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.
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 \( M^b_i \) and actuators \( G^b_j \), 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 disfluences (see Figure 1.c).

According to the hydraulic conditions and the equations of energy and mass conservation, the sum of the discharges entering a node (confluent or disfluent), is equal to the sum of the discharges outgoing from this node. Thus, around an operating point, the discharge \( q^b \) of the HYS downstream the HYS \( b \) resulting from the confluence between several HYS is equal to the sum of the discharges entering a node (confluent or disfluence) between the two nodes \( \mathcal{C} \). Thereafter, the transfer time delay between the nodes \( w_r \). Thereafter, an algorithm lead to the generation of the proportion matrix \( \mathbf{R} \) which is composed of \( m \) lines (measurement points) and of \( n \) columns (actuators). The weighted digraph is browsed for each measurement point \( M^b_i \) following the algorithm given in Table 1. The matrix \( \mathbf{R} \) 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.

Table 1: Assignment function of \( \mathbf{R} \) matrix.

<table>
<thead>
<tr>
<th>Input: weighted digraph.</th>
<th>Output: proportion matrix ( \mathbf{R} ).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initialization of ( \mathbf{R} ) to 0</td>
<td></td>
</tr>
<tr>
<td>For each node ( h )</td>
<td></td>
</tr>
<tr>
<td>If ( h ) is a measurement point</td>
<td></td>
</tr>
<tr>
<td>Run (( h, h, 1, R ))</td>
<td></td>
</tr>
<tr>
<td>EndIf</td>
<td></td>
</tr>
<tr>
<td>EndFor</td>
<td></td>
</tr>
<tr>
<td>Run (( h, c, p, R ))</td>
<td></td>
</tr>
<tr>
<td>For each successor ( d ) of ( c )</td>
<td></td>
</tr>
<tr>
<td>( p_d \leftarrow p_d + w_d )</td>
<td></td>
</tr>
<tr>
<td>Run (( h, d, p_d, R ))</td>
<td></td>
</tr>
<tr>
<td>If ( d ) is a gate</td>
<td></td>
</tr>
<tr>
<td>( R(h, d) \leftarrow R(h, d) + p_d )</td>
<td></td>
</tr>
<tr>
<td>EndIf</td>
<td></td>
</tr>
<tr>
<td>EndFor</td>
<td></td>
</tr>
</tbody>
</table>

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

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 disfluence 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 \( M^b_i \) or \( G^b_j \), 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 \( \mathbf{R} \) which is composed of \( m \) lines (measurement points) of \( n \) columns (actuators). The weighted digraph is browsed for each measurement point \( M^b_i \) following the algorithm given in Table 1. The matrix \( \mathbf{R} \) contains all the discharge proportions of a point to another of the hydrographic networks.
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 $\tau$, see (1), is obtained from the step response of the corresponding transfer function. It is chosen as the time value for which $\Pi_d$ percent of step is reached. The percentage $\Pi_d$ can be tuned from simulation.

In the case of gridded systems, the value of the transfer time delay between the measurement point $M_i^d$ and the gate $G_j^d$ depends on the path to go from the measurement point $M_i^d$ to the gate $G_j^d$ (see Figure 2). $P_{d,d}$ is the set of direct paths to go from the HYS $b$ to the HYS $d$, and $P_{v,d}$ is one of the direct paths to go from the HYS $b$ to the HYS $d$, such as $P_{v,d} \in P_{d,d}$, where $1 \leq v \leq P_{b,d}$, with $P_{b,d}$ the total number of paths which compose $P_{b,d}$. 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 $M_i^d$ and the gate $G_j^d$ are computed by considering each path and constitute the vector $t_{M_i,j}$ ($P_{b,d} \times 1$):

$$t_{M_i,j} = \left[ t_{M_i,j}^1, t_{M_i,j}^2, \ldots, t_{M_i,j}^{P_{b,d}} \right]^T. \quad (1)$$

