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# A reactive control strategy for networked hydrographical system management

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## A B S T R A C T

A reactive control strategy is proposed to improve the water asset management of complex hydrographical systems. This strategy requires the definition of rules to achieve a generic resource allocation and setpoint assignment. A modelling method of the complex hydrographical network based on a weighted digraph of instrumented points is also presented. The simulation results of the strategy applied to a hydrographical system composed of one confluent and two diffuents show its efficiency and its effectiveness.

### Keywords:

Supervision

Hybrid control accommodation

Resource allocation

Setpoint assignment

Networked systems

Water management

## 1. Introduction

Hydrographical systems are geographically distributed networks characterized by great dimensions and composed of dams and interconnected rivers and channels. They are used to route water volumes and satisfy Human usages. Due to the preciosity and scarcity of the water resource, the asset management of hydrographical systems became crucial. Thus, various control algorithms were proposed these last years in the literature (Malaterre & Baume, 1998; Zhuan & Xia, 2007). These methods aim at guaranteeing the setpoints and reject the disturbances in order to reduce the water losses. They were generally applied on local applications with a short-time management period. Mareels et al. (2005) underline that the quality of the irrigation service from a farmer's perspective is determined by the timing of the irrigation water. They remark also that the supervisory control has to ensure that the physical flow capacities are not exceeded. But for hydrographical systems, another risk has to be avoided: the lack of water in certain point of the network. A reactive control loop has also to guarantee ecological flows as ruled by the European Community. In Cantoni et al. (2007), an application to an open-channel irrigation network based on a distributed control structure is detailed. The network aims at supplying with water several farms. The resource consists of one reservoir. Cooperative

control of water volumes using a consensus-based decision algorithm was tested with simplistic assumptions and simplifications to manage water distribution into a parallel ponds network (Tricaud & Chen, 2007). But complex hydrographical systems were not addressed. The hydrographical systems considered herein may integrate several reservoirs and rivers that introduce uncertainties. In addition, advanced methods were proposed to improve the water asset management by considering more important management period. The approach proposed in Faye, Sawadogo, Niang, and Mora-Camino (2010) allows the determination of water management objectives by the resolution of an optimization problem starting from the supervision of the network variables. It consists in adjusting the criteria and the constraints of the optimization problem. However, the complexity of the hydrographical networks and the number of the equipment to be taken into account in the optimization problem require the use of decomposition and coordination techniques of the studied systems as proposed in Mansour, Georges, and Bornard (1998). The control accommodation strategy which was proposed in Duviella, Chiron, Charbonnaud, and Hurand (2007) for one stream channels leads to the allocation of water quantities in excess toward the catchments area and of water quantities in lack amongst the users, taking into account the various requests of the users, the manager objectives, and the system constraints. This strategy is implemented since 2005 to the one stream Neste channel in the southwestern region of France and has improved the water asset management of the Neste hydrographical network. The Neste channel allows the water supply of several Gascogne rivers. The extension of this strategy to more complex

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hydrographical systems requires new modelling solutions, and the proposal for new methods of resource allocation and setpoint assignment.

Naidu, Bhallamudi, and Narasimhan (1997) proposed a hydrographical network modelling. Indexed nodes represent the diffluences, and directed arcs the streams which connect two nodes. The exponent associated to these arcs correspond to the number of the node downstream. This representation was extended to the cases of the confluences in Islam, Raghuwanshi, Singh, and Sen (2005). The control and measurement instrumentations are taken into account by an object-oriented modelling techniques (Chan, Kritpiphat, & Tontiwachwuthikul, 1999) or an XML approach (Lisounkin, Sabov, & Schreck, 2004). It gives the representation of the elements of the hydrographical networks. In Cembrano, Wells, Quevedo, Perez, and Argelaguet (2000), modelling approaches were proposed for the optimal water management of the drinking water distribution networks and sewerage networks. For these last approaches, the representation of the control and measurement instrumentations is allowed without being adapted to integrate computation rules of the discharge propagation upstream to downstream. Finally, a modelling method of the hydrographical networks based on weighted digraph of instrumented points was proposed in Duviella, Chiron, and Charbonnaud (2007a). It was used to define and carry out a control strategy for the asset management of a hydrographical system composed of one confluence and one diffluence.

The contribution of this paper is to address the water asset management of hydrographical networks problem via generic resource allocation and setpoint assignment rules. The considered hydrographical systems are composed of several diffluences and confluences and equipped with control and measurement instrumentations. The first step of the method consists in modelling the hydrographical system and determining the transfer time delay between each equipment of the network. The second step aims at describing the reactive control strategy and proposing the resource allocation and setpoint assignment rules. The modelling method of complex hydrographical systems is presented in Section 2. In Section 3, the reactive control strategy based on resource allocation and setpoint assignment rules is proposed. Finally, the effectiveness of the strategy is shown by simulation within the framework of a hydrographical system integrating a principal stream which supplies a secondary stream for industrial and irrigation uses.

## 2. Complex hydrographical system modelling

Hydrographical networks consist of a finished number of *simple* hydraulic systems (HYS), *i.e.* composed of one stream. A HYS *source* is defined as a HYS which is not supplied by others HYS. A representation is proposed to locate the instrumentation, *i.e.* the sensors and the actuators, and to be able to determine the way to distribute a water quantity measured in a place of the hydrographical network, onto the whole HYS downstream. HYS are indexed by an index  $b$ , and the whole of these indices forms the set  $\mathcal{B} \subset \mathbb{N}$ . Each HYS is equipped with several sensors  $M_i^b$  and actuators  $G_j^b$ , with  $i \in [1, m]$  and  $j \in [1, n]$ , where  $m$  and  $n$  are respectively the total number of measurement points and actuators which equipped the hydrographical network. Exponents will be omitted when not necessary for computation and comprehension.

It is possible to represent the structure of a hydrographical network by distinguishing two elementary configurations such as a confluence (*see* Fig. 1a), or a diffluence (*see* Fig. 1b). According to the hydraulic conditions and the conservation equations of the energy and mass, the sum of the discharges entering a node (confluence or diffluence) is equal to the sum of the discharges outgoing from this node. Thus, around an operating point, the discharge  $q^b$  of the HYS  $b$  resulting from the confluence between several HYS is equal to the sum of the upstream HYS discharges,  $q^b = \sum_{r \in \mathcal{C}^b} q^r$ , where  $\mathcal{C}^b \subset \mathcal{B}$  is the set of the HYS indices upstream to the HYS  $b$ . In addition, the HYS  $r$  resulting from the diffluence of the HYS  $b$  upstream is supplied with a proportion  $w_r$  such that the discharge  $q^r$  verifies the relation:  $q^r = w_r q^b$ . In order to represent diffluences, each HYS of hydrographical systems is associated to a discharge proportion  $w_r$ . For the HYS *source* and for the HYS downstream from a confluence (*see* Fig. 1a) it is equal to 1. The discharge proportion  $w_r$  of the HYS downstream the HYS  $b$  is known and such as  $\forall r \in \mathcal{D}^b, w_r \leq 1$ , and  $\sum_{r \in \mathcal{D}^b} w_r = 1$ , where  $\mathcal{D}^b \subset \mathcal{B}$  is the set of HYS indices resulting from the diffluence of the HYS  $b$  (*see* Fig. 1b).

In the proposed modelling, the hydrographical systems are represented by a weighted digraph of instrumented points in order to determine the discharge proportions between two places of the networks. A discharge measured in a place of the hydrographical network supplies the HYS downstream of this place with discharge proportions according to the structure of the

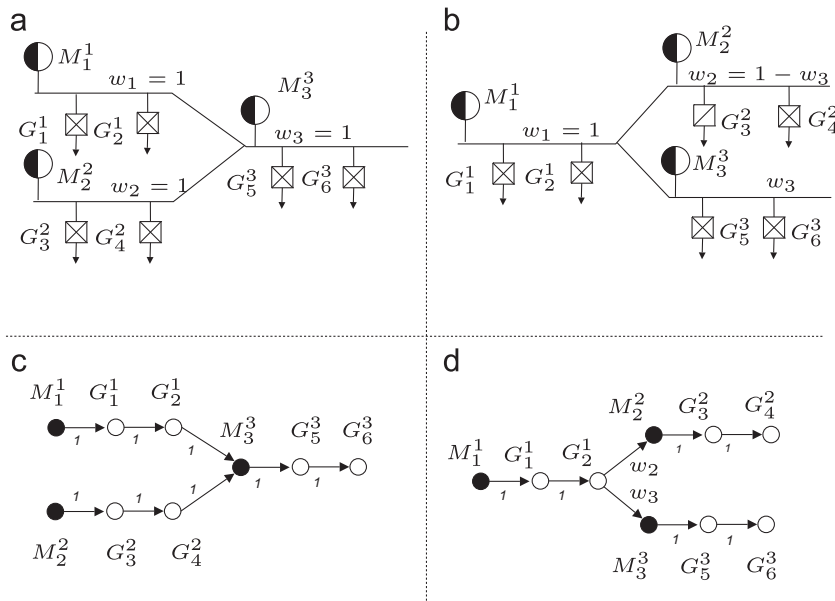


Fig. 1. (a) A confluence, (b) a diffluence, (c) its associated weighted digraph, (d) its associated weighted digraph.

