

Is my spill environmentally safe? Towards an Integrated Management of Wastewater in a river basin using agents that can argue

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Abstract

Wastewater management in river basins is becoming increasingly complex. While there is an urge to reduce the ecological imbalances in fluvial ecosystems, more wastewater has to be treated because of both demographic and industrial growth. Furthermore, given the intrinsic multidimensionality of river basins, its management must take into account all the agents that affect and are affected by the wastewater. In this paper we propose the application of an artificial intelligence based model -*ProCLAIM*- for an integrated wastewater management in river basins. The model provides a framework for an effective and monitored deliberation over the appropriateness of proposed actions in safety critical domains. We illustrate the model's use in a specific situation where a given industry intends to discharge a considerable amount of wastewater due to an emergency. The agents potentially affected by the industry's intended discharge will be able to defend their interest by submitting arguments *for* and *against* the proposed action. These arguments are then evaluated in order to determine the appropriateness of the action. That is, whether the industry's discharge is environmentally safe given the agent's proposed courses of actions.

Keywords: argumentation; integrated management; multi-agent systems; river basin; wastewater

INTRODUCTION

Fast demographic growth, together with an increase of industrial activity, historically placed near the riversides to use water as a resource, has created severe ecological imbalances in fluvial ecosystems. These imbalances have been also influenced by the idiosyncrasy of each river basin (altitude, latitude, geology, rainfall regime, hydrological net, *etc*).

According to the European Union Water Framework Directive (WFD) (European Community, 2000) a river basin *comprises the area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth, estuary or delta*. Accordingly, river basins are multi-dimensional units and their management surpasses administrative boundaries; their scale of problems increase (Smit *et al.*, 1989; Biswas, 2004; Poch *et al.*, 2004) since the state of rivers in a given point depends on what happens on its surroundings and upper stretches of the river. Hence, the WFD introduces the holistic approach to reveal the major pressures, the impact on the receiving waters and the water resources management at river basin level.

Our study case is located in Catalonia, where the majority of river basins have sewer infrastructures and Wastewater Treatment Plants (WWTPs). It is important to highlight that almost all sewer systems are unitary which means pluvial, domestic and even several industrial wastewater streams are collected together, adding another handicap to wastewater management (Metcalf and Eddy, 2003). Peculiarities of Mediterranean rainfall regimes (short duration but intensive rains) (Prat *et al.*, 2000; Munné *et al.*, 2004) together with a high diversification of industries and little integrated wastewater management makes it difficult to reach into a *good ecological status* of rivers defined by WFD (European Community, 2000).

All these elements (sanitation infrastructures and industries) form a complex system in which several agents come together with different goals and interests difficult to manage as a whole without special methodologies (Grondsma, 1989).

In this paper we propose the use of the *ProCLAIM* model (Tolchinsky *et al.*, 2006a) in order to provide support in the wastewater river basin management. *ProCLAIM* defines a setting in which the different agents involved in the river basin management can effectively deliberate over the appropriateness of the proposed actions. Thus, the undertaken actions must accommodate the agents' goals and interests, and more importantly, they must be environmentally safe. Agents in *ProCLAIM* represent each of the stakeholders in the deliberation. These agents may well be autonomous software components (computer systems that are situated in some environment and that are capable of autonomous action in this environment in order to meet its design objectives; Wooldridge, 2001) or human users that participate in the deliberation by means of proxy software agents that provide them support in the construction and retrieval of arguments (Tolchinsky *et al.*, 2006b).

In the following section we introduce and motivate the use of the *ProCLAIM* model. Within the results and discussion we describe the application of the model for the management of wastewater in river basins and we illustrate a scenario application where agents must decide the appropriateness of a punctual industrial discharge into a WWTP. Finally, we give our conclusions.

METHOD: *ProCLAIM* MODEL

Broadly construed, the *ProCLAIM* model consists of a Mediator Agent, MA, directing *proponent agents* in an argument based collaborative decision making dialog, in which the final action should comply with certain domain dependent guidelines. However, the arguments submitted by the *proponent agents* may also persuade the MA to accept decisions that deviate from the guidelines. For example, the MA may be able to reason that the submitted arguments supporting an alternative decision have proven to be correct in previous similar deliberations.

ProCLAIM is of particular value in safety-critical domains where the consequences ensuing from a wrong action may be catastrophic. Guidelines in such sensitive environments usually exist and are created in an attempt to minimize hazardous decisions. Nonetheless, there are circumstances in which an action is appropriate despite deviating from the established guidelines.