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

$$t_{M_i,j} = t_{M_i,n_i} + \sum_{r=n_i}^{r=v} t_{M_i,t_r+1}. \quad (2)$$

where $n_i$ is the first gate downstream $M_i$, $v$ is the index of the path $P_{v,d}$, and $t_{M_i,t_r+1}$ is the transfer time delay between each gate along the path $P_{v,d}$ 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 $T_s$:

$$kd_{M_i,j} = \left\lfloor \frac{t_{M_i,j}}{T_s} \right\rfloor + 1, \quad (3)$$

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:

$$T_{M_i,j} = (k + kd_{M_i,j}) T_s. \quad (4)$$

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

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

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 $q_{j,loc}$ and seasonal weights $\lambda_j$ and $\mu_j$ are given by the Management Objective Generation module according to the water

![Figure 2: Transfer delays between the measurement point $M_i$ and gates $G_j$.](image-url)
contracts and climatic events. The weekly measurement point objective discharge \( Q_{M_{t}} \) 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 \( \delta_{th} \) around \( Q_{M_{i}, \text{obj}} \) and to diagnose the resource states (Duviella et al., 2007). According to the resource state and the discharge discrepancy \( \Delta Q_{M_{i}} = Q_{M_{i}, \text{obj}} - Q_{M_{i}} \), 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 \( q_{M_{i}} \) 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 \( \lambda_{j} \) and \( \mu_{j} \).

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

\[
q_{M_{i}} = \left[ \delta_{1}^{\text{obj}} - \delta_{1}^{\text{obj}}, \ldots, \delta_{1}^{\text{obj}} - \delta_{1}^{\text{obj}}, \ldots, \delta_{n}^{\text{obj}} - \delta_{n}^{\text{obj}} \right]^{T}.
\]

where \( \lfloor x \rfloor \) corresponds to the higher rounding of \( x \), \( n \) is the total number of gates, and \( \delta_{a}^{b} \) 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 \( \lambda_{j} \) and \( \mu_{j} \). 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 \( q_{j, \text{obj}} \) for each gate \( G_{j} \), at time \( kT_{s} \):

\[
f_{M_{i}} = \sum_{j=1}^{n} \left( \delta_{1}^{1} - \delta_{1}^{1} \right) \chi_{M_{i}, j} (q_{j} - q_{j, \text{obj}}) \right) \right). \quad (7)
\]

with \( \chi_{M_{i}, j} = \gamma_{j}^{1} + (\gamma - 1) \frac{1}{\mu_{j}} \), \( \gamma_{j} = \frac{1}{2}(\text{sign}(\Delta Q_{M_{i}}) + 1) \).

The optimization is carried out under constraints:

\[
\begin{align*}
\sum_{j=1}^{n} \left( R(i, j) q_{j} - q_{j, \text{obj}} \right) &= \Delta Q_{M_{i}}, \\
q_{\text{min}} &\leq q_{j} \leq q_{\text{max}},
\end{align*}
\]

where \( q_{\text{min}} \) and \( q_{\text{max}} \) are respectively the minimum and maximum discharges given by gate, river or canal characteristics. In this case, the allocation vector \( q_{M_{i}} \) is such as:

\[
q_{M_{i}} = \left[ \delta_{1}^{1} - \delta_{1}^{1} \right]^{T} \ldots, \left[ \delta_{1}^{1} - \delta_{1}^{1} \right]^{T} \ldots, \left[ \delta_{1}^{1} - \delta_{1}^{1} \right]^{T}.
\]

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 in assigning them to the gates taking into account the transfer 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:
The discrepancy allocation will be weak also, if the discharge proportion \( \beta_M(v, j) \) resulting from \( M_i^h \) and supplying \( G_j^h \) by a single path \( P_{i,j}^h \), is weak, the discrepancy allocation will be weak also.

- if the discharge proportion \( \beta_M(v, j) \) resulting from \( M_i^h \) and supplying \( G_j^h \) by a single path \( P_{i,j}^h \), is important, the discrepancy allocation will be important also.

