Distributed Control of Irrigation Canals

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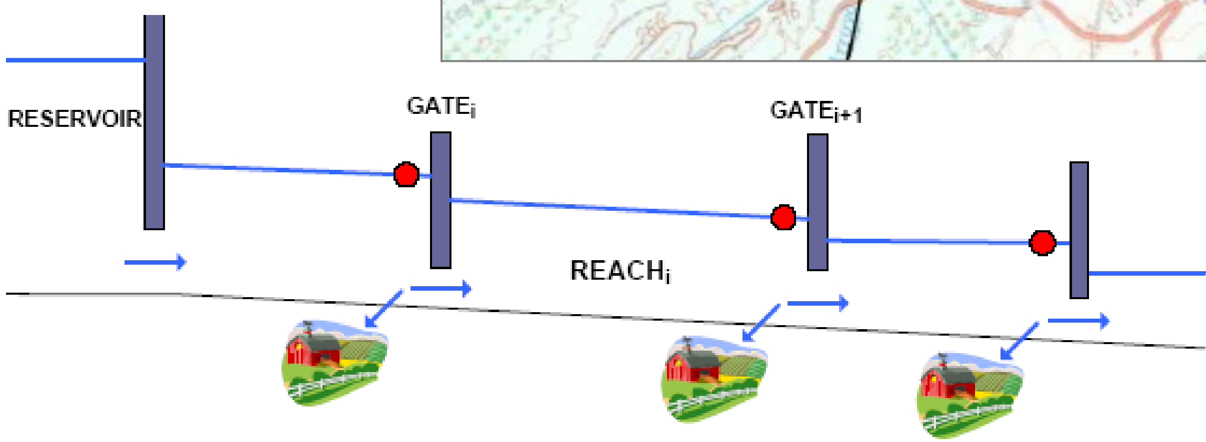
Outline

- Irrigation Canal System
  - Main Elements
  - Operation of an Irrigation Canal
- Models
- Control of Irrigation Canals

Irrigation Canal Scheme



Control structures - Gates

Taintor Gate

Sluice Gates

Two Taintor Gates with side weirs

Side
weirs

Canal elements

Gravity offtake

Wasteweirs

Syphon

Canal Head

Canal Operation Concepts

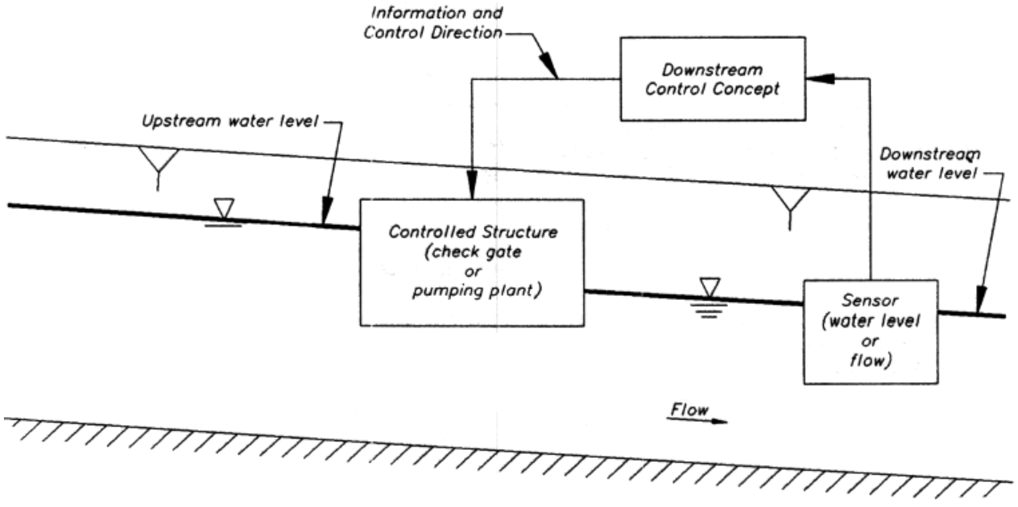
- Supply oriented operation
  - Upstream water supply source or inflow determines the canal system flow schedule
  - Used when the inflow is fixed by a different organization than the canal manager

- Demand oriented operation
  - Downstream water demand (offtakes) determines the canal system flow schedule
  - The inflow is determined by the canal manager accordingly with the demand

Control objectives

- **Main objective**: guarantee flows requested by users. It is necessary to maintain the level of the canal over the off-take gate.
- **Controlled Variables**:
  - levels upstream or downstream the gates.
  - flows through gates, mainly at the head of the canal and secondary canals.
  - Water volume
- **Manipulated variables:**
  - Gate opening
  - flow is considered as a manipulated variable to control levels when a two level controller is used.
- **Disturbances:**
  - Off-takes flows: measured, aggregate values or predicted
  - Rainfall: Measured or predicted
- **Contraints:**
  - Maximum and minimum levels along the canal
  - Maximum and minimum flows
  - Operating levels on reservoir at the tail of the canal

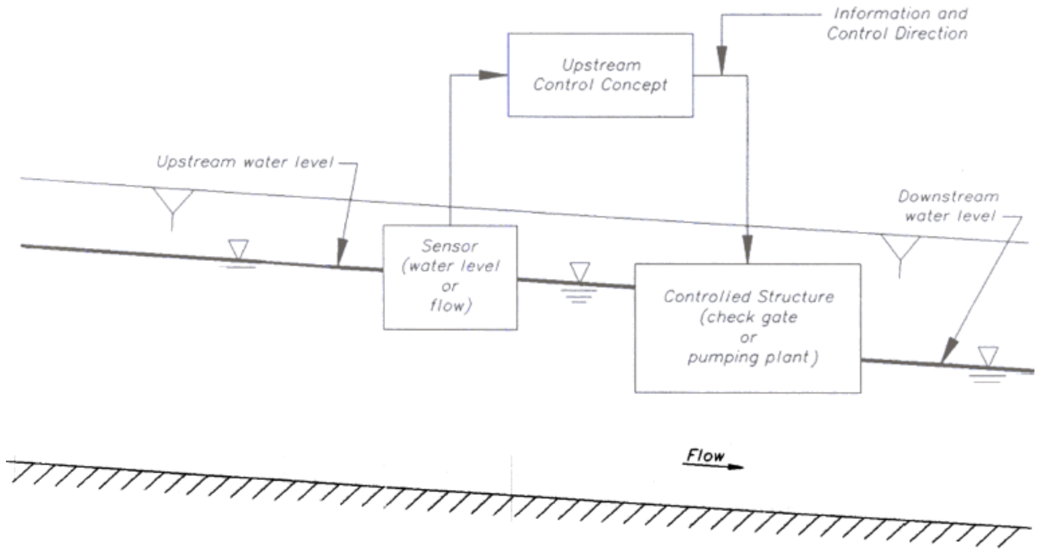
Control Concepts – Downstream Control



(a) Downstream control concept

- Control structure adjustments (gates) are based upon information from downstream (usually levels)
- Downstream control transfers the downstream offtake demand to the upstream water supply source (flow at the head)
- Compatible with demand oriented operation
- Impossible with supply oriented operation

Control Concepts – Upstream Control



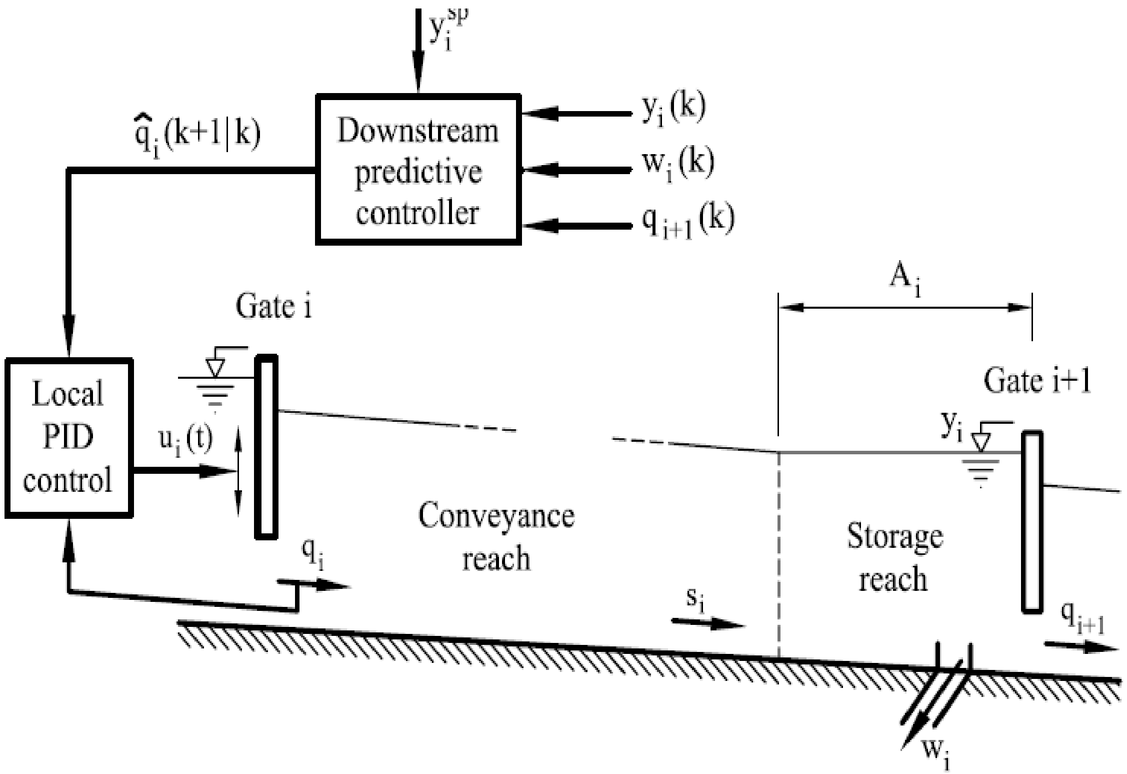
- Control structure adjustments (gates) are based upon information from upstream (usually levels)
- Upstream control transfers the upstream water supply (or inflow) downstream to points of diversion or to the end of the canal
- Compatible with supply oriented operation
- Inefficient with demand oriented operation

