SETPOINT ASSIGNMENT RULES BASED ON TRANSFER TIME DELAYS FOR WATER-ASSET MANAGEMENT OF NETWORKED OPEN-CHANNEL SYSTEMS

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Abstract: The paper presents a new strategy based on a supervision and hybrid control accommodation to improve the water-asset management of networked open-channel systems. This strategy requires a modelling method of the network based on a weighted digraph of instrumented points, and the definition of resource allocation and setpoint assignment rules. Two setpoint assignment rules are designed and evaluated in the case of an open-channel system composed of one difluent and one confluent showing their effectiveness.

1 INTRODUCTION

A hydrographic network is a geographically distributed system composed of dams and interconnected rivers and channels. Weather conditions and human activities have a great influence on the flow discharges. An interesting problem to address deals with the allocation of water quantities in excess toward the catchment area and of water quantities in lack amongst the users. The complex hydrographic network representation, as well as the determination of the discharge allocation on the network, constitute an essential step for the design of reactive control strategies. In (Naidu et al., 1997) a hydrographic network representation by oriented graphs is proposed by considering only the difluences. This representation is modified and extended to the cases of the confluences in (Islam et al., 2005). Cembrano *et al* (Cembrano et al., 2000) proposed a modelling approach for the drinking water distribution networks, and sewerage networks. Object-oriented modelling techniques (Chan et al., 1999) and a XML approach (Lisounkin et al., 2004) allow the representation of the control and measurement instrumentation equipping the hydrographic networks and the drinking water distribution networks. Optimization techniques were proposed in the literature for the water-asset management. The approach proposed in (Faye et al., 1998) allows the adjustment of the criteria and the constraints of an optimization problem starting from the supervision of the network variables. However, the complexity of the hydrographic networks and the number of instrumented points 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 et al., 1998). These techniques are used for the optimal water management of irrigation networks. Finally, in (Duviella et al., 2007), a supervision and hybrid control accommodation strategy is proposed for the water asset management of the Neste canal in the southwestern region in France. This strategy can be adapted for the case of gridded hydrographic networks.

In this paper, the allocation and setpoint assignment rules are proposed for the water asset management of complex hydraulic systems *i.e.* with confluences and difluences. Networked hydraulic systems modelling is presented in section 2. In section 3, identification steps of transfer time delay are presented. The supervision and resource allocation rules are proposed in section 4. Section 5 deals with the design of a water asset management strategy where two setpoint assignment rules are compared. Finally, their evaluation by simulation within the framework of a hydrographic system is carried out.

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2 NETWORKED HYDRAULIC SYSTEM MODELLING

Hydrographic networks are composed of a finite 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 hydrographic network, onto the whole HYS downstream. HYS are indexed by an index b, and all 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, as shown in Figure 1.*a*. Upper indexes are omitted when not necessary for computation and comprehension. The structure of a hydrographic network is described by distinguishing the confluences (*see* Figure 1.*a*) and the difluences (*see* Figure 1.*c*).

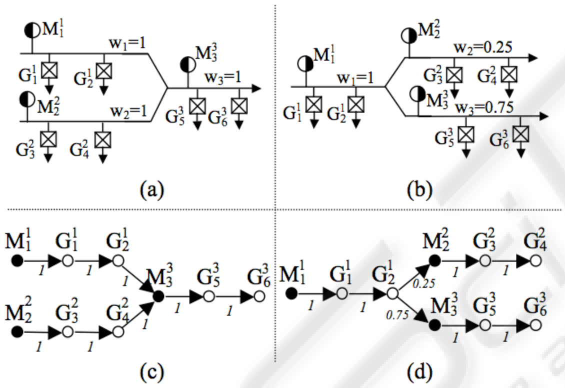

Figure 1: (*a*) A confluence, (*c*) its associated weighted digraph, (*b*) a difluence, (*d*) its associated weighted digraph.