The supplying discharge proportion \( \beta_M(p_M, n) \), where \( p_M \) 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 \( T_{M_i} \) (1 \( \times n \)) updated at each sampling period \( T_s \) and expressed by:

\[
T_{M_i} = \left[ T_{M_i,1} \ldots T_{M_i,j} \ldots T_{M_i,n} \right],
\]

where

\[
\begin{cases}
T_{M_i,j} = 0, & \text{if } \beta_M(1, j) = 0 \\
T_{M_i,j} = T_{M_i,j}', & \text{otherwise}
\end{cases}
\]

and \( v \) such that \( \beta_M(v, j) = \max_{i \in [1, p_M]} \beta_M(i, j) \). When \( \beta_M(1, j) = 0 \) there is no direct path between \( M_i \) and \( G_j \).

At each sample time \( kT_s \), the setpoint assignment matrix \( A_k^M(H_M, n) \), where \( H_M \) is the allocation horizon from \( M_i \), is scheduled according to \( T_{M_i} \) and \( q_M \). The first row of \( A_k^M \) contains the setpoints to be assigned from each gate at the date \((k + h)T_s \), the \( h^{th} \) row the ones to be assigned at the date \((k + H_M)T_s \) as defined in equation 12, the last row the ones to be assigned at the date \((k + H_M + 1)T_s \).

If \( \tau_{M_i}(j) \geq (k + h)T_s \)
\[
A_k^M(h, j) = q_M(j),
\]

Else
\[
A_k^M(h, j) = A_k^M(h, j + 1)
\]

and \( A_k^M(0, j) = q_{jobj} \).

The setpoints are dispatched with the control period \( T_c = \kappa T_s \), where \( \kappa \) is an integer. The control setpoint vector denoted \( u(1 \times n) \) is updated at each date \( k' T_c \), where \( k' = \frac{k}{\kappa} \), thanks to the assignment matrix \( A_k^M \) and the \( \alpha_M(n \times n) \) diagonal control accommodation matrix, with \( H = \frac{1}{\kappa} \max_{l \geq M} (H_{M,l}) \) the control horizon. For each measurement point \( M_i \), the \( \alpha_M \) matrix, the role of which is to capture the measurement point influence on the gates, must be determined. In order to generate the \( \alpha_M \) 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 \( u^k \) (1 \( \times n \)) is calculated by:

\[
u^k(j) = \sum_{i=1}^{m} \alpha_M(j, j)A_i^M(1, j).
\]

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

\[
T_{M_i} = \left[ T_{M_i,1} \ldots T_{M_i,j} \ldots T_{M_i,n} \right],
\]

where \( T_{M_i,j} \) 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 \( p_M < l < p_M \), i.e. when the length \( p_M \) of the \( T_{M_i,j} \) is smaller than \( p_M \).

In this case, the setpoint assignment matrix \( A_k^M(H_M, n) \) is scheduled at each sample time \( kT_s \), ac-
according to \( T_{M} \) and \( q_{M} \):

If \( \exists h \) such that \( T_{M}(v, j) \leq (k + h)T_{s} \)

\[
A_{M}^{k}(h, j) = \sum_{v=1}^{R_{M}} \varphi_{v} \cdot \beta_{M}(v, j) \cdot q_{M}(j)
\]

Else

\[
A_{M}^{k}(h, j) = A_{k-1}(h + 1, j)
\]

\[
\text{Endif}
\]

The control setpoint vector denoted \( u(1 \times n) \) is updated at each date \( kT_{s} \), thanks to the assignment matrix \( A_{M}^{k} \), with \( H = \max_{1 \leq i \leq m} (H_{M}) \) the control horizon.

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 diffuence and one confluence (see Figure 4).

The hydrographic system is subjected to disturbances upstream the measurement points \( M_{1} \) and \( G_{6} \); \( T_{M_{1}} = 3750 \text{ s} \) corresponds to the path \( P_{1}^{1} \); \( T_{M_{1}6} = 2700 \text{ s} \) corresponds to the path \( P_{2}^{1} \).

Then, the hydrographic system (see Figure 4) is represented by the weighted digraph depicted in Figure 5 to determine the matrix \( R \), and then, to determine the matrices \( \alpha_{M_{i}} \) and \( \beta_{M_{i}} \).