Irrigation Canal Control – General Ideas

- Controlled variables: Water level, water volume or discharge (most common, level)

- Two global strategies:
  - Directly manipulate gate opening in order to control levels
  - Two level control
    - Compute required gate discharges in order to control water levels (discharges as manipulated variable)
    - Manipulate gate openings to obtain the requested gate discharges
      - Local Controller (Cascade control)
      - Inverting the gate discharge equation

Irrigation Canal Control – General Ideas

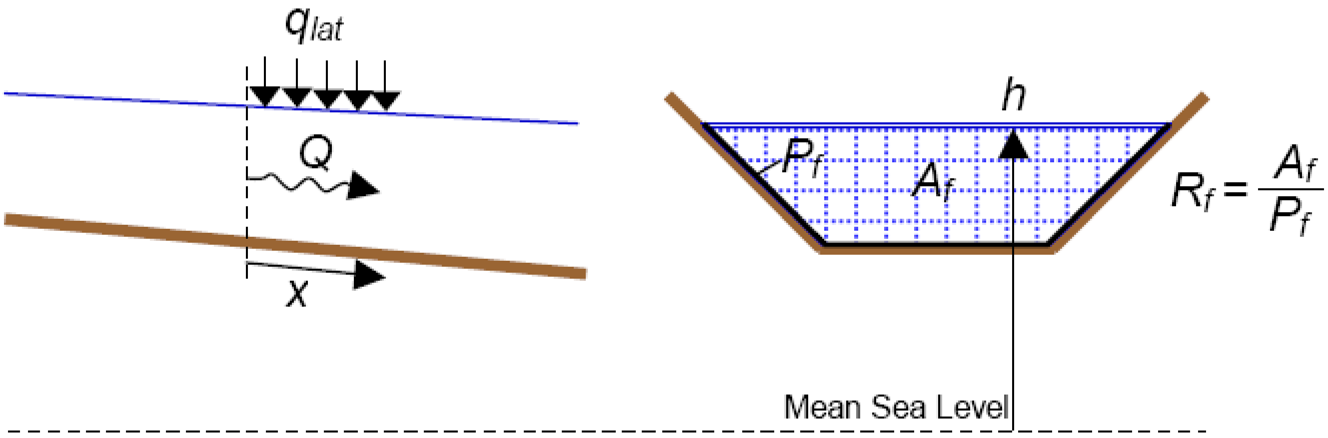


Example of a two level downstream controller. The first level is a predictive controller and the lower level controller is a PID

Outline

- Irrigation Canal System
- Models
  - Saint-Venant equations
  - Models of control structures
  - Control models
- Control of Irrigation Canals

Irrigation Canal Model - Reaches

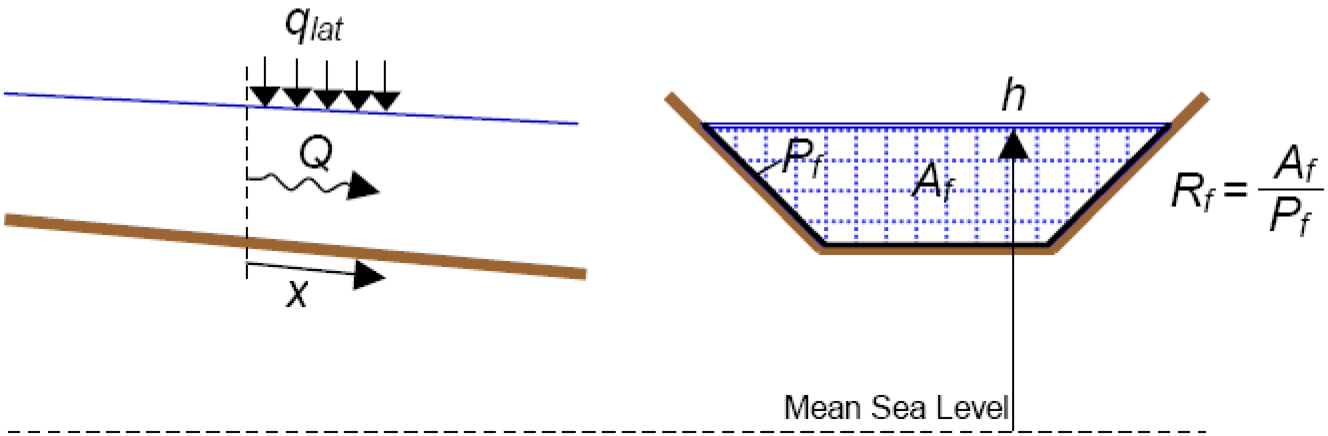


$$\frac{\partial Q}{\partial x} + \frac{\partial A_f}{\partial t} = q_{lat}$$ Mass Balance

$$\underbrace{\frac{\partial Q}{\partial t}} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A_f}\right) + \underbrace{g \cdot A_f \frac{\partial h}{\partial x}} + \frac{g \cdot Q|Q|}{C^2 \cdot R_f \cdot A_f} = 0$$ Momentum Balance

Partial Differential Saint-Venant Equations

Irrigation Canal Model - Reaches



Inertia

Convective acceleration

Gravitational Force

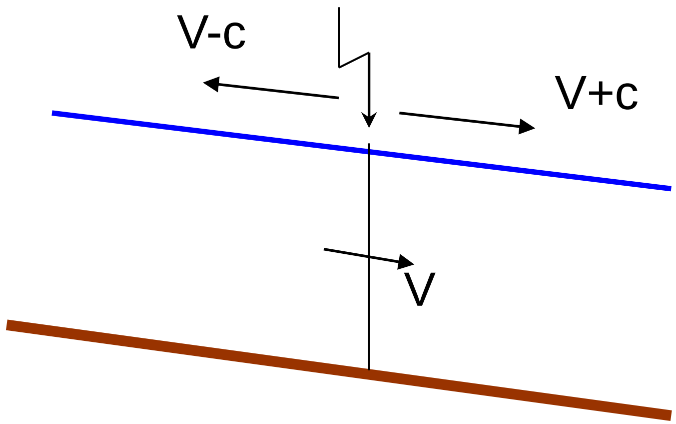
Friction Force

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A_f}\right) + g \cdot A_f \frac{\partial h}{\partial x} + \frac{g \cdot Q|Q|}{C^2 \cdot R_f \cdot A_f} = 0$$

Momentum Balance

Partial Differential Saint-Venant Equations

Saint_Venant Equations – Water Movement



A disturbance, created in a reach, results in two wave movements., one wave travels with velocity V+ c and one travels with velocity V - c.

$$c = \sqrt{\frac{gA_f}{B}}$$

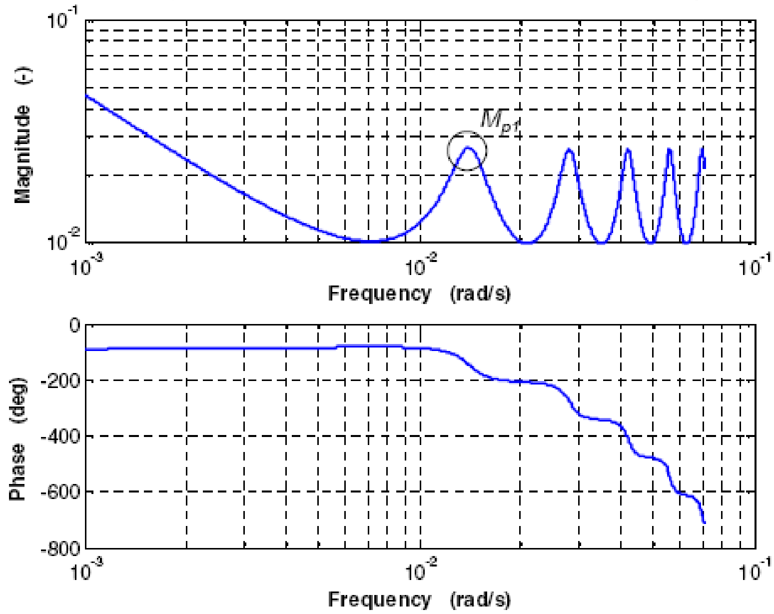
B Top width of wetted cross section

A_f Wetted cross section surface

- Flow Regimes
  - If c>V, **subcritical flow**, a change in flow results in two waves in opposite directions
  - If c=V, **critical flow**, a change in flow results in only one wave travelling downstream
  - If c<V, **supercritical flow**, a change in flow results in two waves travelling downstream
- Subcritical flow is presented in most real irrigation canal

