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Using Multiagent Negotiation to Model Water Resources Systems Operations

Francesco Amigoni, Andrea Castelletti, Paolo Gazzotti,
Matteo Giuliani, Emanuele Mason

Management of Water Resources Systems

- The operations of water resources infrastructures, like dams and diversions, involve multiple conflicting interests and stakeholders
- Centralized approaches [Zeitoun and Warner, *Water Policy*, 2006]
  - Full knowledge
  - Perfect application of the generated policies
- Agent-based approaches [Giuliani et al., *J Water Res Pl-ASCE*, 2015; Yang et al., *Water Resour Res*, 2009]
  Agent = stakeholder
  - Distributed Constraint Processing [Amigoni et al., *AAMAS*, 2015]
  - Negotiation [Adams et al., *J Econ Behav Organ*, 1996; Thoyer et al., *JASSS-J Artif Soc S*, 2001]
    - Agents have full knowledge of the preferences of other agents

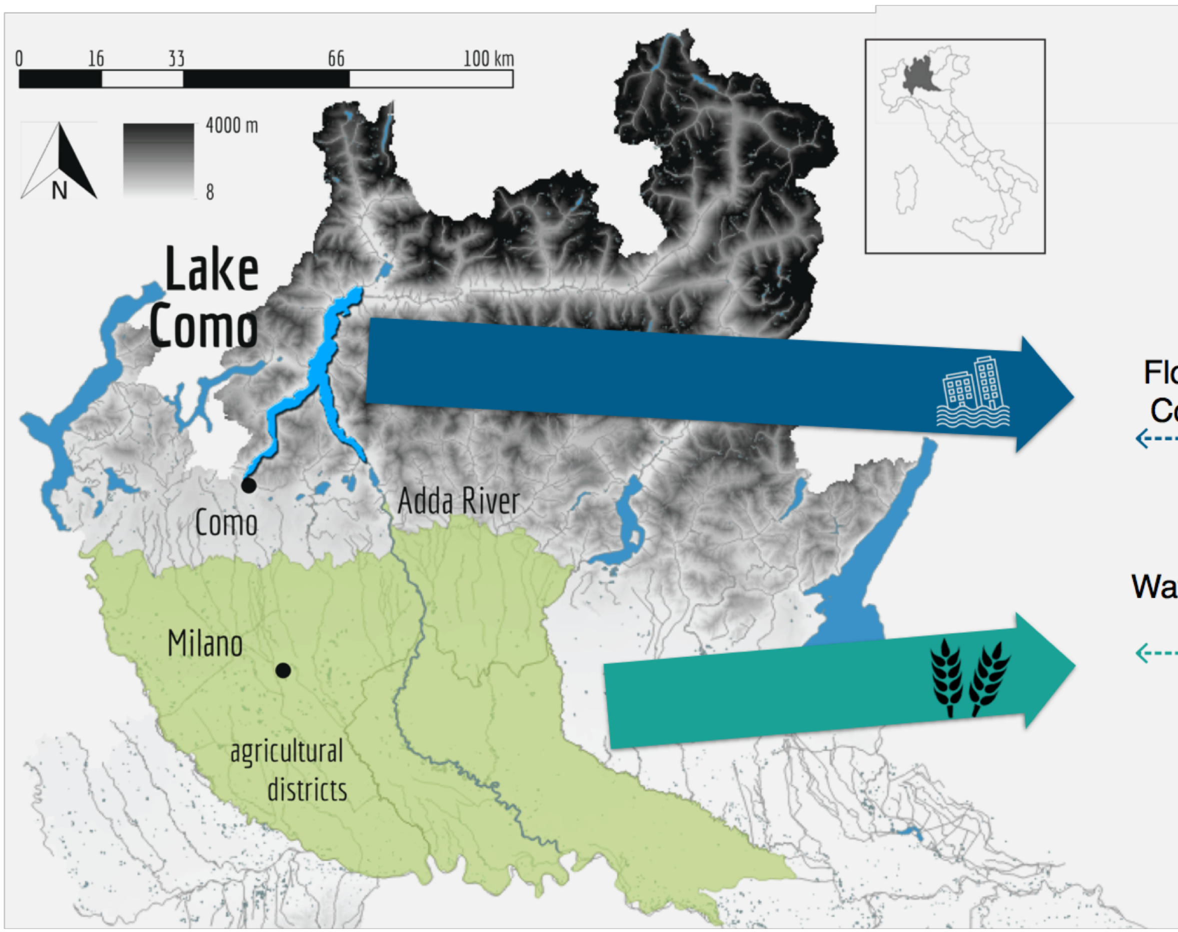
Purpose

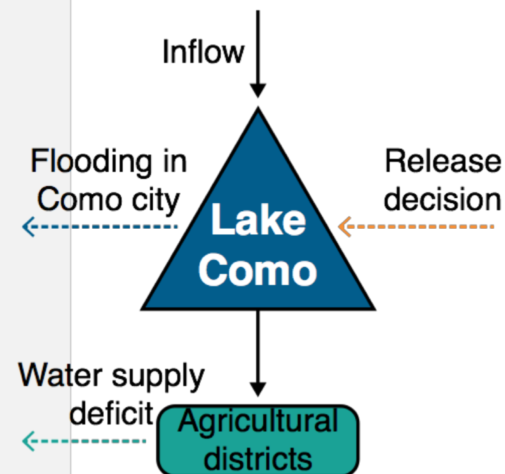
We propose a model based on a general **monotonic concession negotiation** framework that allows the stakeholders-agents of a regulated lake to periodically reach agreements on the lake operating policy that determines the amount of water to release daily