According to the hydraulic conditions and the equations of energy and mass conservation, the sum of the discharges entering a node (confluent or difluent), 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 difluence 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 difluence, each HYS of an hydrographic system is associated to a discharge proportion w_r. For the HYS *source* and

Table 1: Assignment function of **R** matrix.

```
Input: weighted digraph.
Output: proportion matrix R.
Initialization of R to 0
For each node h
  If h is a measurement point
      Run (h, h, 1,R)
  EndIf
EndFor

Run (h, c, p, R),
  For each successor d of c
    p_d ← p.w_d,
    Run (h, d, p_d, R),
    If d is a gate
        R(h,d) ← R(h,d) + p_d
    EndIf
  EndFor
```

for the HYS downstream from a confluence (*see* Figure 1.*a*) it is equal to 1. The discharge proportion w_r of the HYS downstream the HYS b are known and such as $\forall r \in \mathcal{D}^b$, $w_r < 1$, 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 difluence of the HYS b (*see* Figure 1.*b*). A discharge which is measured in a place of the hydrographic network, supplies the HYS downstream with discharge proportions according to the structure of the hydrographic network.

The hydrographic systems are represented by a weighted digraph of instrumented points in order to determine the discharge proportions between two places of the networks. The digraph is composed with a succession of two types of nodes M_i or G_j, represented respectively by full circle and circle and their respective graphs, and arcs indicate the links between the successive nodes (*see* Figure 1.*c* and Figure 1.*d*). The arcs are oriented in the direction of the flow and are weighted by the discharge proportion between the two nodes w_r. Thereafter, an algorithm lead to the generation of the proportion matrix **R** which is composed of m lines (measurement points) and of n columns (actuators). The weighted digraph is browsed for each measurement point M_i following the algorithm given in Table 1. The matrix **R** contains all the discharge proportions of a point to another of the hydrographic networks.

Thereafter, the transfer time delay between the measurement points and the gates, is computed according to the method described in the next section.

3 IDENTIFICATION OF TRANSFER TIME DELAYS

Hydrographic systems consist of several reaches, *i.e.* a part between two measurement points, each reach being composed of Open-Channel Reach Section (OCRS), *i.e.* a part between two gates, between a measurement point and a gate or between a gate and a measurement point. The OCRS dynamics can be modelled by transfer functions according to the modelling method which consists in the simplification of the Saint Venant equations and their linearization around an operating point (Litrico and Georges, 1999; Malaterre and Baume, 1998; Chow et al., 1988). The parameters of the transfer function are considered constant under an operating range around the operating point. In this paper, only disturbances around the operating point are considered. Thus, the variation of the transfer delays for these discharges is sufficiently small in comparison with the chosen control period, and will not have a significant influence on the strategy effectiveness. If large operating conditions are considered, and/or in the case of the "small" control period, it is necessary to consider several time delays function of discharge value, as proposed in (Duviella et al., 2006). For each OCRS (*see* Figure 2), the transfer time delay τ_r is obtained from the step response of the corresponding transfer function. It is chosen as the time value for which Π_Q percent of step is reached. The percentage Π_Q can be tuned from simulation.

In the case of gridded systems, the value of the transfer time delay between the measurement point M_i^b and the gate G_j^d depends on the path to go from the measurement point M_i^b to the gate G_j^d (*see* Figure 2). $\mathcal{P}_{b,d}$ 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 $P_v^{b,d} \in \mathcal{P}_{b,d}$, where $1 \leq v \leq \rho_{b,d}$, with $\rho_{b,d}$ the total number of paths which compose $\mathcal{P}_{b,d}$. 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.

The transfer time delays between the measurement point M_i^b and the gate G_j^d are computed by considering each path and constitute the vector $\mathbf{t}_{M_i,j}$ $(\rho_{b,d} \times 1)$:

$$\mathbf{t}_{M_i,j} = \left[t^1_{M_i,j}, t^2_{M_i,j}, \ldots, t^{\rho_{b,d}}_{M_i,j} \right]^T. \quad (1)$$

Thereafter, the transfer time delay between M_i^b and G_j^d, is computed according to the selected path $P_v^{b,d}$:

$$\begin{cases} t^v_{M_i,j} = t_{M_i,n_i} + \sum_{r=n_i}^{r<j} \tau^v_{r,r+1}, \\ n_i \leq j \leq n, \end{cases} \quad (2)$$