ProCLAIM makes use of three mature Artificial Intelligence (AI) techniques:

- **Multi-agent systems** integrate several agents and allow addressing diverse goals and interests. Consequently, multi-agent systems are able to cope with river basin complexity by integrating several agents (Rendón-Sallard *et al.*, 2006) and thus, addressing the distributed nature of the river basin scenario.
- **Argumentation** has proven to be a suitable approach for reasoning under uncertainty, with inconsistent knowledge sources, and in dialog based communication (Prakken *et al.*, 2002). And so, argumentation allows agents provide the reasons *why* they believe an action is or is not appropriate. Also it provides MA with the means to evaluate these reasons.
- **Case based reasoning** has proven to be an appropriate reasoning and learning approach for ill-structured domains, where capturing experts' knowledge is difficult and/or the domain theory is weak or incomplete (Bergmann *et al.*, 2006) such as the wastewater scenario.

ProCLAIM defines three main tasks for the MA:

- 1) Guide the *proponent agents* on the arguments they can submit at each stage of the deliberation.
- 2) Ensure that the submitted arguments are relevant (*e.g.*, comply with the guidelines).

3) Evaluate the submitted arguments in order to identify the *winning* arguments and thus determine whether a proposed action is appropriate. This last task may require the MA to assign a preference relation among the submitted arguments that are in conflict, as well as, possibly submit additional arguments.

In order to undertake these tasks, MA employs four knowledge resources (see Fig. 1):

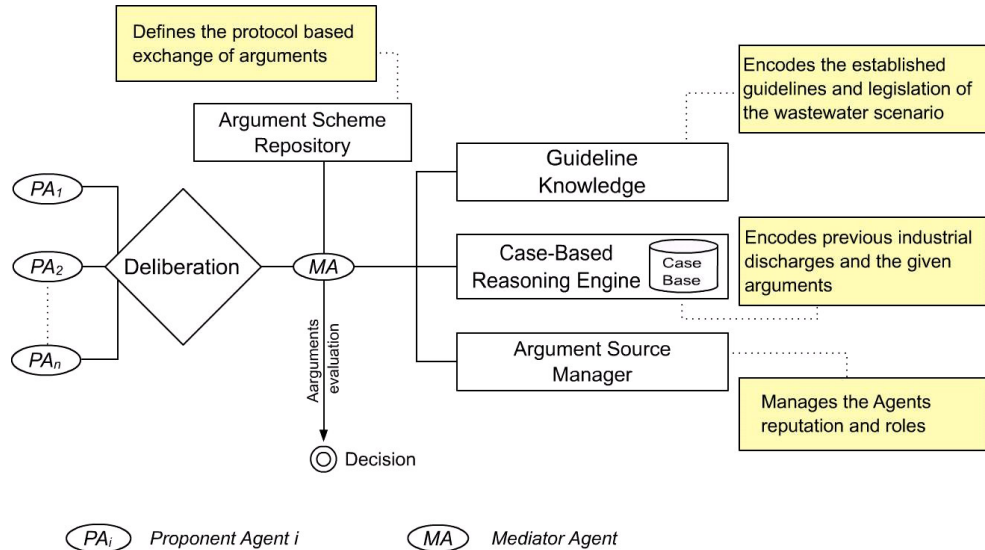


Figure 1. ProCLAIM's Architecture

– **Argument Scheme Repository (ASR):** Stores a set of abstract arguments, or argument schemes, together with their associated Critical Questions (CQs). CQs represent additional relevant factors that might cause an argument to default. Further, CQs associated with each scheme provide a means for assessing a particular instance or segment of argumentation (Walton, 1996). CQs can be expressed as a challenge illocution to an argument, normally to some assumption (as shown later in Results), or as an attacking argument.

MA makes use of a repository of argument schemes and their associated CQs in order to identify the possible argument schemes that the proponent agents can instantiate and submit as arguments at each stage of the deliberation (Remark: While an argument scheme may be of a form: *–Source E is an expert in subject domain S containing proposition A, and E asserts that proposition A (in domain S) is true, then A is true–*, where bold upper-cases are variables. An instantiation of this scheme is, for example, the argument: *– Source john is an expert in domain wastewater treatment containing proposition wastewater_must_be_treat and john asserts that proposition wastewater_must_be_treat is true, then wastewater_must_be_treat is true–*).

