# Role playing games: a methodology to acquire knowledge for integrated wastewater infrastructures management in a river basin scale

P. Prat, M. Aulinas, C. Turon, J. Comas and M. Poch

## ABSTRACT

Current management of sanitation infrastructures (sewer systems, wastewater treatment plant, receiving water, bypasses, deposits, etc) is not fulfilling the objectives of up to date legislation, to achieve a good ecological and chemical status of water bodies through integrated management. These made it necessary to develop new methodologies that help decision makers to improve the management in order to achieve that status. Decision Support Systems (DSS) based on Multi-Agent System (MAS) paradigm are promising tools to improve the integrated management. When all the different agents involved interact, new important knowledge emerges. This knowledge can be used to build better DSS and improve wastewater infrastructures management achieving the objectives planned by legislations. The paper describes a methodology to acquire this knowledge through a Role Playing Game (RPG). First of all there is an introduction about the wastewater problems, a definition of RPG, and the relation between RPG and MAS. Then it is explained how the RPG was built with two examples of game sessions and results. The paper finishes with a discussion about the uses of this methodology and future work.

**Key words** | decision support system, integrated wastewater management, multi-agents system and role playing games

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## INTRODUCITON

Conventional management of wastewater is based on the individual practices of the different elements conforming wastewater cycle (e.g. sewer system and wastewater treatment plants (WWTPs)): the person in charge of one infrastructure takes decisions without considering other facilities. As consequence they do not interact with other managers adopting an individual management that could negatively affect the other infrastructures, provoking any kind of management problems (e.g. one industry could spill a toxic contaminant into the sewer system without warning, and then the WWTP could present operational problems because of this toxic impact). Current management has nothing to do with up to date directives (e.g. CEC 2000) which support integrated river management to achieve a good ecological and chemical status of water bodies (Butler & Schütze 2005).

Wastewater management has a high level of complexity due to interactions between different spatial and temporal scales of the elements that form part of the basin. Decision Support Systems (DSS) are presented as a tool capable to deal with complex systems. Many DSS have been developed in various contexts with successful outcomes (Shielen & Gijsbers 2003; Vanrolleghem *et al.* 2005) (Table 1). Almost all DSS developed were as a part of a system, trying to describe this element with mathematical/statistical models, numerical algorithms and therefore computer simulations (Poch *et al.* 2004). The next step was developing new DSS capable to help decision makers in a bigger scale; DSS which incorporate expert knowledge through artificial intelligence techniques. Different methodologies have been presented in order to develop this kind of DSS (Rizzoli & Young 1997).

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**Table 1** | Examples of DSS in different ambits with success application

| DSS | AMBIT |
|---|---|
| Elbe-DSS (Berlekamp *et al.* 2004) | River |
| ISM (Schroeder & Pawlowsky-Reusing 2005) | Sewer system and WWTP |
| SEWSYS (Ahlman & Svensson 2002) | Sewer system and WWTP |
| SIMBA (Erbe *et al.* 2002) | Sewer system, WWTP and river |
| Synopsis (Butler & Schütze 2005) | Sewer system, WWTP and river |

A promising way to develop a DSS capable to deal with an integrated management is possible through theoretical Multi Agent System (MAS) application (Dick *et al.* 2008). In order to build a DSS based on MAS architecture it is necessary acquire expert knowledge that DSS has to incorporate. A possible way to acquire this knowledge is using Role Playing Games (RPG).

A RPG is a game in which the participants assume the roles of fictional characters and collaboratively create or follow scenarios. Participants determine the actions of their characters based on their characterization, and the actions succeed or fail according to a formal system of rules and guidelines. Within the rules, players can improvise freely; their choices shape the direction and outcome of the game. An RPG has been developed for collective learning or collective actions (Adamatti *et al.* 2005) focused in social agents (Guyot & Honiden 2006). Performing the role allowed players to improve knowledge and understanding of both space-and-time-dynamic processes of the whole system. Rules, flow, and atmosphere of the game can provoke players to react to situation individually and collectively. The game makes them perceive that there are multiple stakeholders taking action in the same system context with differing objectives. RPG can bring better understanding on how individuals behave and interact with the environment and how this may affect the dynamics of the system. It was seen that RPG was beneficial to get an optimum solution in a problematic situation, which can be extrapolated to wastewater infrastructures with the objective to optimize the wastewater infrastructure management.