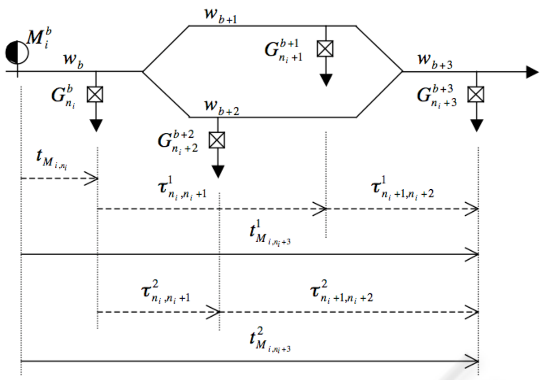

Figure 2: Transfer delays between the measurement point M_i and gates Gj.

where n_i is the first gate downstream M_i, v is the index of the path $P_v^{b,d}$, and $\tau^v_{r,r+1}$is the transfer time delay between each gate along the path $P_v^{b,d}$ as illustrated in Figure 2.

Then, the new setpoints must be assigned to the gates at a time instant taking into account the transfer time delays which are expressed according to the sampling period T_s:

$$kd^v_{M_i,j} = \left\lfloor \frac{t^v_{M_i,j}}{T_s} \right\rfloor + 1, \quad (3)$$

where $\lfloor x \rfloor$ denotes the integer part of x.

The measured water quantity in M_i, following the path with index v, will arrive on gate G_j at the time:

$$T^v_{M_i,j} = \left(k + kd^v_{M_i,j}\right) T_s. \quad (4)$$

Finally, the transfer time delays between the measurement point M_i^b and the gate G_j^d are expressed by the vector $\mathbf{T}_{M_i,j}$ $(\rho_{b,d} \times 1)$:

$$\mathbf{T}_{M_i,j} = \left[T^1_{M_i,j}, T^2_{M_i,j}, \ldots, T^{\rho_{b,d}}_{M_i,j} \right]^T. \quad (5)$$

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

4 SUPERVISION AND RESOURCE ALLOCATION

Supervision and hybrid control accommodation framework is depicted in Figure 3. The hydrographic network is represented by a set of m measurement points M_i and n gates G_j locally controlled. For each gate G_j, a weekly objective discharge $q_{j_{obj}}$ and seasonal weights λ_j and μ_j are given by the Management Objective Generation module according to the water

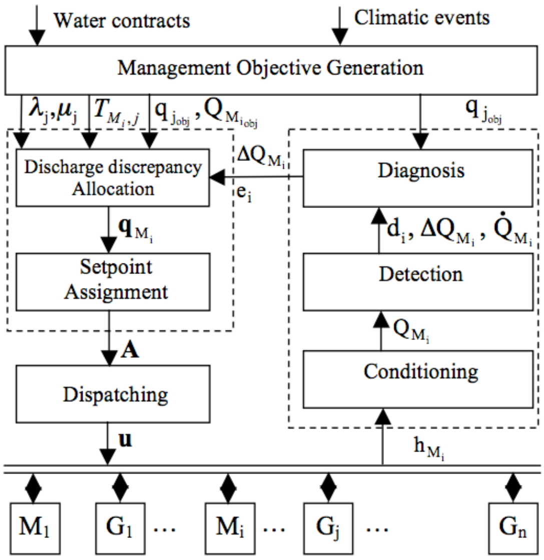

Figure 3: Supervision and hybrid control accommodation framework.

contracts and climatic events. The weekly measurement point objective discharge $Q_{M_{i_{obj}}}$ is known.

For each measurement point M_i ; $i = 1, \ldots, m$, discharge supervision consists in monitoring discharge disturbances and diagnosing the resource state, simultaneously. Limnimeter 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 sample time kT_s, detection and diagnosis automata are used respectively to detect a discharge discrepancy superior or inferior than a detection threshold d_{th} around $Q_{M_{i_{obj}}}$, and to diagnose the resource states (Duviella et al., 2007). According to the resource state and the discharge discrepancy $\Delta Q_{M_i} = Q_{M_{i_{obj}}} - Q_{M_i}$, the hybrid control accommodation consists in determining the setpoints q_j, and in assigning them to the gates taking into account the hydraulic system dynamics. The resource allocation consists in recalculating setpoints with a goal to route resource in excess to dams and to dispatch amongst the users the resource in lack. At each sample 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 tacking into account the seasonal weights λ_j and μ_j.