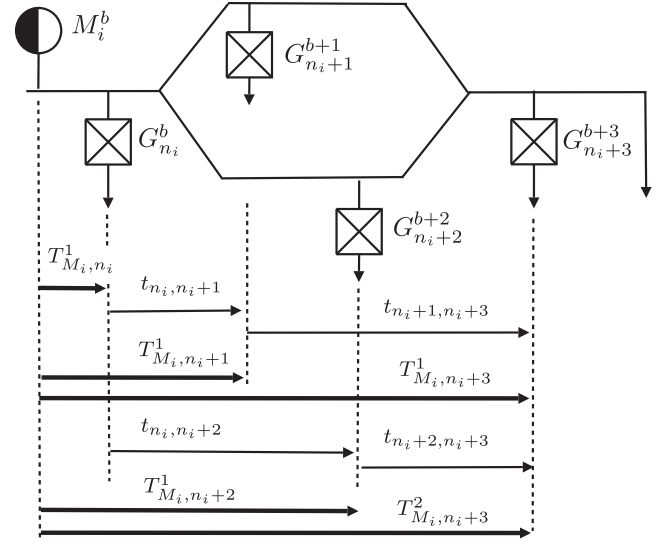
hydrographical network. Thereafter, transfer time delay is introduced to evaluate the water travel time between a measurement point and the gate according to the selected path. Mareels et al. (2005) have discussed the physical meaning of the basic parameters in the grey box model (the dominant time constant, the wave period and time delay) that is presented for open-channel modelling. They derive a rule of thumb linking physical parameters like pool length, critical velocity, Manning coefficient to a reasonable first guess for the coefficients in the grey box model. Herein, an estimation technique of transfer time delay based on a physical model is described.

*Step1: A weighted digraph of instrumented points* is represented by a digraph composed of a succession of two types of nodes  $M_i$  or  $G_j$  (see Fig. 1a and d) represented respectively by full circle and circle, and arcs indicating the links between the successive nodes (see Fig. 1c and d). The arcs are oriented in the direction of the flow and are weighted by the discharge proportion  $w_r$  between the two nodes. The arcs from a diffluence (see Fig. 1d) are weighted by the discharge proportion of the HYS downstream, others are weighted by 1.

Thereafter, in order to compute all the discharge proportions from each measurement point to the gates and from every gate to the gates of the hydrographical network, an algorithm is proposed. It leads to the generation of the proportion matrix  $\mathbf{R}$  composed of  $n$  lines (actuators) and  $m+n$  columns (measurement points and actuators). The weighted digraph is browsed for each measurement point  $M_i$  following the algorithm given in Table 1 in order to build the proportion matrix  $\mathbf{R}$ . The proposed algorithm is a classical depth-first search algorithm as proposed in Cormen, Leiserson, Rivest, and Stein (2001). This matrix contains all the discharge proportions from each measurement point to each gate, and from each gate to other gates in the hydrographical network.

*Step2: The value of the transfer time delays  $T_{M_i,j}$  between the measurement point  $M_i^p$  and the gate  $G_j^d$  depends on the borrowed path to go from the measurement point  $M_i^p$  to the gate  $G_j^d$  (see Fig. 2). A direct path from  $M_i$  to  $G_j$  is a path where not other measurement point can be met between  $M_i$  and  $G_j$ .  $\mathcal{P}^{b,d}$  is the set of direct paths to go from the HYS  $b$  to the HYS  $d$ , and  $P_v^{b,d}$  is one of the direct paths to go from the HYS  $b$  to the HYS  $d$ , such as  $P_v^{b,d} \in \mathcal{P}^{b,d}$ , with  $1 \leq v \leq \rho_{b,d}$ , where  $\rho_{b,d}$  denotes the total number of paths which compose  $\mathcal{P}^{b,d}$ .*

The transfer time delays between the measurement point  $M_i^p$  and the gate  $G_j^d$  are computed by considering each path and are



**Fig. 2.** Example of decomposition of transfer delays between the measurement point  $M_i$  and gates  $G_j$ .

the components of the vector  $\mathbf{T}_{M_i,j} (\rho_{b,d} \times 1)$  expressed as

$$\mathbf{T}_{M_i,j} = [T_{M_i,j}^1, T_{M_i,j}^2, \dots, T_{M_i,j}^{\rho_{b,d}}]^T, \quad (1)$$

where each component  $T_{M_i,j}^v$  is an integer multiple of the sampling period  $T_s$  and computed according to

$$\begin{cases} T_{M_i,j}^v = \left\lfloor \frac{1}{T_s} \left( T_{M_i,n_i}^1 + \sum_{r=n_i}^{r=j^-} t_{r,r^+} \right) \right\rfloor + 1, \\ n_i \leq j \leq n, \end{cases} \quad (2)$$

where  $\lfloor x \rfloor$  denotes the integer part of  $x$ ,  $n_i$  is the index of the first gate downstream  $M_i$ ,  $v$  is the index of the path  $P_v^{b,d}$ ,  $T_{M_i,n_i}^1$  is the transfer time delay between the measurement point  $M_i$  and the gate  $G_{n_i}$ ,  $t_{r,r^+}$  is the transfer time delay between the gate  $G_r$  and its successor  $G_{r^+}$  along the path  $P_v^{b,d}$  as illustrated in Fig. 2, and  $j^-$  is the index of the gate preceding  $G_j$  along the path  $P_v^{b,d}$ .

At the current time  $kT_s$ , the measured water quantity in  $M_i^b$  will reach at the gate  $G_j^d$  by the path  $P_v^{b,d}$  at the time:

$$T_{M_i,j}^v = (k + T_{M_i,j}^v) T_s. \quad (3)$$

The transfer delays  $T_{M_i,n_i}^v$  and  $t_{r,r^+}$  associated to each open-channel reach section (O CRS) are computed from the O CRS dynamics model described thereafter. An O CRS is a part of HYS defined between a measurement point and a gate, between a gate and a measurement point, or between two gates.

Usually, Saint Venant equations are used for the modelling of open-channel dynamics. The analytic resolution of these two coupled partial differential equations (Chow, Maidment, & Mays, 1988) is not possible. As discussed in Kutija and Hewett (2002) and Abbott and Basco (1989) discretization methods can be used to find a solution. Otherwise, a modelling method detailed in Litrico and Georges (1999) based on the simplification and linearization of Saint Venant equations can be used. This method is based on the identification, for each O CRS, of a transfer function plus transfer delay (4) for a reference discharge  $Q_e$  (Duviella, Chiron, & Charbonnaud, 2006), according to the O CRS geometrical characteristics:

$$F(s) = \frac{e^{-\tau s}}{1 + a_1 s + a_2 s^2}, \quad (4)$$

where the coefficients  $a_1$ ,  $a_2$  and the pure delay  $\tau$  are computed according to the identified celerity and diffusion parameters  $C_e$

**Table 1**  
Assignment function of  $\mathbf{R}$  matrix.

Input: weighted digraph, measurement point number $m$ .
Output: proportion matrix $R$ .
Initialization of $R$ to 0
For each node $N_h$
Run ( $N_h, N_h, 1, R$ )
EndFor
Run ( $N_h, N_c, p, R$ ),
For each successor $N_d$ of $N_c$
$p_d \leftarrow p.w_d$ ,
Run ( $N_h, N_d, p_d, R$ ),
If $N_h$ is a measurement point
If $N_d$ is a gate
$R(d, h) \leftarrow R(d, h) + p_d$
EndIf
Else
If $N_d$ is a gate
$R(d, m+h) \leftarrow R(d, m+h) + p_d$
EndIf
EndIf
EndFor