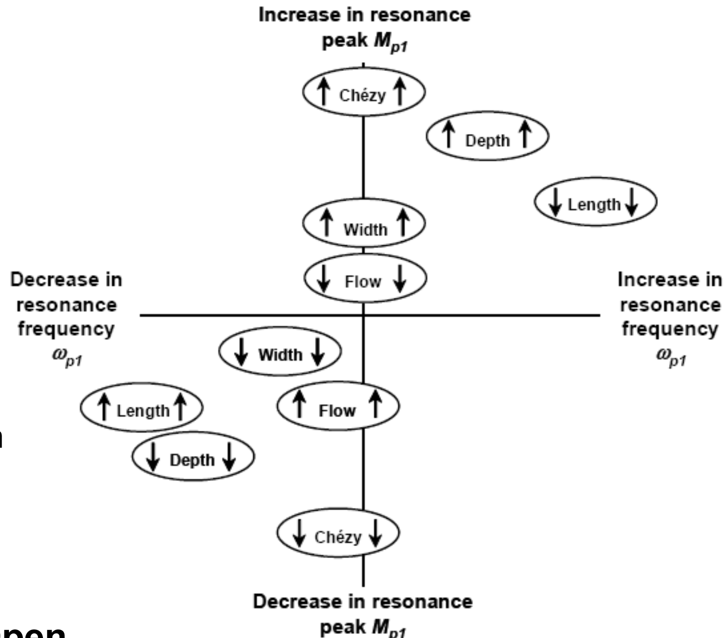
Saint_Venant Equations – Water Movement

Bode diagram of linearized De Saint Venant equations



When a wave arrives at a boundary (a control structure), part of the wave is reflected. If a wave is initiated from one of the boundaries, it returns after a period

$$T_r = \frac{L}{c+V} + \frac{L}{c-V} \qquad \omega = \frac{2\pi}{\frac{L}{c+V} + \frac{L}{c-V}}$$



Influence of changes in parameter values of reach dimension on basic frequency

P.J van Overloop, "Model Predictive Control on Open Water Systems". 2006

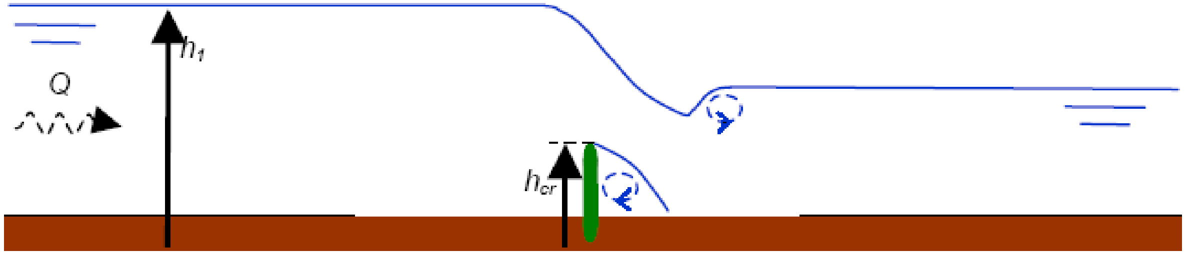
Structure Models – Overshot Gates

Many theoretical or empirical formulas have been proposed, for example:

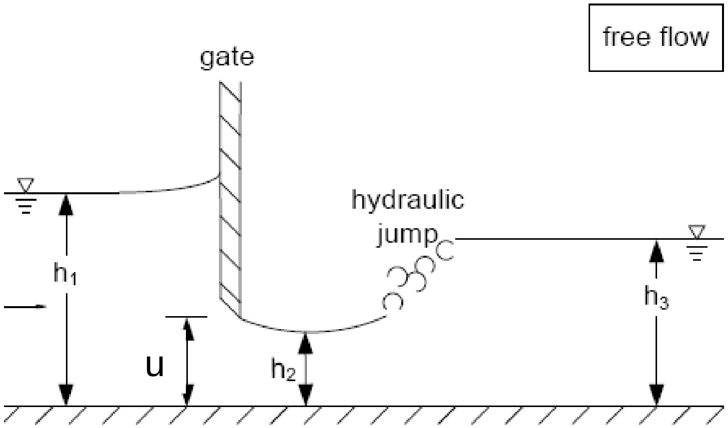
$$Q = C_d L \sqrt{\frac{2}{3} g} (h_1 - h_{cr})^{3/2}$$

L : With of gate

C_d : Discharge coeficient

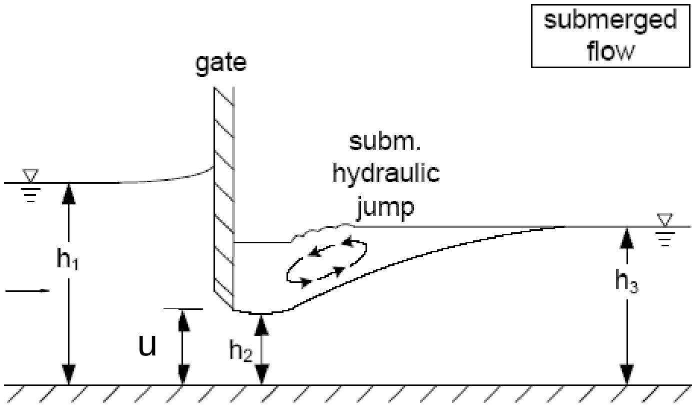


Structure Models – Undershot gates



$$Q = C_d \cdot L \cdot u \sqrt{2 g h_1}$$

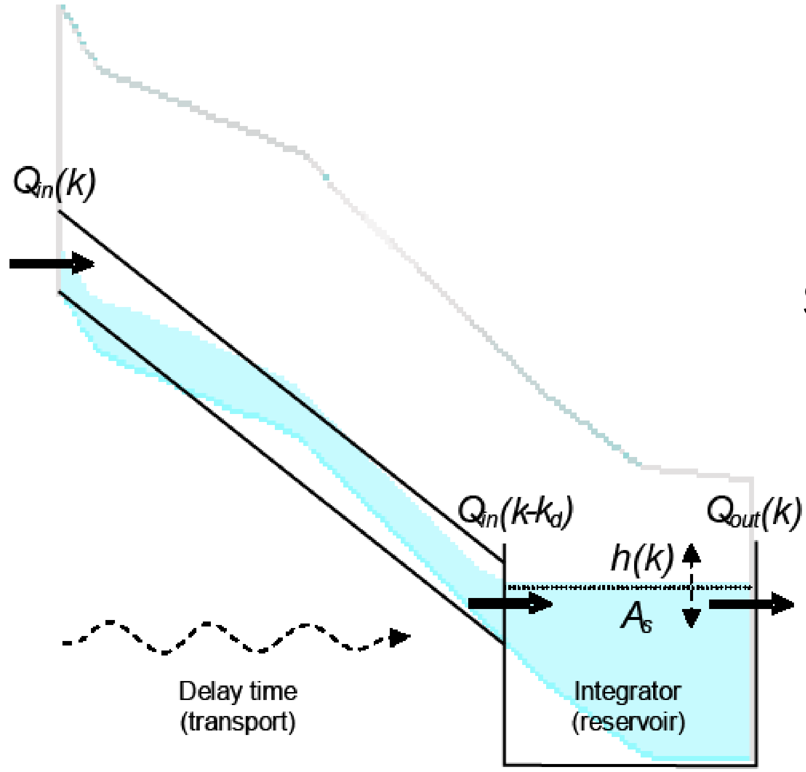
u : Gate opening



$$Q = C_d \cdot L \cdot u \sqrt{2 g (h_1 - h_3)}$$

- Some approaches in bibliography
  - Based on mathematical models
    - Integrator-delay model (Shuurmans, TU Delft)
    - Linearization of Saint-Venant equations (Litrico and Fromion, Cemegraph)
  - Identification models
    - Weyer et al. (University of Melbourne)
    - Rivas Perez (*Havana Polytechnic University)*
    - *Rodellar, Sepulveda (Universidad Politécnica de Cataluña)*

Simplified models for control – ID Model



Integrator-delay simplified model

$$A_s(h(k+1)-h(k)) = T_d(Q_{in}(k-k_d)+q_{in}(k)-Q_{out}(k)-q_{out}(k))$$

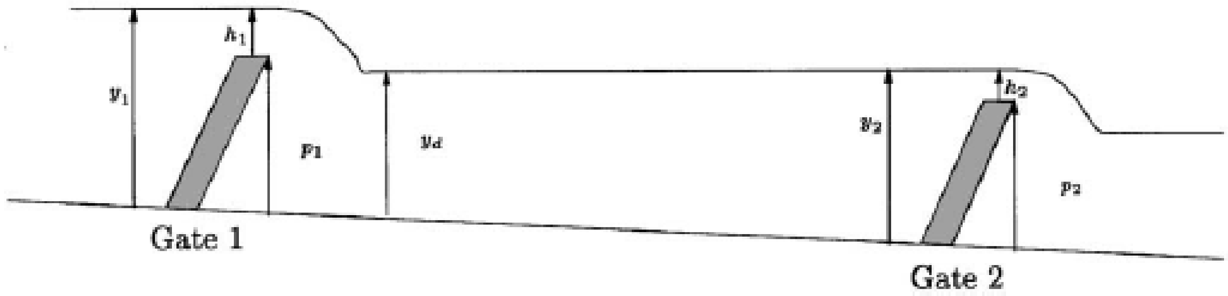
T_d *Sampling time*

$q_{in}(k)$ *Lateral input : rain fall ,...*

$q_{out}(k)$ *Offtakes*

Schuurmans, J. (1997), 'Control of water levels in open channels', Ph.D.-dissertation TUDelft