If the resource state is no diagnose situation, the setpoints are the objective discharges $q_{j_{obj}}$. The allocation vector is such as:

$$\mathbf{q}_{M_i} = \left[\delta^1_{\lceil R(i,1)\rceil} q_{1_{obj}} \ldots \delta^1_{\lceil R(i,j)\rceil} q_{j_{obj}} \ldots \delta^1_{\lceil R(i,n)\rceil} q_{n_{obj}}\right]^T , \qquad (6)$$

where $\lceil \mathbf{x} \rceil$ corresponds to the higher rounding of x, n is the total number of gates, and δ^a_b the Kronecker index, is equal to 1 when $a = b$, and equal to 0 if not.

If the resource state is such as discharge is in lack or in excess**,** the water resource is allocated among the gate downstream the measurement point M_i, according to the weights λ_j and μ_j. The allocation strategy consists in optimizing a cost function by linear programming method for each measurement point. The cost function f_{M_i} is defined as the weighted sum of the differences between the setpoint q_j and the objective $q_{j_{obj}}$ for each gate G_j, at time kT_s:

$$f_{M_i} = \sum_{j=1}^{n} \left(\delta^1_{\lceil R(i,j)\rceil} \chi_{M_{i,j}} (q_j - q_{j_{obj}}) \right), \qquad (7)$$

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

The optimization is carried out under constraints:

$$\begin{cases} \sum_{j=1}^{n} \left(R(i,j)(q_j - q_{j_{obj}}) \right) = \Delta Q_{M_i}, \\ q_{j_{\min}} \leq q_j \leq q_{j_{\max}}, \end{cases} \qquad (8)$$

where $q_{j_{\min}}$ and $q_{j_{\max}}$ are respectively the minimum and maximum discharges given by gate, river or canal characteristics. In this case, the allocation vector $\mathbf{q}_{M_i}$ is such as:

$$\mathbf{q}_{M_i} = \left[\delta^1_{\lceil R(i,1)\rceil} \cdot q_1 \ldots \delta^1_{\lceil R(i,j)\rceil} \cdot q_j \ldots \delta^1_{\lceil R(i,n)\rceil} \cdot q_n\right]^T . \qquad (9)$$

Then, to synchronize the gate control with the water lacks or excess due to the disturbances, the setpoints must be assigned at a time instant tacking into account the transfer time delays $T_{M_i,j}$ between the measurement point M_i and the gate G_j.

5 SETPOINT ASSIGNMENT RULES

The setpoint assignment consists in taking into account the transfer delays before the dispatching of the new computed setpoints at the gates. In the case of gridded systems, two different setpoint assignment rules are proposed.

The first rule consists in considering only one transfer delay $T_{M_i,j}$ from each measurement point M_i to each gate G_j, whatever existing several paths to go from M_i at the gate G_j. The transfer delay between M_i^b and G_j^d is selected as the direct path between M_i^b and G_j^d, which have the greatest supplying discharge proportion. The following assumptions are considered:

Table 2: Assignment function of α and β matrices.

```
Input: weighted digraph.
Output: α_Mi matrix, β_Mi matrices
Initialization of the diagonal of α_Mi to 0
Initialization of β_Mi to 0
g ← first gate successor of M_i
Run (M_i, g, 1, α_Mi, β_Mi)

Run (M_i, c, p, α_Mi, β_Mi)
  For any successor d of c
    p_d ← p.w_d
    If d is a gate
      Run (M_i, d, p_d, α_Mi, β_Mi)
      α_Mi(d,d) ← α_Mi(d,d) + p_d
      l = 1
      While (β_Mi(l,d) ≠ 0)
        l++
      EndWhile
      β_Mi(l,d) ← p_d
    EndIf
  EndFor
```

- if the discharge proportion $\beta_{M_i}(v,j)$ resulting from M_i^b and supplying G_j^d by a single path $P_v^{b,d}$, is weak, the discrepancy allocation will be weak also,
- if the discharge proportion $\beta_{M_i}(v,j)$ resulting from M_i^b and supplying G_j^d by a single path $P_v^{b,d}$, is important, the discrepancy allocation will be important also.

The supplying discharge proportion β_{M_i} ($\rho_{M_i} \times n$), where ρ_{M_i} is the maximum number of paths between M_i and the gates G_j, is computed for each measurement point M_i according to the algorithm given in Table 2 and the weighted digraph of the system.

