Here fuzzy techniques are of great interest to qualify and compose these evaluations [3].

The purpose of this global modelling is that irrigation system is viewed as hybrid dynamical system subject to continuous operations broken by discrete events [4].

3. STRUCTURE OF THE DECISION SUPPORT SYSTEM

The above hybrid model of irrigation systems operations leads to the definition of a finite set of discrete operational situations or states, to which can be attached different short-term goals. It appears that the operations of such systems are impaired by different stochastic events such as device failures, heavy rains, dry periods and new long term goals. So the approach proposed here is to do first an on-line detection state transitions, then to identify the current situation, and finally to reformulate, following an adaptive philosophy, an optimization problem whose goals and constraints are in accordance with the current situation [4].

So different problems arise here to make effective this approach:
- the definition of a set of discrete operational situations,
- the design of a Knowledge Based System sub-component,
- the formulation of short term optimization problems.

State Identification

The definition of such a system must follow some basic considerations:
- only significant events with respect to the management of the water resource must be taken into consideration,
- the combinatorial multiplication of cases generated by the different operations states of each subsystems must be contained,
- every operational situation must be covered by the set of discrete situations.

Relevant discrete events for the operations of this kind of systems are: saturation events, failure events, discrete decisions events.

Therefore, these states can be considered to be composed of three complementary components:
- a supply component related with the distribution of the resource along the irrigation system and involving mainly water levels in reaches and reservoir,
- a system component related with the operational state of its devices (sensors and actuators),
- a demand component related with past deficits and short term predictions (meteorology).

So, the different states can be characterized by a triplet (p, q, r) with $p \in O$, $q \in S$, $r \in D$, where O is the discrete set of sub-states related with the supply component, S is the set of sub-states related with the system component and D is the set of sub-states related with the demand component.

A qualitative description represented in figure 2, shows the Knowledge Based System analysis of the situation.

The pair (i , j) determines the operational situation which can be "normal", "critical", "disastrous". Making a decision consists in determining which pair (i , j) among the possible pairs must be associated to the state operation [1].

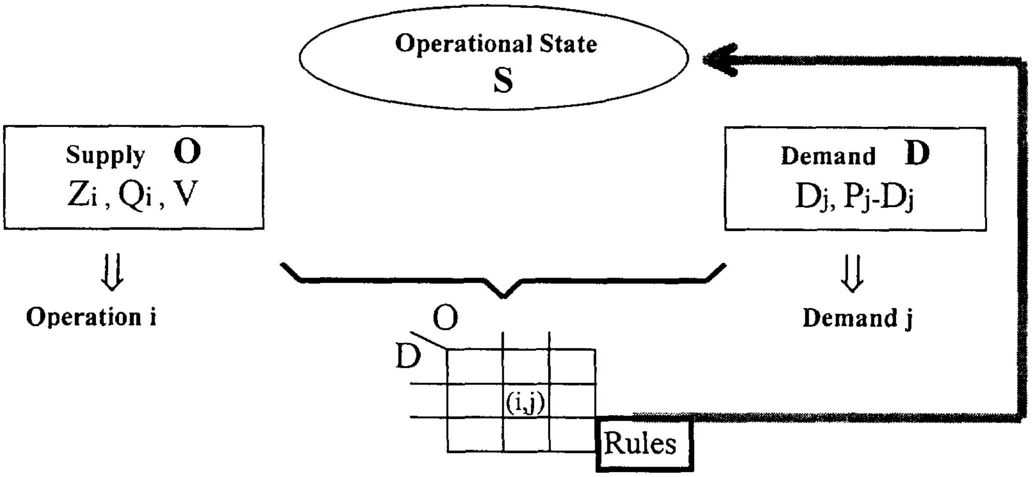

Figure 3: State Identification

Here the State Knowledge Based System is devoted to two different tasks:

- identification of present state and consequently detection of state transitions,
- diagnose of the current situation.

The identification task can be achieved for each component of the states. In relations with the supply component, the identification function may be realised using crisp or smooth definitions of the boundaries of the discrete state and IF-THEN rules can be used to determine the effective membership of the supply component.

