Modelling water user behaviour

From smart metered data to agent based modelling

(PART II)

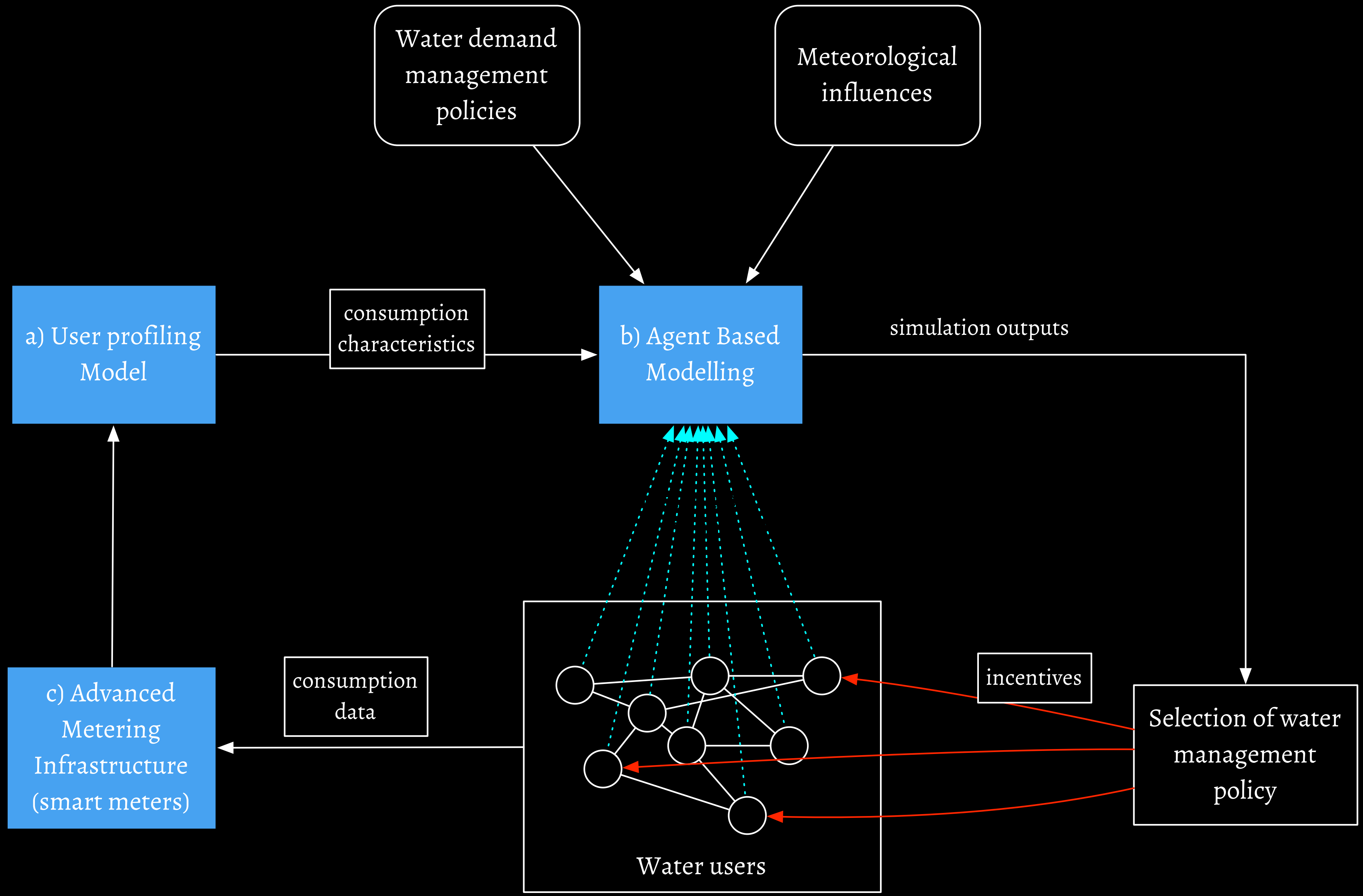
Smart Systems for Water Management
Monte Verità, 22-25 August 2016

Alessandro Facchini (IDSIA)

The social dilemma of water conservation

- Conflict between private and public interests.
- Two possible angles of approach:
    - *structural*: apply strategies that intervene directly in the outcome of the dilemma, e.g. (install water meters and) use price policy by charging based on usage
    - *social-psychological*: intervene to alter the way people value and think about the resource

Agent based policy design loop



An Agent Based Model is...

- ... a computational model composed of computational objects - *agents* - interacting within and with an *environment*, i.e. a virtual worlds represented by some mathematical structure (e.g. a grid or a network)

- Agents

    - have their own goals and behaviours

    - are autonomous, with a capability to adapt and modify their behaviours

    - are characterised by their own attributes and decision rules (agents are diverse and heterogenous)

A landscape of ABMs for water consumption

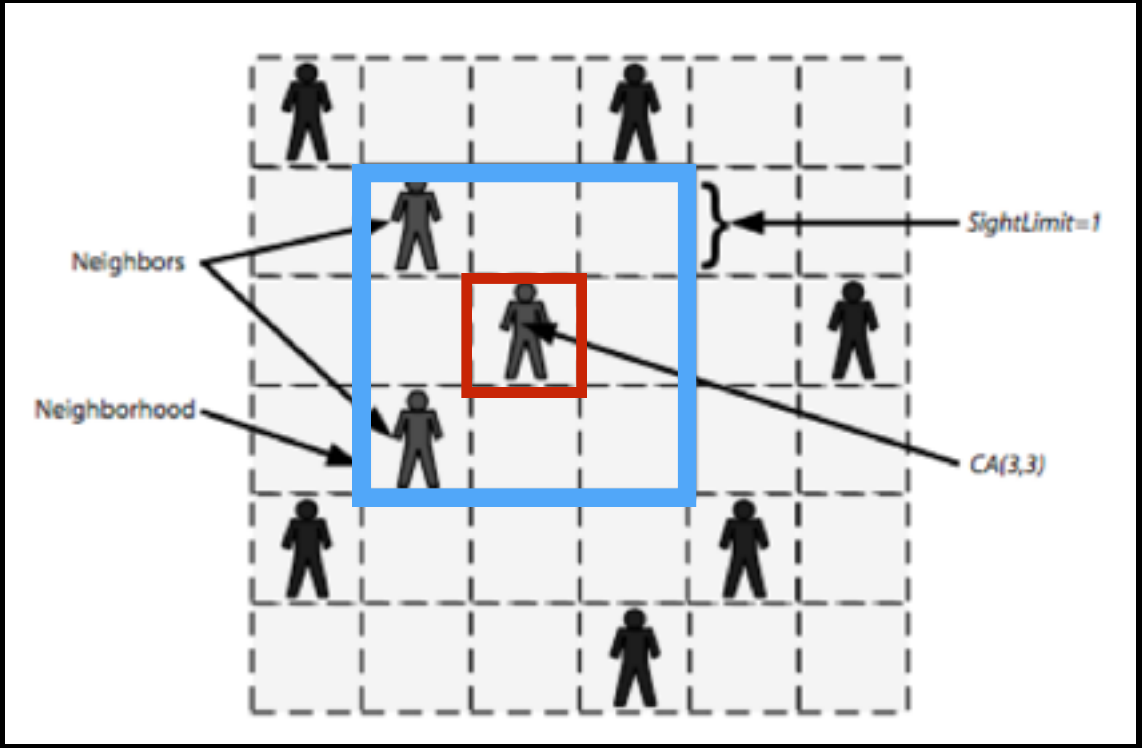
Model	Danubia	Dawn	FIRMA Thames	FIRMABAR I & II	Memetic	SmartH2O
Area of study	Danube upper basin	Thessaloniki	South region of England	Barcelona & Valladolid	-	Tegna & Valencia
Diffusion of water saving technology	Y	-	-	Y	Y	Y
Water pricing	-	Y	-	-	-	[Y]
Diffusion of water saving actions and attitudes	Y	Y	Y	Y	Y	Y
Meteorological conditions	-	Y	Y	-	-	[Y]
Urban dynamics	-	-	-	Y	-	-

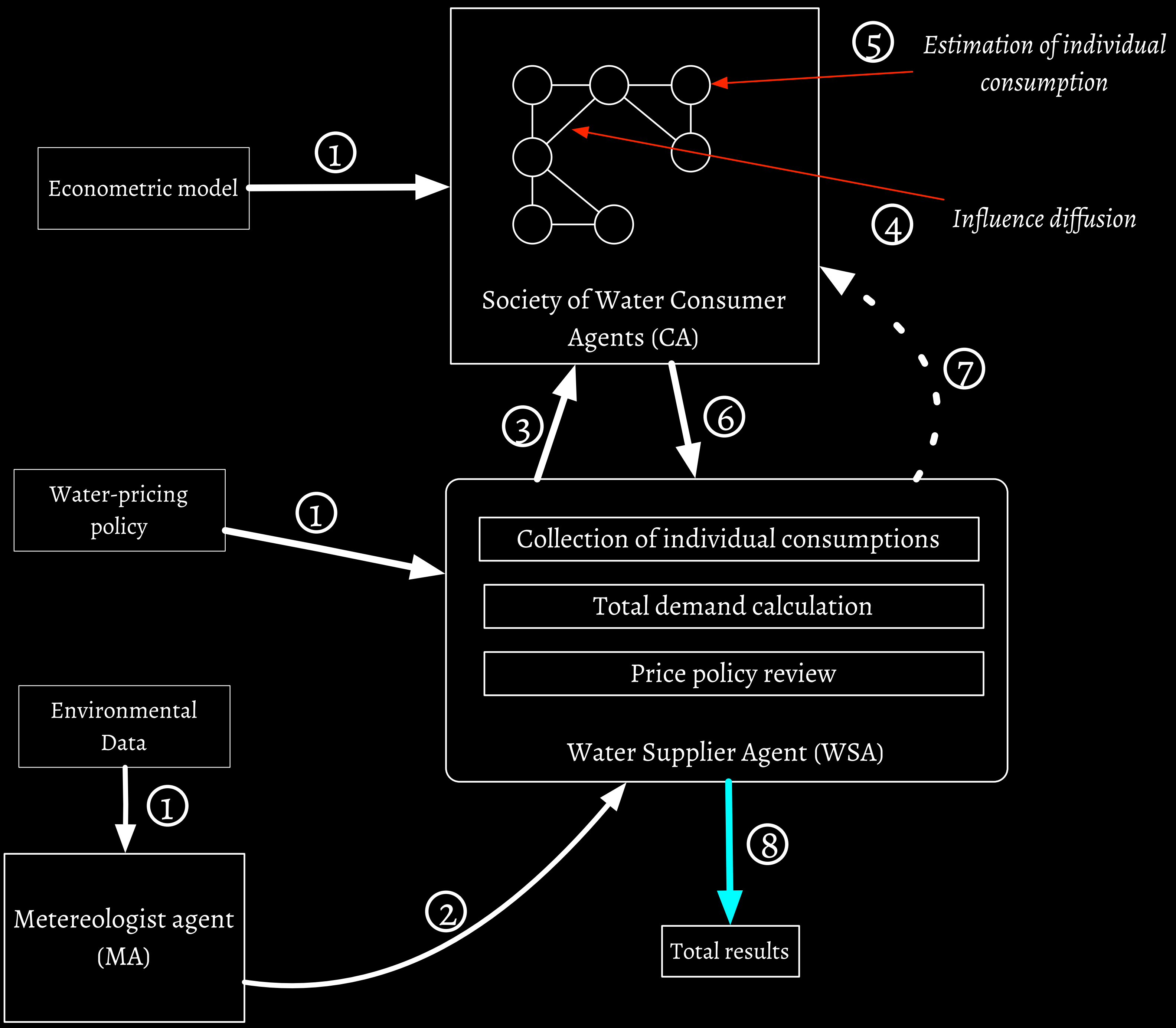
DAWN

- I.N. Athanasiadis, A.K. Mentes, P.A. Mitkas., and Y.A. Mylopoulos. " A hybrid agent-based model for estimating residential water demand". *Simulation* 81 (3): 175-187 (2005)

- aims at estimating the water consumption under different scenarios of pricing policies, and taking into account
    - social interaction,
    - the propagation of water conservation signals among individual consumers.