Thus, the set of allocation dates starting from M_i is denoted $\mathcal{T}_{M_i}$ ($1 \times n$) updated at each sampling period T_s and expressed by:

$$\mathcal{T}_{M_i} = [T_{M_i,1} \ldots T_{M_i,j} \ldots T_{M_i,n}], \tag{10}$$

where

$$\begin{cases} T_{M_i,j} = 0, & \text{if } \beta_{M_i}(1,j) = 0 \\ T_{M_i,j} = T^v_{M_i,j}, & \text{otherwise,} \end{cases} \tag{11}$$

and v such as $\beta_{M_i}(v,j) = \max_{l \in [1,\rho_{M_i}]} \beta_{M_i}(l,j)$. When $\beta_{M_i}(1,j) = 0$ there is no direct path between M_i and G_j.

At each sample time kT_s, the setpoint assignment matrix $\mathbf{A}^k_{M_i}$ ($H_{M_i} \times n$), where H_{M_i} is the allocation horizon from M_i, is scheduled according to $\mathcal{T}_{M_i}$ and $\mathbf{q}_{M_i}$. The first row of $\mathbf{A}^k_{M_i}$ contains the setpoints to be assigned to each gate from M_i at the date $(k+1)T_s$, the h^{th} row the ones to be assigned at the date $(k+h)T_s$ as defined in equation 12, the last row the ones to be assigned at the date $(k+H_{M_i})T_s$.

$$\begin{array}{l} \text{If } \mathcal{T}_{M_i}(j) \geq (k+h)T_s \\ \quad A^k_{M_i}(h,j) = q_{M_i}(j), \\ \text{Else} \\ \quad \text{If } 1 \leq h < H_{M_i} \\ \quad\quad A^k_{M_i}(h,j) = A^{k-1}_{M_i}(h+1,j) \\ \quad \text{Else} \\ \quad\quad A^k_{M_i}(h,j) = q_{j_{obj}} \\ \quad \text{Endif} \\ \text{Endif} \end{array} \tag{12}$$

and $A^0_{M_i}(h,j) = q_{j_{obj}}$.

The setpoints are dispatched with the control period $T_c = \kappa T_s$, where κ is an integer. The control setpoint vector denoted $\mathbf{u}$ ($1 \times n$) is updated at each date $k'T_c$, where $k' = \frac{k}{\kappa}$, thanks to the assignment matrix $\mathbf{A}^{k'}_{M_i}$ and the α_{M_i} ($n \times n$) diagonal control accommodation matrix, with $H = \frac{1}{\kappa} \max_{1 \leq i \leq m} (H_{M_i})$ the control horizon. For each measurement point M_i, the α_{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 α_{M_i} matrix, the weighted digraph (*see* Figure 1.*c* and 1.*d*) is browsed using the algorithm given in Table 2, for each measurement point M_i. The control setpoint vector $\mathbf{u}^{k'}$ ($1 \times n$) is calculated by:

$$u^{k'}(j) = \sum_{i=1}^{m} \alpha_{M_i}(j,j) A^{k'}_{M_i}(1,j). \tag{13}$$

The second rule consists in considering the several direct transfer delays $\mathbf{T}_{M_i,j}$ from each measurement point M_i to each gate G_j. The set of allocation dates starting from M_i is denoted $\mathcal{T}_{M_i}$ ($\rho_M \times n$), where ρ_M is the maximum number of paths between the measurement points M_i and the gates G_j. The matrix $\mathcal{T}_{M_i}$ is updated at each sampling period T_s and expressed by:

$$\mathcal{T}_{M_i} = [\mathbf{T}_{M_i,1} \ldots \mathbf{T}_{M_i,j} \ldots \mathbf{T}_{M_i,n}], \tag{14}$$

where $\mathbf{T}_{M_i,j}$ is the set of the transfer time delays between the measurement point M_i and the gate G_j. The value of $T_{M_i,j}(l)$ is fixed to 0 for $\rho_{M_i} < l \leq \rho_M$, *i.e.* when the length ρ_{M_i} of the $\mathbf{T}_{M_i,j}$ is smaller than ρ_M.