The RPG described is also based in MAS architecture but in artificial intelligence sense. MAS and RPG have both been developed separately and offer promising potential for synergetic joint use in the field of renewable resource management, for research, training and negotiation support. While MAS may give more control over the processes involved in RPG, role playing games are good at explaining the content of MAS (Barreteau *et al.* 2001).

Practical reasoning is a fundamental argumentation structure for multi-agent computing, where rational software agents need to engage in interactive communication, including the speech acts of putting forward an argument and questioning it (Wooldridge 2002). Argumentation schemes are a utilized method in order to develop agent's reasoning. Schemes are a tool for analyzing and evaluating arguments used in everyday and legal discourse. Schemes have now proved to be a central tool in argumentation theory used to analyze informal fallacies (Walton 2007). The RPG will permit us develop a correct schemes and find out the critical questions that might cause an argument to default.

The paper presents an RPG developed to acquire knowledge on integrated wastewater infrastructures management, emphasizing the construction of the RPG and its functioning. Finally, an case study and conclusions of sessions played with experts and what game has brought to us are presented.

## METHODOLOGY

The development of a RGP involves 3 different stages (Figure 1). The first step is the problem analysis. Usually this study is based on a literature research. The objective of this step is acquiring information on RPG previously developed, as well as to clearly define the objective of the RPG to be developed and the elements involved in the RPG. Moreover, this literature research may allow the characterization of these elements and their potential relationships. Depending on the problem to be solved, expert knowledge and/or historical data can be also used in this step.

Second step involves the definition of:

- Objectives of each element: every element has 2 objectives: its particular target and the goal intended to be attained through the collaboration of all the elements.

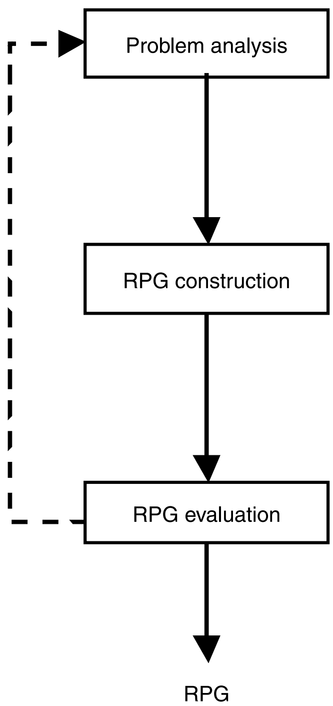


**Figure 1** | Diagram flow to develop a RPG.

- Role of each element: a role is a set of connected behaviors, rights and obligations as conceptualized as actors in a situation; it is mostly defined as an expected behavior in a given situation. A role can be also defined as the functional or social part that an agent plays in a multi-agent environment in the context of agent systems (Biswas 2008).
- Scenarios: a postulated sequence of possible events that will be the outline or synopsis of the RPG.

Once the RPG is constructed the evaluation of the overall system starts. This evaluation entails the addressing of situations to detect whether objectives, roles and scenarios have been successfully defined and implemented. A group of experts on wastewater infrastructures management participates in this process, each expert being a player of the RPG developed. Whenever the RPG must be reformulated, redesigned or refined, the system will be modified, updated and reevaluated.

## RESULTS

The objective of the RPG developed is to acquire knowledge about the integrated management of hydraulic infrastructures at river basin scale. The elements involved in the RPG are: (1) communities, (2) industries, (3) sewer systems, (4) pluvial tanks, (5) sewer system bypass, (6) WWTPs and (7) water bodies. For each element, the particular objectives were identified and defined (Table 2), being the commune objective improve integrated management with the final objective of guarantee or upgrade the good quality of water bodies (CEC 2000).

