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The Advantages of Using a Computer-Based Integrated Assessment to Promote Cooperative Behavior in Groundwater Management

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The ultimate goal of environmental impact assessment is to guarantee that benefits generated by a development project will not cause highly negative effects on the environment or public health. The fulfillment of this goal depends on the willingness of proponents and society to cooperate. The information management, its accessibility to community and the educational level of participants are of great relevancy too. Cooperation is not always attainable due to conflicts between individual and community interests. Conflict leads to a variety of cooperative and non-cooperative responses, depending on the information available to the actors. In order to capture the tendency in which a community perceives the proposals, we introduced an information index. We prove that computer models have a direct impact on this information index. This computer-based approach, leads the EIA to the paradigm of adaptive environmental assessment and management. To implement this, a system based on artificial intelligence and game theory was used to resolve a study case of conflict in groundwater management.

Keywords: Environmental Sociology; Environmental Management; Artificial Intelligence; Optimal Management; Game Theory

Introduction

Societies have become more participate and aware of the effects that the environment suffers as a consequence of development projects. As a result, the question of how development should be conducted to assure sustainability and society cooperation arose. In order to anticipate and avoid negative consequences derived from any development project, environmental impact assessment tools, EIA, were created (Pérez-Maqueo, 2004).

The main objective of the EIA is the evaluation and prediction of the positive and negative effects that a project may have on the environment. For this purpose, its proponent is compelled to assess the possible environmental consequences it may cause. Although society may participate directly in the evaluation of these assessments, the decision to approve the project rests, in most cases, with authorities. But EIA is much more than a predictive tool. Given the intrinsic quality of EIA as a forum for public participation, and as a consensus tool for decision making, it is regarded as a valuable route to sustainability (Lawrence, 1997). Furthermore, it is considered the best control option for projects that cannot be easily regulated through legal standards or land use plans (Pérez-Maqueo, 2004).

A cooperative behavior between proponents and society members is an indispensable condition to reach the optimal benefit for every part. In the best case, this agreement should not only consider the interests of directly involved parties, but also those of other sectors of society, including future generations. Developers must carry out a reliable EIA, and society must develop confidence in it, otherwise, a non-cooperative behavior could emerge due to distrust among them (Pérez-Maqueo, 2004).

Unfortunately, cooperation is not always possible because individual and community interests may be in conflict. For instance, in order to save money, a proponent could hide or fail to acknowledge the negative effects of a project. Other sectors of the society could exaggerate the importance of the environmental impacts of it to obtain overcompensation (Pérez-Maqueo, 2004).

If these non-cooperative behaviors occur, short and medium terms conflicts come about. Decisions may be made outside the EIA framework, and influenced by external interests. If this non-cooperative situation prevails, the investment could plunge into uncertainty, the development could be constrained and the confidence in EIA lost (Pérez-Maqueo, 2004).

As the complexity of interactions in socio-ecological systems grows, the successful management becomes a more difficult task. Traditional approach of EIA's concentrates on technological development (hard path) as the only solution to environmental problems. On the other hand, adaptive management which addresses directly the links between social and ecological systems, is now recognized as a promising alternative approach. This emerging approach incorporates the stakeholders in the decision process, making this so called "soft path" require special tools to facilitate collaboration between experts and stakeholders (Magnuszewski et al., 2005).

To meet the new challenges of sustainability, assessment must be able to integrate: multi-objective and multi-agent problems, social and natural sciences, multiple scales of analysis, models of the system components and the use of multiple decentralized databases (Jakeman and Letcher, 2003). In the particular case of groundwater highly sophisticated models are required and for most multi-objective optimization problems, there are no satisfactory deterministic algorithm available. By contrast, genetic algorithms (GA) have been proved to be highly suitable for this task (Back, 1995; Fogel, 2006). Therefore the main objective of this paper is to explore under what conditions cooperation emerges and how the combination of resource modelling and optimization would be used to improve this emergence. We also highlight the importance of information in the decision making processes.