In this case, the setpoint assignment matrix $\mathbf{A}^k_{M_i}$ ($H_{M_i} \times n$) is scheduled, at each sample time kT_s, according to $\mathcal{T}_{M_i}$ and $\mathbf{q}_{M_i}$:

$$
\begin{array}{l}
\text{If } \exists v \text{ such as } \mathcal{T}_{M_i}(v,j) \geq (k+h)T_s \\
\quad A^k_{M_i}(h,j) = \sum_{v=1}^{\rho_M} \varphi_v.\beta_{M_i}(v,j).q_{M_i}(j) \\
\text{Else} \\
\quad \text{If } 1 \leq h < H_{M_i} \\
\quad\quad A^k_{M_i}(h,j) = A^{k-1}_{M_i}(h+1,j) \\
\quad \text{Else} \\
\quad\quad A^k_{M_i}(h,j) = \alpha_{M_i}(j,j).q_{j_{obj}} \\
\quad \text{Endif} \\
\text{Endif}
\end{array}
\quad (15)
$$

where $\varphi_v = 1$ if $\mathcal{T}_{M_i}(v,j) \geq (k+h)T_s$, $\varphi_v = 0$ otherwise, and $A^0_{M_i}(h,j) = \alpha_{M_i}(j,j).q_{j_{obj}}$.

The control setpoint vector denoted $\mathbf{u}$ $(1 \times n)$ is updated at each date $k'T_c$, thanks to the assignment matrix $\mathbf{A}^{k'}_{M_i}$, with $H = \frac{1}{\kappa} \max_{1 \leq i \leq m} (H_{M_i})$ the control horizon. The control setpoint vector $\mathbf{u}^{k'}$ $(1 \times n)$ is calculated by:

$$u^{k'}(j) = \sum_{i=1}^{m} A^{k'}_{M_i}(1,j). \quad (16)$$

The setpoint dispatching leads to the application of the most recently calculated setpoints. This method increases the control strategy reactivity, because discharge variations between two control dates are taken into account.

6 SIMULATION RESULTS

The proposed setpoints assignment rules have been evaluated for a hydrographic system composed of one difluence and one confluence (*see* Figure 4).

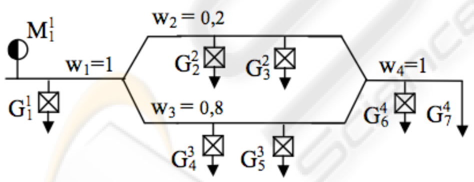

Figure 4: Hydrographic system composed of one difluence and one confluence.

The hydrographic system is composed of 4 HYS, equipped with 6 gates, G^1_1 to G^4_6, and 1 measurement point M^1_1. The discharge downstream the gate G^1_1 fed the HYS which is equipped with the gates G^2_2 to G^2_3 with the discharge proportion w_2 and the HYS which is equipped with the gates G^3_4 to G^3_5 with the discharge proportion w_3. The discharge proportion w_2 is equal to 0.2 and w_3 to 0.8. The gates G^4_7 which corresponds to the canal outputs, is not controlled. 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 3.

Table 3: Gate parameters.

Gate	$q_{j_{obj}}$ $[m^3/s]$	$q_{j\min}$ $[m^3/s]$	$q_{j\max}$ $[m^3/s]$	λ_j	μ_j
G^1_1	1.1	0.05	0.85	10	10
G^2_2	0.3	0.1	0.9	1	4
G^2_3	0.4	0.15	1.2	1	4
G^3_4	1.9	0.1	1.4	4	1
G^3_5	1.6	0.1	0.9	1	4
G^4_6	0.9	0.05	1.8	10	10
G^4_7	1.8	0.05	0.75	–	–

The use of the proposed rules requires the identification of the transfer time delays. The set of HYS which are characterized by trapezoidal profile have been modelled according to the transfer time delay identification steps. The matrix, $\mathbf{T}_{M_i}$, of transfer time delays between M_1 and each gate, expressed in seconds, are given by:

$$\mathbf{T}_{M_i} = \begin{bmatrix} 850 & 1750 & 2700 & 1450 & 2050 & 3750 \\ 0 & 0 & 0 & 0 & 0 & 2700 \end{bmatrix}. \quad (17)$$

There are two identified transfer time delays between M_1 and G_6; $T^1_{M_1,6} = 3750$ s corresponds to the path $P^{1,4}_1$; $T^2_{M_1,6} = 2700$ s corresponds to the path $P^{1,4}_2$.