**Table 2**  
Continuous transfer functions  $F(s)$  corresponding to  $C_L$ .

$C_L$	$F(s)$
$C_L \leq \frac{4}{9}$	$\frac{1}{1+a_1s}$
$\frac{4}{9} < C_L \leq 1$	$\frac{e^{-ts}}{1+a_1s}$
$1 < C_L$	$\frac{e^{-ts}}{1+a_1s+a_2s^2}$

and  $D_e$ , and to the adimensional coefficient  $C_L$  which is defined by

$$C_L = \frac{2C_e X}{9D_e}, \quad (5)$$

where  $X$  is the OCRS length,  $C_e$  and  $D_e$  are expressed as

$$\begin{cases} C_e = \frac{1}{L^2} \frac{\partial J}{\partial Q_e} \left[ \frac{\partial L}{\partial x} - \frac{\partial}{\partial y} J \right], \\ D_e = \frac{1}{L} \frac{\partial J}{\partial Q_e}, \end{cases} \quad (6)$$

where  $L$  is the surface width,  $y$  the discharge depth,  $J$  the friction slope expressed with the Manning–Strickler relation as  $J = Q_e^2 P^{4/3} / K^2 S^{10/3}$ , where  $K$  is the Strickler coefficient,  $P$  the wetted perimeter and  $S$  the wetted surface.

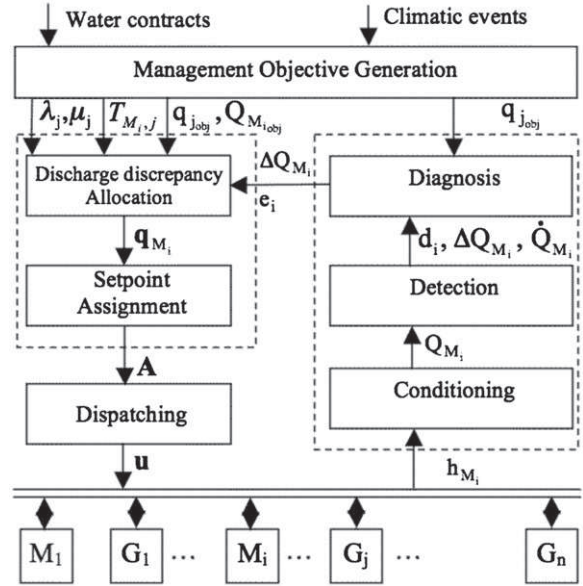
As displayed in Table 2, the order of the transfer function depends on the  $C_L$  value. When  $C_L \leq \frac{4}{9}$ , the OCRS is short and can be modelled by a first order transfer function without delay, when  $\frac{4}{9} < C_L \leq 1$ , a delay is added to a first order transfer function and when  $C_L > 1$ , the OCRS is long enough and can be modelled by a second order transfer function with delay.

The delays  $T_{M_i, n_i}^1$  and  $t_{r, r^+}$  are computed from the step response of the transfer function which is identified around the reference discharge  $Q_e$ , and corresponds to the time to reach 50% of the step response. Thus, the transfer delay  $T_{M_i, j}^v$  is determined (see Eq. (2)).

The complex hydrographical network representation, as well as the identification of the transfer time delays, constitutes an essential step for the design of reactive control strategies.

### 3. Resource allocation and setpoint assignment

For hydrographical networks equipped with dams located upstream and downstream on the catchment area, several management levels are usually considered. The first consists of the implementation of new dams, channels, equipments, etc., with a management horizon over 10 years. The second is the volume management level which aims at allocate the water resource amongst the catchment areas in order to supply users and to conserve a sufficient volume in the downstream dams for local supplying. The efficiency of the volume management is important for guaranteeing the balance between the stock and the demand all over on the management horizon. To achieve these objectives, managers consider weekly objective discharge. Finally, the third is the discharge management level with a sample periods of several minutes, it consists in maintaining water levels at reference setpoints value by rejecting perturbations. In this context, a reactive strategy based on supervision and hybrid control accommodation framework, accounting for second and third levels is proposed and is depicted in Fig. 3. The hydrographical network is represented by a set of  $m$  measurement points  $M_i$  and  $n$  gates  $G_j$  locally controlled. In general, the gates are controlled according to the implementation of PI controller. In recent years, other more efficient algorithms have been proposed in the literature. In Duviella et al. (2010), two control algorithms, one based on LPV



**Fig. 3.** Supervision and hybrid control accommodation framework for reactive control.

approach, the second on multimodelling approach, allow effective control of gate on large operating range. Whatever the efficiency of local control is, the reactive strategy leads to the definition of new setpoints according to the capacity of each HYS, in order to avoid flood and HYS drying.

For each gate  $G_j$ , a weekly objective discharge  $q_{jobj}$  and seasonal weights  $\lambda_j$  and  $\mu_j$  are computed by the management objective generation (MOG) module according to the water contracts and climatic events. The weights  $\lambda_j$  and  $\mu_j$  reflect the priorities on the water uses when the resource is in excess or in lack respectively. The weekly measurement point objective discharge  $Q_{M_iobj}$  is known. The transfer time delays  $T_{M_i, j}$  are also given by MOG module.

For each measurement point  $M_i$ ,  $i = 1, \dots, m$ , discharge supervision consists in monitoring discharge disturbances and diagnosing the resource state, simultaneously. Firstly, level-meter measurements are conditioned by a low-pass filter on a sliding window which removes wrong data due to transmission errors for instance. Based on the discharge value  $Q_{M_i}$  which is determined at each time  $kT_s$ , detection and diagnosis automata are used respectively to detect a discharge discrepancy and to diagnose the resource states (Duviella et al., 2007). The sample period  $T_s$  which is chosen according to the dynamics of the hydrographical systems, generally corresponds to several minutes.

The concurrent hybrid automaton (see Fig. 4) is designed for each measurement point  $M_i$ . The concurrent hybrid automaton formalism is drawn from the concurrent hybrid automata proposed in Blackmore, Funiak, and Williams (2008), and Hofbauer and Williams (2002). The five pertinent states retained correspond respectively to no-discrepancy state  $E_0$ , two states where the discharge discrepancy is either positive ( $E^+$ ) or negative ( $E^-$ ) and constant  $C$ , and two states where the discharge discrepancy is either positive ( $E^+$ ) or negative ( $E^-$ ) and no constant  $-C$ . Transitions between states are defined as conditions on the measured discharge value and variation:

$$\begin{cases} d_i : [|\Delta Q_{M_i}| > th_i], \\ \psi_i : [\Delta Q_{M_i} < 0], \\ \omega_i : [|\dot{Q}_{M_i}| < dth_i], \end{cases} \quad (7)$$



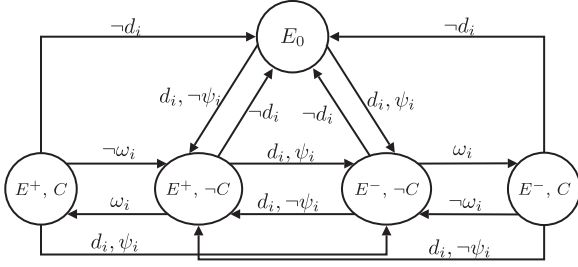


Fig. 4. Hybrid automaton for the measurement point  $M_i$ .

with

$$\Delta Q_{M_i} = Q_{M_i, \text{obj}} - Q_{M_i}, \quad (8)$$

where  $Q_{M_i}$  is the measured discharge,  $Q_{M_i, \text{obj}}$  is the management objective of the measurement point  $M_i$ ,  $\dot{Q}_{M_i}$  the estimate derivative of  $Q_{M_i}$ ,  $th_i$  and  $dth_i$  respectively the detection and diagnosis thresholds.

According to the resource state and the discharge discrepancy (see relation (8)), the hybrid control accommodation consists in determining the setpoints  $q_j$ , and in assigning them to the gates taking into account the hydrographical system dynamics. The resource allocation consists in recalculating setpoints with an objective to route resource excess to dams and to distribute amongst users the resource in lack. At each time  $kT_s$ , the resource allocation leads to the determination of allocation vector  $\mathbf{q}_{M_i}$  which is composed of the new computed setpoints. The allocation vector is computed according to the resource state  $e_i$  taking into account the seasonal weights  $\lambda_j$  and  $\mu_j$ .