- 3 type of agents:
  - water consumers (CA),
  - supplier (WSA) and
  - meteorologist (MA)
- the society of CAs is distributed over a 2D grid




Econometric model
1
Society of Water Consumer Agents (CA)
5
Estimation of individual consumption
4
Influence diffusion
7
3
6
Water-pricing policy
1
Collection of individual consumptions
Total demand calculation
Price policy review
Water Supplier Agent (WSA)
Environmental Data
1
Metereologist agent (MA)
2
8
Total results

DAWN

1. Initialisation of econometric model and water-price policy
2. MA informs WSA about meteorological conditions
3. WSA informs CAs about meteo and asks to determine the water demand
4. each CA interacts with its neighbours
5. each CA estimates its demand...
6. and sends it back to WSA
7. WSA decides to revise (or not) its policy and starts new cycle (go to 2)
8. iteration is over: total results

- Water demand is given by:

$$C(i,t) = \alpha + \beta\boldsymbol{X}(i,t) + \gamma\boldsymbol{Z}(i) + \delta\boldsymbol{S}(i,t) + v(i) + \varepsilon(i,t)\ [\mathrm{m}^3]$$

where:

- $\boldsymbol{X}(i,t)$ is a vector of price variables
- $\boldsymbol{Z}(i)$ is a vector of community-specific variables
- $\boldsymbol{S}(i,t)$ is a vector of social variables (excluded in $\boldsymbol{Z}$)
- α, β, γ and δ are elasticities (to be estimated)
- $v(i)$ is the unexpected water consumption regime
- $\varepsilon(i,t)$ is the error term

- a social variable S is determined by each CA_i at time t as

$$S(i,t)=f(sw_{i(1)} + \ldots + sw_{i(k)})$$

where:

- ✳ $sw_{i(j)}$ is the social weight that CA_i receives from its neighbour $i(j)$
- ✳ f is a diffraction function adjusting the sum of social weights

The case of Thessaloniki (metrop. area)

- Data on households and community variables collected by a field survey in 1356 households, and confronted with data covering period from Jan. 1994 until April 2000

Variable		Elasticity	Standard Deviation
Marginal price	*MP*	−0.340	0.0851
Marginal price squared	MP^2	−0.308	0.0654
Marginal price cubed	MP^3	0.158	0.0843
Temperature	*TEM*	0.100	0.0975
Rainfall	*RNF*	−0.015	0.0127
Well-informed consumers	*WIC*	−0.368	0.1253
Family income	*INC*	0.351	0.1894
Having many children	*CHI*	0.194	0.0631
Car washing	*CAR*	0.055	0.0322
Watering plants	*W*	0.128	0.0583
Cleaning balconies	*B*	0.043	0.0191
Cleaning pavements	*P*	0.032	0.0220
Household residents	*RES*	0.026	0.0075

Table 1 *in Athanasiadis et al. (2005). Variables and elasticities.*

Social interaction submodel

- Well-informed consumer variable (WIC) sets as average value for the whole society at t_0 and
- WIC increases by an average of 6% every 3 years following:

$$(0.06/36)(t-t_0)\mathrm{WIC}(t_0) + \mathrm{WIC}(t_0)$$

Social interaction submodel

- Clustering of CAs in four types based on questionnaire

Consumer Type	Population (%)	Ability to Promote	Consumption Reduction
A: Opinion leaders	10	High	Low
B: Socially apathetic	20	None	None
C: Opinion seekers	30	Low	High
D: Opinion receivers	40	Low	Low

Table 2 *in Athanasiadis et al. (2005).*

Social interaction submodel

type of agent	social weight	diffraction function
A *opinion leader /early adopter*	$sw_A = 2\ sw_C$	f_A with low slope
B *socially apathetic*	$sw_B = 0$	$f_B = 0$
C *opinion seeker*	$sw_C = (0.06/36)\mathrm{WIC}$	slope f_C double of slope f_A
D *opinion receiver*	$sw_D = sw_C$	$f_D = f_A$

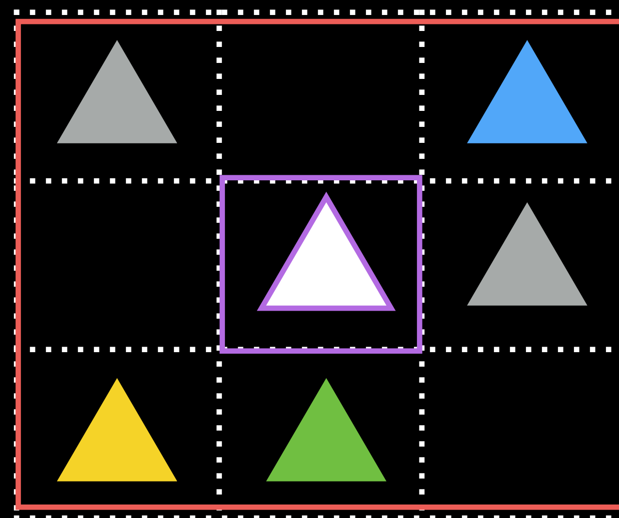
Example

opinion leader (A)

socially apathetic (B)

opinion seeker (C)

opinion receiver (D)



WIC=10

"social pressure" on agent *i*:

$$2^*(0.06/36)^*10 + 0 + 0 + (0.06/36)^*10 + (0.06/36)^*10 = 2/30$$

Example

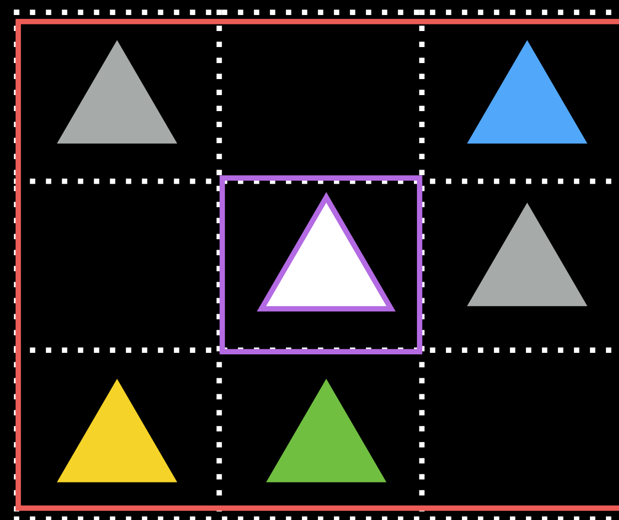
opinion leader (A)

socially apathetic (B)

opinion seeker (C)

opinion receiver (D)

WIC=10



“social pressure” on agent *i*:
2/30

	diffraction function	social weight	impact on water demand
A	$f_A(x)=2x$	$sw_A= 1/30$	$\delta S_A(i,t) = -0.368^*(2^*2/30) = -0.05$
B	$f_B(x)= 0$	$sw_B= 0$	$\delta S_B(i,t) = 0$
C	$f_C(x)= 2f_A(x) = 4\,x$	$sw_C= 1/60$	$\delta S_C(i,t) = 2^*\delta S_A(i,t) = -0.1$
D	$f_D(x)= f_A(x) = 2\,x$	$sw_D= 1/60$	$\delta S_D(i,t) = \delta S_A(i,t) = -0.05$

Simulation

- 100 CAs randomly distributed on a 12x12 square grid
- period simulation: 2004-2010
- time step: one month

Simulation

Scenario	A	B	C	D	E
Water price	adjusted to real price	+5%	+7,5%	adjusted to real price	adjusted to real price
educational/ information policy	no	no	no	medium scale	major scale

- *the implementation of an education or information policy is encoded within the social diffusion model.*