Then, the hydrographic system (*see* Figure 4) is represented by the weighted digraph depicted in Figure 5 to determine the matrix $\mathbf{R}$, and then, to determine the matrices α_{Mi} and β_{M_i}.

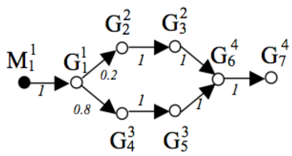

Figure 5: Graph for the determination of $\mathbf{R}$ and α_{Mi}.

The matrix $\mathbf{R}$ is given by:

$$\mathbf{R} = \begin{bmatrix} 1 & 0.2 & 0.2 & 0.8 & 0.8 & 1 \end{bmatrix}. \quad (18)$$

The diagonal matrix α_{M_1} is given by:

$$\alpha_{M_1} = diag\{1, 0.2, 0.2, 0.8, 0.8, 1\}. \quad (19)$$

The matrix β_{M_1} is given by:

$$\beta_{M_1} = \begin{bmatrix} 1 & 0.2 & 0.2 & 0.8 & 0.8 & 0.2 \\ 0 & 0 & 0 & 0 & 0 & 0.8 \end{bmatrix}. \quad (20)$$

The objective discharges of M_1 correspond to 8 m^3/s. The hydrographic system is subjected to disturbances upstream the measurement points M_1 (*see*

Figure 6.a). The detection threshold is selected as d_{th}= 0.15 m^3/s. Figure 6 shows discharges measured on M_1, and the new setpoints which have been dispatched at the gates which were controlled, *i.e.* G_1 in (b) and G_6 in (c), and the discharges resulting at the canal ends q_7 in (d) in case 1: the case where only one transfer time delay is considered (the first rule is used without any assumption about the discharge proportion values), the transfer time delay considered is $T^1_{M_1,6}$ (dashed line), in case 2: the case where the first rule is applied, thus the time delay considered is $T^2_{M_1,6}$ (dotted line), and in case 3: the case where the second rule is applied (continuous line).

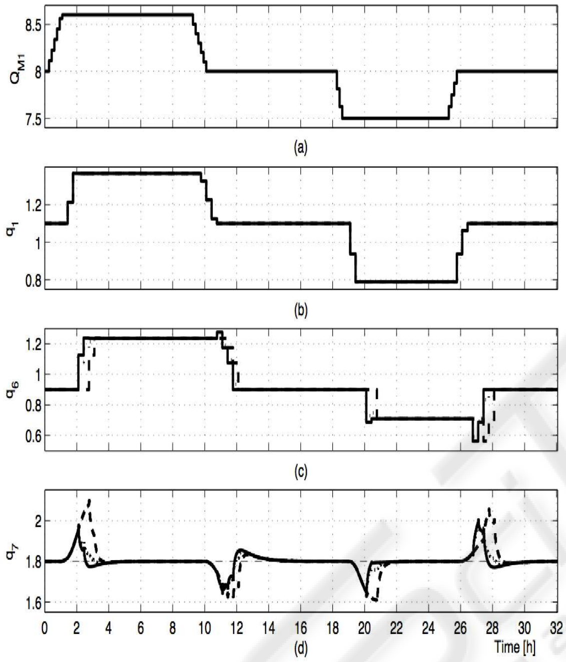

Figure 6: Discharges in $[m^3/s]$ (a) Q_{M_1}, (b) q_1, (c) q_6, and (d) the resulting discharges q_7.