Identification Models I



First and third order non-linear and linear models for a reach with overshot gates

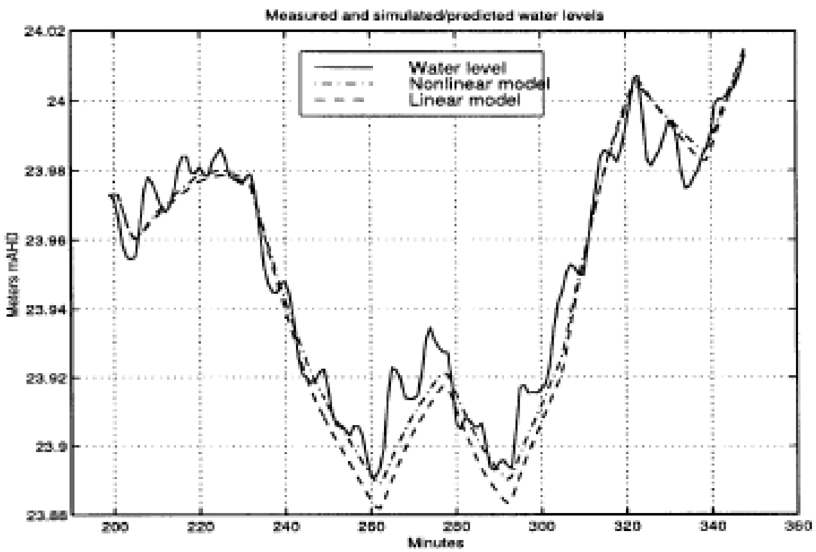
Non-linear model

$$y_2(t+1) = y_2(t) + c_1 h_1^{3/2}(t-\tau) + c_2(y_2(t) - p_2(t))^{3/2}$$

Linear model

$$y_2(t+1) = y_2(t) + c_1 h_1(t-\tau) + c_2(y_2(t) - p_2(t))$$

Parameters: $c_1 \;\; c_2 \;\; \tau$



E. Weyer. System identification of an open water channel. Control Engineering Practice 9, 2001

Identification Models II

Third order models for the wave dynamics

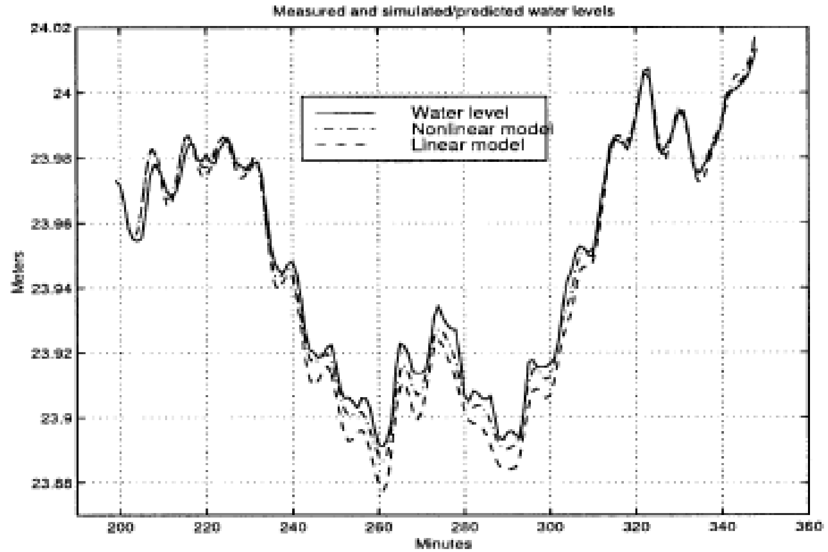
$$\dddot{y}(t) + a_1\ddot{y}(t) + a_2(t)\dot{y}(t) = Inflow - Outflow$$

Non-linear model

$$y_2(t+1) = c_1 h_1^{3/2}(t-\tau) + c_3 h_1^{3/2}(t-\tau-1) + c_5 h_1^{3/2}(t-\tau-2)$$
$$+ c_2(y_2(t) - p_2(t))^{3/2} + c_4(y_2(t-1) - p_2(t-1))^{3/2} +$$
$$c_6(y_2(t-2) - p_2(t-2))^{3/2} + y_2(t) +$$
$$(1-a_1)(y_2(t) - 2y_2(t-1) + y_2(t-2)) +$$
$$(1-a_2)(y_2(t) - 2y_2(t-1))$$

Parameters: c_1 c_2 c_3 c_4
c_5 c_6 a_1 a_2 τ

E. Weyer. System identification of an open water channel. Control Engineering Practice 9, 2001



Conclusions:

The models can be used for accurate simulation of the water levels at least 7.5 h ahead of time

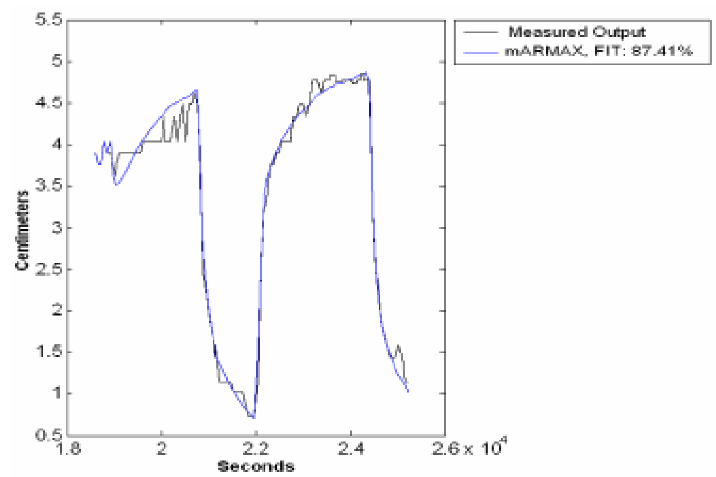
(2) The models are valid under both high and low flow conditions

Identification Models III

Second order Model

Rivas Perez et al. *System identification for control of a main irrigation canal pool*. Proceedings of the 17th World Congress

$$T_1 T_2 \frac{d^2 y_1(t)}{dt^2} + (T_1 + T_2)\frac{dy_1(t)}{dt} + y(t) = Ku_1(t-\tau)$$



ARX higher models and Laguerre Models

Sepulveda, Instrumentation, model identification and control of an experimental irrigation canal. PhD Dissertation. Universidad Politécnica de Cataluña.

Outline

- Irrigation Canal System
- Models
- Control of Irrigation Canals
  - Decentralized control
  - Distributed control

Irrigation Canal Control – Common solutions

- Most of the implemented techniques are based on local PI
  - EL-FLO: A PI controller with a filter applied to downstream control.
  - P+PR: A PI applied to upstream control.
  - BIVAL: The controlled variable used both upstream and downstream measures (volume control)

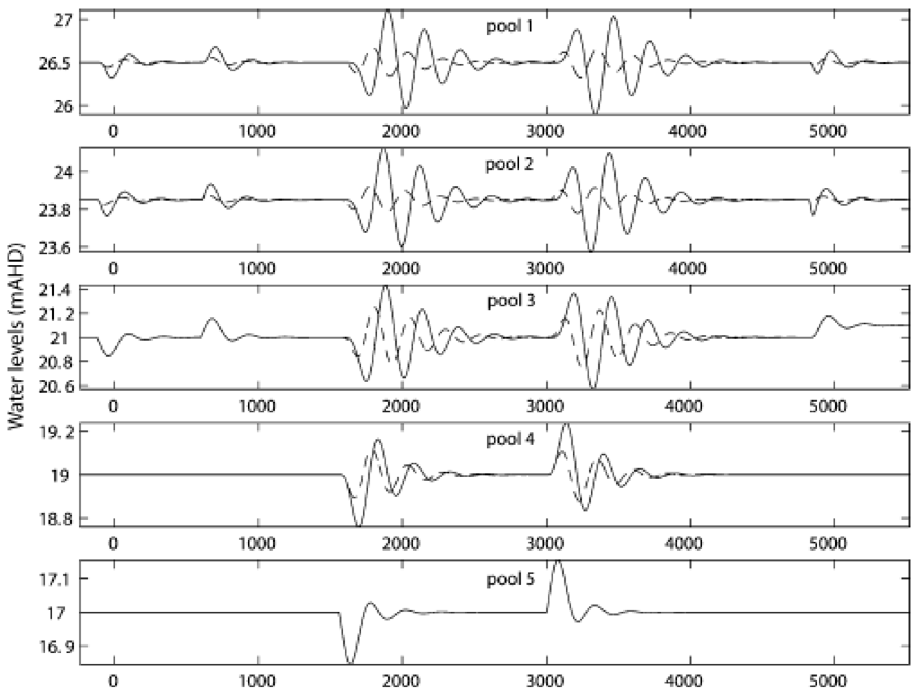
$$y = \alpha y_{up} + (1 - \alpha) y_{dwn}$$

  - AVIS: P controller for radial gates (upstream control)
  - AMIL:P controller for radial gates (downstream control)
  - PIR: PI+ Smith predictor

Malaterre et al., "Classification of Canal Control Algorithms", ASCE Journal of Irrigation and Drainage Engineering. Jan./Feb. 1998, Vol. 124, .