No need for agents to know all their preferences

Case study

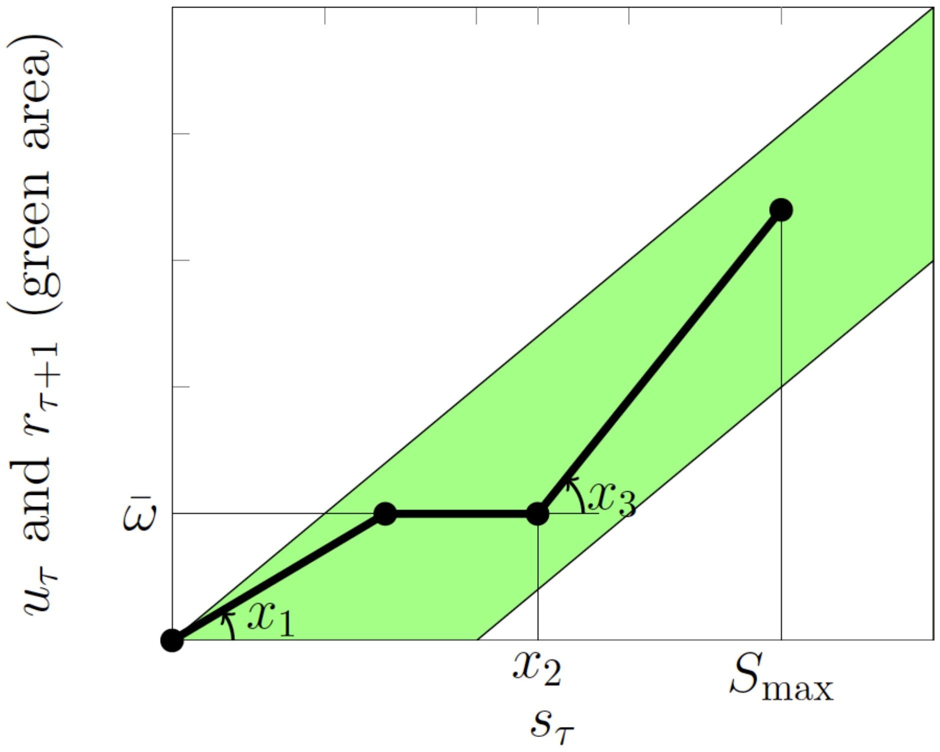
Lake Como system, in Northern Italy





Case study: release policy

The water release at day τ, r_τ, is controlled using the *standard operating policy* [Draper and Lund, *J Water Res Pl-ASCE*, 2004] according to the volume of water stored in the reservoir s_τ



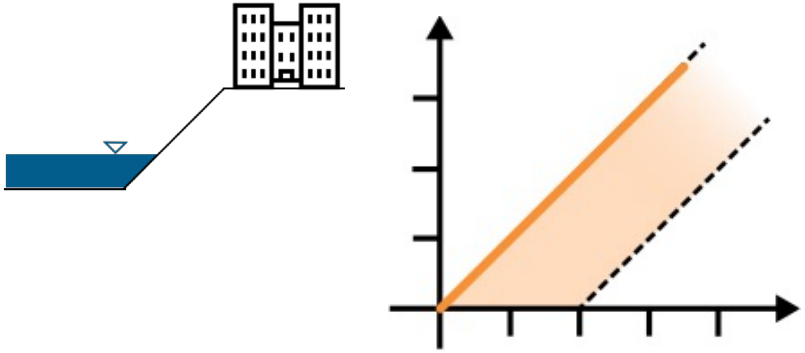
Feasibility region (green)

The shape of the policy depends on x_1, x_2, x_3

Case study: agents-stakeholders

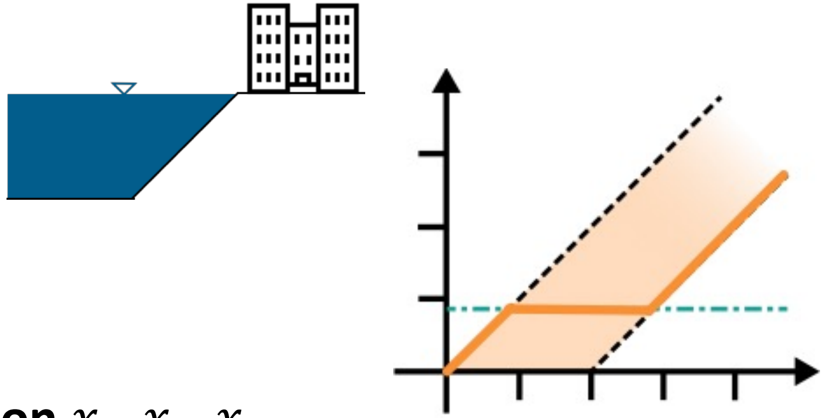
city agent: communities living on the lake shores, who are worried about floods

Its cost function prefers **low** water levels



irr agent: farmers in the downstream irrigation districts, who need constant water supply $\bar{\omega}$ to grow crops

Its cost function prefers **high** water levels



Agents then negotiate on x_1, x_2, x_3

Negotiation

A negotiation is performed for a block B_j of b days

We consider a monotonic concession protocol with a mediator

Negotiation develops in steps $0, 1, \dots, t, \dots$

At step 0, agents calculate their best proposals p_i^0 and send them to the mediator

At each step t:

1. The mediator calculates the current agreement $a^t = \mathcal{A}(\{p_1^t, p_2^t, \dots, p_n^t\})$ and send it to the agents
2. Agents calculate their proposals $p_i^{t+1} = \mathcal{F}_i(p_i^t, a^t)$ and send them to the mediator

Point-based protocol
[Amigoni and Gatti, *Auton Agent Multi-Ag*, 2007]

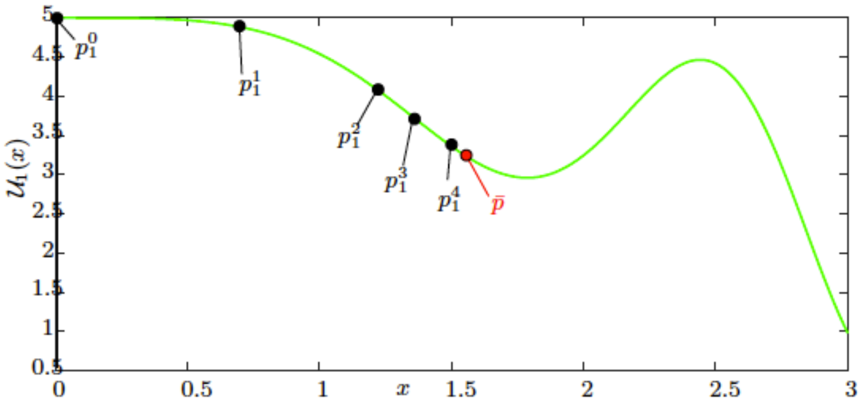
A proposal is a **vector of values** $p_i^t = [x_1, x_2, x_3]$, namely the release policy that agent i would like to adopt at step t