If the resource state  $e_i$  is no diagnose situation (denoted  $E_0$ ), the setpoints are the objective discharges  $q_{j, \text{obj}}$ . The allocation vector is such as

$$\mathbf{q}_{M_i} = [\delta_{[R(1,i)]}^1 q_{1, \text{obj}} \dots \delta_{[R(j,i)]}^1 q_{j, \text{obj}} \dots \delta_{[R(n,i)]}^1 q_{n, \text{obj}}]^T, \quad (9)$$

where  $[x]$  corresponds to the higher rounding of  $x$ ,  $n$  is the total number of gates, and  $\delta_b^a$  the Kronecker index, is equal to 1 when  $a=b$ , and equal to 0 otherwise.

If the resource state  $e_i$  is such as discharge is in lack (denoted  $E^-, C$ ) or in excess (denoted  $E^+, C$ ), the water resource is allocated among the gate downstream of the measurement point  $M_i$ , according to the weights  $\lambda_j$  and  $\mu_j$ . The allocation strategy is done by optimizing the cost function using a linear programming method for each measurement point:

$$f_{M_i} = \sum_{j=1}^n (\delta_{[R(j,i)]}^1 \chi_{M_{i,j}} (q_j - q_{j, \text{obj}})), \quad (10)$$

with  $\chi_{M_{i,j}} = \gamma 1 / \lambda_j + (\gamma - 1) / \mu_j$ ,  $\gamma = \frac{1}{2} (\text{sign}(\Delta Q_{M_i}) + 1)$ .

The optimization is carried out under four constraints:

$$\begin{cases} \sum_{j=1}^n (q_j - q_{j, \text{obj}}) = \Delta Q_{M_i}, \\ q_{j, \text{min}} \leq q_j \leq q_{j, \text{max}}, \quad 1 \leq j \leq n, \\ |q_j - q_{j, \text{obj}}| \leq |R(j,i) \Delta Q_{M_i}|, \quad 1 \leq j \leq n, \\ q_o - q_{o, \text{obj}} = R(o,i) \Delta Q_{M_i} - \sum_{l=1}^{o-1} \delta_{[R(l,i)]}^1 R(o,m+l) (q_l - q_{l, \text{obj}}), \quad o \in \{j | G_j \in \mathcal{O}\}, \end{cases} \quad (11)$$

where  $q_{j, \text{min}}$  and  $q_{j, \text{max}}$  are respectively the minimum and maximum discharges given for gate  $G_j$ , river or canal characteristics,  $\delta_b^a$  the Kronecker index, and  $\mathcal{O}$  is the set of the latest downstream controlled gates, i.e. the gates preceding hydrographical network outlets.

The first two constraints aim at allocating the totality of discharge discrepancies amongst the gates while preserving the new setpoints inside the operating range of each gate. The third constraint is related to the network structure. The gate  $G_j$  can absorb at the maximum  $R(j,i) \Delta Q_{M_i}$  of the discrepancy measured on  $M_i$ , according to the proportion matrix  $\mathbf{R}$ . The fourth constraint is applied only for the latest downstream controlled gate  $G_0$ . Its objective consists in checking that the totality of discharge discrepancies is allocated on the upstream gates. In this case, the allocation vector  $\mathbf{q}_{M_i}$  is such as

$$\mathbf{q}_{M_i} = [\delta_{[R(1,i)]}^1 q_1 \dots \delta_{[R(j,i)]}^1 q_j \dots \delta_{[R(n,i)]}^1 q_n]^T. \quad (12)$$

If the resource state is such as discharge is no constant, in lack (denoted  $E^-, -C$ ) or in excess (denoted  $E^+, -C$ ), in order to avoid numerous re-allocation, the water resource is allocated on the smallest number of gates, taking into account the network structure. The set of selected gates have to change at each detection time, in order to avoid the control of the same gates at each time. The selection process has to allow for the weights  $\lambda_j$  and  $\mu_j$  of gates, and the network structure. Thus, it is necessary to determine *a priori* the sets  $\mathcal{L}_{M_i}^{\lambda}$  and  $\mathcal{L}_{M_i}^{\mu}$  composed of sets of gates, denoted  $\mathcal{L}_{M_i, g}^{\lambda}$ , able to be re-allocated alternately, according to the network structure and to the proportion matrix  $\mathbf{R}$ . The set  $\mathcal{L}_{M_i}^{\lambda}$  (resp.  $\mathcal{L}_{M_i}^{\mu}$ ) is composed of gates which have the most important positive weights  $\lambda_j$  (resp. negative weights  $\mu_j$ ). Furthermore, each set of gates is such that the sum of the proportion coefficients given in the proportion matrix  $\mathbf{R}$  for each gate of the set  $\mathcal{L}_{M_i, g}^{\lambda}$  is equal to one and such that each gate of the set  $\mathcal{L}_{M_i, g}^{\lambda}$  belongs to different HYS. The set  $\mathcal{L}_{M_i}^{\lambda}$  of all sets  $\mathcal{L}_{M_i, g}^{\lambda}$  of gates is expressed as

$$\begin{cases} \mathcal{L}_{M_i, g}^{\lambda} = \left\{ C_u^b | n_i \leq u \leq n, \lambda_u = \max_{1 \leq j \leq n} (\lambda_j) \right\}, \\ \mathcal{L}_{M_i}^{\lambda} = \left\{ \mathcal{L}_{M_i, g}^{\lambda} | \forall G_u^b, G_v^d \in \mathcal{L}_{M_i, g}^{\lambda}, u \neq v \wedge b \neq d; \sum_{u | G_u \in \mathcal{L}_{M_i, g}^{\lambda}} R(u,i) = 1 \right\}. \end{cases} \quad (13)$$

At each  $kT_s$ , because the discrepancy is not constant, the discrepancy which is not yet absorbed by the previous assigned gates  $\Delta q^k$  is expressed as

$$\Delta q^k = \Delta Q_{M_i}^k - \Delta Q_{M_i}^{k-1}. \quad (14)$$

The set of gates  $\mathcal{L}_{M_i, l}^{\lambda}$  is selected according to the minimum and maximum discharges given for each gate  $G_u$  belonging to the set, i.e.  $q_{u, \text{min}}$  and  $q_{u, \text{max}}$ , and to the request criterion  $S_l$  storing the number of times the set of gates  $\mathcal{L}_{M_i, l}^{\lambda}$  was already requested and

**Table 3**  
Assignment function of  $\alpha$  and  $\beta$  matrices.

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Input: weighted digraph.  
Output:  $\alpha_{M_i}$  matrix,  $\beta_{M_i}$  matrices  
Initialization of the diagonal of  $\alpha_{M_i}$  to 0  
Initialization of  $\beta_{M_i}$  to 0  
Run  $(M_i, N_{n_i}, 1, \alpha_{M_i}, \beta_{M_i})$   
Run  $(M_i, N_c, p, \alpha_{M_i}, \beta_{M_i})$   
For any successor  $N_d$  of  $N_c$   
   $p_d \leftarrow p \cdot w_d$   
  If  $N_d$  is a gate  
    Run  $(M_i, N_d, p_d, \alpha_{M_i}, \beta_{M_i})$   
     $\alpha_{M_i}(d,d) \leftarrow \alpha_{M_i}(d,d) + p_d$   
     $l = 1$   
    While  $(\beta_{M_i}(l,d) \neq 0)$   
       $l++$   
    EndWhile  
     $\beta_{M_i}(l,d) \leftarrow p_d$   
  EndIf  
EndFor

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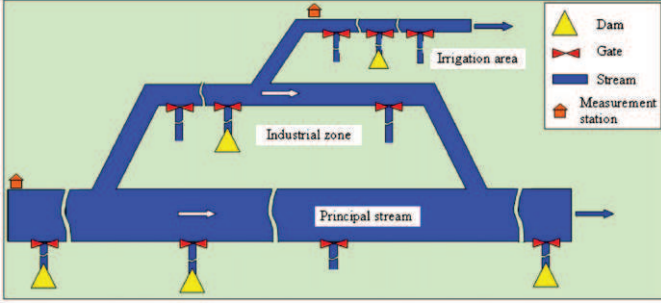


Fig. 5. Networked hydrographical system.

associated to each set of gates (it is a similar procedure for  $\mathcal{L}_{M_i, l}^\mu$ ):

$$\begin{cases} |l|S_l = \min_{g | \mathcal{L}_{M_i, g}^\lambda \in \mathcal{L}_{M_i}^\lambda} S_g, \\ \forall G_u \in \mathcal{L}_{M_i}^\lambda, \quad q_{u, \min} \leq q_u^{k-1} + R(u, i) \Delta q^k \leq q_{u, \max}. \end{cases} \quad (15)$$