Decentralized control

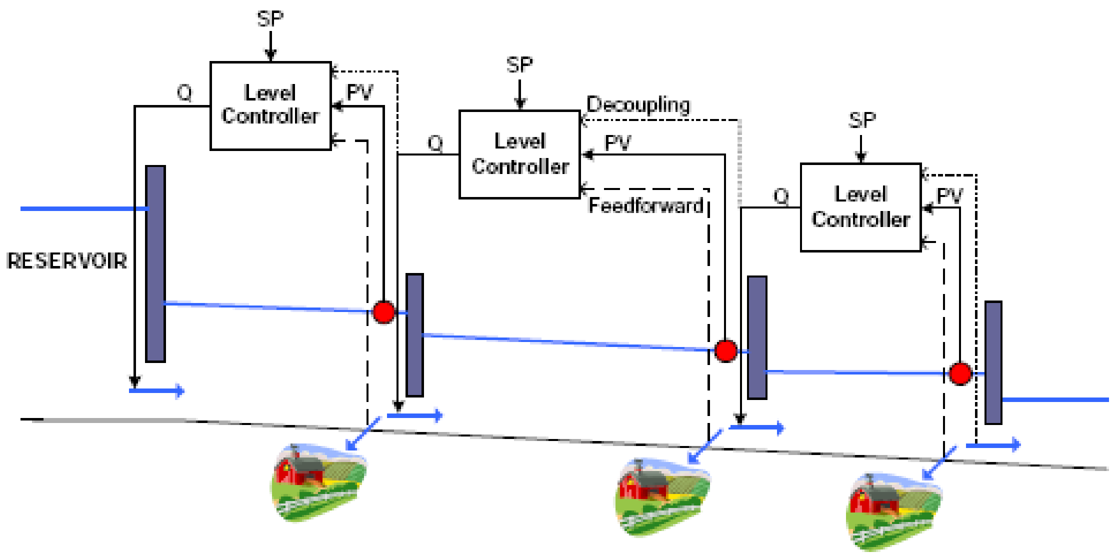
- The most used solution in practice consist of a PI compensator and a filter
  - The compensator need at least one pole in s=0 to achieve zero steady-state waterlevel error for step load disturbances
  - Several PI tuning rules based on ID model: Schuurmans, Litrico…
  - The low pass filter diminish the controller sensibility to wave resonance
  - A typical problem is the level error amplification upstream (Cantoni, et al. 2007)



Decentralized Control: Decoupling and Feedforward

- Decoupling: Feedforward control considering the flow at the next gate (u_{i+1}) as a disturbance
  - This flow is always measured (or computed) – no additional cost
  - Diminish the interrelationship among coupled variables – reduction of the amplification error problem
- Feedforward – offtake discharges
  - Not always available a reliable measure.

$$u_i(s) = C_i(s)e_i(s) + F_d(s)u_{i+1}(s) + F_{ff}(s)d_i(s)$$



MPC approaches

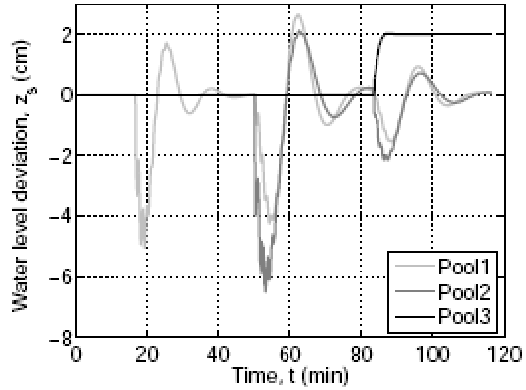
- Decentralized
  - "Predictive Control Applied to ASCE Canal 2". K. Akouz et al. IEEE International Conference on Systems, Man, and Cybernetics. (1998).
  - "Decentralized Predictive Controller for Delivery Canals".S. Sawadogo et al. IEEE International Conference on Systems, Man, and Cybernetics, volume 4.(1998).
  - *"A Simulink-Based Scheme for Simulation of Irrigation Canal Control Systems"*. J. A. Mantecón et al.. SIMULATION (2002)
  - "Predictive control method for decentralized operation of irrigation canals". M. Gómez et al. Applied Mathematical Modelling 26 (2002)

- Centralized
  - "Multivariable predictive control of irrigation canals. Design and evaluation on a 2-pool model". P.O. Malaterre. International Workshop on the Regulation of Irrigation Canals: State of the Art of Research and Applications (1997).
  - "Instrumentation, model identification and control of an experimental irrigation canal". C.A. Sepulveda. PhD. Thesis. (1997)
  - Model Predictive Control on Open Water Systems. P.J. Overloop. PhD. Thesis. (2006)
  - "Predictive Control with constraints of a multi-pool irrigation canal prototype". O. Begovich. Latin American Applied Research, 37 (2007)
  - "Adaptive and non-adaptive model predictive control of an irrigation canal" J.M. Lemos et al. Networks and heterogeneous media. Volume 4, Number 2, (2009).

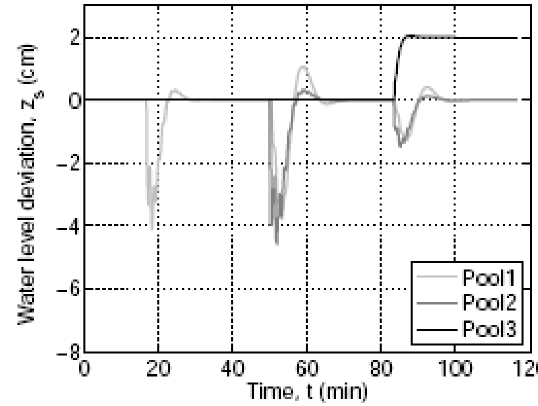
Some comparative results

A three reaches canal:

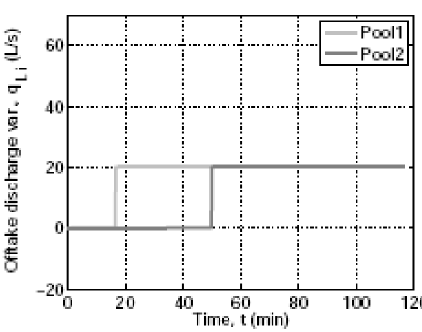
- T=1000 s: Offtake increment in Pool1.
- T= 3000 s: Offtake increment in Pool2.
- T= 5000 s: Water level set point increment in Pool3.



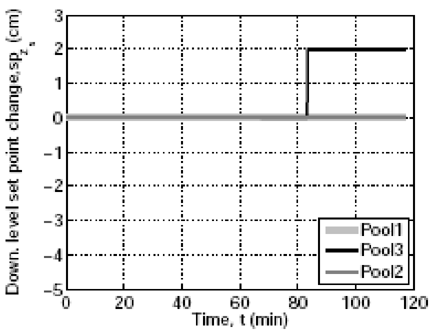
(a) Schuurmans PI



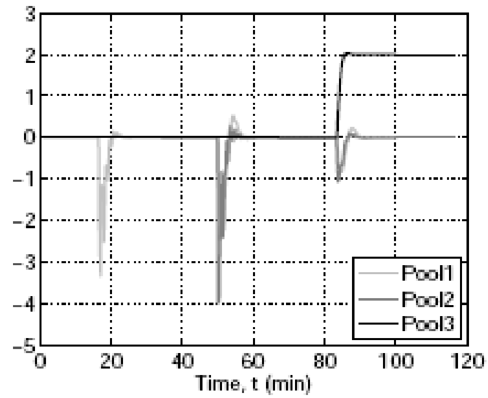
(c) Schuurmans PIF



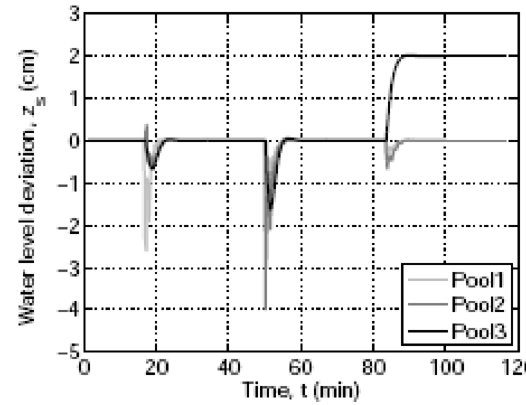
(a) Unscheduled offtake discharge signals