During the RPG construction a simple model to describe every element was developed using an Excel spreadsheet. These interfaces have become the core of the RPG since in these workspaces:

(a) The player can introduce their beliefs (informational state) and desires (motivational state).
(b) They content the basic characteristics of the agents: Every element have been characterized by: flow rate ($m^3$/day) and wastewater composition ($g/m^3$) based on: Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS) and Nitrogen (N-NT). Workspace from industrial parks and sewer systems also content information

**Table 2** | Objectives and sub-objectives of the elements involved in the RPG

| River basin element | Sub-objectives | Objective |
|---|---|---|
| Communities | | Guarantee or upgrade the good quality of water bodies |
| Industries | Improve their benefits | |
| Sewer systems | Transport wastewater to WWTP | |
| Wastewater tanks | Store wastewater in case of sewer overflow | |
| Sewer system bypass | Bypass wastewater between two WWTPs | |
| WWTPs | Spill treated water to receiving media fulfilling the legislation thresholds | |

related to storage tanks, characterized by its storage capacity ($m^3$) and wastewater composition ($g/m^3$).

(c) They allow to make matter balance based on the wastewater-flow that circulates for each element and pollutant concentration.

To evaluate the RPG constructed a case study composed by 2 communities (Com1 and Com2), 3 industrial parks (I1, I2 and I3), 2 sewer systems (SS1 and SS2) and 2 WWTPs (WWTP1 and WWTP2) that discharge treated water in the same river, was built. The basin is divided in two parts, one formed by Com1 connected to its particular SS1 and WWTP1. SS1 also receives water from I2. The second part has the same elements: Com2, SS2 and WWTP2 but it differs because SS2 receives water from two industrial parks, I1 and I3. There was also consideration of infrastructures that give support to the management: (a) I1 and I3 have industrial tanks in order to store industrial wastewater in case of necessity; (b) sewer systems have tanks to store wastewater; and (c) between WWTP1 and WWTP2 there is a connection channel that permits bypass wastewater form WWTP1 to WWTP2 (Figure 2). These infrastructures permit give solutions in front of problematic management situations, where sometimes all the wastewater could not be treated. Table 3 summarizes the characteristics of every element.

In order to develop the game, each infrastructure was represented for one player/agent that assumes a given role. The selection of the participants was carefully done according to the objectives planed and the four possible ways of playing the game (Lankford & Sokile 2003):

1. With students and researchers of water management to self-teach about common property management of wastewater.
2. With users of water to facilitate local decision-making regarding the generated wastewater. This type of games also allows outside researchers to observe what the games reveals in terms of current problems and proposed solutions.
3. With higher-level managers to give an appreciation of the beneficial and negative outcomes that formal decision-making might have on infrastructure wastewater management on the scale of a river basin.