Whatever the setpoint assignment rules used are, there is a peak of approximately 0.15 m^3/s on G_7 at the 2^{nd}, 11^{th}, 20^{th} and 27^{th} hours (*see* Figure 6.d), due to the detection threshold d_{th} and the occurrence of the discharge discrepancies on Q_{M_1}. When the transfer time delay is $T^1_{M_1,6}$, the setpoints are assigned too late, and the discharges at the end of the hydrographic system are not close to the objective value q_{7obj}. These results show the importance of the transfer time delay. The results are improved when the first rule is used with $T^2_{M_1,6}$, because of better evaluation of transfer time delay. Finally, the performances are also improved when the second rule is applied, the effective transfer time delays are taken into account because all direct paths are considered. The maximum and minimum discharges reached at G_7 and the water volume V which was not allocated are displayed in Table 4. The maximum discharge discrepancy at G_7 corresponds to 9.5 % of the objective discharge q_{7obj} when the second rule is used and to 10.5 % in the other case. The second rule leads to spare an additional water quantity of 42 m^3 during 32 hours, in comparison to the use of the first rule. The differences between the two strategies are weak. In addition, these differences decrease for hydrographic systems which are equipped by a great number of measurement points, because, in this case, the number of direct paths is weak.

Table 4: Criteria computed when the different rules are used.

Case	$\max(q_7)$ $[m^3/s]$	$\min(q_7)$ $[m^3/s]$	V $[m^3]$
case 1	2.09	1.59	1815
case 2	1.99	1.63	1099
case 3	1.97	1.63	1057

7 CONCLUSION

The resource allocation and setpoint assignment rules constitute a generic approach allowing the water resource valorization whatever the configuration of the hydrographic networks is. Multiple graph representations make it possible to identify the information for implementing the proposed supervision and hybrid control accommodation strategy. Two rules of setpoint assignment have been proposed, tested and compared within the framework of a networked open-channel system composed of one difluent and one confluent. Although the second rule leads to the best performances, its implementation is more complex than the one for the first rule. The choice between the two strategies could be carried out only by considering the hydrographic system with this equipment.

REFERENCES

Cembrano, G., Wells, G., Quevedo, J., Perez, R., and Argelaguet, R. (2000). Optimal control of a water distribution network in a supervisory control system. *Control Engineering Practice*, 8:1177–1188.

Chan, C., Kritpiphat, W., and Tontiwachwuthikul, P. (1999). Development of an intelligent control system for a municipal water distribution network. *IEEE Canadian conference on Electrical and Computer Engineering*, 2:1108–1113.

Chow, V. T., Maidment, D. R., and Mays, L. W. (1988). *Applied Hydrology*. McGraw-Hill, New York, Paris.

Duviella, E., Chiron, P., and Charbonnaud, P. (2006). Hybrid control accommodation for water-asset management of hydraulic systems subjected to large operating conditions. *ALSIS06, 1st IFAC Workshop on Applications of Large Scale Industrial Systems, Helsinki, Finland, August 30-31 2006*.

Duviella, E., Chiron, P., Charbonnaud, P., and Hurand, P. (2007). Supervision and hybrid control accommodation for water asset management. *Control Engineering Practice (CEP)*, 15:17–27.

Faye, R. M., Sawadogo, S., Niang, A., and Mora-Camino, F. (1998). An intelligent decision support system for irrigation system management. *IEEE International Conference on Systems, Man and Cybernetics, SMC'98, October 11-14, San Diego, USA*, 4:3908–3913.

Islam, A., Raghuwanshi, N. S., Singh, R., and Sen, D. J. (2005). Comparison of gradually varied flow computation algorithms for open-channel network. *Journal of irrigation and drainage engineering*, 131(5):457–465.

Lisounkin, A., Sabov, A., and Schreck, G. (2004). Interpreter based model check for distribution networks. *IEEE international conference on industrial informatics, INDIN'O4, 24-26 juin*, pages 431–435.

Litrico, X. and Georges, D. (1999). Robust continuous-time and discrete-time flow control of a dam-river system. (i) modelling. *Applied Mathematical Modelling 23*, pages 809–827.

Malaterre, P.-O. and Baume, J.-P. (1998). Modeling and regulation of irrigation canals: Existing applications and ongoing researches. *IEEE International Conference on Systems, Man, and Cybernetics*, 4:3850–3855.

Mansour, H. E. F., Georges, D., and Bornard, G. (1998). Optimal control of complex irrigation systems via decomposition-coordination and the use of augmented lagrangian. *IEEE, International Conference on Control Applications, Trieste, Italy*, pages 3874–3879.

Naidu, B. J., Bhallamudi, S. M., and Narasimhan, S. (1997). GVF computation in tree-type channel networks. *Journal of hydraulic engineering*, 123(8):700–708.