When EIA's Fails

In recent years, the federal government in México was planning to build a new international airport in the vicinities of México e City. Authorities announced that after analyzing all sites suited to build the airport, they had concluded that only two satisfied the technical requirements. First, the problem was perceived as a stag hunt game, while for environmental associations it became a matter of concern for the probable environmental impacts it could generate. The government decided to conduct a comparative study between both locations, to improve their credibility in the decision making process. Academic institutions were invited to perform an environmental diagnostic evaluation (not an EIA). Experts reported that both sites would be subjected to similar environmental costs. The final site was chosen then, considering the technical, aeronautical and economic viability of the project. Nevertheless, as social aspects were neglected in the analysis, once the results of the study were made public, local inhabitants protested against the project arguing land propriety and low compensation prices. They stated they would not move from the site. The conflict generated different ways of protests: blocking highways, decision-makers kidnapping, violent and armed confrontations, wounded people and even the death of one of the project's opponents. Although the government increased the compensation payments, no agreements were reached. Finally an alternative location to get on the project was looked for.

It has been stated (Wathern, 2001) that EIA possess several flaws which render it to fail. They were becoming increasingly lengthy and unwieldy as a result of some kind of "measure everything" syndrome. They are deficient as an impact predicttion tool because of the highly dynamic disposition of natural systems, not to mention that the technical nature of EIA's reports break down communication between EIA's personnel and decision makers or society.

As discussed by Alshuwaikhat (2005), despite the existence of good EIA guidelines and legislation, environmental degradation continues to be a major concern in developing countries. In many cases, EIA has not been effective due to legislation, organizational capacity, training, environmental information, participation, diffusion of experience, donor policy and political will. EIAs have not been able to provide environmental sustainability assurance (ESA) for these countries (Sadler, 1999). This failure and the inherent limitations of EIA lead to the consideration of strategic environmental assessment (SEA). It is the proactive assessment of alternatives to proposed, in the context of a broader vision, set of goals or objectives to assess the likely outcomes of various means to select the best alternative(s) to reach desired ends (Noble, 2000).

As a response to these alleged weaknesses, much effort has been made to achieve an integrated assessment (IA) such as the adaptive environmental assessment and management approach (Holling, 1978). It combines different academic disciplines to obtain concise data based predictive knowledge that provides useful input for decision makers as noted by (Rotmans & Dowlatabadi, 1997; Rotmans, 1998; Toth & Hizsnyik, 1998) and (Sluijs et al., 2001; Van Asselt & Rijkens-Klomp, 2002).

In this IA framework, small workshops can be used to get together scientists, decision makers, society representatives and computer modeling experts. The goal is that participants reach a consensus on the important features and relationships that characterized the system under study. This must be achieved in such a way that the fundamental interrelations of social and natural processes appear transparent to all, scientists and non-scientists (Siebenhner, 2004).

Particularly in the IA of very complex systems, such as climate change or groundwater, computer models are the dominant means of scientific knowledge production. They have demonstrated suitability to accomplish a common understanding of environmental-social problems, analyze the causes and impacts of the problems, explore and examine management options and support the formulation of objectives and restricttions (Tuinstra et al., 1999; Hisschemller et al., 2001). But even in more simple systems, compared to human experts, computer models are often reckoned as more comprehensive and reliable, which usually improve the perception that society has of a project (Siebenhner, 2004).

A Computer-Based IA for Groundwater

Groundwater is the most intensive extracted natural resource nowadays, it provides around 70% of drinkable water in the European Union and more than 50% in the rest of the world. It is the corner stone of the Asian's "green revolution", sustain wide rural areas in the subsaharian zone and more than 1200 million people living depend on it in cities all over the world (Zektser & Margat, 1997; Stephen et al., 1998; Burke & Monch, 2000).

Let us picture that the groundwater management authority in México's National Water Commission (CNA), desired to design a sustainable policy plan, in order to avoid overexploitation, for an aquifer with considerable extraction and for which society's demand is expected to grow in the near future.