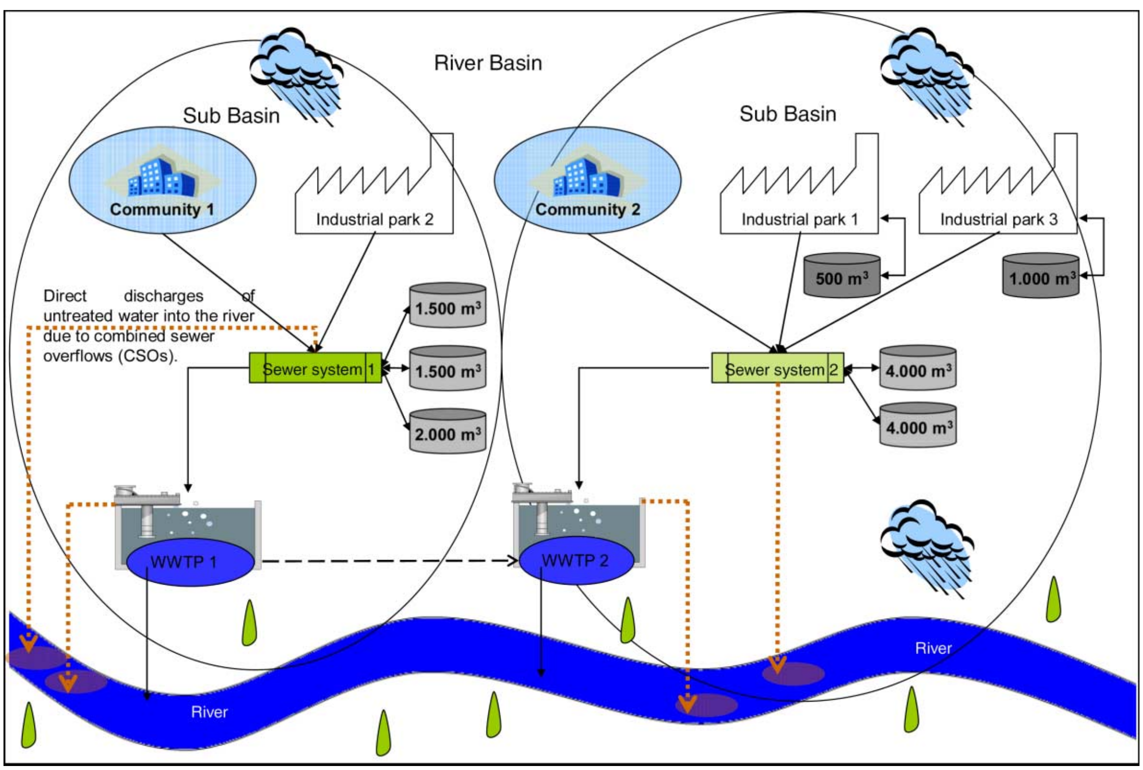


Figure 2 | River basin structure proposed for the case study.

**Table 3** | Characteristics of river basin elements

| | Com1 | Com 2 | I1 | I2 | I3 | WWTP1* | WWTP2* |
|---|---|---|---|---|---|---|---|
| FLOW $m^3$/day | 3,429.92 | 14,875 | 2,500 | 1,500 | 5,000 | 7,000 | 27,000 |
| COD g/$m^3$ | 580 | 580 | 800 | 1,500 | 1,500 | 450 | 650 |
| BOD g/$m^3$ | 250 | 250 | 750 | 1,000 | 1,000 | 300 | 550 |
| TSS g/$m^3$ | 245 | 245 | 650 | 200 | 100 | 800 | 700 |
| N-NT g/$m^3$ | 40 | 40 | 90 | 20 | 20 | 60 | 50 |

*Design parameters for WWTPs. In normal conditions WWTP described could treat wastewater below characteristics presented.

4. With both higher-level institutions and users to generate a comprehensive picture of how mutual collaboration, flexibility and support is required to manage wastewater infrastructure.

A part from players there was an observer of the session and a note keeper, who permitted us to make conclusions of each game and performance it in order to improve the efficiency of the game. Another figure was the master; his role was managing the group and leads the game in order to bring up different situations. He/she sets limits to portraying what the characters perceive. The previous preparation of the game and the pre-established situations is also what master decides to do. The master can not interact like the other ones, since he/she is the arbitrator and narrator of the game. Once players have been selected, it's started a game session (Figure 3). First of all, the river basin is presented to the players (Figure 2), and everyone has to become familiar with their agent.

To build the different environments, different problematic scenarios were randomly posed. There have been described three different types of problematic situations: (1) organic shock; (2) toxic shock; and (3) hydraulic shock. These three types of problem permitted developing situations with just one problem or a combination of them. The different problematic situations were introduced by the master through a protocol (Table 4); the magnitude of the problem was determined by chance. Other times the master indicated the problem and the magnitude as a consequence of some kind of problem on the different elements that integrate the basin. Moreover, in each scenario sewer systems have to define the rain. There is protocol to determine the quantity of the rain: players need to throw away different kinds of dice in order to determine the amount of rain water ($m^3$/day).

Once the scenarios were built, the agents updated the date in their respective workspace, and looked for their possibilities in order to improve the management and respecting the individual goals. The agents took a decision that influenced other agents; these decisions could be taken individually or as a group, optimizing the resources available. They have taken decisions as agents and give a solution. According to the response they had a score on the workspace. If the water characteristics are under legal limits it represents a good river management, so they will have positive points, but if characteristics are over legal limits they will have negative points.

The game has been played twice with researchers of water management (first group according to Lankford & Sokile (2003) classification). The first role playing game was a testing game. Playing with researchers had been the