For a given set of states, the human operator interference is necessary to define tactics to be followed. For other situations, tactics to be followed can be deduced directly from the current state transition. The states transitions that should be submitted to the human operator must be defined beforehand by expert analysis. With respect to the demand component, short term predictions of demand, based on past statistical data and current deficits are corrected according to external perturbations such as heavy or sustained rains, or such as breakdowns in the distribution network. So, if the subsequent discretization leads to identify the current discrete state in relation to water demand, this function provides also another valuable information for the management of the resource: an updated short term prediction of demand to be used in the optimization process.

The diagnose system operates as an alert system for the human operational manager and must be able to submit to him intricate tactical choices.

Short terms problems

According to the chosen tactics, a set of relevant objectives and effective constraints is selected to define the current short term optimization problem which defines on line reference values for the control system. An acceptable formulation [2] of the standard tactical optimization problem is of the linear form:

$$\min_{P_i^t, Q_i^t} \sum_{t=t_0}^{t_0+T} \sum_{i=1}^{N} \lambda_{it}(D_i^t - P_i^t).\Delta t \qquad (o_1)$$

with $Z_i(t+1)=Z_i(t)+[\sum_{\tau<t}(h_{t\tau}.Q_i(\tau))-Q_{i+1}(t)-P_i(t)-S_i(t)]\Delta t/\sigma_i$

$$i = 1 \text{ to } N \qquad (s_1)$$

$$V_{t+1} = V_t + (e_t - Q_{1t} - S_{0t}).\Delta t \qquad (s_2)$$

under the restrictions:

$$\left.\begin{array}{ll} 0 \le Q_i(t) \le \tilde{Q}_i(t) & (r_1) \\ 0 \le P_i(t) \le \min\left\{\tilde{P}_i(t), D_i^t\right\} & (r_2) \\ 0 \le S_{it} \le S_i^{max}(Z_i(t)) & (r_3) \\ Z_i^{min} \le Z_i(t) \le Z_i^{max} & (r_4) \\ V_{min}^t \le V(t) \le V_{max}^t & (r_5) \\ 0 \le S_{0t} \le S_0^{max}(V(t)) & (r_6) \end{array}\right\} i = 1 \text{ to } N$$

where D_i^t is the predicted or assigned demand rate and P_i^t is the delivery rate for period (t, t+Δt) at reach i, $\{\lambda_{it}, i = 1 \text{ to } N, t \in [t_0, t_0+T]\}$ is a set of deficit weightings for the objective function.

r_1 and r_2 are flow capacity restrictions, r_4 and r_5 are state restrictions.

At the end of the optimization the final time constraints can be such as:

$$\underline{Z}_{i\,max}^{t+T+1} \ge Z_i^{t+T+1} \ge \underline{Z}_{i\,min}^{t+T+1} \qquad i = 1 \text{ to } N \qquad (t_1)$$

$$\underline{V}_{t+T}^{max} \ge V_{t+T} \ge \underline{V}_{t+T}^{min} \qquad (t_2)$$

Note that the optimization objective can be written equivalently as:

$$\max \sum_{t=t_0}^{t_0+T} \sum_{i=1}^{N} \lambda_{it}(P_i^t.\Delta t) \qquad (o_2)$$

where predicted or assigned demand rates are no more present.

To solve this optimization problem, a program named DYPLEX (from "dynamic simplex") has been developed [5]. DYPLEX is composed of four ingredients:

- the revised simplex method,
- an augmented version of the original problem,
- a compacted representation of the sparse vectors and matrices,
- an improved selection process for the pivot element.

Typically, the horizon of optimization for this problem is a week and the time is discretized on an hourly basis.

It becomes clear that to the supply component substates transitions are attached variations in the transfer coefficients of the state equations (s_1) and to the maximum values of downstream outflows , restriction (r_1) and spilled outflows, restrictions (r_3) and (r_6).