Then, the allocation vector  $\mathbf{q}_{M_i}^k$  is given by

$$\begin{cases} \mathbf{q}_{M_i}^k = [\delta_{R(1, i)}^1 (q_1^{k-1} + B_1 R(i, 1) \Delta q^k) \dots \delta_{R(u, i)}^1 (q_u^{k-1} + B_u R(i, u) \Delta q^k) \\ \dots \delta_{R(n, i)}^1 (q_n^{k-1} + B_n R(i, n) \Delta q^k)]^T, \\ \text{with } B_u = \begin{cases} 1 & \text{if } G_u \in \mathcal{L}_{M_i, l}^\lambda, \\ 0 & \text{otherwise.} \end{cases} \end{cases} \quad (16)$$

Then, the new setpoints must be assigned to the gates at a time taking into account the transfer delays. Two setpoint assignment rules were defined and compared in the case of networked hydrographical systems in Duviella, Chiron, and Charbonnaud (2007b). The setpoint assignment rule which leads to the best performances consists in considering the several direct transfer delays  $\mathbf{T}_{M_i, j}$  (see relation (1)) starting from  $M_i$  to each gate  $G_j$ . Due to these paths, it is necessary to consider supplying discharge proportions  $\beta_{M_i}(v, j)$  which correspond to the discharge resulting from  $M_i^p$  and supplying  $G_j^d$  by the path  $P_v^{b, d}$ . The supplying discharge proportion  $\beta_{M_i}(\rho_{M_i} \times n)$ , where  $\rho_{M_i}$  is the maximum number of paths between  $M_i$  and all the gates  $G_j$ , is computed for each measurement point  $M_i$  according to the algorithm given in Table 3 and the weighted digraph of the system.

The set of allocation times starting from  $M_i$  is denoted  $\Gamma_{M_i}(\rho_{M_i} \times n)$ . The matrix  $\Gamma_{M_i}$  is updated at each sampling period

Table 4  
Gate parameters.

Gate	$q_{j, \text{obj}}$	$q_j \text{ min}$	$q_j \text{ max}$	$\lambda_j$	$\mu_j$
$G_1^1$	1	0.3	5	10	1
$G_2^2$	1	0.25	3	1	1
$G_3^3$	1.5	0.5	3.5	10	1
$G_4^3$	0.8	0.2	2	1	10
$G_5^3$	0.3	0.15	2.5	10	1
$G_6^3$	0.6	0.15	2	1	10
$G_7^4$	0.9	0.2	2.5	1	10
$G_8^5$	4	1	7	10	1
$G_9^5$	2	0.5	5	1	10
$G_{10}^6$	0.5	0.1	3	10	1
$G_{11}^3$	0.4	0.2	1	-	-
$G_{12}^6$	8	4	10	-	-

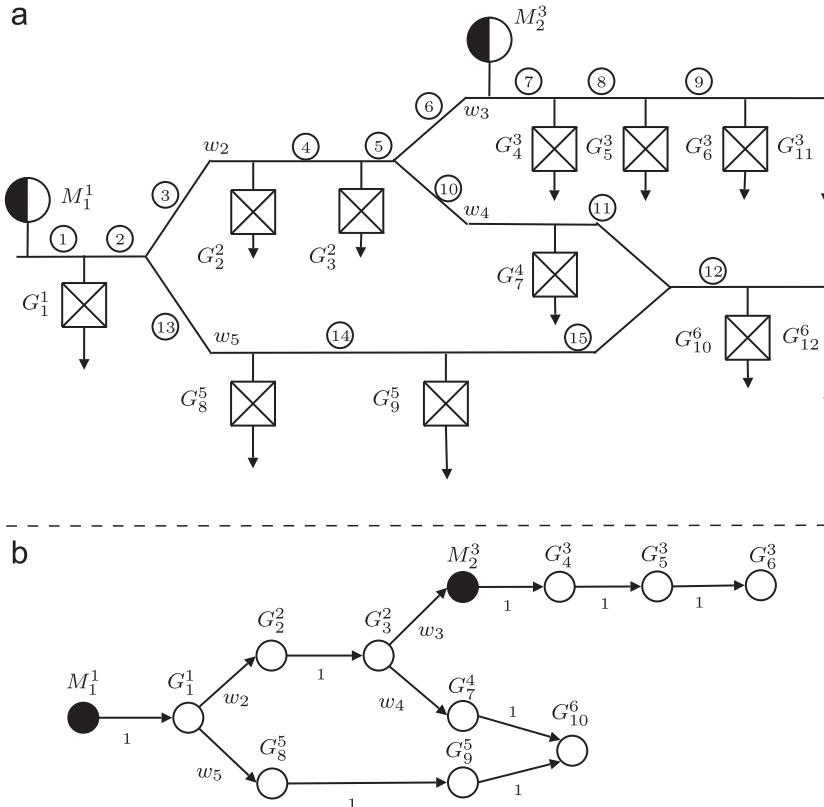


Fig. 6. (a) Networked hydrographical system representation, (b) its associated digraph representation for  $\mathbf{R}$  and  $\alpha_{M_i}$  determination.



$T_s$  and its elements are expressed by

$$\Gamma_{M_i}(v,j) = \begin{cases} T_{M_i,j}^v & \text{if } n_i \leq j \leq n \text{ and } 1 \leq v \leq \rho_{b,d}, \\ 0 & \text{if } (1 \leq j < n_i) \text{ or } (n_i \leq j \leq n \text{ and } \rho_{b,d} < v \leq \rho_{M_i}), \end{cases} \quad (17)$$

where  $T_{M_i,j}^v$  is defined by Eq. (2).

At each time  $kT_s$ , the setpoint assignment matrix  $\mathbf{A}_{M_i}^k$  ( $H_{M_i} \times n$ ), where  $H_{M_i}$  is the allocation horizon from  $M_i$ , is scheduled according to  $\Gamma_{M_i}$  and  $\mathbf{q}_{M_i}$ . The allocation horizon  $H_{M_i}$  corresponds to the greatest transfer delay from  $M_i$  which is expressed according to  $T_s$ . The first row of  $\mathbf{A}_{M_i}^k$  contains the setpoints to be assigned to each gate from  $M_i$  at the time  $(k+1)T_s$ , the  $h$ th row the ones to be assigned at the time  $(k+h)T_s$  as defined in Eq. (18), and the last row the ones to be assigned at time  $(k+H_{M_i})T_s$ :

$$A_{M_i}^k(h,j) = \begin{cases} \sum_{v=1}^{\rho_{M_i}} \varphi_v \beta_{M_i}(v,j) q_{M_i}(j) & \text{if } \exists v \text{ such as } T_{M_i,j}^v \leq (k+h)T_s, \\ A_{M_i}^{k-1}(h+1,j) & \text{else if } 1 \leq h < H_{M_i}, \\ q_{j,obj} & \text{otherwise,} \end{cases} \quad (18)$$

where  $\varphi_v = 1$  if  $\Gamma_{M_i}(v,j) \geq (k+h)T_s$ ,  $\varphi_v = 0$  otherwise, and  $A_{M_i}^0(h,j) = q_{j,obj}$ .

The setpoints are dispatched with the control period  $T_c = \kappa T_s$ , where  $\kappa$  is an integer. The control setpoint vector denoted  $\mathbf{u}$  ( $1 \times n$ ) is updated at each time  $k'T_c$ , where  $k' = k/\kappa$ , thanks to the assignment matrix  $\mathbf{A}_{M_i}^{k'}$  and the  $\alpha_{M_i}$  ( $n \times n$ ) diagonal control accommodation matrix, with  $H = (1/\kappa) \max_{1 \leq i \leq m} (H_{M_i})$  the control horizon which corresponds to the greatest transfer delay expressed according to  $T_c$ . For each measurement point  $M_i$ , the  $\alpha_{M_i}$  matrix, the role of which is to capture the measurement point influence on the gates, must be determined. In order to generate the  $\alpha_{M_i}$  matrix, the weighted digraph (see Fig. 1c and d) is

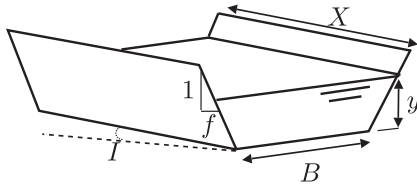


Fig. 7. Geometrical characteristics of a trapezoidal profile.