– **Guideline Knowledge (GK):** This component enables the MA to check whether the arguments comply with the domain knowledge, in particular, whether the arguments are valid instantiations of schemes in the argument scheme repository (the ASR can thus be regarded as an abstraction of the GK).

– **Case-Based Reasoning Engine (CBRE):** This component enables MA to assign strengths to the submitted arguments on the basis of their associated evidence gathered from past deliberations, as well as provide additional arguments deemed relevant in previous similar situations.

– **Argument Source Manager (ASM):** Depending on the source from whom, or where, the arguments are submitted, the strengths of these arguments may be readjusted by the MA. Hence, this component manages the knowledge related to the agents' roles and/or reputations, and/or the

types of certificates, or references that may empower agents to undertake some exceptional actions.

The agents' submitted arguments shape a graph of interacting arguments, where the interaction is based on the attack relation (see Fig. 2). In order to decide whether a proposed action is appropriate the MA has to evaluate this argument graph to determine which the *winning* arguments are. This involves referencing the three knowledge resources GK, CBRe and ASM to assign strength to the arguments and possibly submit additional arguments relevant for the subject under debate (Tolchinsky *et al.*, 2006a). In that way, the appropriateness of a proposed action is decided taking into account 1) the consented guidelines 2) gathered evidence from past recorded similar cases, and; 3) the proponent agents' role or reputation with respect to the subject under debate.

RESULTS AND DISCUSSION

To illustrate the potentialities of agents for the integrated wastewater management in a river basin we now present an application of *ProCLAIM* in a reduced scenario conformed by the following software agents (note that words in *italics* make reference to the actors represented by the agents):

- *Ind*: agent representing the food industry *ind*. *Ind*'s interest is to discharge the wastewater where it is less costly, commonly into sewer system and if not into the nearest WWTP.
- *Sewer*: agent representing the transport of wastewater from industry to the nearest WWTP. In order to spill wastewater into this hydraulic infrastructure, *Ind* needs an authorization which limits both the quantity and quality of the spill.
- *Wwtp1*: agent representing the nearest WWTP to *ind*. This facility cannot nitrify/denitrify properly. Its goal is to spill treated wastewater below legal limits.
- *Wwtp2*: agent representing the nearest WWTP to *wwtp1*. It is able to nitrify/denitrify. The goal of *wwtp2* is also to spill treated wastewater below legal limits.
- *River*: agent representing the final receiving media of treated wastewater. This agent represents the river's interest which is to reduce the damage of the arriving discharges.

Usually *ind* spills wastewater into the sewer system. In this scenario *ind* arrived to a critical situation in which it has to discharge a considerable amount of wastewater (*w*) with high concentration of nitrogen not allowed to be spilled into the sewer system. On the assumption that agents are social and benevolent, before undertaking any action that may affect other agents of the system, agents deliberate over the appropriateness of their intended action. Therefore, in this case, the deliberation process starts when *Ind*, guided by MA, proposes an action in the form of the argument:

A₁: Industry *ind* has to discharge the wastewater *w*; and no contraindications are known for spilling *w* into *wwtp1*. Then *ind* can discharge *w* into *wwtp1*.

A₁ is an argument instantiating scheme AS₁ of ASR captured in Table 1 (note that words in bold upper-case represent variables while bold lower-case represent constants –instantiated variables–). The argument is valid, and therefore distributed to the agents immediately affected by the intended action, *i.e.* *wwtp1* and *river*. These agents are then directed to question the validity of A₁, via its associated CQs (see Table 1). In particular, *wwtp1* can follow the CQ: —*Is there a load L of a substance S in wastewater W that the WWTP cannot assume?*— in order to submit:

A₂: Discharge *w* of *ind* contains a load *l* of *nitrogen*; and load *l* of *nitrogen* is untreatable by the *wwtp1*. Therefore *ind* should not spill *w* into *wwtp1* (see Fig. 2a)