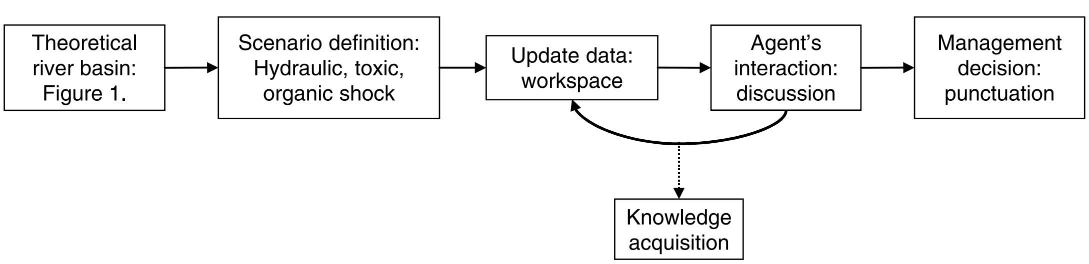


**Figure 3** | Procedure to acquire knowledge.

**Table 4** | Problematic scenarios posed during the RPG sessions (the problematic situations are marked in bold)

| | Day 1 | Day 2 |
|---|---|---|
| Community 1 | Normal state | Normal state |
| Community 2 | Normal state | Normal state |
| Industry 1 | Normal state | Normal state |
| Industry 2 | **Organic shock** | Normal state |
| Industry 3 | **Spill 8.000 m³/day** | Normal state |
| Sewer system 1 | Define episode of rain | Define episode of rain |
| Sewer system 2 | Define episode of rain | Define episode of rain |
| WWTP 1 | Normal state | Normal state |
| WWTP 2 | Normal state | Normal state |
| | **DAY 3** | **DAY 4** |
| Community 1 | Normal state | **Doubled population** |
| Community 2 | Normal state | Normal state |
| Industry 1 | **DQO: 1,600 g/m³ FLOW: 3.000 m³/dia** | **Not discharging** |
| Industry 2 | Normal state | Normal state |
| Industry 3 | Normal state | Normal state |
| Sewer system 1 | Define episode of rain | Define episode of rain |
| Sewer system 2 | Define episode of rain | Define episode of rain |
| WWTP 1 | Normal state | Normal state |
| WWTP 2 | **Decrease treatment yield** | Normal state |

possibility to know the lacks and inconsistencies of the game. It was based on searching which were the errors and how the game could be improved to approach the current reality. During the game it was set up with aspects diverging from or matching reality and they become familiar with Excel spreadsheets that were complicated and some time was necessary to understand which were the aspects to modify during the session. The main observation was: when an agent acts individually it does not maximize the general goal (improve integrated management), when it takes the other agents into account the general goal is however the one that prevails. On the other hand it was a positive appraisal of the index that has been described and it was suggested to incorporate knowledge apart from the numerical model that had been prepared, incorporating case based reasoning, incorporating an index as individual goal and trying to prioritize qualitative arguments. The argumentation that results from the game is very numerical, this provokes that the answers are limited, it is necessary to give more freedom for new possibilities, as for example: adding flocculating which will improve the yield of the WWTP.

According to these observations, the RPG was modified, updated and reevaluated. Contrarily to first RPG, the observations of the second RPG were focused on integrated management and the results obtained. The spreadsheets had been well evaluated. Besides it was reflected:

- It is follow a lineal argumentation.
- The WWTP have the most important role.
- It has been demonstrated that through the argumentation there arise improvements of the management.
- General goals still prevail over individual goals.
- Overflows of the sewer system were not enough negatively evaluated (volume of water that is spilled directly to the river without treatment and is a negative impact to water bodies).

In order to study the usability of the RPG developed, the second game was reproduced without integrated management, and not including the pluvial tanks or the bypass. The results are shown in Table 5; it is also showed in the Figure 4.

In both cases, the game starts with ecological state of the river of 0 points. The protocol defined for the game starts with a high problematic situation, requiring that each management achieve negative points. In the other scenarios, integrated management got positive points and at the end of the four scenarios the river basin management has improve. On the other hand, non integrated management does not permit achieving positive score of river basin management. Besides, in each scenario get more negative points that they diminished still more the ecological state of the river.

Playing the game permitted us to acquire knowledge about the integrated management of hydraulic infrastructures composing a river basin:

**Table 5** | Results of integrated management and current management

| | Integrated management | | Current management | |
|---|---|---|---|---|
| | Result scenario | Balance | Result scenario | Balance |
| Scenario 1 | −63.75 | −63.75 | −143.75 | −143.74 |
| Scenario 2 | +20 | −43.7 | −20 | −163.75 |
| Scenario 3 | +50 | 6.25 | −20 | −183.75 |
| Scenario 4 | +50 | **56.25** | −83.6 | **−267.35** |