### Table 3: Gate parameters.

<table>
<thead>
<tr>
<th>Gate</th>
<th>( q_{\text{job}} )</th>
<th>( q_{\text{min}} )</th>
<th>( q_{\text{max}} )</th>
<th>( \lambda_{j} )</th>
<th>( \mu_{j} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( G_{1} )</td>
<td>1.1</td>
<td>0.05</td>
<td>0.85</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>( G_{2} )</td>
<td>0.3</td>
<td>0.1</td>
<td>0.9</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>( G_{3} )</td>
<td>0.4</td>
<td>0.15</td>
<td>1.2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>( G_{4} )</td>
<td>1.9</td>
<td>0.1</td>
<td>1.4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>( G_{5} )</td>
<td>1.6</td>
<td>0.1</td>
<td>0.9</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>( G_{6} )</td>
<td>0.9</td>
<td>0.05</td>
<td>1.8</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>( G_{7} )</td>
<td>1.8</td>
<td>0.05</td>
<td>0.75</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

The objective discharges \( q_{\text{job}} \), maximum and minimum discharges \( q_{\text{max}}, q_{\text{min}} \), and their associated weights, are given in Table 3.

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 \( T_{M_{i}} \), of transfer time delays between \( M_{1} \) and each gate, expressed in seconds, are given by:

\[
T_{M_{i}} = \begin{bmatrix}
850 & 1750 & 2700 & 1450 & 2050 & 3750 \\
0 & 0 & 0 & 0 & 0 & 0 \\
2700 & 0 & 0 & 0 & 0 & 0 \\
1450 & 0 & 0 & 0 & 0 & 0 \\
2050 & 0 & 0 & 0 & 0 & 0 \\
3750 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

There are two identified transfer time delays between \( M_{1} \) and \( G_{6} \); \( T_{M_{1}6} = 3750 \text{ s} \) corresponds to the path \( P_{1}^{1} \); \( T_{M_{1}6} = 2700 \text{ s} \) corresponds to the path \( P_{2}^{1} \).

Then, the hydrographic system (see Figure 4) is represented by the weighted digraph depicted in Figure 5 to determine the matrix \( R \), and then, to determine the matrices \( \alpha_{M_{1}} \) and \( \beta_{M_{1}} \).

The matrix \( R \) is given by:

\[
R = \begin{bmatrix}
1 & 0.2 & 0.2 & 0.8 & 0.8 & 1
\end{bmatrix}
\]

The diagonal matrix \( \alpha_{M_{1}} \) is given by:

\[
\alpha_{M_{1}} = \text{diag} \{ 1, 0.2, 0.2, 0.8, 0.8, 1 \}
\]

The matrix \( \beta_{M_{1}} \) is given by:

\[
\beta_{M_{1}} = \begin{bmatrix}
1 & 0.2 & 0.2 & 0.8 & 0.8 & 0.2 \\
0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

The objective discharges \( M_{1} \) correspond to 8 \( m^{3}/s \). The hydrographic system is subjected to disturbances upstream the measurement points \( M_{1} \) (see Figure 5).
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 $T_{1M_1,6}^1$ (dashed line), in case 2: the case where the first rule is applied, thus the time delay considered is $T_{2M_1,6}^2$ (dotted line), and in case 3: the case where the second rule is applied (continuous line).

![Discharge Diagrams](image)

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 $d_0$ and the occurrence of the discharge discrepancies on $Q_{M_1}$. When the transfer time delay is $T_{1M_1,6}^1$, 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 $T_{2M_1,6}^2$, 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.

<table>
<thead>
<tr>
<th>Case</th>
<th>$\max(q_7)$ [m$^3$/s]</th>
<th>$\min(q_7)$ [m$^3$/s]</th>
<th>$V$ [m$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>case 1</td>
<td>2.09</td>
<td>1.59</td>
<td>1815</td>
</tr>
<tr>
<td>case 2</td>
<td>1.99</td>
<td>1.63</td>
<td>1099</td>
</tr>
<tr>
<td>case 3</td>
<td>1.97</td>
<td>1.63</td>
<td>1057</td>
</tr>
</tbody>
</table>

### 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 confluent 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


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.