$$p_i^{t+1} = \mathcal{F}_i(p_i^t, a^t) = p_i^t + \alpha_i \cdot (a^t - p_i^t)$$

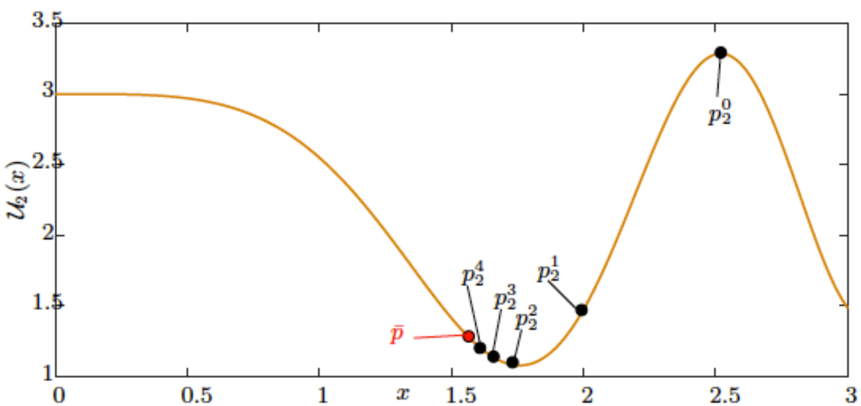
$\alpha_i \in [0,1]$: concession coefficient of agent i

a^t is the average of proposals p_i^t

Agreement: $a^t = p_1^t = p_2^t = \cdots = p_n^t$



(a) Utility function of agent 1 (and p_1^t)

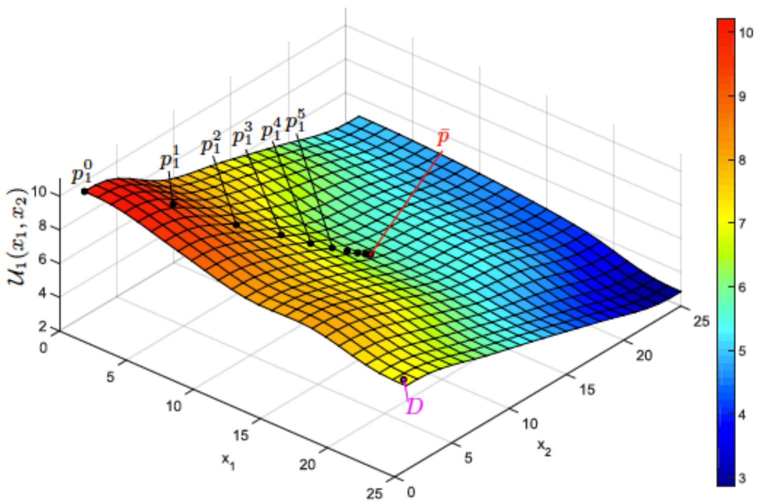


(b) Utility function of agent 2 (and p_2^t)

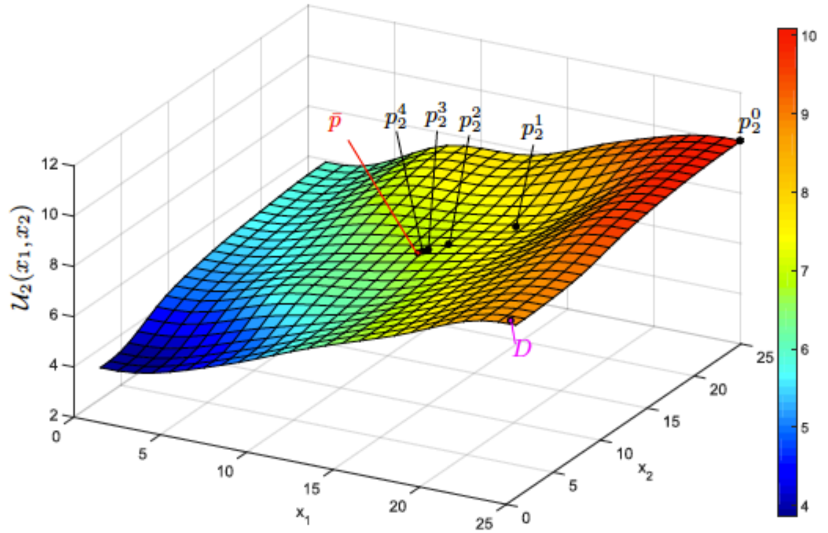
Point-based protocol: properties

Convergence is guaranteed if all $\alpha_i > 0$ (and the negotiation space is not empty)

Pareto optimality of the agreement is not guaranteed



(a) Utility function of agent 1 (and p_1^t)



(b) Utility function of agent 2 (and p_2^t)

Set-based protocol
[Badica and Badica, *Proc. BCI*, 2012]

A proposal is a **set of vectors of values** $p_i^t = \{[x_1, x_2, x_3]\}$, namely the set of release policies that agent i could adopt at step t

$$p_i^t = \mathcal{P}_i(\Gamma_i^t) = \{x \in \mathbb{R}^m | \mathcal{U}_i(x) \geq \Gamma_i^t\}$$