Since a couple of decades ago, long term planning for groundwater management has been carried out with computational modeling (Routh, 1877; Bennet, 1979; Jones et al., 1987) in which optimization techniques have become more common as time goes by. Nevertheless, as the underground flow is governed by second order partial differential equations, its control is hard to calculate and management issues are even harder to respond to because of their multi-objective and multi-constraints nature. For this real world problem, no deterministic algorithm seems to be fast and robust enough to be used; instead, genetic algorithms or more generally, evolutionary computation, have proved to be most adequate (Andrei, 2004b; Bellman, 1957; Das & Datta, 1999a).

Considering the above, we coupled a standard open source groundwater modeling software MODFLOW (USGS, 2008) with a free software genetic algorithm optimization tool GA-toolbox (Sastry, 2006) and a game theory analysis free software Gambit (McKelvey et al., 2007). We call this implementation as Natural Resources Optimal Management System: SMORN. It can resolve a multi-objective optimal control problem, with m constraints for groundwater flow. To illustrate the SMORN capabilities, we used real data from Duero's river basin in Michoacan México. We aimed a three objective function problem: maximize the total water extraction, minimize the mean drawdown and minimize the mean drawdown velocity. The first objective function is clearly designed to obtain the maximum benefit from the aquifer, meanwhile the second and third seek to lower aquifer impacts and possible subsidence problems. SMORN optimization converges to four different types of optimal solution: the first one corresponds to an extraction privileged type of solution; the second, privileges the aquifer conservation and the two others offer an intermediate solution where extraction and conservation are in equilibrium.

These normalized values could be interpreted as payoffs for a hypothetical player that pursues to take the most profit from a specific objective function. Considering the results presented, a CNA's authority could increase the possibility for aquifer cooperation, but even in that case, what type of solution should be implemented? Since genetic algorithms provide Pareto front solutions indistinguishable from the optimization point of view, the best answer to the question could seem choosing the one that privileges extraction. However, the authorities have also to consider those sectors of society that could protest against that posture, so what should be done? Consider this as a game of four players, being: a management authority (*admin*); aquifer users (*user*); a sector of the society concerned mostly with aquifer conservation (*aquifer*); and a player that personifies chance (chance). Bearing this in mind we construct payoffs as follows: User's payoffs are conceptualized as the proportion of water extraction permitted by the authority taken from the maximum normalized water extraction rate; Aquifer's payoffs are calculated by the grade of conservation contemplated in the management policy adopted by the authority, considering the mean drawdown and mean drawdown velocity control; Admin's payoffs are conceptualized as the image perception from each part of this hypothetical society.

We use Gambit free software to analyze the game proposed as shown in **Figures 1** and **2**. The first move is made by admin, who mostly decides if a management plan must be implemented or not. If admin decides not to implement a management plan, then an arbitrary use of aquifer takes place; situation in which user can decide whether to continue the actual exploittation of the aquifer or make an undefined change. In the first case payoffs are calculated from original water extraction rates data; in the second one no payoff can be assigned due to uncertainty.

Conversely, admin could decide to implement a management plan, in which user may cooperate or not, this is represented as a chance move with a probability of occurrence called convincing index. If user does not cooperate, like in the preceding case, two options arise: user may continue with the current use of the aquifer or make an undefined change. In case user cooperates, then four types of optimal calculated solutions are available for selection. Finally it takes place a chance move with a probability called confidence index.

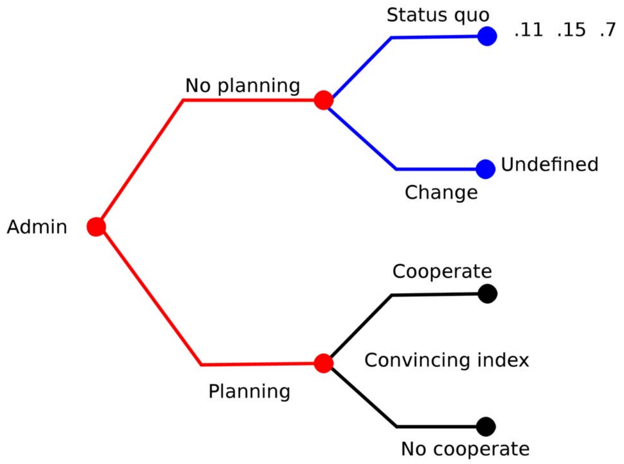

Figure 1.
First part of the extended game that represents the decision making process for this problem where conflicted interests compete. The order in the payoffs is admin, user and aquifer. Color red is for admin, blue for user and black for chance.