Table 1. Fragment of the schemes in the ASR

Scheme ID	Scheme description	Critical question ID	Critical question
AS ₁	Industry I have to discharge the wastewater W And no contraindications are known for spilling W into a WWTP , Then Industry I can discharge W into a WWTP	AS ₁ _CQ ₁	Is there a load L of a substance S in W that the WWTP cannot assume?
		AS ₁ _CQ ₂	Is there a condition C of the WWTP that prevent from discharging the spill S ?
		AS ₁ _CQ ₃	Are there meteorological conditions MC that difficult the discharge of spill S ?
AS ₂	Discharge W of industry I contains a load L of a substance S And load L of a substance S is untreatable by the WWTP Therefore I should not spill W into WWTP	AS ₂ _CQ ₁	Is there a course of action A to treat load L of substance S in order to reduce damage on the river R ?
AS ₃	If WWTP1 bypasses W to WWTP2 , And WWTP2 can treat the load L of substance S of wastewater W Therefore, river R will not result in a harmful condition H	AS ₃ _CQ ₁	Will load L of substance S in wastewater W be reduced to a <i>safe</i> concentration?
AS ₄	If following course of action A , And WWTP2 can reduce the load L of substance S of the wastewater W into a level of load L' of substance S' , Therefore the load L' of substance S' will not represent a harmful situation H for river R	AS ₄ _CQ ₁	Is load L' of substance S' harmful for the river R ?
AS ₅	Given circumstances C And a spill containing a load L' of substance S' Therefore load L' of substance S' can cause damage D to the river R	AS ₅ _CQ ₁	Is there a course of action A to prevent damage D to the river R ?
		AS ₅ _CQ ₂	Is there a course of action A to treat damage D to the river R ?

Now, A₂ is itself subject to critical questioning by the proponent agents. And thus *wwtp1* may propose an alternative course of action via a new argument:

A₃: If *wwtp1* bypasses *w* to *wwtp2*; and *wwtp2* can treat the load *l* of *nitrogen* of *w*.
Therefore, *river* will not result in the harmful situation *death_of_fishes*.

If MA deems A₃ to be a valid argument, stronger than A₂, the initial argument A₁ would be a winning argument (see Fig. 2b). And thus, Ind's proposed discharge would be deemed as appropriate. Now, again A₃ is subjected to critical questioning by the proponent agents, including *wwtp2*. In particular MA will direct *wwtp2* to question whether it can assume *w*. Assuming that *wwtp2* agrees with A₃, *river* may still challenge A₃ (see Fig. 2c) via the CQ: *Will load L of substance S in wastewater W be reduced by WWTP2 to a concentration that is environmentally safe for the river?*

In order to defend the proposed action appropriateness, *wwtp2* will have to answer this challenge (see Fig. 2d), for example, by submitting the argument:

A₄: If following course of action *nitrify_denitrify*; *wwtp2* can reduce the load *l* of *nitrogen* of the wastewater *w* into a level of load *l'* of *nitrogen*. Then the load *l'* of *nitrogen* will not represent the harmful situation *death_of_fishes* for river *R*.

To which, the agent *River* may answer with the following counterargument:

A₅: Given circumstances *temp_high* and *pH level*; and a spill containing a load *l'* of substance *nitrogen*, therefore, can cause damage *death_of_fish* to the river *R*.

Once the argument graph is constructed the MA has to determine which the *winning* arguments are. Note that in this example (see Fig. 2), arguments *A₂* and *A₃* mutually attack each other, as well as *A₄* and *A₅*. This bidirectional attack is an impasse for deciding whether argument *A₁* should be accepted or rejected, and so, whether the spill is environmentally safe or not. In order to resolve this impasse, the MA assigns strength to the arguments. In that way, if *A₂* is deemed stronger than *A₃*, or *A₅* stronger than *A₄*, the proposed action would be deemed inappropriate. However, if the MA deems both *A₃* stronger than *A₂* and *A₄* stronger than *A₅*, *ind's* spill would be deemed appropriate (see Fig. 2e). The MA derives the arguments' strength from the consented guidelines (GK), the gathered experience (CBRe) and from the role of the agent's submitting the argument (ASM). In this example, we assume that *Wwtp1's* proposed action (to bypass *ind's* spill to *wwtp2*) is consented by the guidelines and that no undesirable side effect resulted from this action is recorded in the CBRe. Thus, argument *A₃* is deemed stronger than *A₂* by the MA. Hence, deciding whether *ind* can spill its wastewater into *wwtp1* involves determining whether argument *A₄* is stronger than *A₅* or vice versa. That is, whether the concentration of ammonia *wwtp2* estimates to discharge to the river is environmentally safe or not.