acceptable offers given the acceptability threshold Γ_i^t

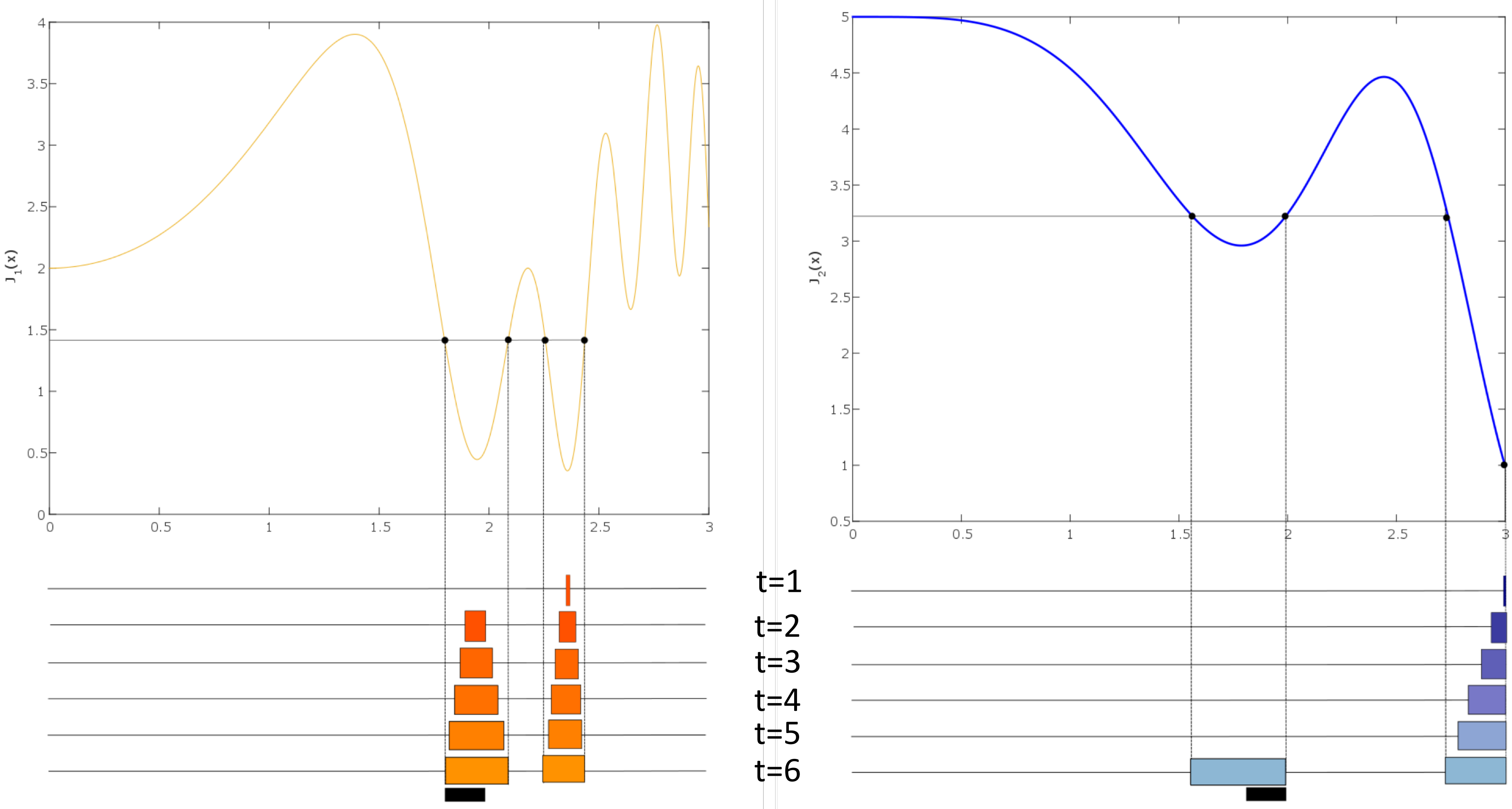
$$\Gamma_i^{t+1} = \Gamma_i^t - c_i$$

c_i: concession step of agent i

$$a^t = \bigcap_{i=1}^{n} p_i^t = \bigcap_{i=1}^{n} \mathcal{P}_i(\Gamma_i^t)$$

Agreement: $a^t \neq \emptyset$

Set-based protocol: example



Set-based protocol: properties

Convergence is guaranteed (if the negotiation space is not empty)

Pareto optimality of the agreement is guaranteed by construction

- with infinitely small c_i: the first agreement found is Pareto optimal
- with finite c_i: the first set of agreements found contains at least a Pareto optimal agreement

Simulations

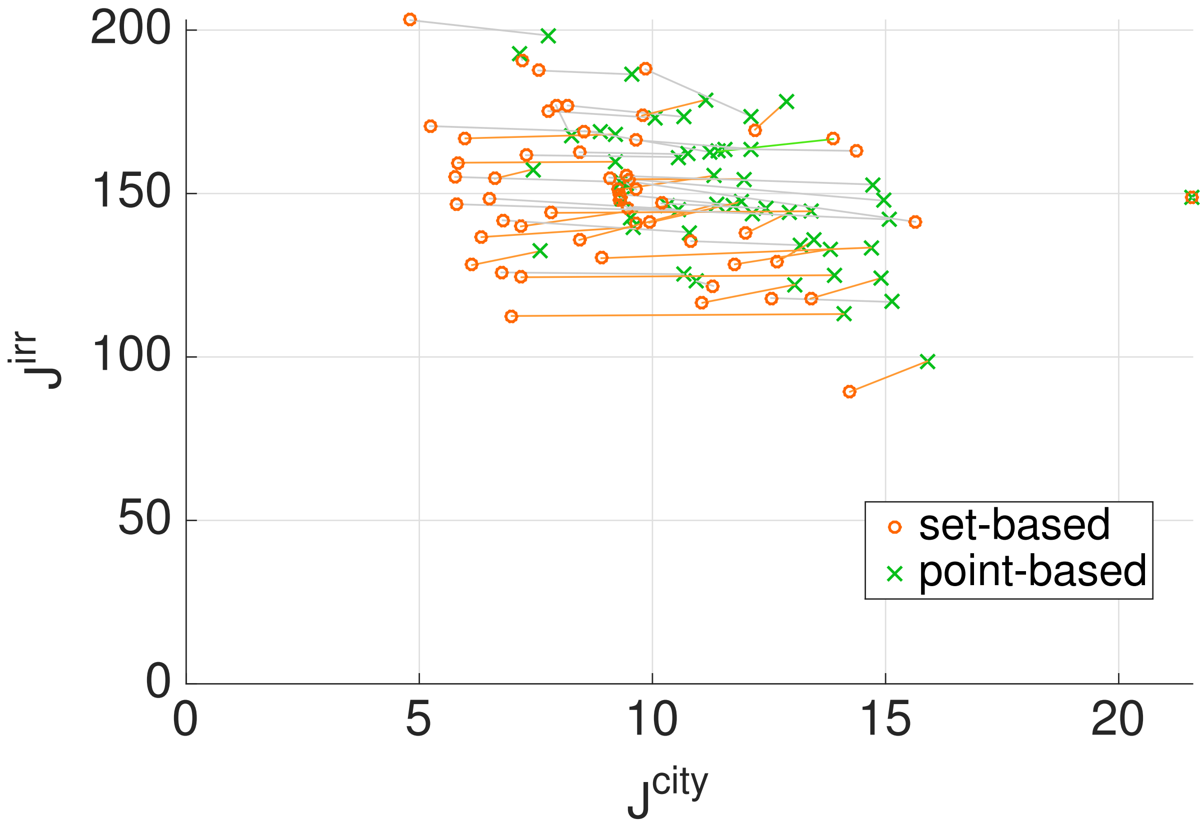
We generate inflow values q_τ from a normal distribution $\mathcal{N}(\mu_q, \sigma_q)$

Data are synthetic but trigger realistic conflicts between floods and water demands, similar to those observed in real systems

A negotiation is performed for each block B_j, namely every b days

In negotiation for B_{j+1}, cost functions of the agents are calculated considering costs incurred by the agents over B_j