(b) Water level reference signals



(b) Decentralized PC + decoupling

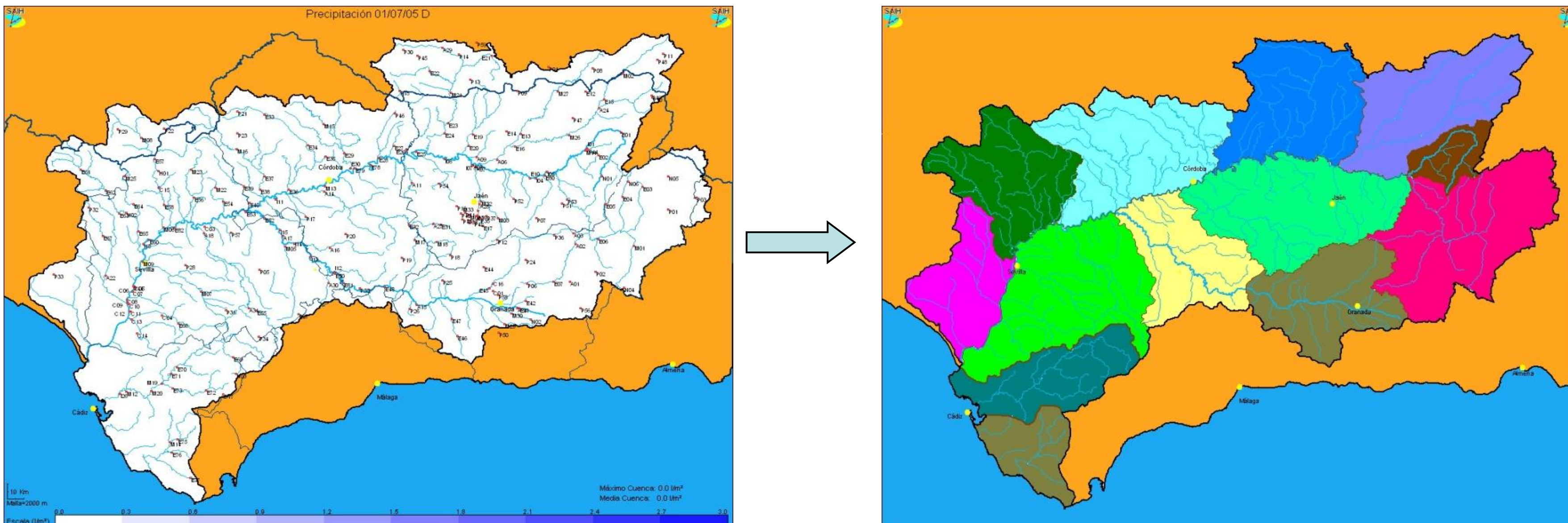


(d) Centralized PC

Sepulveda, Instrumentation, model identification and control of an experimental irrigation canal. PhD Dissertation. Universidad Politécnica de Cataluña.

Why distributed Control?

- Coordination between sub-systems is needed, i.e. the avoidance of upstream disturbance amplification in canals consisting of canal reaches in series
- The number of reaches and gates can be high (near one hundred in the Postrasvase Tajo-Segura): computational limitations for a Centralized MPC
- Different section of the canal can be managed by different Control Centers and even by different organizations.



DECISIONS TAKEN IN ONE HYDROGRAPHICAL AREA CAN INFLUENCE OTHER CLOSE AREAS

Why distributed Control?

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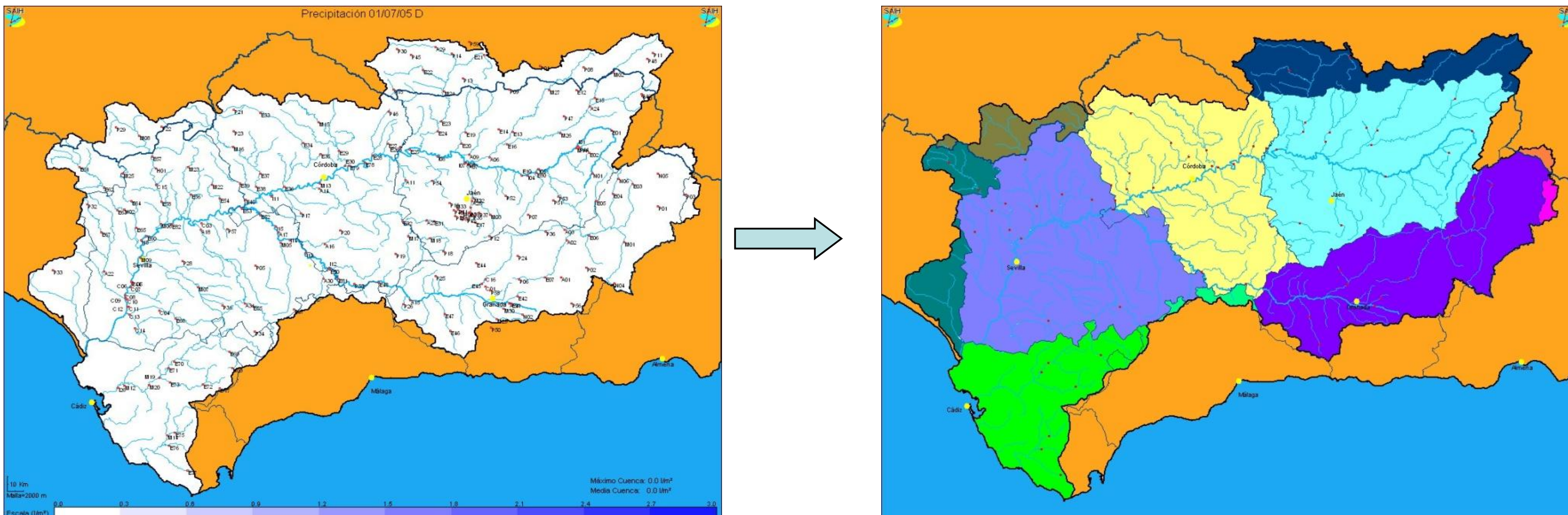


DISTRIBUTED CONTROL CAN TACKLE WITH POLITICAL DECISIONS TAKEN IN DIFFERENT PROVINCES

Distributed approaches to Irrigation Canal

- **Decentralized predictive controller for delivery canals**
  S. Sawadogo, R. M. Faye, P. O. Malaterre and F. Mora-Camino.
  Proceedings of the 1998 IEEE International Conference on Systems, Man, and Cybernetics (San Diego, California), 1998
- **Optimal control of complex irrigation systems via decomposition -coordination and the use of augmented Lagrangian**
  H. El Fawal, D. Georges and G. Bornard
  Proceedings of the 1998 International Conference on Systems, Man, and Cybernetics (San Diego, California), 1998.
- **Decentralized adaptive control for a water distribution system.**
  G. Georges.
  Proceedings ofthe 3rd IEEE Conference on Control Applications (Glasgow, UK), 1999.
- **Cooperative Control of Water Volumes of Parallel Ponds Attached to An Open Channel Based on Information Consensus with Minimum Diversion Water Loss.**
  Christophe Tricaud and YangQuan Chen
  Proceedings of the 2007 IEEE International Conference on Mechatronics and Automation, Harbin, China, 2007,
- **Distributed controller design for open water channels**
  Y. Li and M. Cantoni,
  Proceedings of the 17th IFAC World Congress, Korea, 2008.
- **Distributed Model Predictive Control of Irrigation Canals**
  R.R Negenborn, P.J. Overloop, T. Keviczky and B. De Shutter
  NETWORKS AND HETEROGENEOUS MEDIA Vol. 4-2, 2009.
- **Performance Analysis of Irrigation Channels with Distributed Control.**
  Yuping Li and Bart De Schutter.
  2010 IEEE International Conference on Control Applications. Yokohama, Japan, 2010
- **A hierarchical distributed model predictive control approach to irrigation canals: A risk mitigation perspective.**
  A. Zafra-Cabeza, J.M.Maestre, Miguel A.Ridao, E.F.Camacho and L. Sánchez
  Journal of Process Control - Special Issue on HD-MPC.2011

A serial distributed MPC

- Control strategy: Downstream control
  - Controlled variable: Downstream level
  - Manipulated variables: Flows at the gates (set-point provided to the local flow controllers)
- Subsystems: A gate and the downstream reach
- Each controller requires the current state of its subsystem and predictions of the values of interconnecting variables.
- The controllers perform several iterations consisting of local problem solving and communication with neighbors.
- Serial communication scheme: One agent after another performs computations
- Iterative method based on Lagrange Multipliers.

"DISTRIBUTED MODEL PREDICTIVE CONTROL OF IRRIGATION CANALS"
R.R Negenborn, P.J. Overloop, T. Keviczky and B. De Shutter
NETWORKS AND HETEROGENEOUS MEDIA Vol. 4-2, (2009)

A serial distributed MPC: Models

ID Model:

$$h_i(k+1) = h_i(k) + \frac{T_c}{c_i} q_{in,i}(k - k_{d,i}) - \frac{T_c}{c_i} q_{out,i}(k) + \frac{T_c}{c_i} q_{ext,in,i}(k) - \frac{T_c}{c_i} q_{ext,out,i}(k)$$