Results

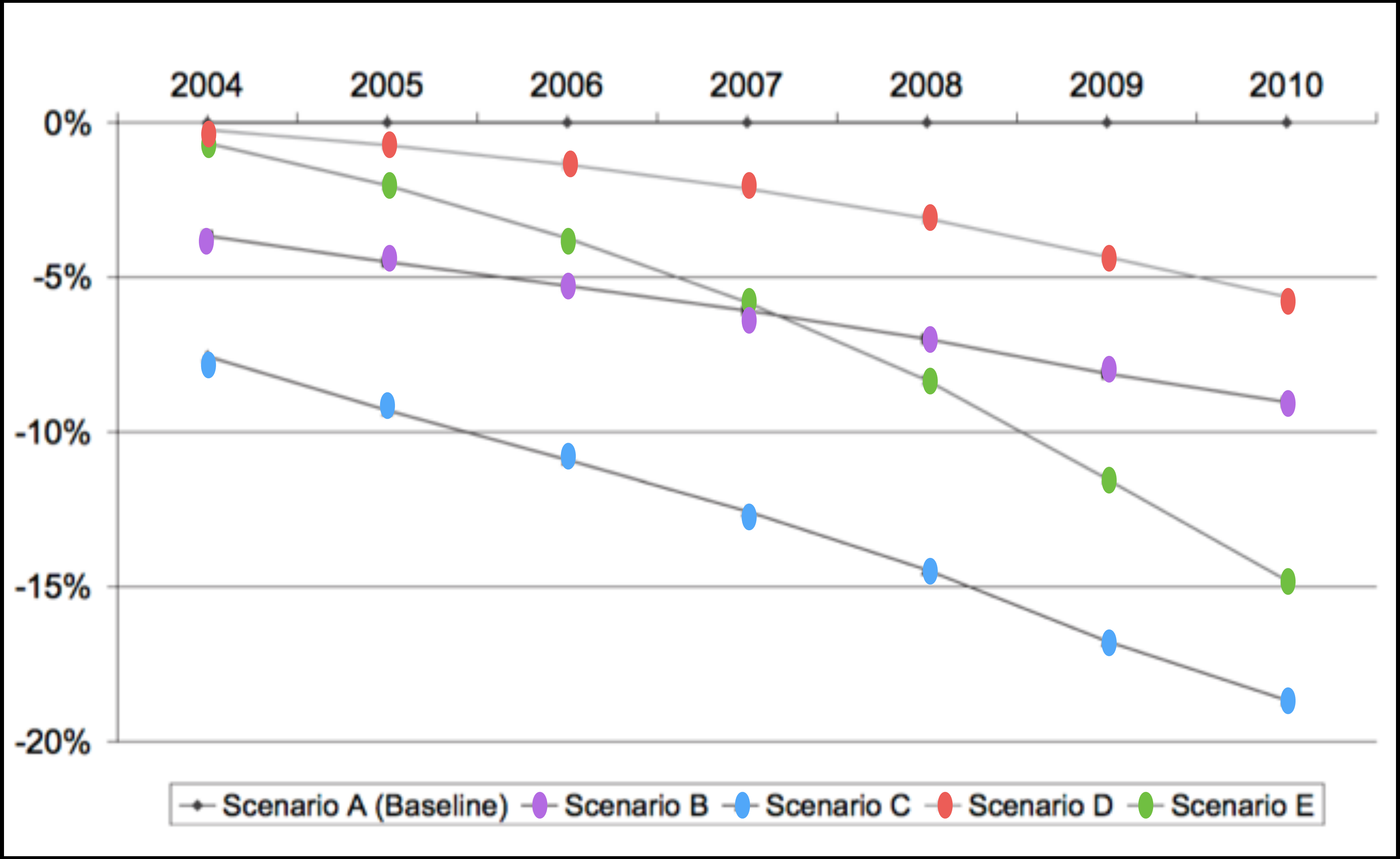


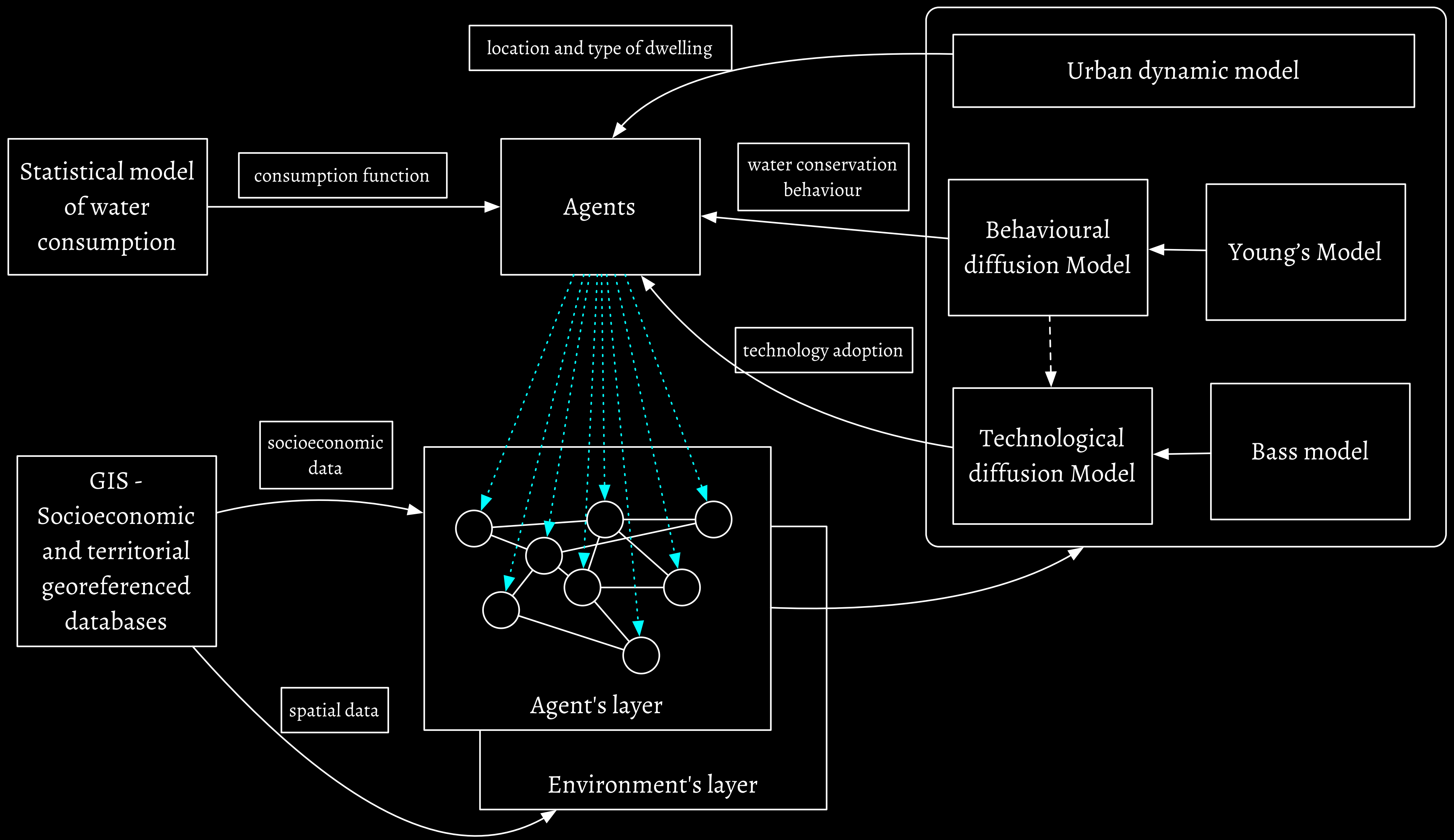
Figure 12 *in Athanasiadis et al. (2005). Per capita reduction in the evaluation of the five scenarios.*

FIRMA Valladolid

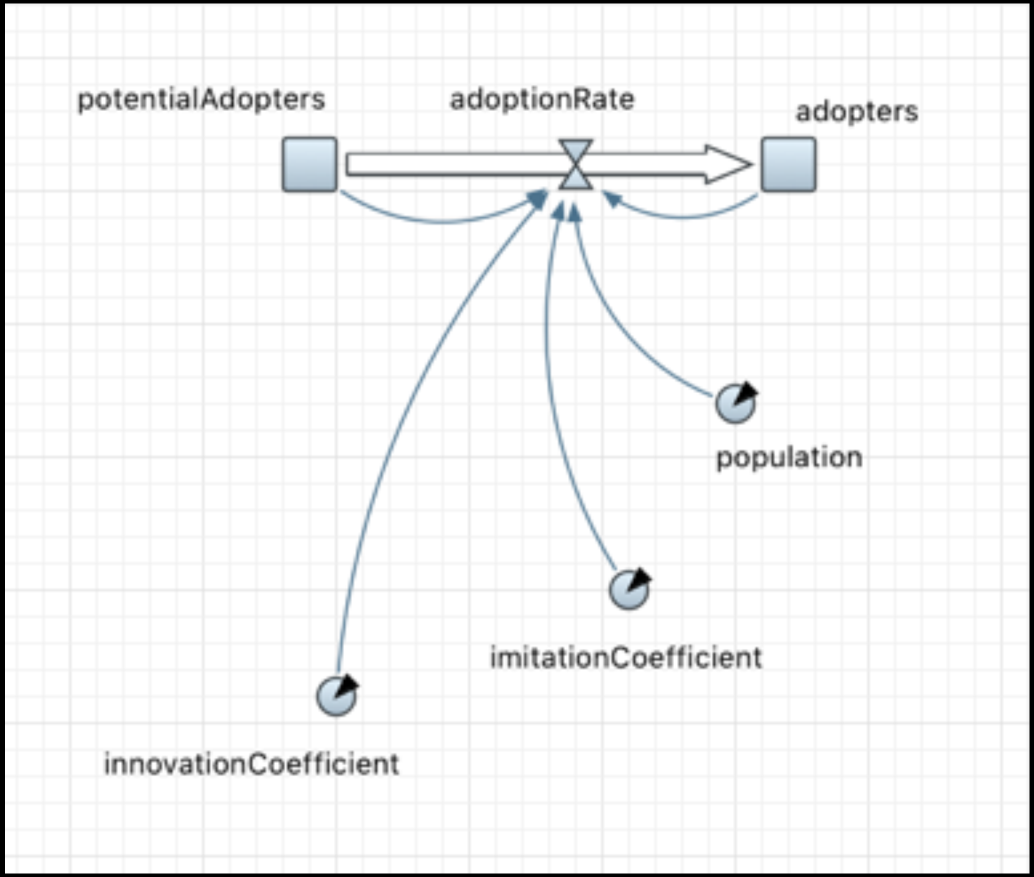
- J. M. Galan, A. Lopez-Paredes, and R. Del Olmo. "An agent-based model for domestic water management in Valladolid metropolitan area". *Water Resources Research*, 45(5) (2009)

- aims at verifying the influence of urban dynamics (e.g. changes in territorial model) and socio-geographic effects, like technological and opinion dynamics, in domestic water demands

FIRMABAR Valladolid



Bass technology diffusion model



aR = pA*(inC + imitC*adopters/population)

Young's opinion diffusion model

H. Peyton Young
(Johns Hopkins U.)

Aims at capturing diffusion and social pressure

(Also used in work on Orb river, published as:
Edwards et al.: "The relevance of aggregating a water consumption model cannot be disconnected from the choice of information available on the resource". *Simul. Mode. Pratc. Theory*, 13, 287-307 (2005))

Young's opinion diffusion model

- *Binary case*: each agent can either adopt behaviour E or not (hence adopt behaviour NE)

- The choice of a behaviour is determined by a utility function ***U*** that depends on :
    - the agent's current behaviour
    - the behaviour of its social network
    - an exogenous parameter (p_E) that measures the social pressure towards behaviour E

Young's opinion diffusion model

- Utility function:

$$\boldsymbol{U}(A, E / E) = a\, V(A,E) + p_E$$

$$\boldsymbol{U}(A, E / NE) = a'\, V(A,E) + p_E$$

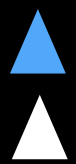
$$\boldsymbol{U}(A, NE / E) = b\, V(A,NE)$$

$$\boldsymbol{U}(A, NE / NE) = b'\, V(A,NE)$$

- The probability of an agent to maintain its behaviour E is given by the formula:

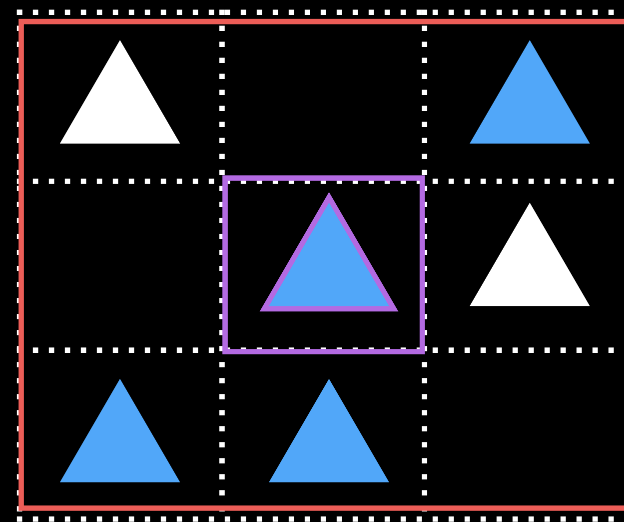
$$Pr(A, E / E) = \frac{e^{\beta \mathbf{U}(A,E/E)}}{e^{\beta \mathbf{U}(A,E/E)} + e^{\beta \mathbf{U}(A,NE/E)}}$$

Example



E

NE



$V(A,E)=3/5$

$V(A,NE)= 2/5$

$a=b'=0.7$ *and* $a'=b=0.3$

$p_E=0.5$

$\beta = 0$

$\mathbf{U}(A, E / E) = a^* V(A,E) + p_E = 0.92$

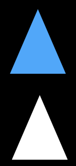
$\mathbf{U}(A, NE / E) = b^* V(A,NE) = 0.12$

$Pr(A, E / E) = 0.69$

$Pr(A, NE / E)) = 0.31$

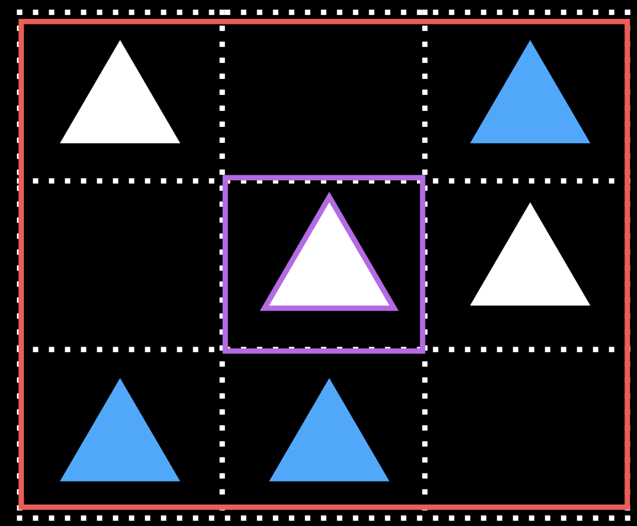
$= 1- Pr(A, E / E)$

Example



E

NE



$V(A,E)=3/5$

$V(A,NE)= 2/5$

$a=b'=0.7$ *and* $a'=b=0.3$

$p_E=0.5$

$\beta = 0$

$\mathbf{U}(A, E / NE) = a'*V(A,E) + p_E = 0.68$

$\mathbf{U}(A, NE / NE) = b'*V(A,NE) = 0.28$

$Pr(A, E / NE) = 0.6$ $(< Pr(A, E / E))$

$Pr(A, NE / NE)) = 0.4$

$= 1- Pr(A, E / NE)$

Urban dynamics model

- *Assumption*: agents prefer to live
  - among those that are similar to themselves and
  - in dwellings according to their present economic resources.
- The larger is this difference, the most likely an agent will try to move to another area

Model based on:

- I. Benenson et al.: "Entity-based modeling of urban residential dynamics: The case of Yaffo, Tel Aviv", *Environ. Plann. B*, 29: 491–512 (2002)

Results of simulations

- Simulations over 10 years, time step 3 month, with 12’500 agents
- Higher adoption rates are produced with higher values of p_E
- The impact of the immigration effect and the change of the territorial model can be reduced significantly to just 2 – 6% of increase in most of the diffusion scenarios

Purposes of the SmartH2O ABM

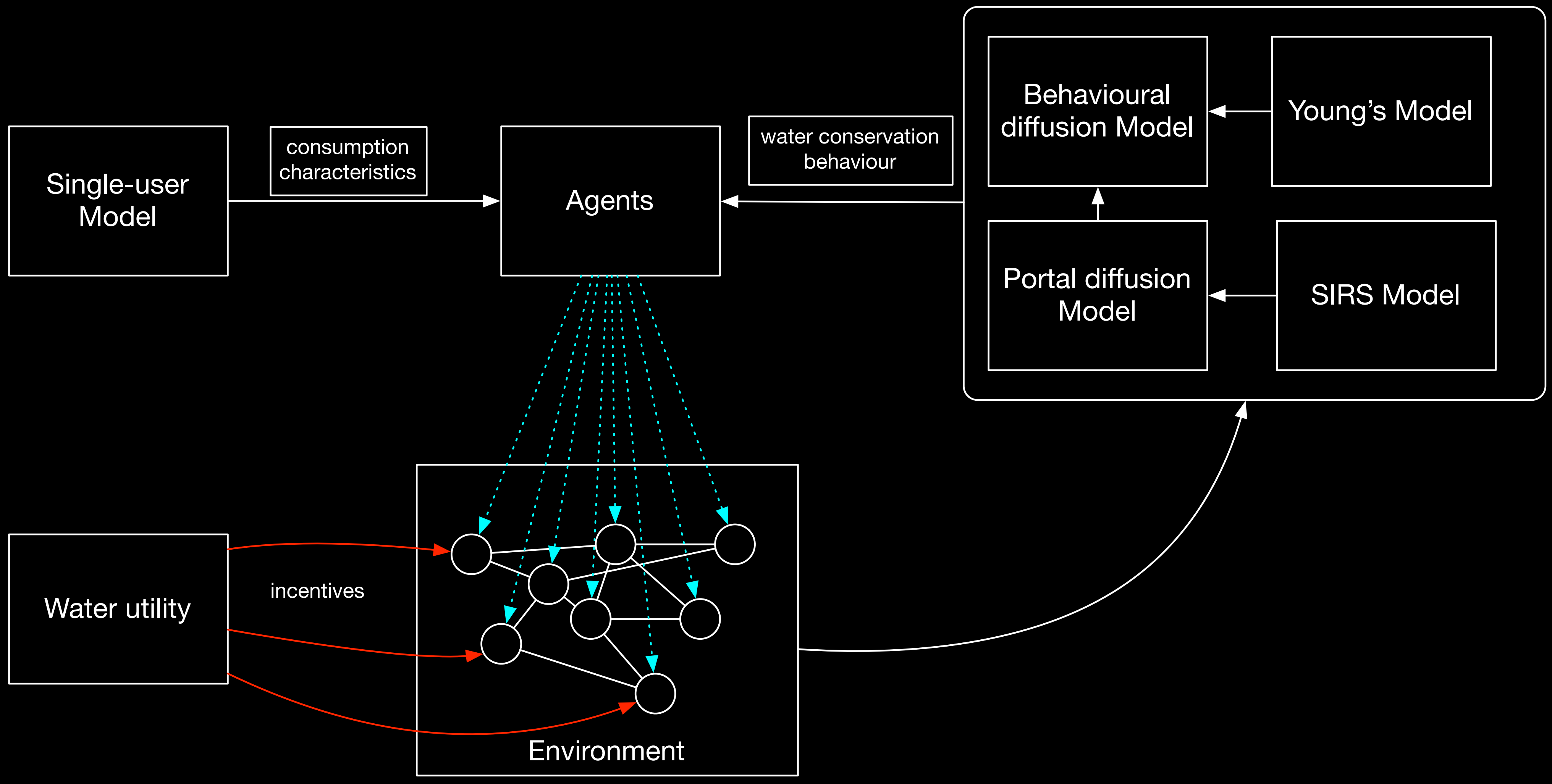
Modelling the aggregate water usage based on:

- the specific socio-psychographic attributes of the agents
- their current level of water usage
- other exogenous factors

and focusing on the diffusion of:

1. The adoption of the SmartH2O gamified platform and
2. A water-saving attitude within active platform users due to
   - social pressure and
   - the participation to gaming activities and challenges proposed by the portal