Simulations: point-based protocol vs. set-based protocol

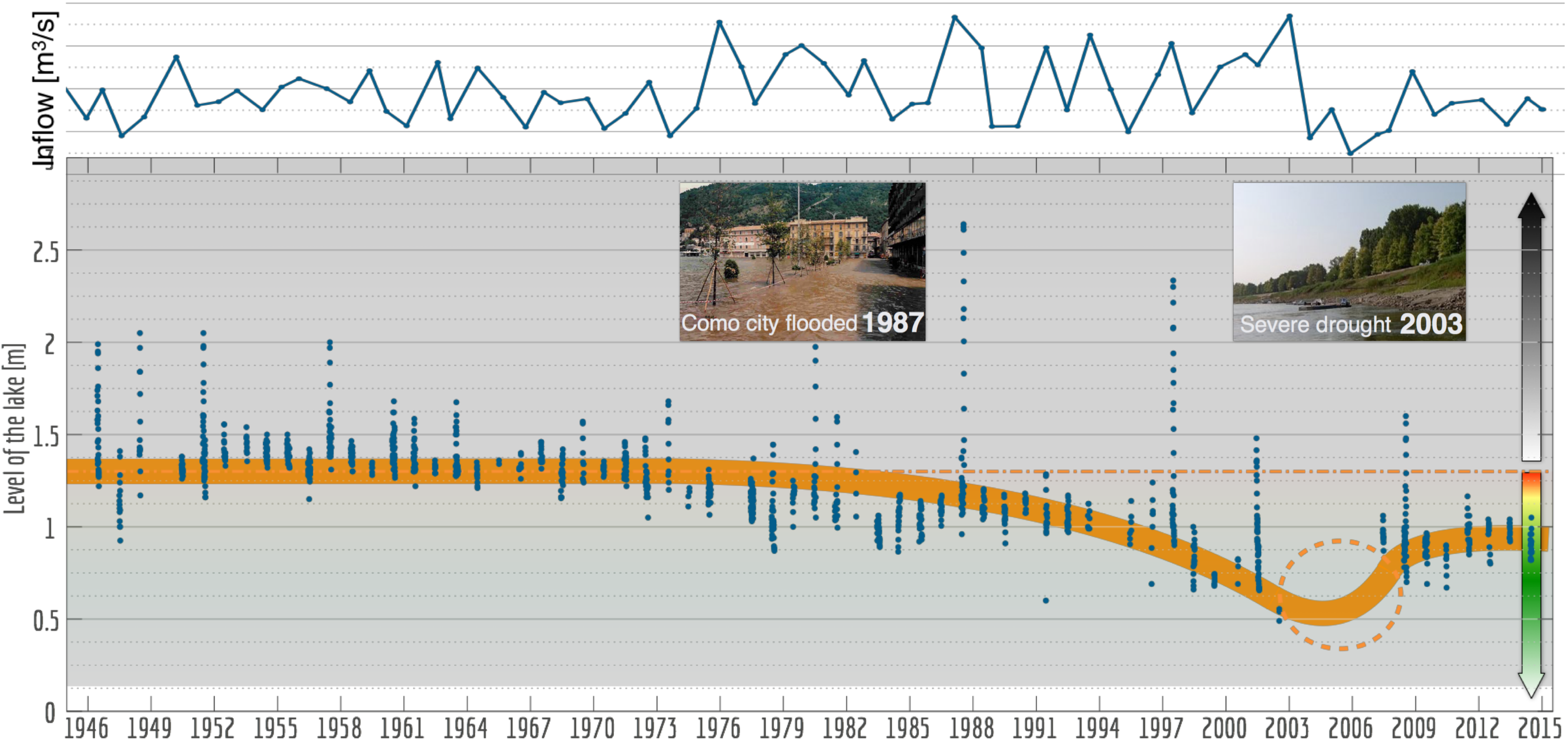


Agreements relative to the same blocks B_j

The color of the line segments shows the dominance

Simulations: reproducing observed trends
Observed data

Observed level of the Como lake 1946-2015, with a rather constant inflow



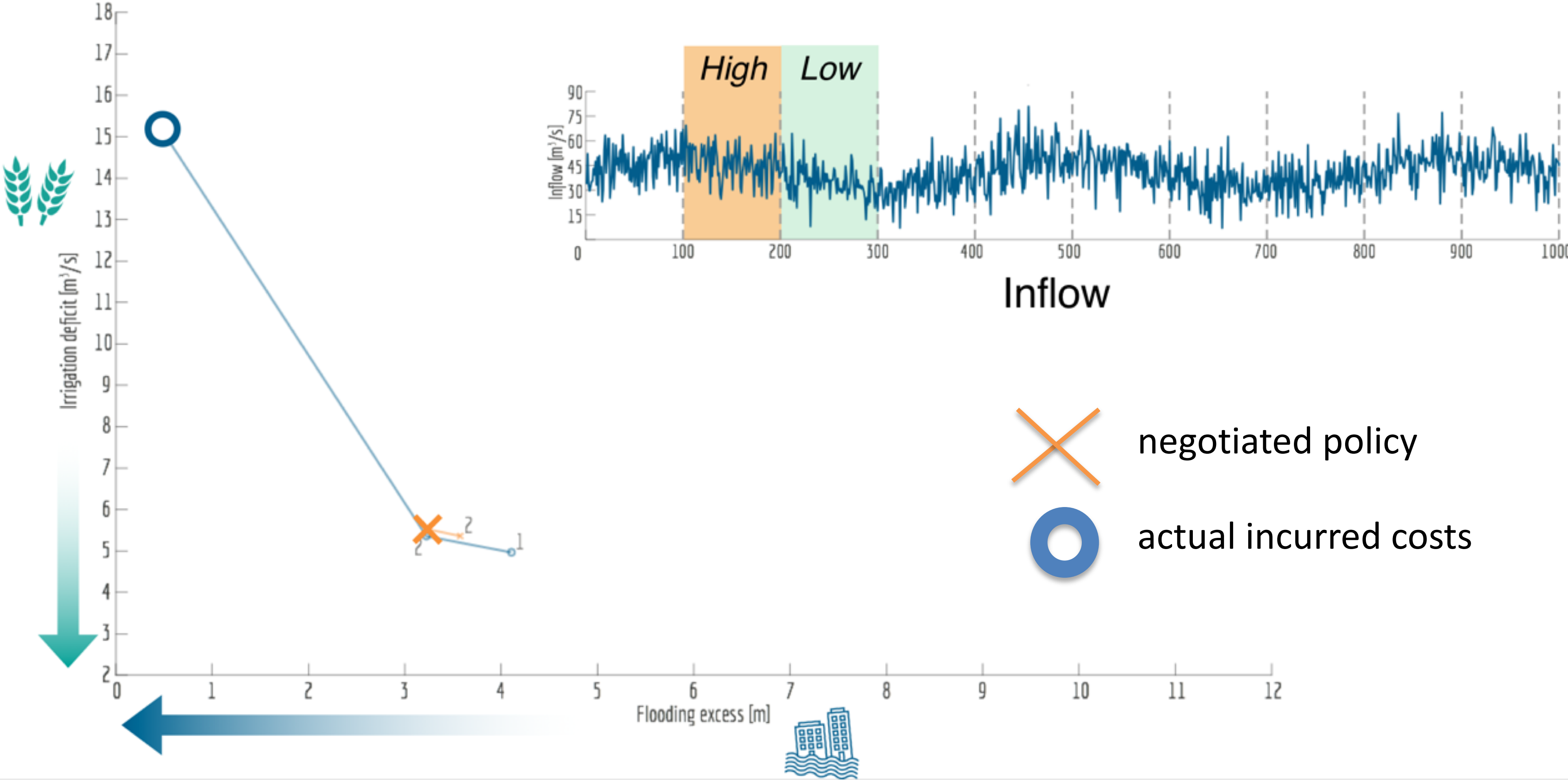
Simulations: reproducing observed trends
Model