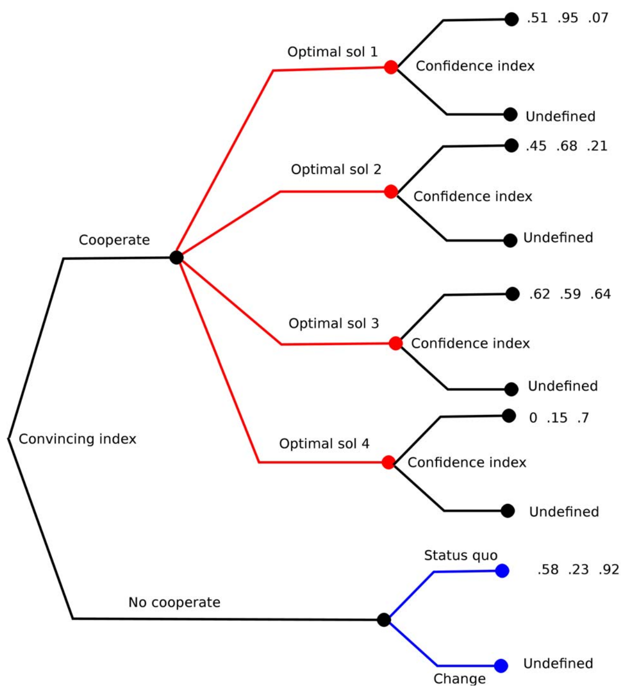

Figure 2.
Second part of the extended game that represents the decision making process for this problem where conflicted interests compete. The order in the payoffs is admin, user and aquifer. Color red is for admin, blue for user and black for chance.

Being the game as described, we calculate the Nash equilibria for the strategic associated game to find the optimal strategies for all players. In game theory, a Nash equilibrium is the set of strategies obtained when the total payoff of no player increases unless another one changes his strategy. In this example two types of Nash equilibria are found. The first kind is characterized by admin choosing not to plan and user maintaining current use of aquifer. In the second type, admin chooses to plan, while the proportions of users that cooperate choose the optimal solution number three, and the part that does not, continues with the current use of the aquifer.

When convincing and confidence indexes are small both types of Nash equilibria are presented but if one of these is greater than .5 then only the second type is found. On account of this, the Information index is defined as the product of the convincing and confidence indexes that represents the quality of the project's information, the way in which it has been displayed and the grade of confidence that society has over the proponent and authorities.

In this way we could evaluate the emergency of cooperation in function of the Information index. This kind of game theory analysis seems to be very useful in conflict scenarios, but that it only provides the best solutions must be recalled. That is a second benefit of Pareto solutions, for having a wider range of solutions provides a great opportunity to negotiate in case some users show themselves reluctant to cooperate with the optimal solutions.

Discussion

In each case EIAs are regulated under norms and rules enforced by a central authority who decides whether the implementation of a project is suitable or not, based on environmental, economic and social terms. In this way the central authority ensures law will be applied if the proponent defects, increasing users confidence. However cooperation could be at risk cause, even though coercion could avoid the trust dilemma, it is important to remember that a coercive force is useful as long as defectors are efficiently punished by the authority (Ostrom et al., 1999). Unfortunately there are many cases in which the institutional capacity to monitor the restrictions incorporated by the authority is not adequate, and leaves non-fulfillment of conditions without sanction (Pardo, 1997). On the other hand, sometimes (for example in public projects) government is perceived as the interested party on top of both, proponent and society, and not as the referee.