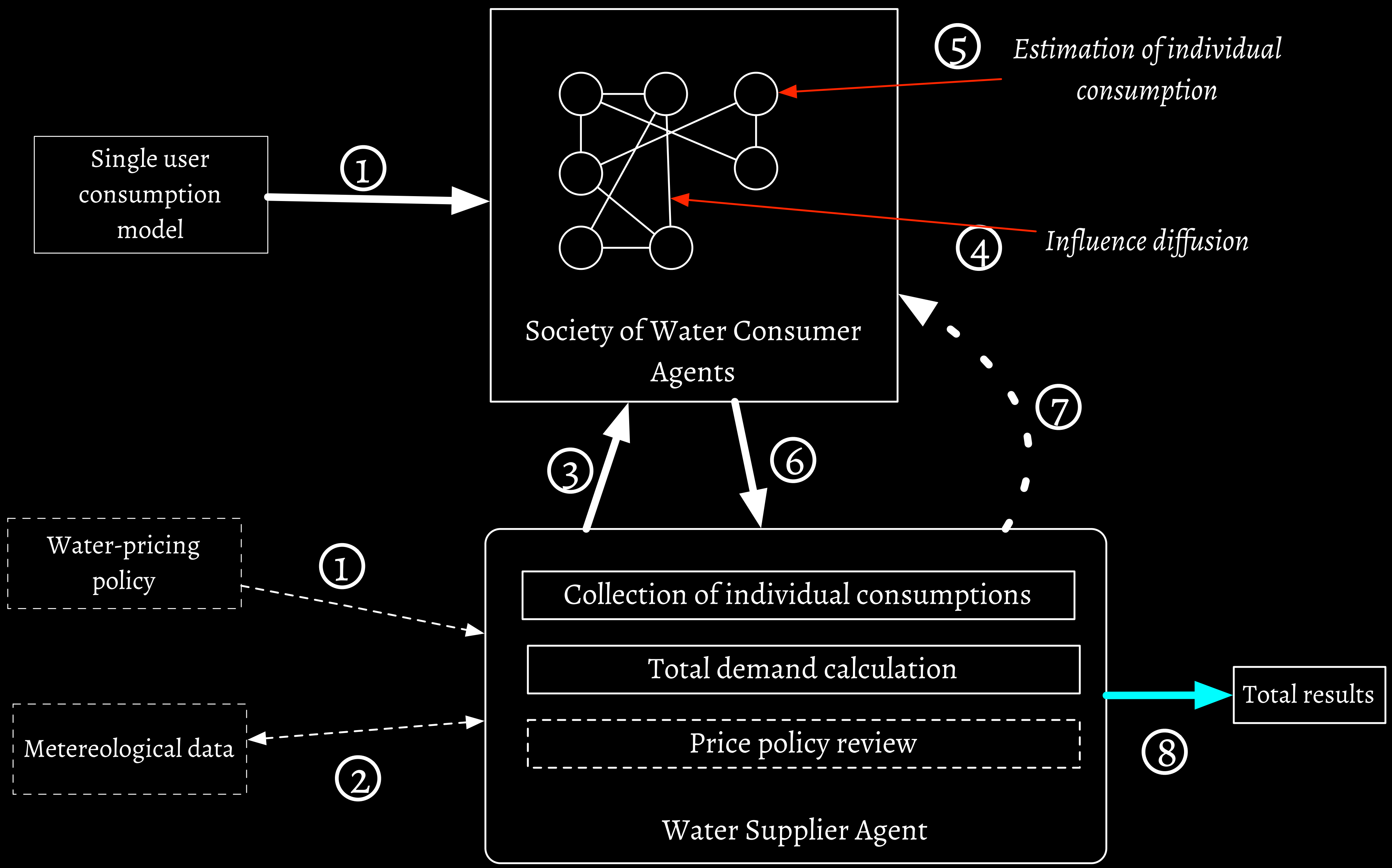
SmartH2O ABM structure



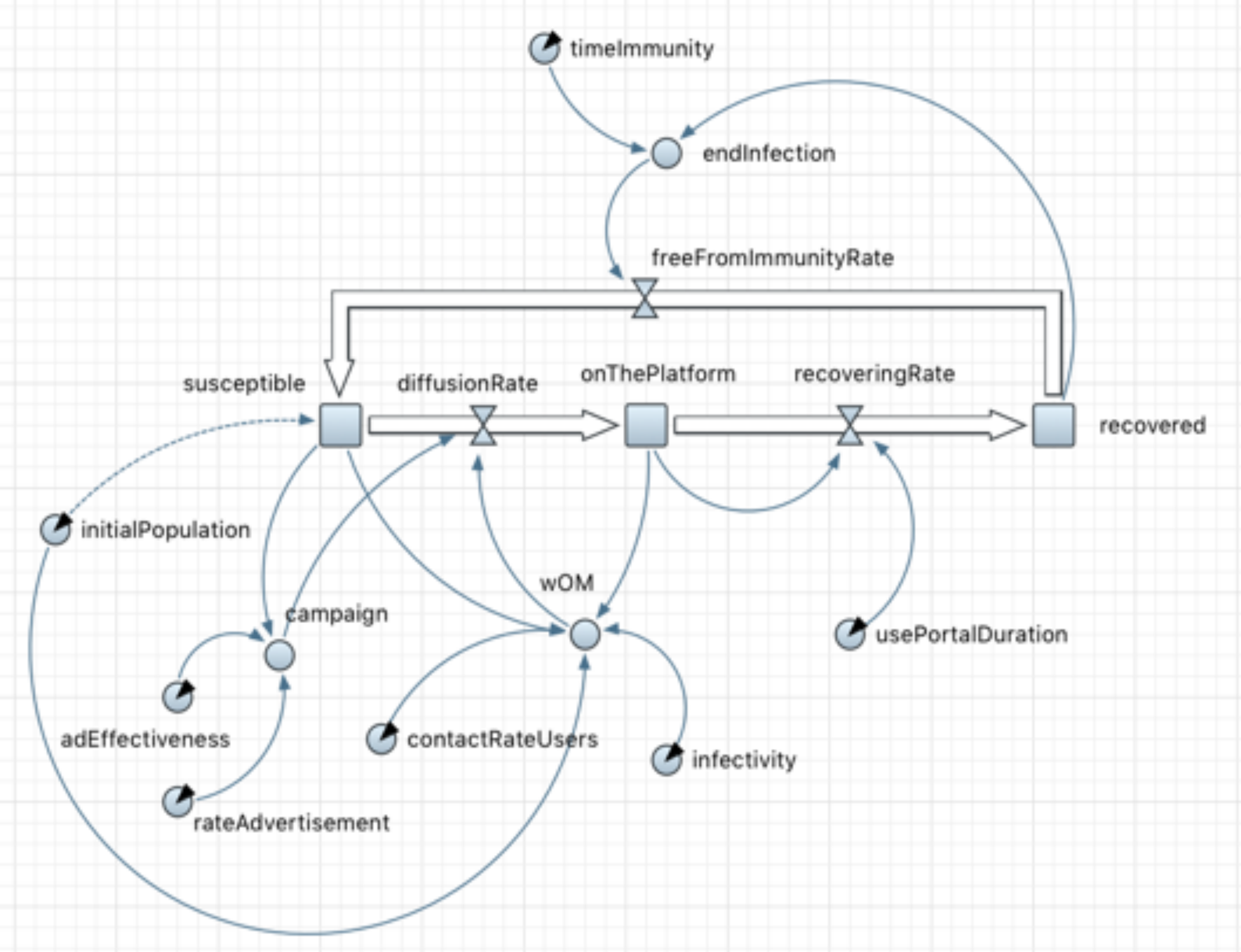
State variables and scale

- Two types of agents: Water Supplier and Households.
- Households agents are localised on the map of the geographic area of interest (environment)
- State variables of Households:
    - socio-psychographic attributes of users,
    - water usage patterns,
    - attitude towards responsible water use (E vs NE)
    - role in the portal diffusion model
- Time scale: daily
- Simulation period: one year