Table 5  
Geometrical characteristics of the OCRS.

OCRS	B (m)	f	X (m)	l	K
1	6	0.8	1000	$5 \times 10^{-4}$	70
2	6	0.8	200	$5 \times 10^{-4}$	70
3	2	0.6	4000	$5 \times 10^{-4}$	70
4	2	0.6	600	$5 \times 10^{-4}$	70
5	2	0.6	100	$5 \times 10^{-4}$	70
6	2	0.6	500	$2 \times 10^{-4}$	70
7	2	0.6	3000	$2 \times 10^{-4}$	70
8	2	0.6	1500	$3 \times 10^{-4}$	70
9	2	0.6	2000	$3 \times 10^{-4}$	70
10	0.6	0.95	3000	$3 \times 10^{-4}$	70
11	0.6	0.95	1500	$3 \times 10^{-4}$	70
12	6	0.8	2000	$2 \times 10^{-4}$	70
13	6	0.8	5000	$4 \times 10^{-4}$	70
14	6	0.8	2000	$4 \times 10^{-4}$	70
15	6	0.8	3000	$3 \times 10^{-4}$	70

browsed using the algorithm given in Table 3, for each measurement point  $M_i$ .

The control setpoint vector  $\mathbf{u}^k$  ( $1 \times n$ ) is calculated by

$$u^k(j) = \sum_{i=1}^m \alpha_{M_i}(j,j) A_{M_i}^k(1,j). \quad (19)$$

The setpoint dispatching leads to the application of the most recently calculated setpoints. This method increases the control strategy reactivity and its robustness in performance, because resource states have been diagnosed in real time and discharge variations between two control times are taken into account.

#### 4. Simulation results

The networked hydrographical system which is considered in this article (see Fig. 5) consists of a principal stream which supplies a secondary stream for industrial and irrigation uses. This system is equipped with two measurement stations and 10 controlled gates. PI controller is designed for each controlled gate. A telecontrol system allows the flow discharges measurement and the gate control at distance. These controlled gates supply other streams for various uses, and catchment areas downstream to stock the volume of water.

The hydrographical system is subjected to disturbances which are naturally routed from upstream to downstream and make not possible to satisfy the uses. Disturbances are from natural disorders like strong local rain or from human activities, like industrial and agricultural activities. Thus, an efficient water asset management consists in avoiding overflow and lack of water at the ends of the network, to valorize the water in lack fairly done between users and to stock in dams the water in excess. The proposed strategy which satisfies these objectives is evaluated in this case.

The hydrographical system is composed of one confluence and two diffluences. The six HYS are equipped with 10 gates,  $G_1^1$ – $G_{10}^6$ , and two measurement points  $M_1^1$  and  $M_2^2$ . The HYS 1 supplies the HYS 2 and the HYS 5 with the discharge proportions  $w_2$  and  $w_5$ , respectively; the HYS 2 supplies the HYS 3 and the HYS 4 with the discharge proportions  $w_3$  and  $w_4$ . Finally, the HYS 4 and 5 supply the HYS 6. The discharge proportion  $w_2$  is equal to 0.3,  $w_5$  to 0.7,  $w_3$  to 0.6 and  $w_4$  to 0.4. These proportions are constant around the considered operating point. The hydrographical outputs are noted  $G_{11}^3$  and  $G_{12}^6$ , but they are not controlled. The indices of the gates  $G^6$  and  $G^{10}$  which are located just upstream these canal outputs,

Table 6  
Continuous transfer function of the OCRS.

OCRS	$Q_e$	$a_1$	$a_2$	$\tau$	t (s)
1	20	445	0	0	310
2	20	90	0	0	60
3	6	1810	0	755	2000
4	5	406	0	0	280
5	3	70	0	0	50
6	2	575	0	0	400
7	2	3450	0	0	2380
8	1	1590	0	75	1180
9	1	1840	0	385	1660
10	1	3020	0	820	2910
11	1	1300	0	0	900
12	8	1560	0	0	1080
13	14	1750	0	870	2090
14	10	1080	0	70	820
15	8	1760	0	250	1470

compose the set  $\mathcal{O} = \{6,10\}$ . The gate characteristics, i.e. objective discharge  $q_{j,obj}$ , maximum and minimum discharges  $q_{j,max}$ ,  $q_{j,min}$ , and their associated weights, are given in Table 4. Maximum and

minimum discharges are determined according to the capacity of each HYS.

To apply the proposed strategy, the first step consists in modelling the network. The hydrographical system (see Fig. 5) is represented by the weighted digraph depicted in Fig. 6 to determine the matrices  $\mathbf{R}$ ,  $\alpha_{M_i}$  and  $\beta_{M_i}$ , according to the algorithms given in Tables 1 and 3 respectively. The matrix  $\mathbf{R}$  is given by relation (22). The diagonal matrices  $\alpha_{M_1}$  and  $\alpha_{M_2}$  are given by

$$\alpha_{M_1} = \text{diag}\{1,0.3,0.3,0,0,0,0,0.12,0.7,0.7,0.82\},$$

$$\alpha_{M_2} = \text{diag}\{0,0,0,1,1,1,0,0,0,0\}. \quad (20)$$

The matrices  $\beta_{M_1}$  and  $\beta_{M_2}$  are given by

$$\beta_{M_1} = \begin{bmatrix} 1 & 0.3 & 0.3 & 0 & 0 & 0 & 0.12 & 0.7 & 0.7 & 0.12 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.7 \end{bmatrix},$$

$$\beta_{M_2} = [0 \ 0 \ 0 \ 1 \ 1 \ 1 \ 0 \ 0 \ 0 \ 0]. \quad (21)$$

The values of  $\alpha_{M_1}$ , i.e. from the measurement point  $M_1$  to the gates, are equal to 0 for the gates  $G_4$ – $G_6$  because there is no direct path between  $M_1$  and these gates. For the other gates, the proportions  $w_i$  associated to each diffidence are taken into account.

The value of  $\mathbf{R}(j,1)$ , i.e. from the measurement point  $M_1$  to the gates, is equal to 1 for the gate  $G_1$  because there is no diffidence between this measurement point and this gate, and equal to 0.82 ( $0.3 \times 0.4 + 0.7$ ) for the gate  $G_{10}$  taking into account the two paths existing from  $M_1$  to  $G_{10}$  and the proportions  $w_i$  associated to each diffidence. The value of  $\mathbf{R}(j,m+2)$ , i.e. from the gate  $G_2$  to the other gates ( $m=2$ ), is equal to 0 for upstream gates like  $G_1$ , equal to 1 for gates on the same HYS like  $G_2$  and  $G_3$ , and equal to 0.6 for

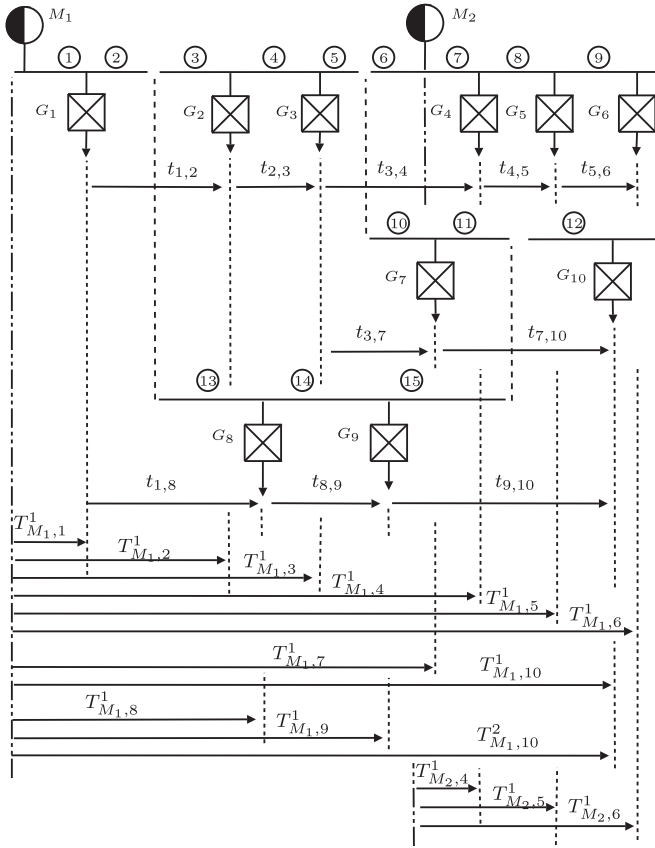


Fig. 8. Time delays between measurement points and gates.