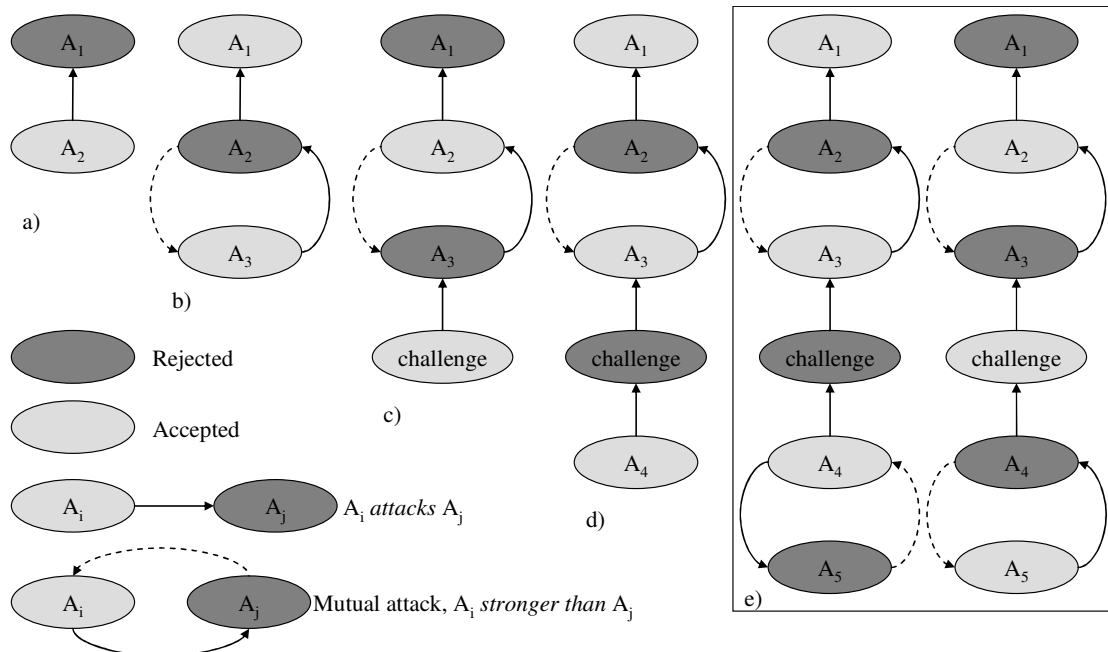


Figure 2. Argument graph that captures the moves in a dialog over the appropriateness of an industrial wastewater spill into a WWTP.

While the MA will derive from the GK resource that *wwtp2* can reduce the load *l* of **nitrogen** below legal limits (*i.e.* A_4 is stronger than A_5), from the ASM resource, the MA will derive that on matters regarding safety of the *river*, *river*'s arguments are more reliable than those of *wwtp2*'s, and thus A_5 should defeat A_4 (see Fig. 2e). Finally, the CBRe will provide an assessment over the arguments' strength on the basis of previous similar experiences. Thus, depending on assessment of the knowledge resources and the degree of confidence in their assessment, the MA will determine that A_5 is stronger than A_4 , and so, the spill is unsafe, or that A_4 is stronger than A_5 and so, the spill is safe.

If A_1 is finally deemed as a *winning* argument, the agents' proposed course of action is deemed appropriate. However, if A_1 is rejected, an alternative course of action will have to be proposed for treating *ind*'s wastewater that avoids environmental damage.

CONCLUSIONS

Climatic and hydrological conditions, combined with demographics, motivate the use of decentralized agent-based institutions for water management in a river basin. In particular, wastewater management in a river basin dimension concerns several agents that may put together their interests that may be in conflict. In reference to the quantity and quality of industrial wastewaters, they often meet critical situations in which a quick, efficient and informed decision must be taken in order to minimize the impact to the receiving media (namely here the sewer system, the WWTP or a river). Managing such systems requires integrated methodologies able to cope with this complexity, usually characterized by the uncertainty or approximate knowledge of biological and ecological systems.

In this paper we have briefly described the theoretical model *ProCLAIM* that enables an efficient exchange of information as well as an argumentation process over this information to support decision making in the above mentioned situations. This framework allows an increase of communication and interaction between the participating agents and consequently to reach a more justified and consensued decision. The argument schemes and CQs encoded in the ASR should allow the proponent agents address all the relevant issues with respect to the matter under debate, such as important climatic events (rainfall variability, seasonal temperature, *etc.*) and other frequent scenarios such as the availability or not of storage tanks, bypass channels, *etc.* Moreover, thanks to the organization and structure of information the time in decision making can be reduced. For these reasons, besides developing in detail the nitrogen scenario, we will focus the future work on the construction of an Argument Scheme Repository in order to undertake an effective based dialog over agents involved in river basin management.

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