The observed behavior of the lake regulator can be naturally captured in our model (set-based protocol) by setting the values of concession steps c_i according to the past performance of the agents

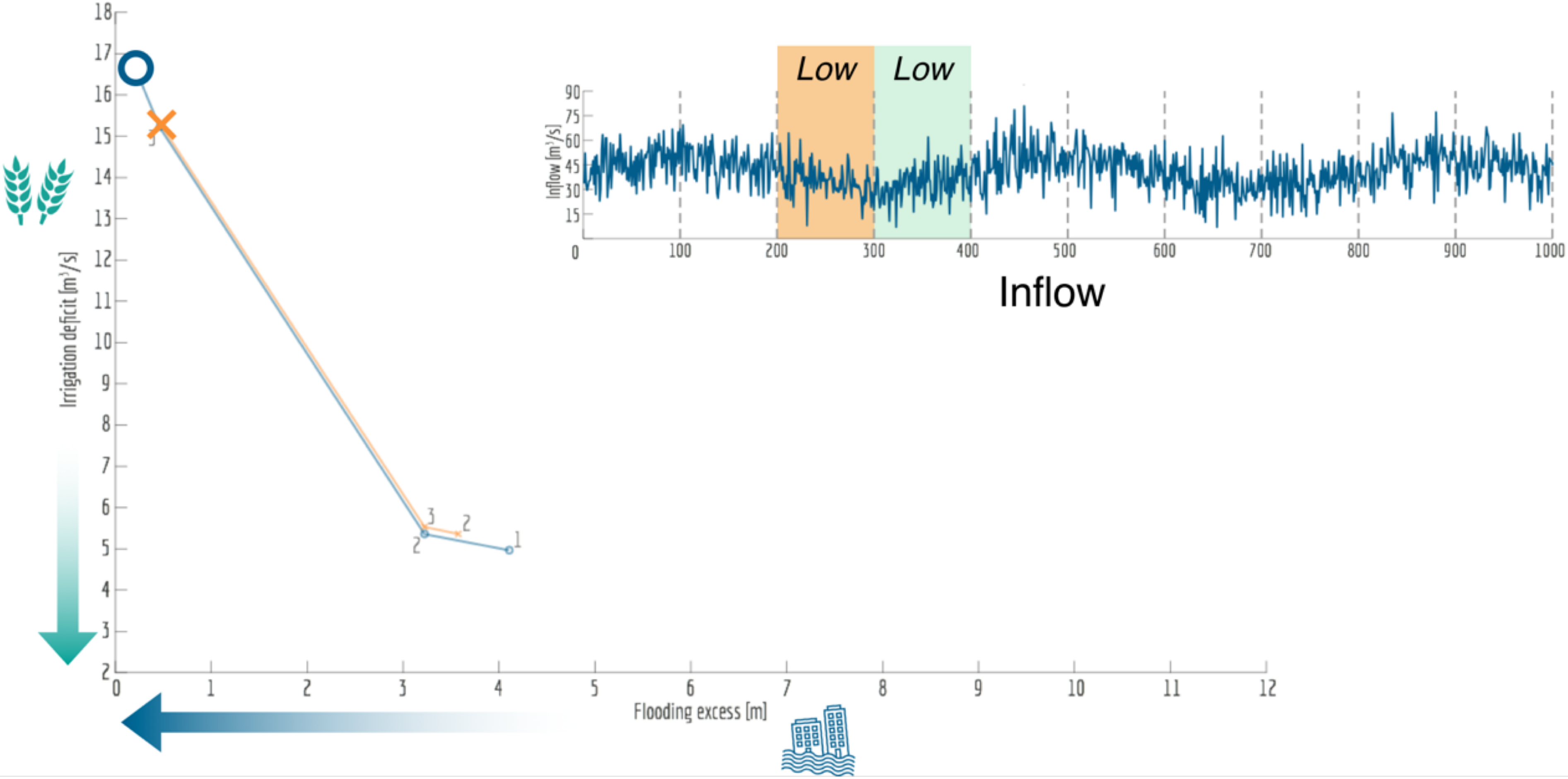
Informally, while negotiating the policy for block B_j agent i will use a concession step c_i which depends on the "satisfaction" of agent i in blocks $B_{j-1}, B_{j-2}, \ldots$

- If the city agent has recently experienced floods, its c_i will be small, namely the city agent will be rigid in conceding