The success of EIAs also depends on how reliable is the communication between the society and the proponent. In this sense, communication based on a formal quantitative and scientific analysis that allows an estimation of probable effects, has several advantages (Porter, 1995). According to Suter (Suter, 1993) amongst these advantages are the ability to establish the basis to compare and prioritize risks; a greater credibility in EIAs; the chance to focus on the assumptions and the data on which the predictions are made; and to separate the scientific process of estimating magnitude from management decisions (risk management). Following Sinclair and Diduck (Sinclair & Diduck, 1995) who emphasize that education is a precondition to advance public involvement, we consider vital to improve the understanding society has on the role of EIA's. In addition, Schenider (Schneider, 1997) states that society requires literacy about how scientific and decision making elements interact.

The worst scenario appears when society defects even if the proponent is willing or compelled to cooperate. Even if, as a suboptimal payoff, mitigation or compensation measures are imposed, a cooperative behavior from society cannot be expected, rendering the above tools limited.

Within the theoretical development of game theory, some solutions have been proposed for situations in which defection seems the most rational choice. A recommended way to cope with these cases is to restructure payoffs using transfer payments or others means, so that the affected sector sees the outcome as equitable (Lejano & Davos, 1999). However, the major drawback is when, even if the proponent cooperates, for example by compensating the affected sectors, they reject the proposal in order to gain an overcompensation (Pérez-Maqueo, 2004). Nash (Nash, 1950) suggested a reviewing scheme to avoid cases in which one of the parties involved tried to get additional benefits. The aim of this scheme is to maximize the benefits of each party by means of arbitration. Once parties reach an agreement, a contract could be celebrated. This contract should contain all concerned issues like mitigation measures, monitoring programs and compensations discussed previously. They could also be complemented by environmental assurance bonds (Pérez-Maqueo, 2004). These bonds should guarantee the rights of proponent and society under conditions of uncertainty (Costanza & Cornwell, 1992). Let us consider that the proponent agrees to make a financial deposit to cover any damage the project could generate on the environment. If such damage occurred, then the bond would be used to compensate the affected segment of society. If there were no damage, then the bond would be returned to the proponent, with the interests accumulated along that period.

Certainly, the above tools and recommendations do not guarantee that cooperation will emerge in each project (or in terms of game theory in one shot game). However they can still be useful if both, cooperation and defection, are behaviors that could spread or influence other segments of society. In this sense, one of the main issues is to understand how cooperation could be achieved in situations where individual interests are at odds with common welfare. One of the hypotheses is that cooperation could be attained by convincing the parties of the benefits of indirect reciprocity (Nowak & Sigmund, 1998). Simulation models and computerized experiments (Millinski et al., 2002) show that cooperation pays off by means of indirect reciprocity because this behavior increases the chance of receiving a cooperative response from others. Although, in a one shot game society may not reciprocate the cooperative behavior from proponents, it would confer them reputation for new projects. In addition, reputation is an important asset that is positively correlated with cooperative actions among players in our society (Millinski et al., 2002). The recent implementation of environmental management system (EMS) such as Eco-Management and Audit scheme, ISO 14000 and BS 7750 and voluntary environmental compliance audits promoted by the Mexican's Environmental enforcement agency (PROFEPA), are examples of tools that enhance reputation and that operate independently from the authority enforcement. Society can also generate reputation, but it depends on how many of the segments of it are recognized as cooperative players that reach agreements with proponents. Possibly, in the future, proponents will endeavor to conduct their projects in sites where society satisfies this condition. And hopefully, the selective process between proponents and society will lead a fair development in the future.

Finally, we used a computer-based IA, which incorporates evolutionary computation and game theory, to promote cooperation. Cooperation dependency to a proposed Information index was analyzed. The information index is constructed to contemplate not only the quality of the information, but also the way in which it is displayed to society, as well as the confidence rapport over the proponent and authorities. We showed that cooperation can not be ensured unless information index is complete enough, which can be achieved by considering the following key points: 1) scientific approach to environmental problems and the use of computer simulation promotes cooperation but only if adequate translation is made to make this scientific knowledge accessible to all participants; 2) as information index includes proponent's credibility, mechanisms to track the reputation of participants like the mentioned above are highly recommended.

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