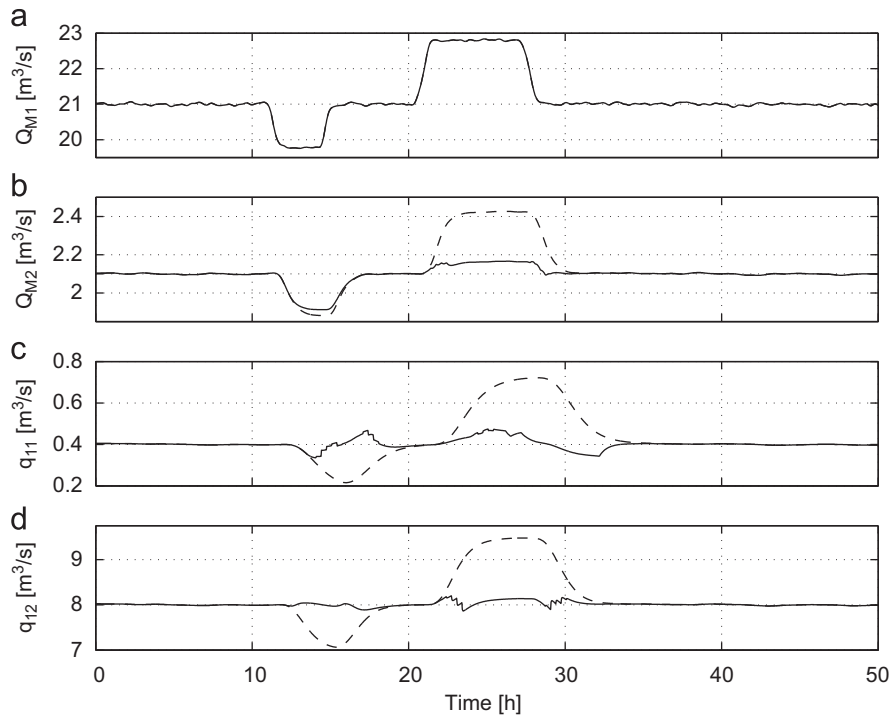


Fig. 9. Discharges with (continuous line) and without (dashed line) reactive control strategy (a)  $Q_{M_1}$ , (b)  $Q_{M_2}$ , and resulting discharges on (c)  $G_{11}$  and (d)  $G_{12}$ .

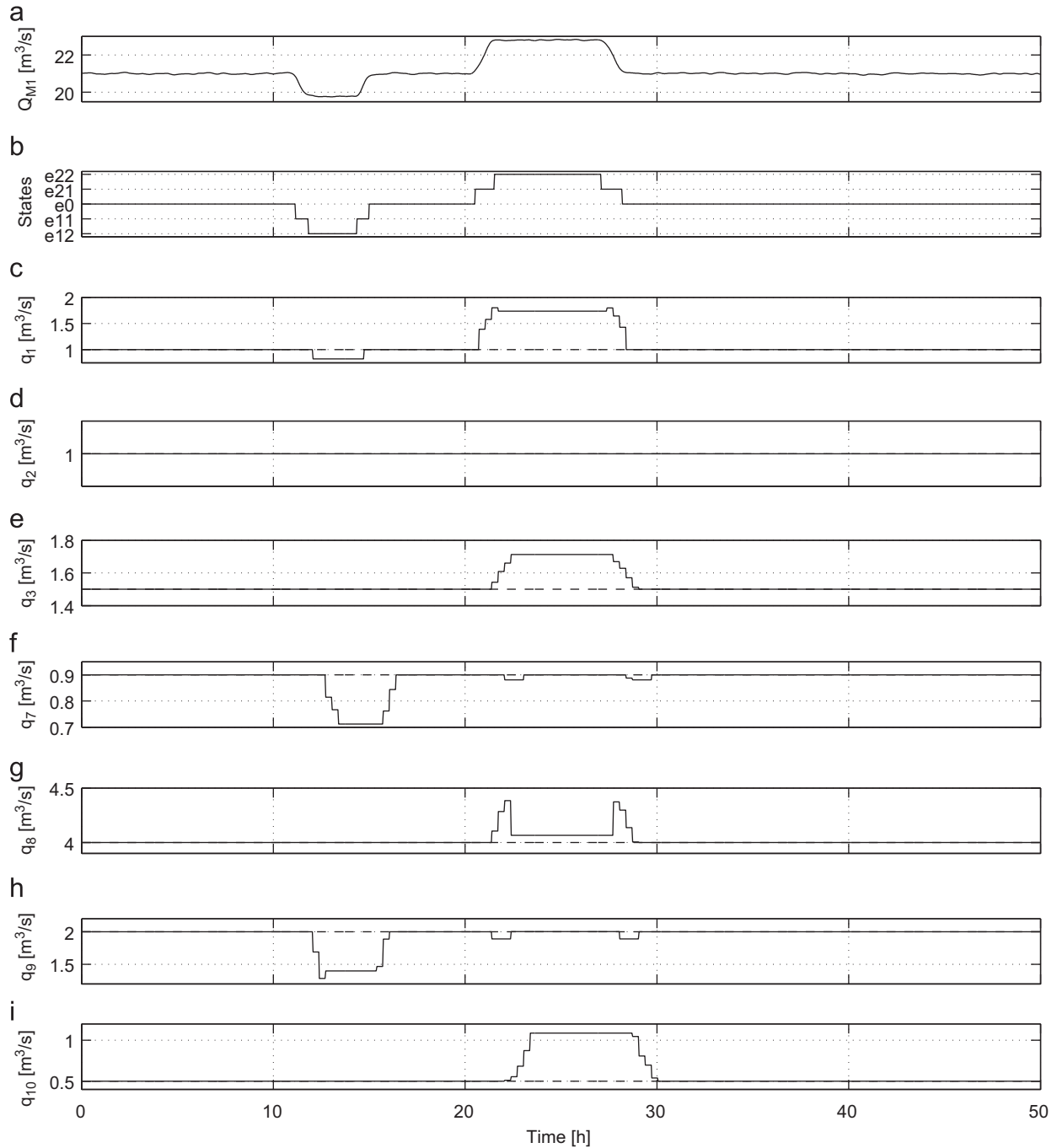
gates  $G_4$  and  $G_6$  because of the diffuence:

$$\mathbf{R} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.3 & 0 & 0.3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.3 & 0 & 0.3 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.18 & 1 & 0.18 & 0.6 & 0.6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.18 & 1 & 0.18 & 0.6 & 0.6 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.18 & 1 & 0.18 & 0.6 & 0.6 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.12 & 0 & 0.12 & 0.4 & 0.4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.7 & 0 & 0.7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.7 & 0 & 0.7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0.82 & 0 & 0.82 & 0.4 & 0.4 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \end{bmatrix} \quad (22)$$

The second step consists in modelling the HYS according to the specific length and profile section of each OCRS, to determine the transfer time delays  $T_{M_i,j}$ . The OCRS are numbered from 1 to 15 (see Fig. 6a). The OCRS with trapezoidal profile is characterized by the bottom width  $B$ , the average fruit of the banks  $f$ , the profile length  $X$ , the discharge depth  $y$  and the slope  $I$  (see Fig. 7). The geometrical characteristics of the OCRS are given in Table 5.

For trapezoidal profiles, the celerity and diffusion parameters  $C_e$  and  $D_e$  are expressed as

$$\begin{cases} C_e = \frac{Q_e}{L^2} \left[ -f + \frac{L}{3} \left( \frac{2B}{Py} + \frac{5L}{S} - \frac{2}{y} \right) \right], \\ D_e = \frac{Q_e}{2LJ}, \end{cases} \quad (23)$$



**Fig. 10.** (a) Discharge  $Q_{M_1}$ , (b) diagnosed states from  $M_1$ . Setpoint assigned, with (continuous line) and without (dashed line) reactive control strategy, to (c) gate  $G_1$ , (d) gate  $G_2$ , (e) gate  $G_3$ , (f) gate  $G_7$ , (g) gate  $G_8$ , (h) gate  $G_9$  and (i) gate  $G_{10}$ .

with  $L=B+2fy$ ,  $S=yB+fy^2$ ,  $P=B+2y\sqrt{1+f^2}$ , and the slope  $J$  is equivalent to the reach slope  $I$  for a non-critical discharge.