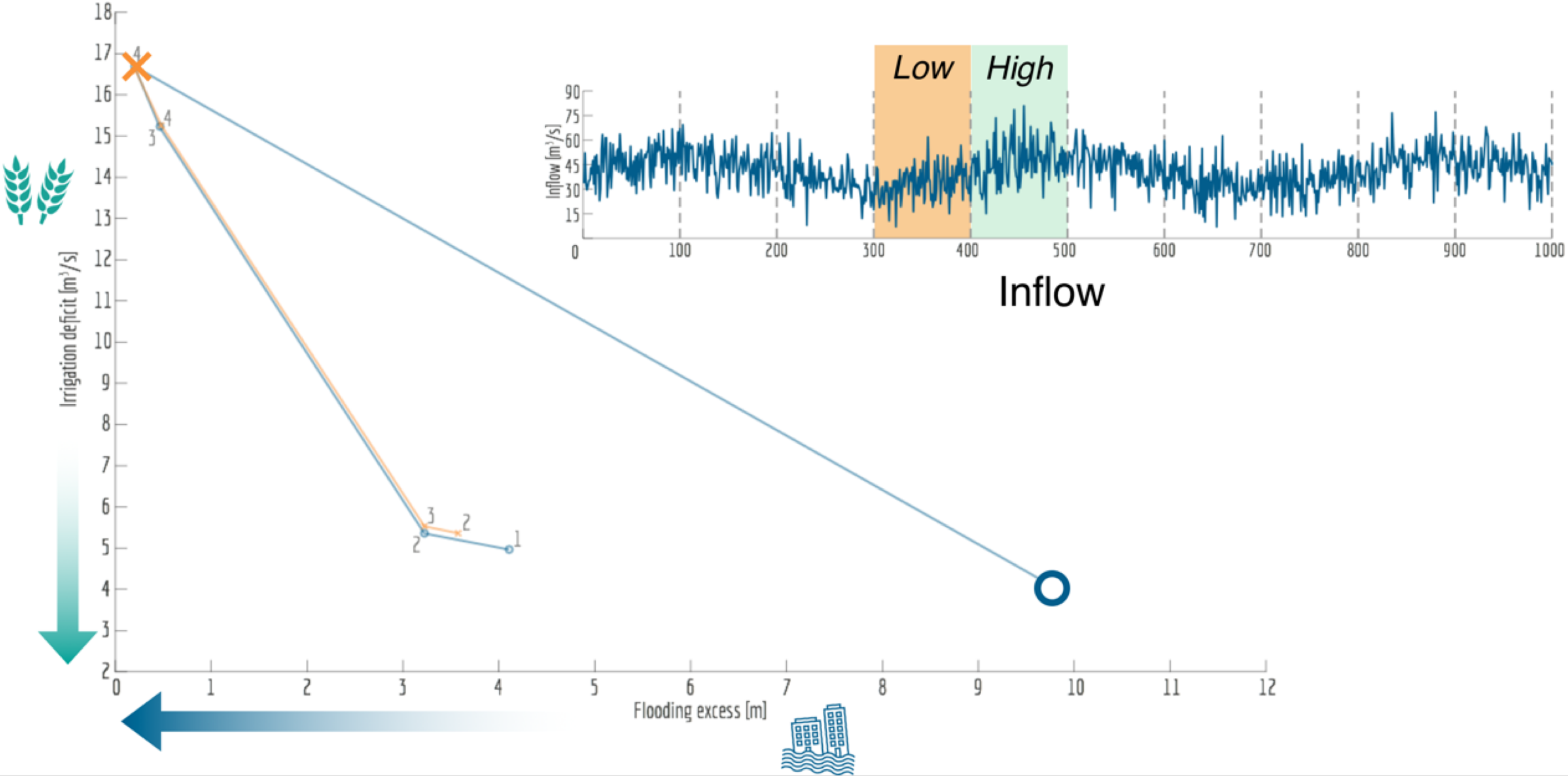
Simulations: reproducing observed trends
Drought occurrence



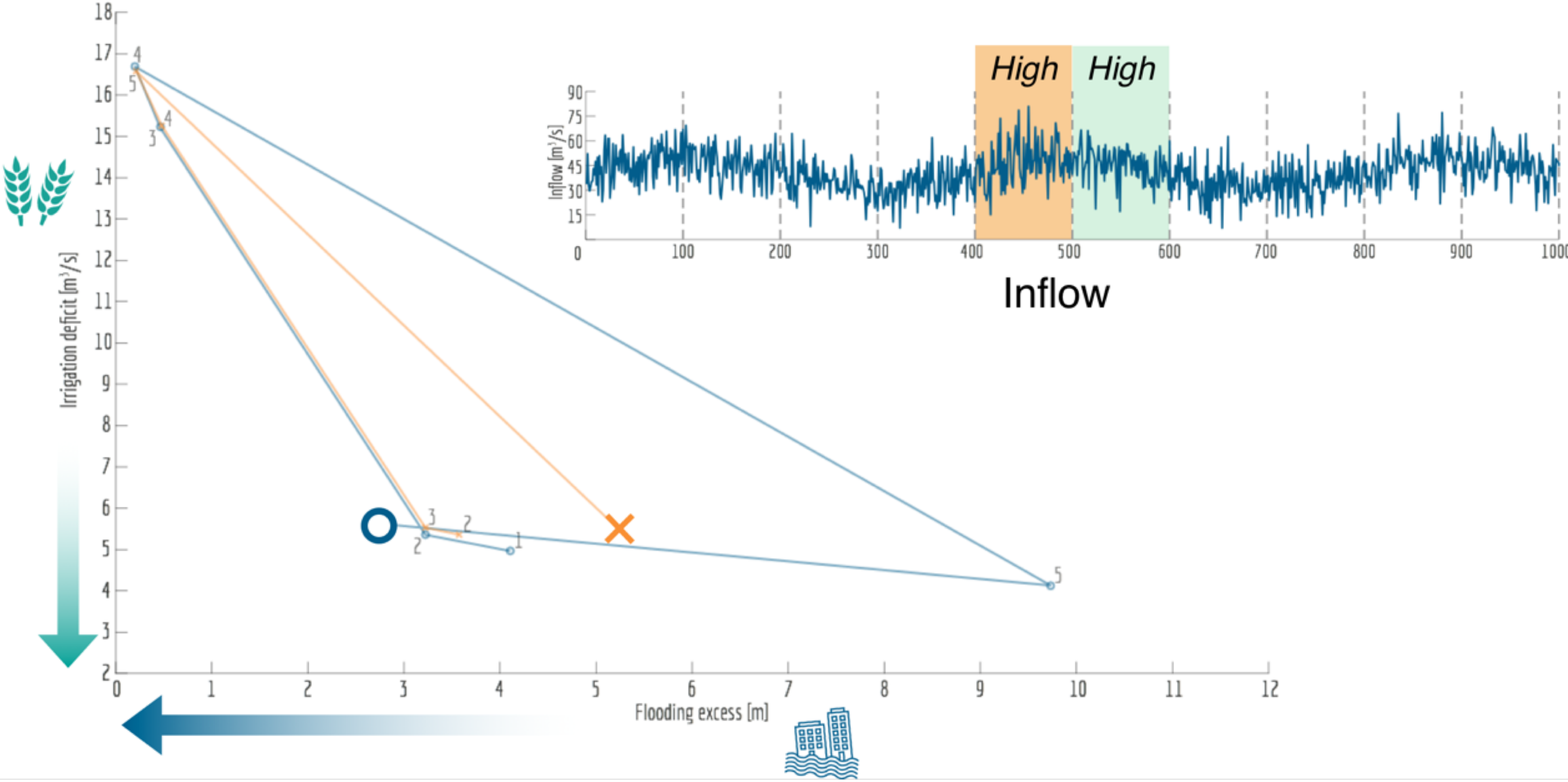
Simulations: reproducing observed trends
Drought reaction