State-Space Model:

$$x_i(k+1) = A_i x_i(k) + B_{1,i} u_i(k) + B_{2,i} d_i(k) + B_{3,i} v_i(k)$$

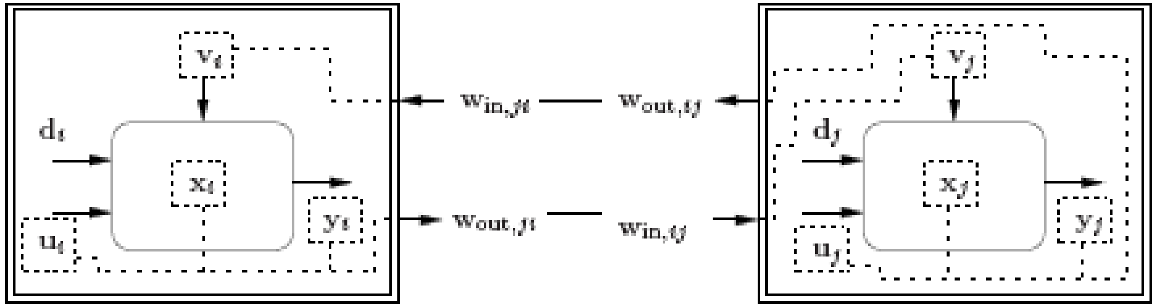
$$y_i(k) = C_i x_i(k)$$

where

$$x_i(k) = \begin{bmatrix} h_i(k) \\ q_{in,i}(k - k_{d,i}) \\ \ldots \\ q_{in,i}(k-1) \end{bmatrix} \qquad d_i(k) = \begin{bmatrix} q_{ext,in,i}(k) \\ q_{ext,out,i}(k) \end{bmatrix}$$

$$u_i(k) = q_{in,i}(k) \qquad v_i(k) = q_{out,i}(k) \qquad y_i(k) = h_i(k)$$

A serial distributed MPC: Interconnecting variables



$$w_{in,i}(k) = v_i(k)$$

$$w_{out,i}(k) = K_i \left[x_i^T(k) \quad u_i^T(k) \quad y_i^T(k) \right]$$

K_i *is a* interconnecting output selection matrix

and an interconnecting constraint:

$$w_{in,ji}(k) = w_{out,ij}(k)$$

$$w_{out,ji}(k) = w_{in,ij}(k)$$

$$w_{in,j_{i,down}i}(k) = q_{out,i}(k)$$

$$w_{out,j_{i,up}i}(k) = q_{in,i}(k)$$

$j_{i,down}$: index of the downstream canal reach of reach i

$j_{i,up}$: index of the upstream canal reach of reach i

A serial distributed MPC: Control algorithm

- The controllers solve their control problems in the following serial iterative way:
  - Set the iteration counter and initialize the Lagrange multipliers arbitrarily.
  - One controller after another solves its optimization problem:

$$\min \; J_{local,i} + \sum_j J^{(s)}_{inter,i}(w_{in,ji}(k), w_{out,ji}, \lambda))$$

  - Update the Lagrange Multipliers with the new values of the interconnecting variables
  - Send and receive the multipliers from the neighbor agent
  - Move on to the next iteration until a stopping condition is satisfied
- The controllers implement the actions until the beginning of the next control cycle

A serial distributed MPC: Control objective

- The deviations of water levels from provided set-points are minimized

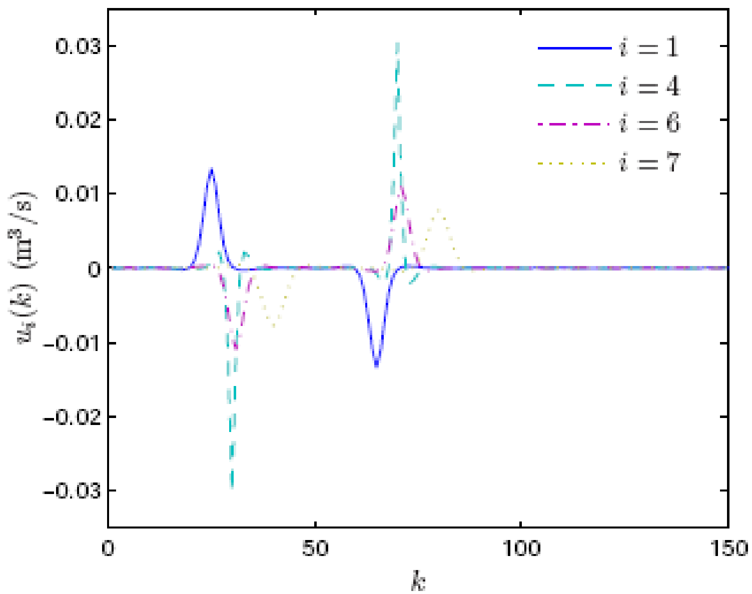
- The changes in the set-points provided to the local flow controllers are minimized to reduce equipment wear

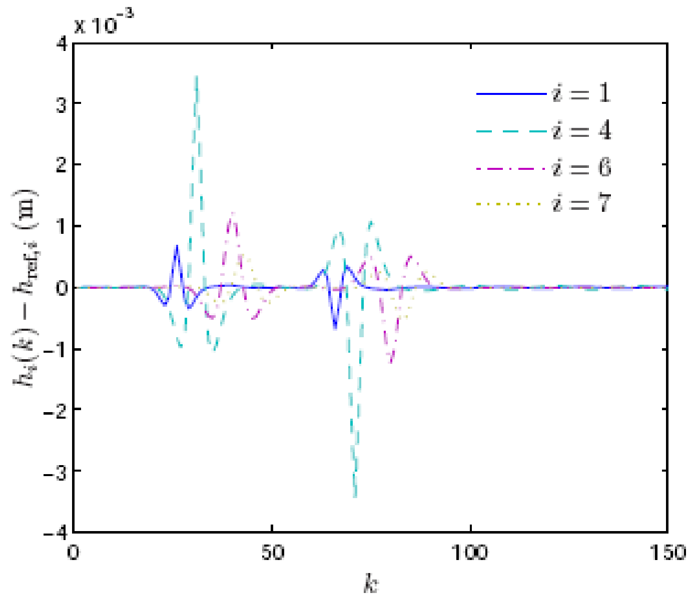
$$J_{local,i} = \sum_{l=0}^{N-1} p_{h,i}(h_i(k+1+l) - h_{ref,i})^2 + \sum_{l=0}^{N-1} p_{u,i}(u_i(k+l) - u_i(k+1+l))^2$$

$$J_{inter,i} = \begin{bmatrix} \tilde{\lambda}_{in,ji}(k) \\ -\tilde{\lambda}_{out,ij}(k) \end{bmatrix}^T \begin{bmatrix} \tilde{w}_{in,ji}(k) \\ \tilde{w}_{out,ji}(k) \end{bmatrix} + \frac{\gamma_c}{2} \left\| \begin{matrix} \tilde{w}_{in,prev,ij}(k) - \tilde{w}_{out,ji}(k) \\ \tilde{w}_{out,prev,ij}(k) - \tilde{w}_{in,ji}(k) \end{matrix} \right\|_2^2$$

A serial distributed MPC: Simulation Results

- 7 reaches canal
- The length of the canal is almost 10 km
- Maximum capacity of the head gate is 2.8m3/s
- Control cycle length: 240 s.
- Prediction horizon length; 31 (to take into account the total delay in the irrigation canal
- Scenario: a sudden increase of 0.1m3/s at control cycle k = 30 in the water offtake of canal reach 3 and a sudden decrease of 0.1m3/s at control cycle k = 70 in the same canal reach.





A HD-MPC approach based on risk management

- This approach shows how **risk management** can be applied to **optimize the Irrigation Canal operation** in order to consider **process uncertainties**.
- The proposed method, for the use of risk metrics, **forecasts the water level of reaches**, benefits and costs associated to IC.
- Formulation of a Hierarchical and Distributed MPC (HDMPC) to optimize the strategic plan (mitigation actions) that optimizes the operation of the IC.
  - Higher Level: MPC with a risk-based strategy
  - Lower Level: DMPC to optimize the operation (based on the DMPC based on game theory presented previously)

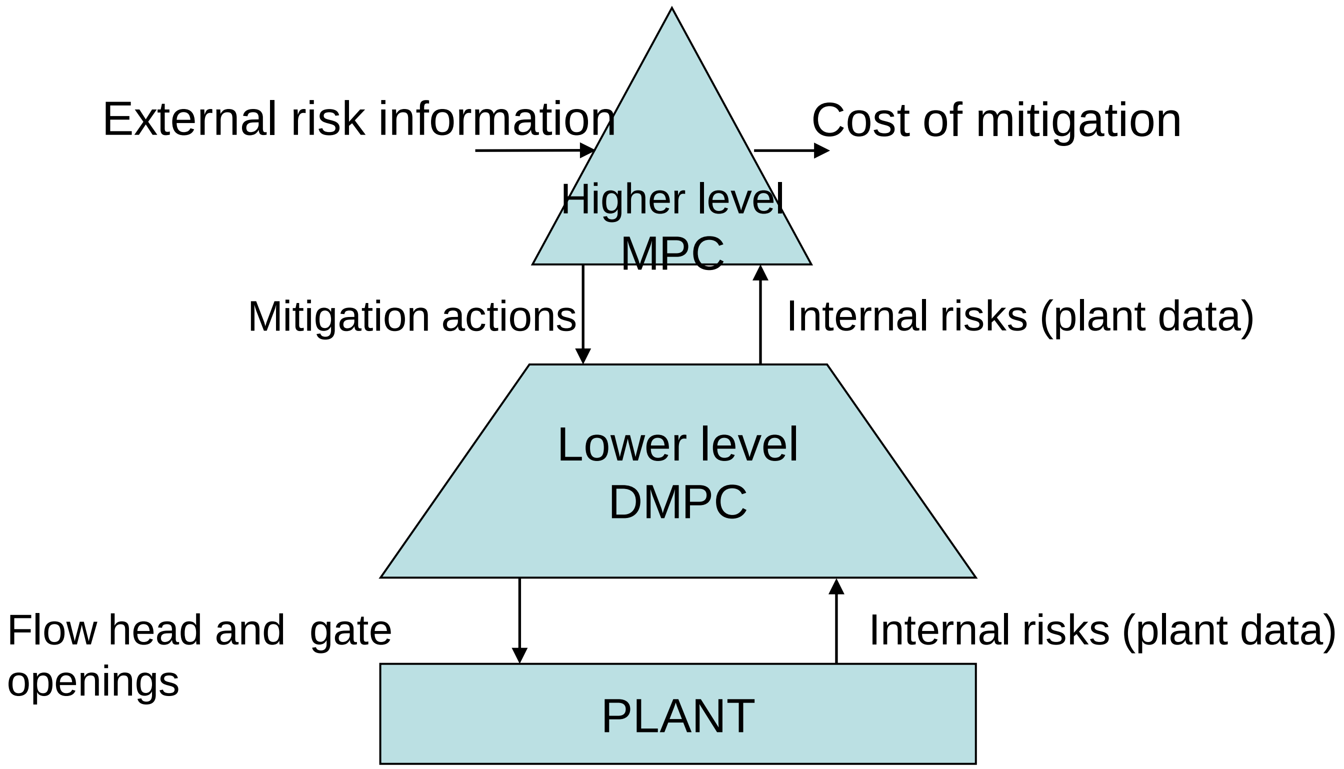
"A hierarchical distributed model predictive control approach to irrigation canals: A risk mitigation perspective"