In the studied case, the transfer function is estimated for one operating point for each OCRS. Parameters of the transfer functions identified for reference discharges,  $Q_e$ , are given in Table 6. The response time  $t$  is computed from the step response of every identified model so that 50% of the step response is reached. Then, the transfer delays  $T_{M_i,j}^v$  are calculated using Eq. (2) and the sample time  $T_s$  (equal to 120 s), while computing the transfer delays  $T_{M_i,\pi_i}^v$  and  $t_{r,r+}$  with the response time  $t$  according to the hydrographical network configuration (see Fig. 8).

Finally, the transfer time delays  $T_{M_i,j}^v$  are used to determine, according to relation (17), the matrices  $\Gamma_{M_1}$  and  $\Gamma_{M_2}$ :

$$\Gamma_{M_1} = \begin{bmatrix} 3,20,23,0,0,0,47,21,28,49 \\ 0,0,0,0,0,0,0,0,0,64 \end{bmatrix}^T, \quad (24)$$

$$\Gamma_{M_2} = [0,0,0,20,30,44,0,0,0,0]^T. \quad (25)$$

Taking into account the network structure, the fourth constraints defined by (11) are specified for the measurement point  $M_1$  as relation (26) and for the measurement point  $M_2$  as relation (27):

$$\begin{cases} q_6 - q_{6,obj} = R(6,1)\Delta Q_{M_1} - R(6,3)(q_1 - q_{1,obj}) - R(6,4)(q_2 - q_{2,obj}) \\ \quad - R(6,5)(q_3 - q_{3,obj}) - R(6,6)(q_4 - q_{4,obj}) - R(6,7)(q_5 - q_{5,obj}), \\ q_{10} - q_{10,obj} = R(10,1)\Delta Q_{M_1} - R(10,3)(q_1 - q_{1,obj}) - R(10,4)(q_2 - q_{2,obj}) \\ \quad - R(10,5)(q_3 - q_{3,obj}) - R(10,9)(q_7 - q_{7,obj}) - R(10,10)(q_8 - q_{8,obj}) \\ \quad - R(10,11)(q_9 - q_{9,obj}), \end{cases} \quad (26)$$

where the values of  $R(j, 1)$  are provided by the relation (22):

$$q_6 - q_{6,obj} = R(6,2)\Delta Q_{M_2} - R(6,6)(q_4 - q_{4,obj}) - R(6,7)(q_5 - q_{5,obj}), \quad (27)$$

where the values of  $R(j, 2)$  are provided by relation (22).

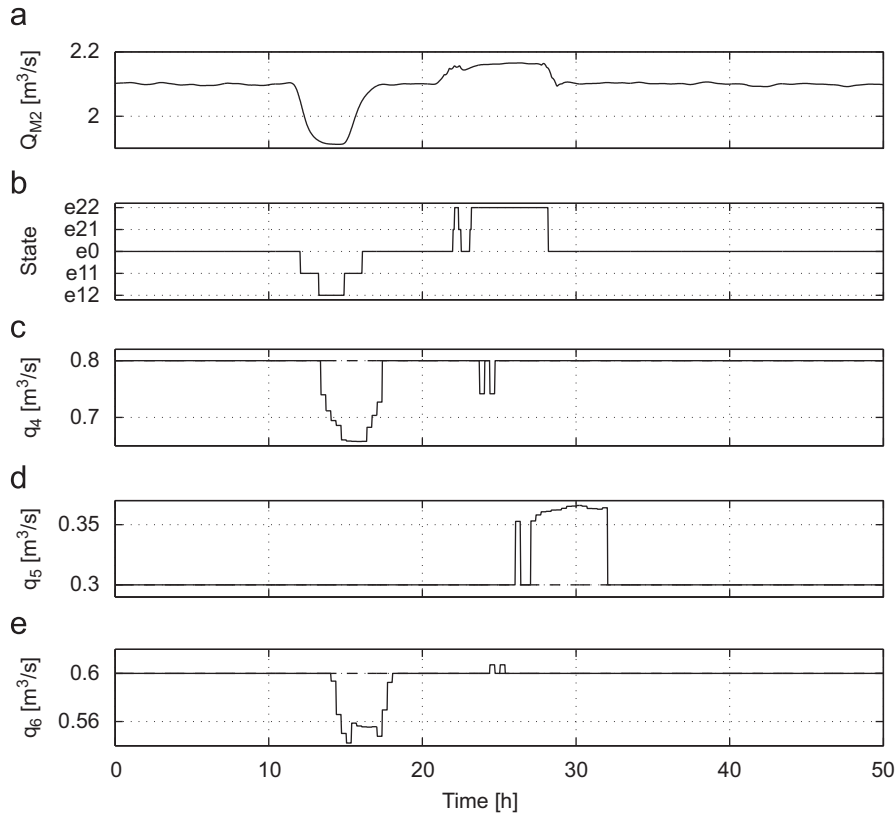
According to the network structure, the sets  $\mathcal{L}_{M_1}$  and  $\mathcal{L}_{M_2}$  of sets of gates able to be re-allocated is given by relation (28) for water in excess, and by relation (29) for water in lack.

$$\begin{cases} \mathcal{L}_{M_1}^\lambda = \{\{G_1\}, \{G_3, G_8\}, \{G_5, G_{10}\}\}, \\ \mathcal{L}_{M_1}^\mu = \{\{G_4, G_7, G_9\}, \{G_6, G_7, G_9\}\}. \end{cases} \quad (28)$$

$$\begin{cases} \mathcal{L}_{M_2}^\lambda = \{\{G_5\}\}, \\ \mathcal{L}_{M_2}^\mu = \{\{G_4\}, \{G_6\}\}. \end{cases} \quad (29)$$

The objective discharges of  $M_1$  and  $M_2$  correspond respectively to 21 and 2.1 m<sup>3</sup>/s. The hydrographical system is subjected to disturbances upstream of the measurement points  $M_1$  (see Fig. 9a). The measured discharge on  $M_2$  is shown in Fig. 9b. The discharges resulting at the canal ends  $G_{11}$  and  $G_{12}$  in the case where no reactive strategy is used (dashed line) and where the reactive strategy is applied (continuous line) are shown in Fig. 9c and d. Figs. 10 and 11 show the measured discharges in (a), the corresponding resource states diagnosis in (b), and the new setpoints which have been dispatched at the gates in continuous line when the strategy is applied and in dashed line when it is not applied. The diagnosed resource state on  $M_1$  is depicted in Fig. 10b, and the setpoints dispatched on gates  $G_1, G_2, G_3, G_7, G_8, G_9$  and  $G_{10}$  respectively in Figs. 10c–i. Fig. 11b shows the diagnosed resource state on  $M_2$ , and the setpoints dispatched on gates  $G_4, G_5$  and  $G_6$  respectively in Figs. 11c–e.

When the reactive control strategy is used, nearly 84% of the discrepancy volumes upstream  $M_1$  are allocated amongst the



**Fig. 11.** (a) Discharge  $Q_{M_2}$ , (b) diagnosed states from  $M_2$ . Setpoint assigned, with (continuous line) and without (dashed line) reactive control strategy, to (c) gate  $G_4$ , (d) gate  $G_5$  and (e) gate  $G_6$ .

gates according to their weights. This strategy leads to a water dispatching of 52 000 m<sup>3</sup> among the 62 000 m<sup>3</sup> of discrepancy volumes during 50 h. The water volumes are conserved by their storage in dams, and represent 19 500, 5000, 1200, 3000 and 13 500 m<sup>3</sup> for dam downstream G<sub>1</sub>, G<sub>3</sub>, G<sub>5</sub>, G<sub>8</sub> and G<sub>10</sub> respectively. Moreover, the discharges at the end of the hydrographical system are close to the objective values 0.4 m<sup>3</sup>/s for G<sub>11</sub> and 8 m<sup>3</sup>/s for G<sub>12</sub> (see Fig. 9c and d). The discharge discrepancies around the objective values on G<sub>11</sub> and G<sub>12</sub> do not exceed 0.07 and 0.2 m<sup>3</sup>/s respectively.

## 5. Conclusion

The resource allocation and setpoint assignment rules have been defined to cope with the water asset management of complex hydrographical systems. It is a generic approach allowing the water resource valorization whatever the configuration of the hydrographical networks is. Multiple graph representations make it possible to identify the information for implementing the proposed supervision and hybrid control accommodation strategy. The simulation results show the effectiveness of the strategy which is efficient to manage the water resource in the case of a complex hydrographical system.

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