To the system component substate transitions, are attached variations to the maximum values of downstream outflows (equation r_1) and to maximum values of downstream pumped flows (equation r_2), determining $\tilde{P}_i(t)$ within the interval $[0,\min\{\,P_i^{max}, D_i^t\,\}]$.

Also, either or not the satisfaction of the current demand is postponed until the failed devices are restored, the demand rates appearing in restriction r_2 must be modified.

To the demand component substate transitions, are attached adaptations of the criterion weightings.

The above approach of the Decision Support System is represented in figure 3.

4. APPLICATION

A three-reach canal with pumping station is considered for the simulation. Two cases are studied for validation and structuring the approach:

- water resource management evaluation with nominal conditions including a strategic resource allocation and demand evaluation,
- evaluation of the strategy to face device failures.

Thus four modules have been implemented: a physical module which describes the system, a demand modules which evaluates uncertain users behavior, a decision module to face device failure and an optimization module which determines references values and thresholds.

In fig. 4 are displayed water levels in normal operating conditions. Here, a nominal water level is assumed in each reach with a random demand.

Fig. 5 displays water level variation with failed pump in reach 2. The strategy adopted in this case consists of stocking water in the second reach and postponing current demand until the failed device is restored. This results in an increase of water level in reach 2.

Fig. 6 takes up again the previous case but here, there is saturation in the upper water level in reach 2.

Fig. 7 shows references values and thresholds from the optimization module. These values were perceived to be the evaluation of water deliveries and inflows.

5. CONCLUSION

In this communication, a decision support system for irrigation system has been considered. It appears that to be effective, such a decision support system is strongly rely with knowledge techniques and adaptive optimization. The paper brings out the organization to help managers in fulfilling the control task and the evaluation of water deliveries references and thresholds for optimal operations. So, the main advantage of this idea is that it is a global combined approach permitting to evaluate dynamically inflows and deliveries. The proposed approach has been validated trough a simulation study involving optimization in presence of failed devices.