A. Zafra-Cabeza, J.M.Maestre, Miguel A.Ridao, E.F.Camacho and L. Sánchez

Journal of Process Control - Vol 21-5 - Special Issue on HD-MPC (June-2011)

HD-MPC and Risk Management

- **General structure**



Lower level: DMPC approach

- Downstream control, considering underflow gates and gate position as manipulated variable
- Each subsystem corresponds with a reach
- The Integrator delay model has been used for the reach movement and the flow through the gates as manipulated variables
- Each agent has only partial information of the system. Agents optimize according to a local cost function
- Low communicational requirements
- Cooperative solution: Cooperative algorithm from a game theory point of view. The different agents must reach an agreement on the value of the shared inputs

Lower level: DMPC approach

ID Model: $$h_i(k+1) = h_i(k) + \frac{T_c}{c_i} q_{in,i}(k - k_{d,i}) - \frac{T_c}{c_i} q_{out,i}(k) + \frac{T_c}{c_i} q_{ext,in,i}(k) - \frac{T_c}{c_i} q_{ext,out,i}(k)$$

State state model: $$x_i(k+1) = A_i x_i(k) + \sum_{j \in n_i} B_{ij} u_j(k) + d_i(k)$$

where: $$u_1(k) = q_{in,i}(k)$$
$$u_2(k) = q_{out,i}(k)$$

There is no coupling between the states of the agents (only coupled by the actuations)

Each agent has local information about the state and knows how it is affected by the different inputs

Inputs are not assigned to agents

Lower level: Cost functions

- **Agents optimize according to a local cost function**

$$J_i(x_i, \{U_j\}_{j \in n_i}) = \sum_{k=0}^{N-1} L_i(x_i(k), \{u_j(k)\}_{j \in n_i})$$

$$L_i(x_i, \{u_j\}_{j \in n_i}) = (x_i - \hat{h}_i(t))^T Q_i (x_i - \hat{h}_i(t)) + \sum_{j \in n_i} u_j^T S_{ij} u_j$$

- **Control objective: Global Performance Index**

$$\sum_{i=1}^{M_x} J_i(x_i(t), \{U_j(t)\}_{j \in n_i})$$

- **The different agents must reach an agreement on the value of the shared inputs**

Lower level: Algorithm

1. Each agent p measures its current state $x_p(t)$
2. Agents try to submit their proposals randomly. To this end, each agent asks the neighbors affected if they are free to evaluate a proposal.
3. In order to generate its proposal, each agent p minimizes J_p solving the following optimization problem:

$$
\begin{aligned}
\{U_j^p(t)\}_{j\in n_p} = \; & \arg \min_{\{U_j\}_{j\in n_p}} J_p(x_p, \{U_j\}_{j\in n_p}) \\
& s.t. \\
& x_{p,k+1} = A_p x_{p,k} + \textstyle\sum_{j\in n_p} B_{pj} u_{j,k} \\
& x_{p,0} = x_i(t) \\
& x_{p,k} \in \mathcal{X}_p, \; k = 0, \dots N \\
& u_{j,k} \in \mathcal{U}_j, \; k = 0, \dots N-1, \; \forall j \in n_p \\
& x_{p,N} \in \Omega_p \\
& U_j = U_j^s(t), \; \forall j \notin P_p
\end{aligned}
$$

4. Each agent i affected by the proposal of agent p evaluates the predicted cost corresponding to the proposed solution. To do that, the agent calculates the difference between the cost of the new proposal and the cost of the current accepted proposal. The difference is sent back to agent p.
5. Once agent p receives the local cost increments from each neighbor, it can evaluate the impact of their proposal.
6. The algorithm returns to Step 1 until the maximum number of proposals has been made or the sampling time ends.
7. The first input of each optimal sequence is applied and the procedure is repeated the next sampling time from Step 1.

Lower level: Case study

Benchmark: postrasvase Tajo-Segura in the south-east of Spain

6,680km

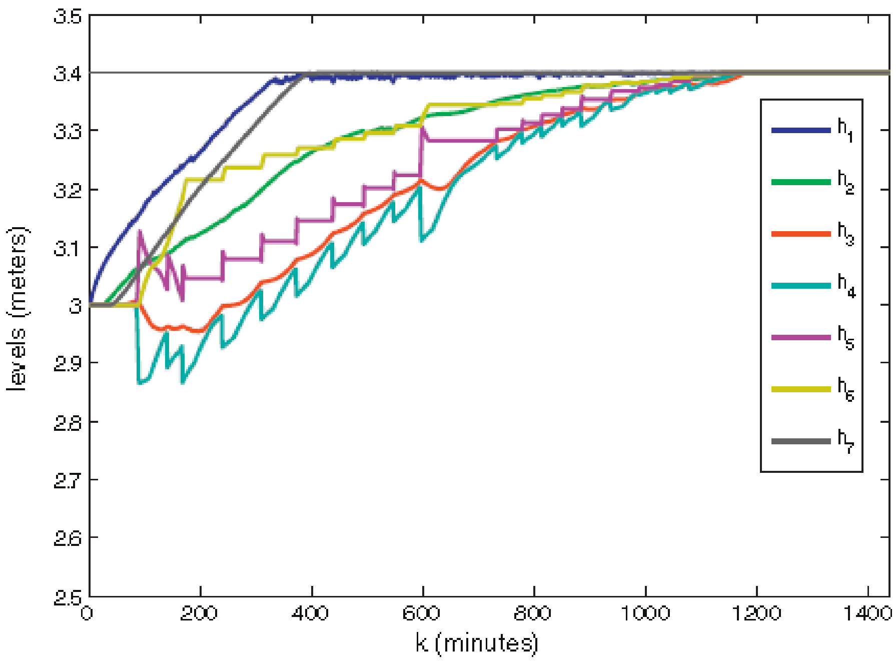
17,444km

7 main gates
17 off-take gates
7 subsystem in DMPC

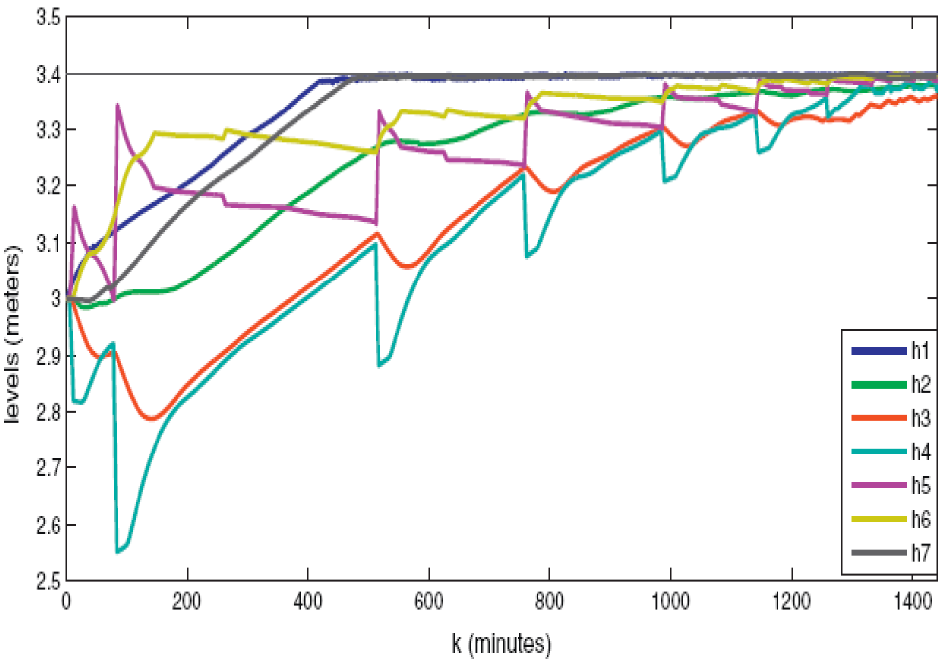
- Lower Level
  - Control water management in canals by satisfying demands
  - Controlled variables: downstream levels
  - Manipulated variables: flow at the head and the position of the gates
  - Sampling time: 1 minute
  - Nc=5
  - The prediction horizon for each reach is the control horizon plus the delay of the reach :Np(i)=Nc+Ki
  - 7 agents

Case study: Lower level results

- Scenario: All reaches begin with a water level of 3.0 m and there is a change of set points for all the reaches to 3.40m (from higher level, day 150)



Nominal case. No disturbances



Measure disturbances