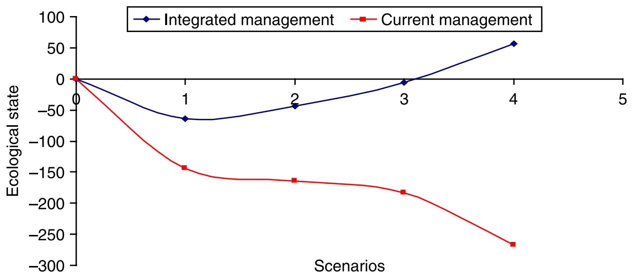


**Figure 4** | Evolution of the ecological status of water bodies with or without integrated wastewater infrastructures.

- It followed a lineal argumentation between agents, and also they follow a lineal communication.
- The information exchanged among elements is extremely quantitative, since the game was planned with wastewater parameterization.
- It was a source of information that MAS has to incorporate in their programming.
- It showed the reasoning that the experts follow to make an integrated river basin management based on hydraulic infrastructures.

## DISCUSSION

Current directives defend an integrated river basin management with the final objective to improve the ecological and chemical status of water bodies (e.g. CEC 2000). Different strategies has been developed by other authors to achieve these objectives, a lot of them based on simulation models (Fu *et al.* 2007) that permit us to make simulations about the management of one river problem but not in Real Time Control (RTC). Recently, integrated models have been developed (Solvi *et al.* 2005) offering a new integrated management possibilities in RTC. Often those models are difficult to implement and required experts on models and not with up to day management in order to run, apply them in a real case, and obtain successful results.

To confront the complexity associated with integrated wastewater infrastructures management, the possibility had been described of building a better management through a DSS that incorporates heuristic knowledge through artificial intelligence techniques rather than only numerical models. The RPG is a correct approach to artificial world, and to acquire required knowledge to build the DSS. In the RPG each player has behaved as intelligent agent, and was shown which is the way to built a MAS and which is the knowledge that has to be incorporated in that system. When different agents interact important knowledge emerges, optimizing the resources available, which means that industrial tanks, pluvial or storm tanks, bypass, and WWTP are optimized. The optimization of fallacies will generate more possibilities to improve the management. The interactions between agents permit to amortize the effects of some problematic situations, given more time to resolve the conflict, besides, managers understand the up to date wastewater problems (some times all wastewater could not be treated and is discharged to the river) allowing some kind of schedules at the time to spill to the WWTP.

Furthermore it is expected to find the best communications technique between agents and the protocol of communication. The scenario will be developed under described situations which built the environment, different environment types require somewhat different agent programs to deal with them effectively (Russell & Norvig 2003).

An integrated game has been developed that permits us to justify that (1) RPG is a useful tool to acquire knowledge and (2) it is useful to improve wastewater system performance. Besides this, it is necessary to improve the game in order to acquire more knowledge about the integrated management of wastewater infrastructures and in a future can build the DSS based on MAS. One way to improve the RPG is playing the game with experts of the WWTPs, sewer systems or industry management, because they could have some knowledge and reasoning that experts from university do not have. By this way, it could be possible to include other problematic situations that can occur in this integrate management framework. Another way to improve the RPG could be introducing simplified models (not time consuming) that simulate the real conditions of the elements in RTC, and taking into account other problems and wastewater treatment techniques (Henze *et al.* 1986).

## FUTURE WORK

Next step of the RPG will be based on the use of agent's platform, which will permit us built the game in artificial intelligence environment, and starting to programming a

DSS with theoretical MAS. The platform chosen is the Recursive Porous Agent Simulation toolkit (REPAST) is a free open source toolkit that was developed by Sallach, Collier, North, Howe, Vos, and others (Collier *et al.* 2003). REPAST focuses on modelling social behaviour, but is not limited to social simulation.

## REFERENCES


Adamatti, D. F., Sichman, J. S., Rabak, C., Bommel, P., Ducrot, R. & Camargo, M. E. 2005 *Conference on Multi-agent modelling for environmental management, 21–25 March 2005, Bourg Saint Maurice–Les Arcs, France*.

Ahlman, S. & Svensson, G. 2002 Modelling substance flows in urban sewer systems using MATLAB/Simulink. *Proceedings of the Ninth International Conference on Urban Drainage, 8–13 de setembre de 2002. Portland, USA*.