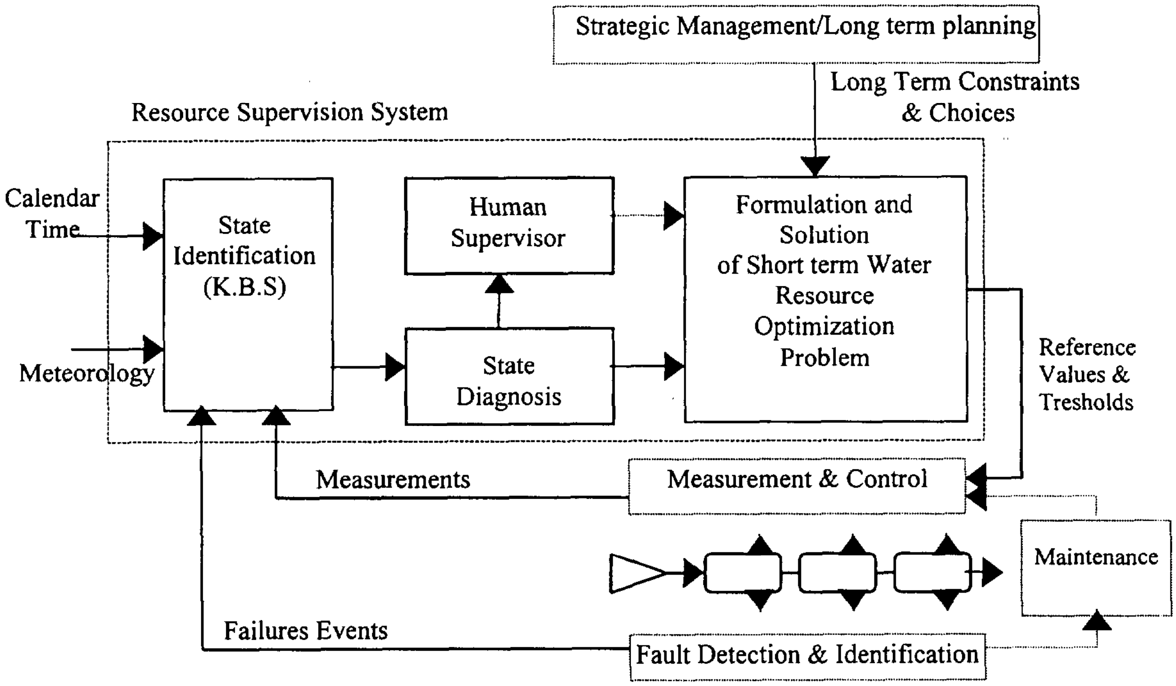

Figure 3: Structure of the Decision Support System

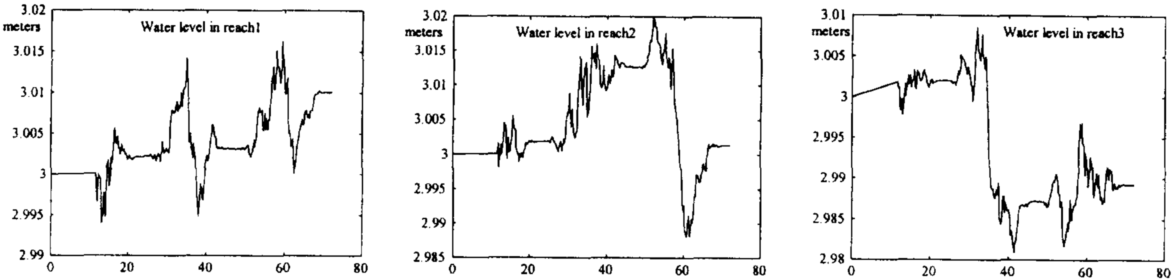

Fig. 4: Water level in normal operating conditions

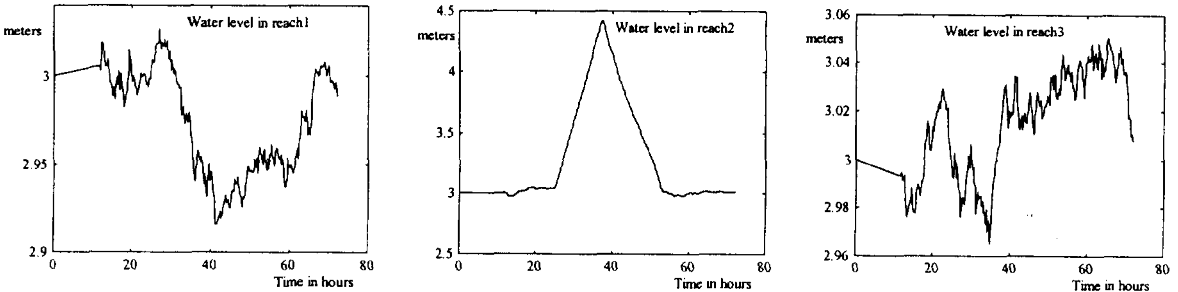

Fig. 5: Water level in presence of failed device in reach 2 without saturation