Process overview

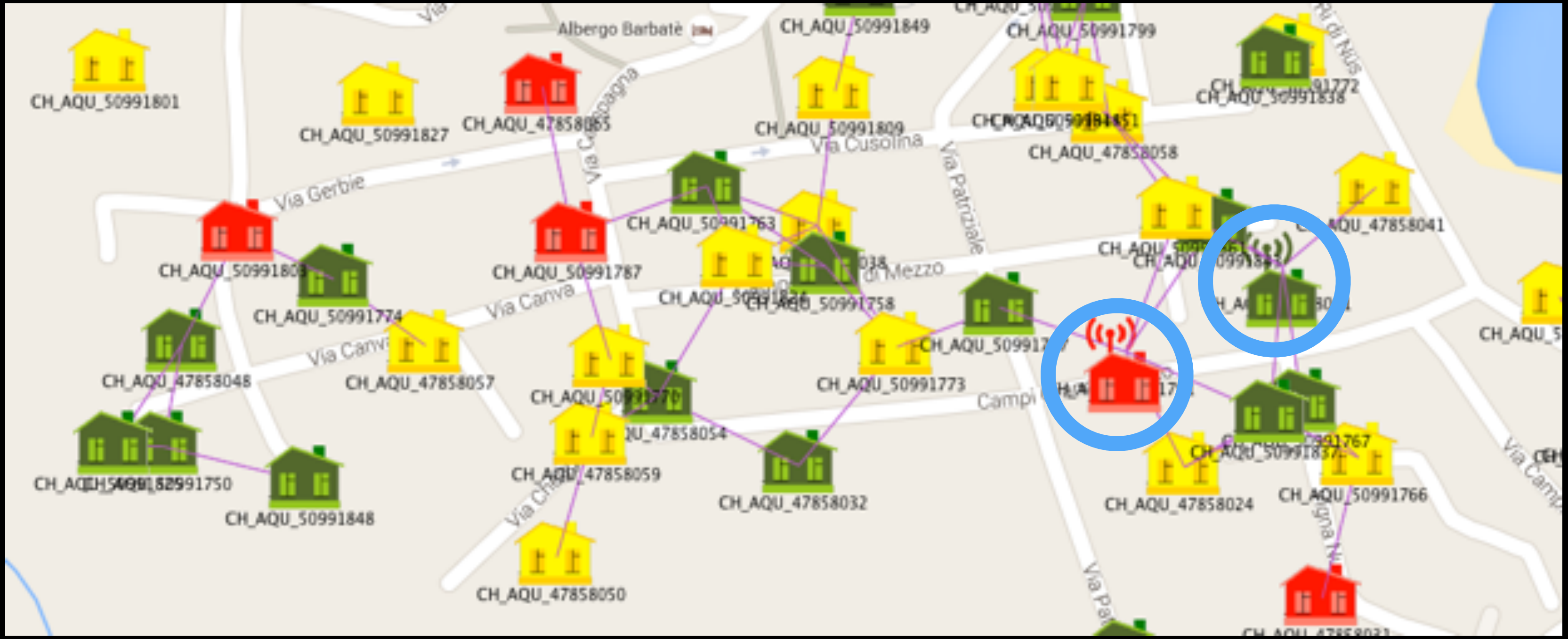


Portal diffusion submodel

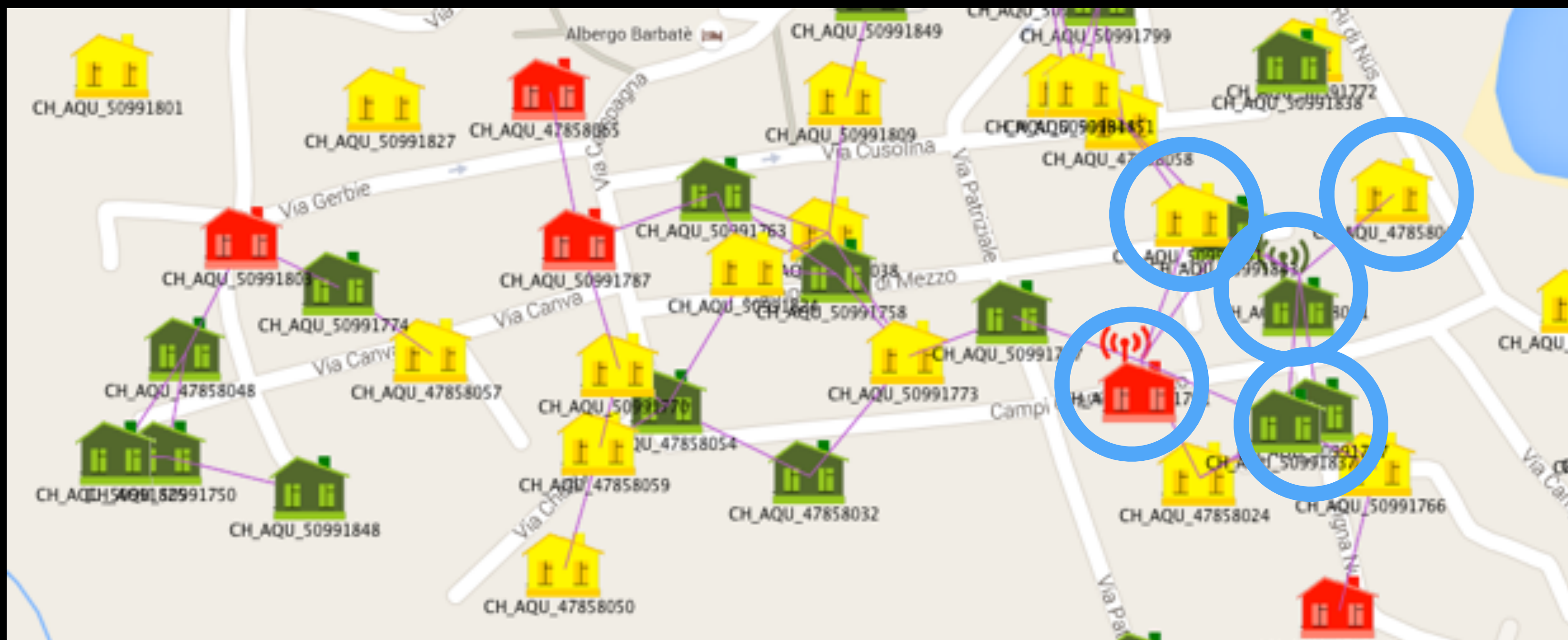


SIRS model

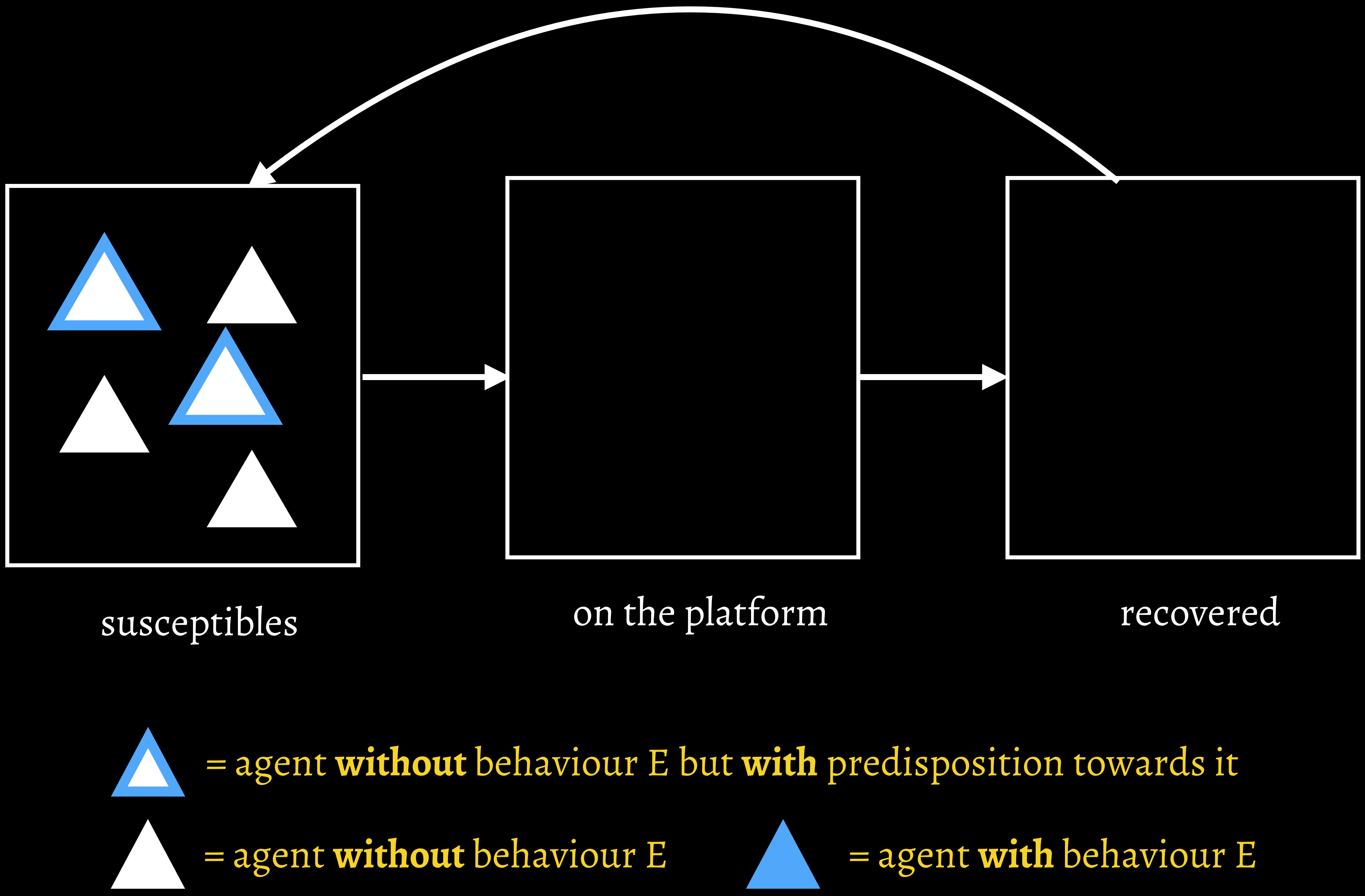
Portal diffusion submodel



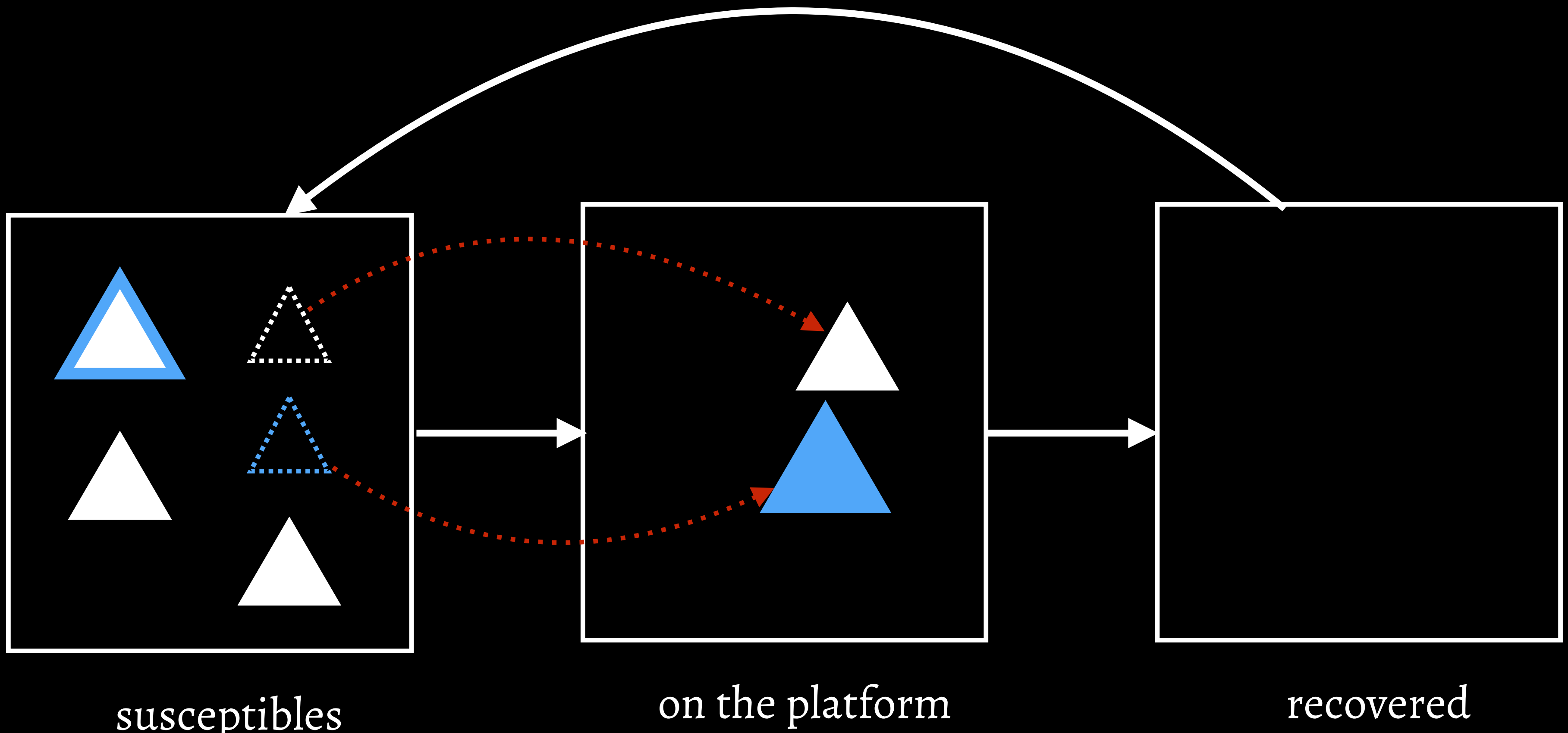
Portal diffusion submodel



Young diffusion submodel: assumptions



Young diffusion submodel: assumptions

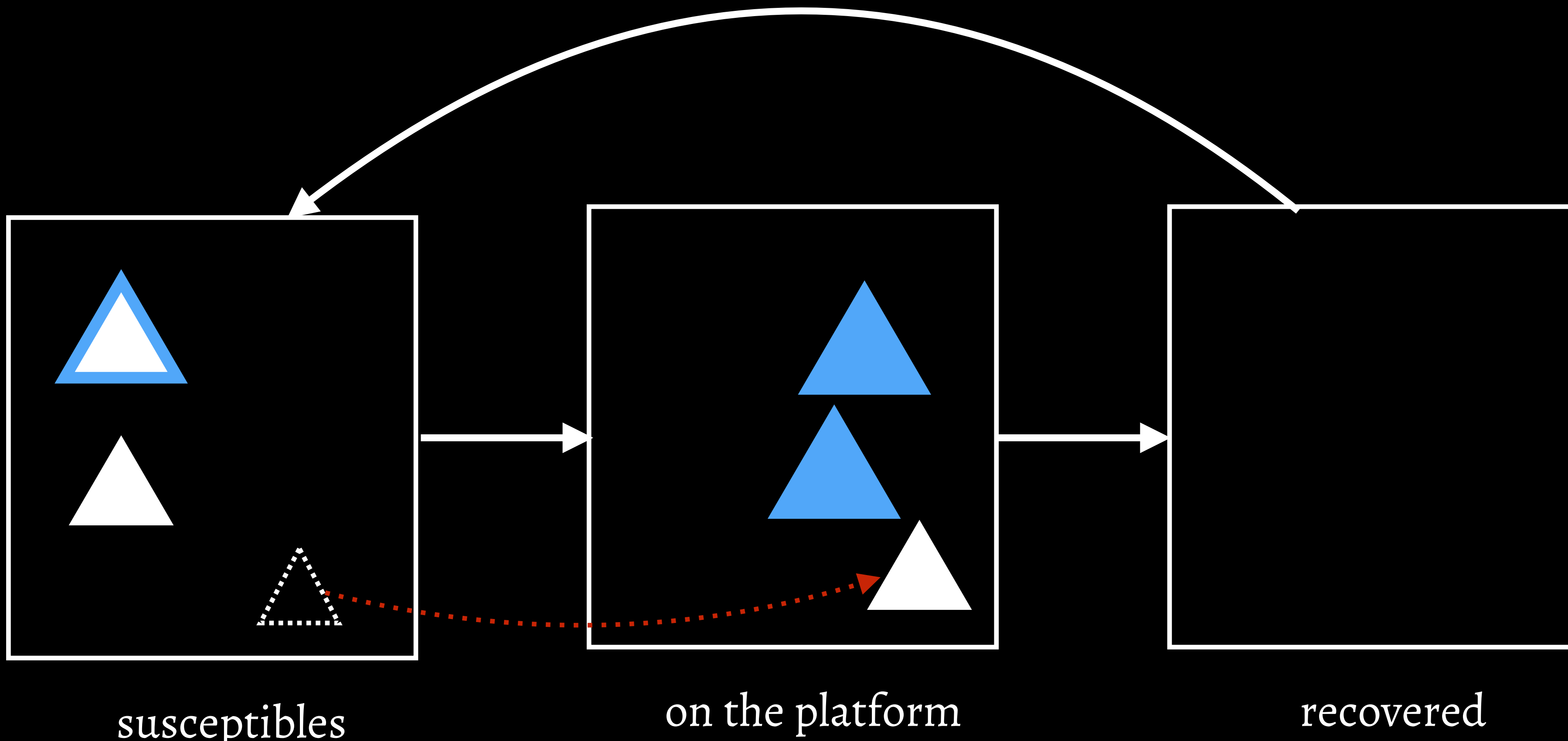


= agent **without** behaviour E but **with** predisposition towards it

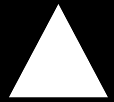
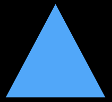
= agent **without** behaviour E