Barreteau, O., Bousquet, F. & Attonaty, J. M. 2001 Role-playing games for opening the black box of multi-agent systems: method and lessons of its application to Senegal River Valley irrigated systems. *J. Artif. Soc. Soc. Simul.* **4**(2).

Berlekamp, J., Graf, N., Hess, O., Lautenbach, S., Reimer, S. & Matthies, M. 2004 Integration of Moneris and GREAT-ER in the Decision Support System for the German Elbe River Basin. *Proceedings of International Environmental Modelling and Software Society, iEMSs. 14–17 Juny de 2004. University of Osnabrück, Germeny*.

Biswas, P. K. 2008 Towards an agent-oriented approach to conceptualization. *Appl. Soft Comput.* **8**(1), 127–139.

Butler, D. & Schütze, M. 2005 Integrating simulation models with a view to optimal control of urban wastewater systems. *Environ. Modell. Softw.* **20**(4), 415–426.

CEC (Council of the European Communities) 2000 Directive 2000/60/EC of the European parliament and of the council of 23 October 2000 establishing a framework for community action in the field of water policy. European Union, Luxembourg.

Collier, N., Howe, T. & North, M. J. 2003 Onward and upward: the transition to Repast 2.0. *First Annual North American association for Computational Social and Organizational Science Conference*. (Pittsburgh, PA, USA), North American Association for Computational Social and Organizational Science.

Dick, J. M., Theo, A., Aloys, W. J. & Harry, J. P. 2008 A multi-agent paradigm as structuring principle for planning support systems. *Comput. Environ. Urban Syst.* **32**(1), 29–40.

Erbe, V., Risholt, L. P., Schilling, W. & Londong, J. 2002 Integrated modelling for analysis and optimisation of wastewater systems–the Odenthal case. *Urban Water* **4**(1), 63–71.

Fu, G., Butler, D. & Khu, S. 2007 Multi objective optimal control of integrated urban wastewater systems. *Environ. Modell. Softw.* **23**(2), 225–234.

Guyot, P. & Honiden, S. 2006 Agent-based participatory simulations: merging multi-agent systems and role-playing games. *J. Artif. Soc. Soc. Simul.* **9**(4).

Henze, M., Grady, C. P. L., Gujer, W., Marais, G. V. R. & Matsuo, T. 1986 Activated sludge model No.1. *LAWQ Scientific and Technical report 1. IAWQ, London, UK*.

Lankford, B. A. & Sokile, C. 2003 Reflections on the river basin game: role-playing facilitation of surface water allocation in contested environments. *The ICID 20th European Regional Conference, 17–19 September 2003, Montpellier, France*.

Poch, M., Comas, J., Rodríguez-Roda, I., Sánchez-Marrè, M. & Cortés, U. 2004 Designing and building real environmental decision support systems. *Environ. Modell. Softw.* **19**(9), 857–873.

Rizzoli, A. E. & Young, W. J. 1997 Delivering environmental decision support systems: software tools and techniques. *Environ. Modell. Softw.* **12**(2–3), 237–249.

Russell, R. & Norvig, P. 2003 *Artificial intelligence: a modern approach*, 2nd edition. Prentice-Hall International Edition, New Jersey, USA.

Shielen, R. M. J. & Gijsbers, P. J. A. 2003 DSS-large rivers: developing a DSS under changing societal requirements. *Phys. Chem. Earth* **14–15**(28), 635–645.

Schroeder, K. & Pawlowsky-Reusing, E. 2005 Current state and development of the real-time control of the Berlin Sewage System. *Water Sci. Technol.* **52**(12), 181–187.

Solvi, A.-M., Benedetti, L., Gillé, S., Schosseler, P., Weidenhaupt, A. & Vanrolleghem, P. A. 2005 Integrated urban catchment modelling for a sewer-treatment-river system. *Tenth International Conference on Urban Drainage, 21–26 August 2005, Copenhagen, Denmark*.

Vanrolleghem, P. A., Benedetti, L. & Meirlaen, J. 2005 Modelling and real-time control of the integrated urban wastewater system. *Environ. Modell. Softw.* **20**(4), 427–442.

Walton, D. 2007 Evaluating practical reasoning. *Synthese* **157**(2), 197–240.

Wooldridge, M. 2002 *An Introduction to Multiagent Systems*. John Wiley & Sons, London, England.