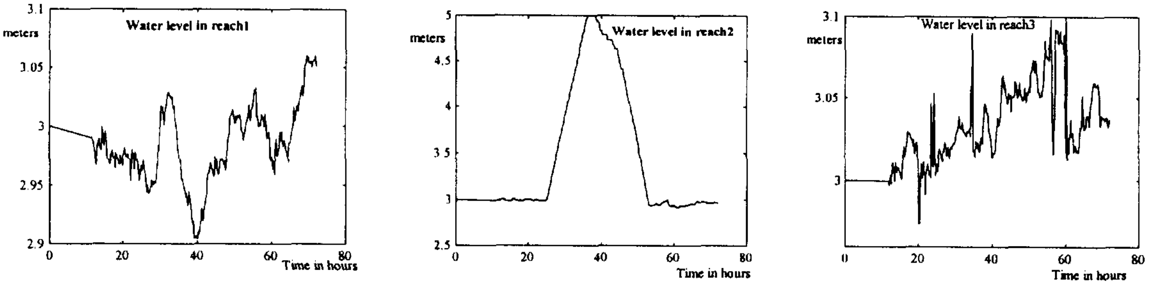

Fig. 6: Water level in presence of failed device in reach 2 with saturation

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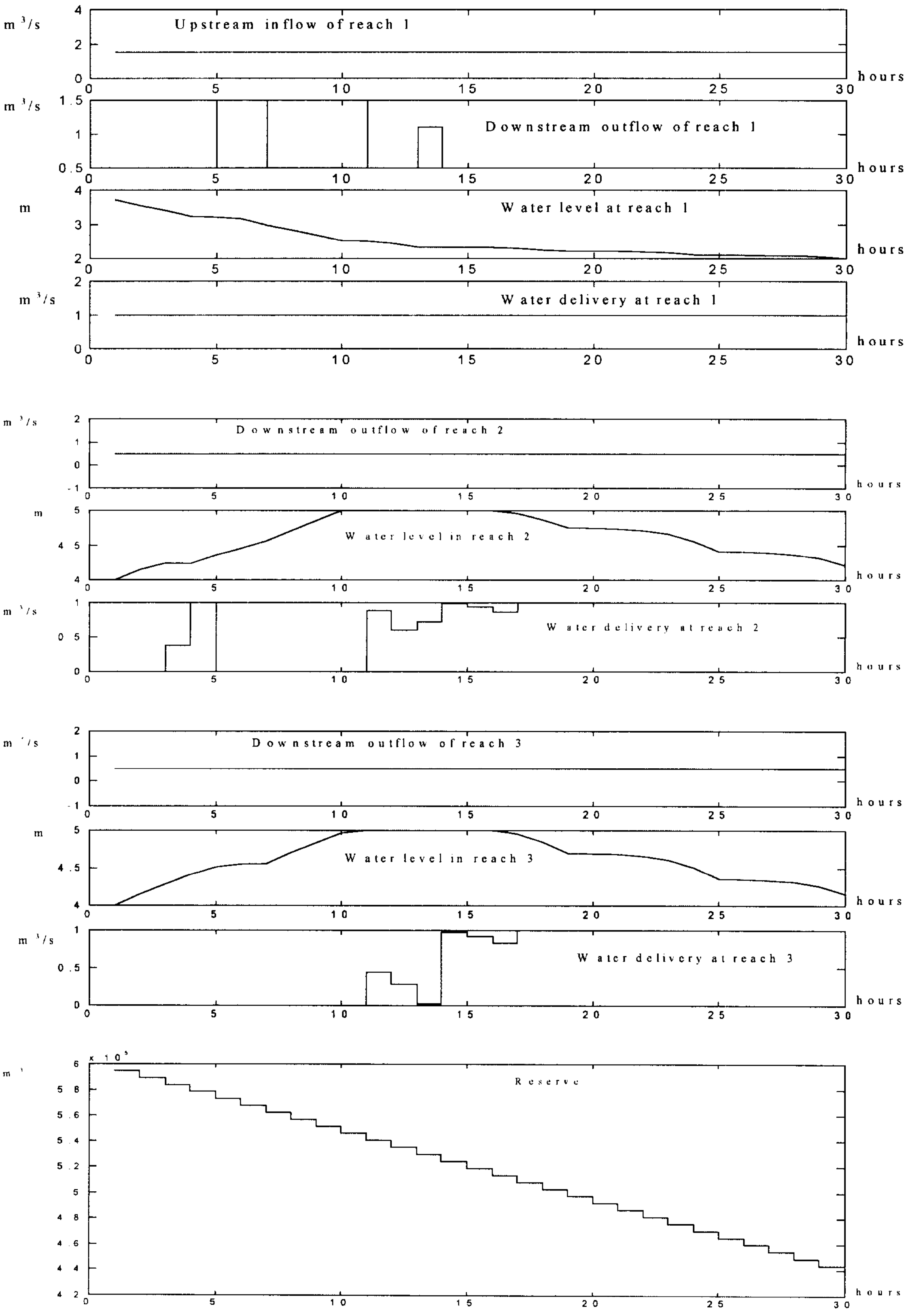

Figure 7: Optimal reference values of a three-reach canal