= agent **with** behaviour E

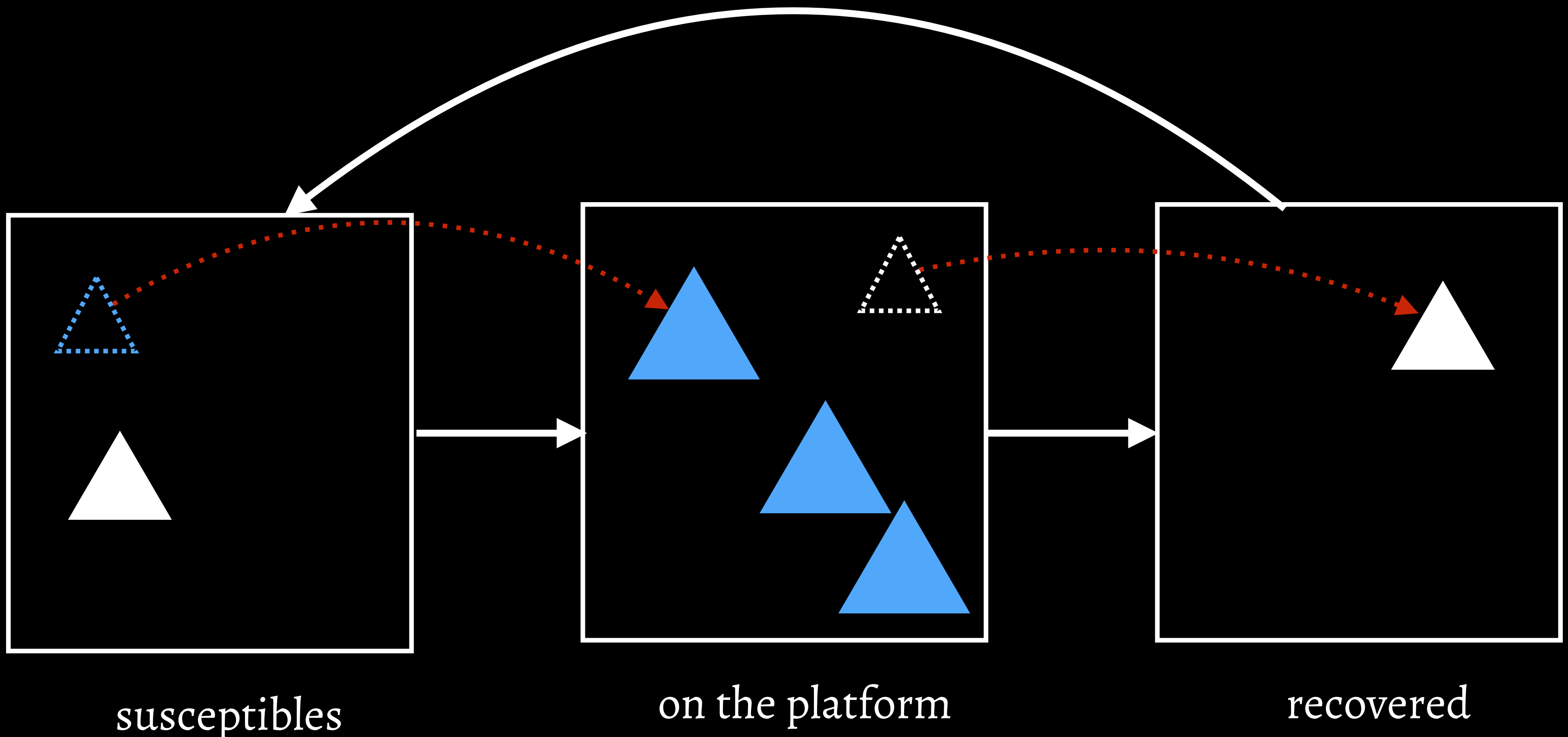
Young diffusion submodel: assumptions

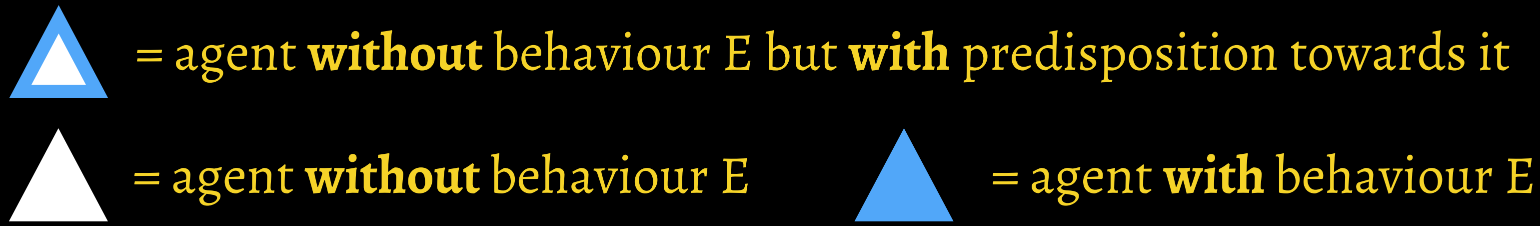


 = agent **without** behaviour E but **with** predisposition towards it

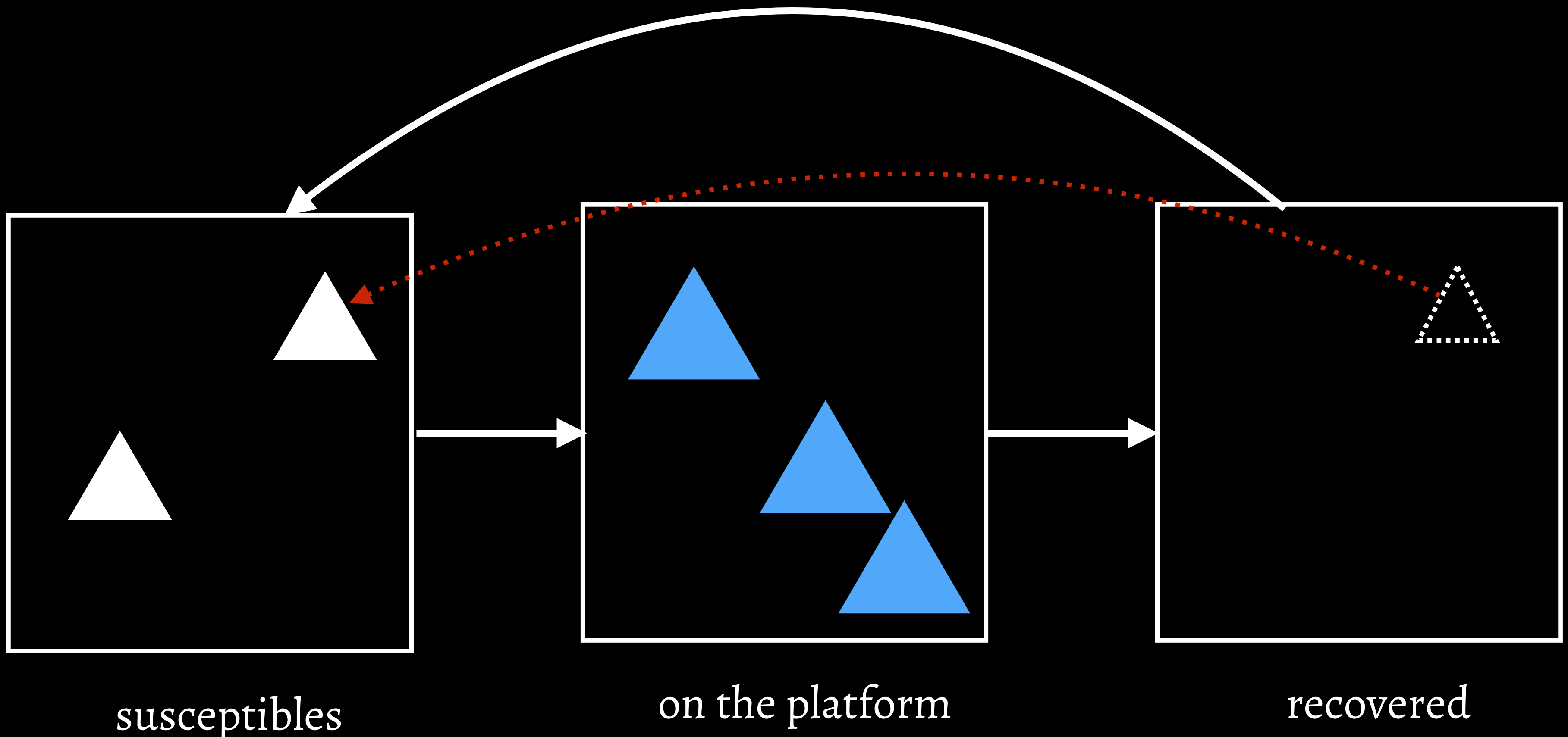
 = agent **without** behaviour E  = agent **with** behaviour E

Young diffusion submodel: assumptions





Young diffusion submodel: assumptions



= agent **without** behaviour E but **with** predisposition towards it

= agent **without** behaviour E = agent **with** behaviour E

Alessandro Facchini, IDSIA

Young diffusion submodel: assumptions

- A SmartH2O portal user is a household agent whose variable **onThePlatform** is true
- All agents who are not portal users are assume to have behaviour NE by default,
- A non portal user can have a predisposition for E, which is initialised once she becomes a portal user
- A portal user can adopt either a water-saving (E) or a non-water-saving (NE) behaviour
- The adoption of an E behaviour leads to a decrease in water usage in the player's household, achieved e.g. by shortening the shower time, or by adopting water saving technologies.