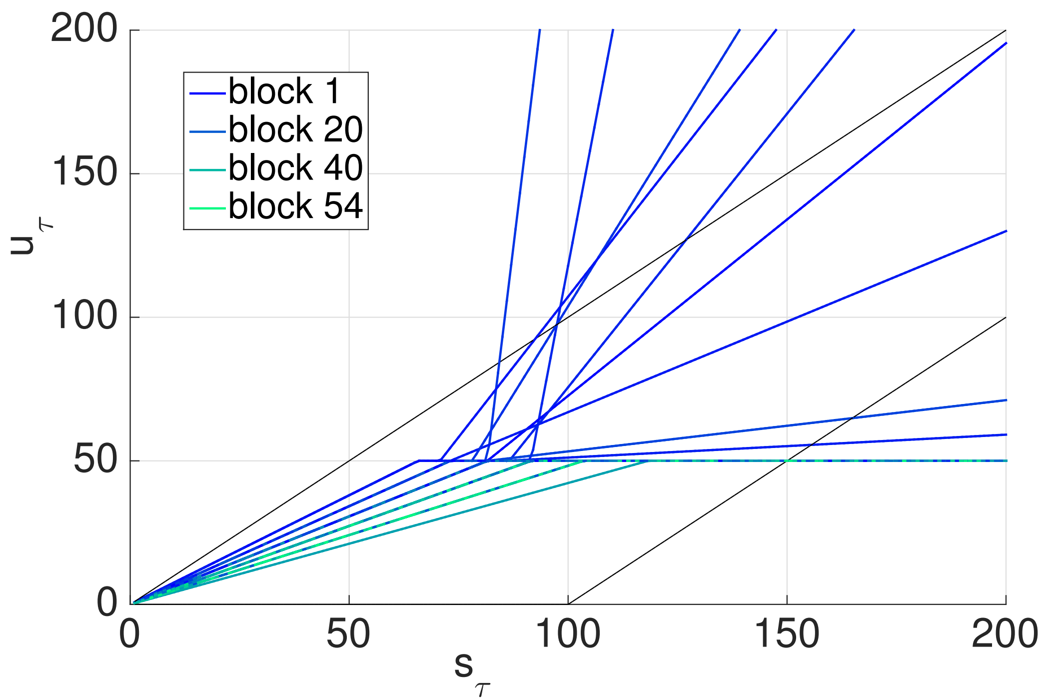
Simulations: reproducing observed trends
Flood occurrence



Simulations: reproducing observed trends
Flood reaction



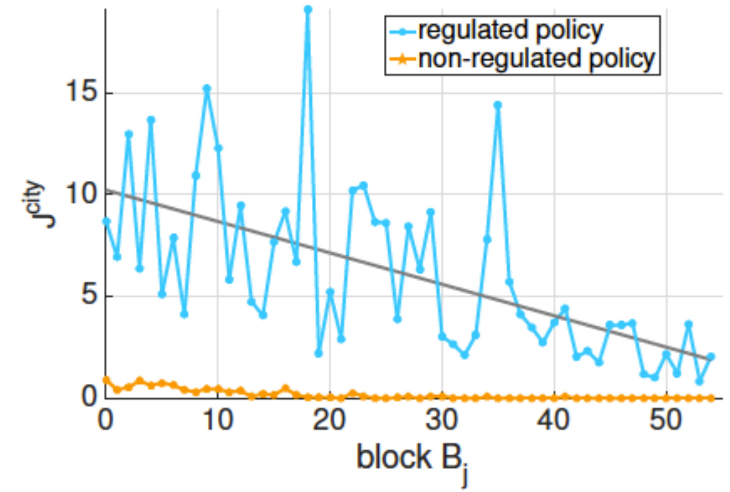
Simulations: decreasing inflow (1)



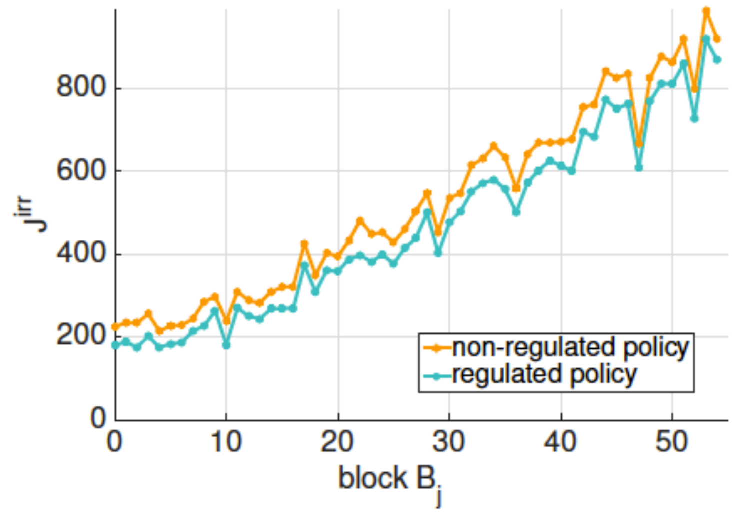
Release policies obtained with the set-based protocol for inflow q_τ with a decreasing mean μ_q

Simulations: decreasing inflow (2)

Costs of the agents with the set-based protocol for inflow q_τ with a decreasing mean μ_q



(a) city agent



(b) irr agent

Conclusions

We propose a monotonic concession negotiation approach to model the interaction between agents that represent different interests in the management of water resources systems

The model is expressive and can naturally capture observed behaviors

Future work

- Application to real data (ongoing)
- Investigation of theoretical properties, like the distance between initial proposals and final agreement

Thanks!