Young behavioural diffusion submodel

- The choice of a behaviour is determined by the utility function U that depends on:
  - the agent's current behaviour,
  - the behaviour of its social network (on the platform),
  - social pressure toward behaviour E (p_E)
  - role in the portal diffusion model

Applications to SmartH2O case study in Tegna

- Hourly measurements of 256 smart meters in Tegna (October 2014/February 2015 - now) and their psychographic attributes
- Parameters of Young's model, as in Edwards et al., (2005) and Galan et al., (2009).
- Boolean parameter indicating a predisposition toward the adoption of behaviour *E*: 10.8% true (based on the results of a pricing survey conducted in Ticino among SES customers)
- Adoption of behaviour *E* once on the platform leads to a reduction of 5% in water usage (WaterSmart)

Application to SmartH2O case study

Scenario	*Factor A* rateAdv. | adEffect.	*Factor B* contactR. | infect.	*Factor C* usePortalD.	*Factor D* timeImmunity
1	1/week | 10%	1/week | 10%	3 months	3 weeks
2	1/week | 10%	1/week | 10%	1 month	3 weeks
3	1/month | 5%	1/month | 5%	3 months	3 weeks
4	1/month | 5%	1/month | 5%	1 month	3 weeks

Table 1. *Robustness of the ABM model to the parameter p_E (social pressure) for 4 different scenarios. Such scenarios are generated based on the analysis on the portal diffusion model.*

Application to SmartH2O case study

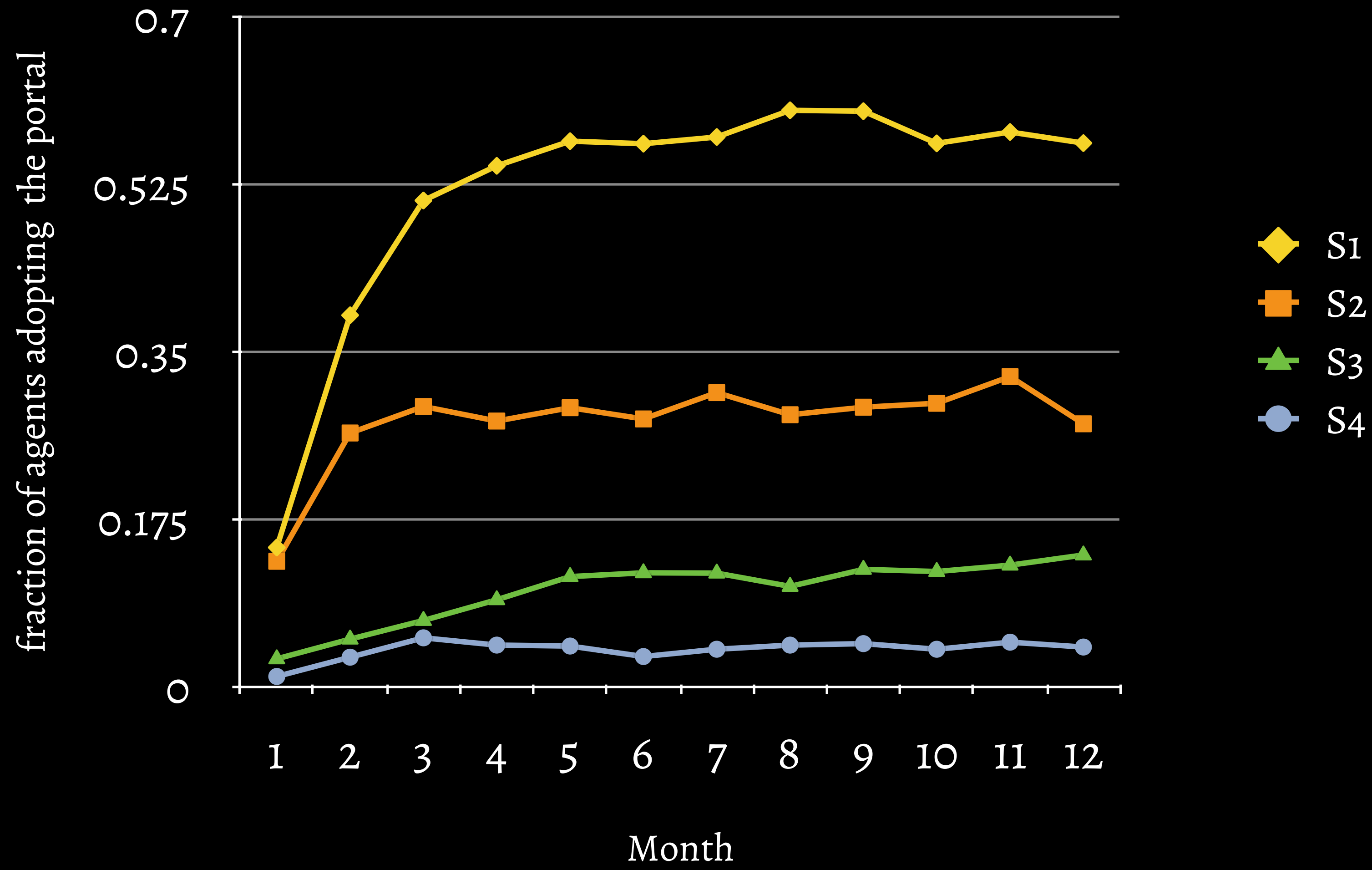


Figure 1. *Fraction of users using the SmartH2O portal as function of time in the four scenarios listed in Table 1 with p_E=1. 95% confidence interval (not reported) are always below 0.07.*

Application to SmartH2O case study

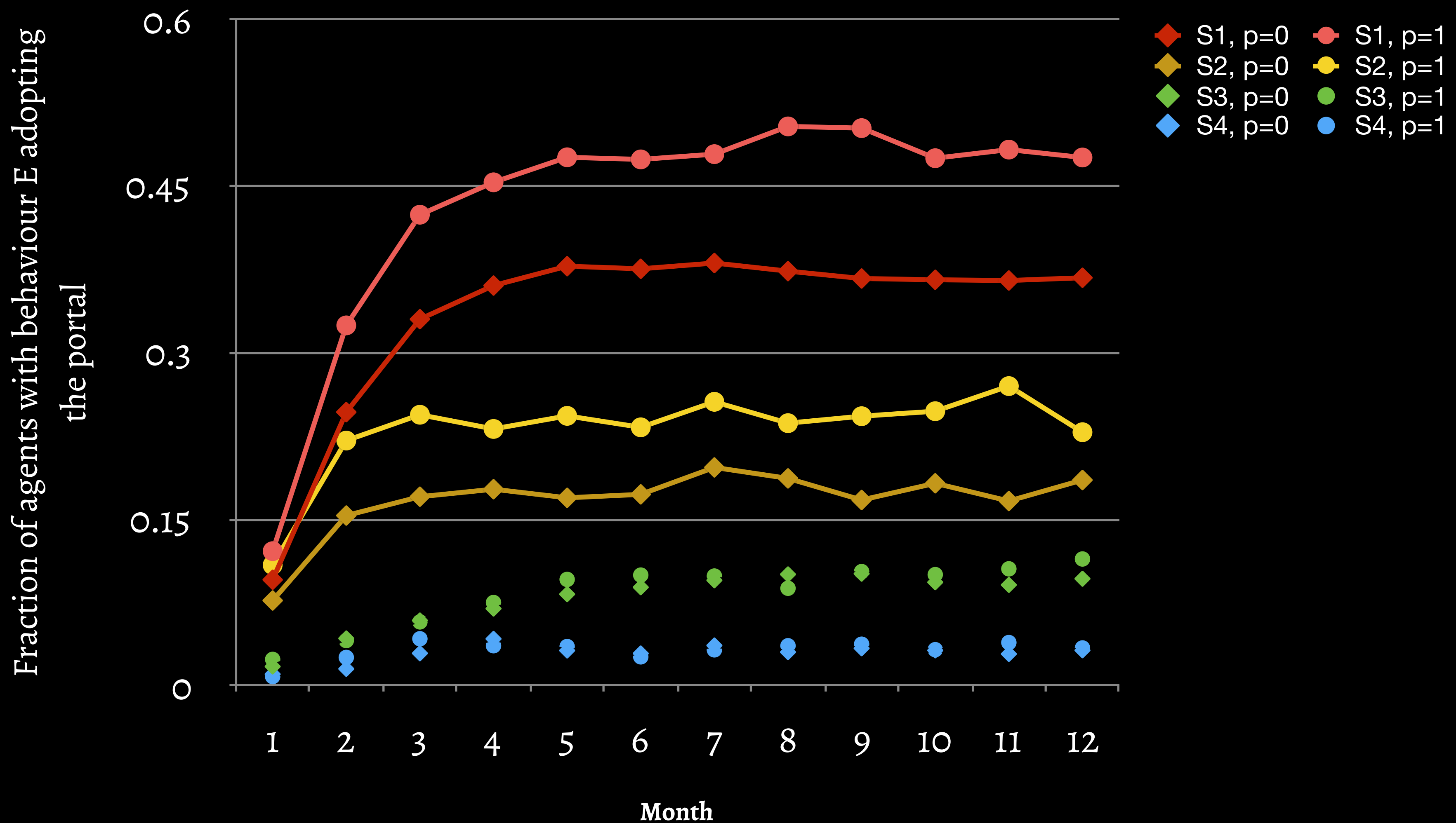


Figure 2*. Fraction of agents that are both portal and adopt behaviour E after 12 months, according to minimal and maximal values of* p_E *(social pressure) and type of scenario.*

Application to SmartH2O case study

Scenario	Value of social pressure p_E	Reduction (%) on daily consumption, last six months
1	0	1.83 (± 0.57)
	0.25	1.91 (± 0.51)
	0.5	2.09 (± 0.58)
	0.75	2.32 (± 0.51)
	1	2.50 (± 0.53)
2	0	0.90 (± 0.55)
	0.25	0.98 (± 0.58)
	0.5	1.01 (± 0.52)
	0.75	1.08 (± 0.54)
	1	1.12 (± 0.57)

Table 2. *Influence of emergence of behaviour E among portal users on water consumption under different scenarios.*

Comments

- Bigger integration of water price policies
- "Feedback" of Young's model to technological diffusion model (cf. FIRMA Valladolid)
- (Role of network structure in diffusion model)

Conclusions

- We have developed an ABM that models the adoption of a water awareness platform by a group of potential users
- We have assumed that the awareness of self consumption can lead to a change in behaviour depending on the user attitude
- We plan to use the ABM model to evaluate the impact on water consumption behaviour of water awareness campaign
- Model validation is in progress in the two main case studies of the SmartH2O project, in Switzerland and in Spain

sH2O

the smart H2O project

A European project on water sustainability

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