© IWA Publishing 2002 Journal of Hydroinformatics | 04.3 | 2002

Multicriteria analysis for choosing wastewater sewerage solutions

Jérôme Le Gouévec and Olivier Blanpain

ABSTRACT

Today, more and more French communities have a critical point of view concerning the performance of their wastewater sewerage systems. The main reason is linked to the methodology of the studies in the design phase. The process is neither adapted to the complexity of the decision-making task, nor to a general management of the wastewater sewerage in a territory. In order to make these studies more coherent and the choices more rational, we propose a new formulation of the methodology as an alternative to the current one. Our approach relies on decision-making support which borrows concepts from expert systems and multicriteria analysis in order to structure the reasoning process and to take into account the very different criteria a real decision-making task often implies. We show that this support has to be interactive and iterative in order to ensure that coherent and relevant solutions are chosen.

Key words | decision-making, systemic modelling, multicriteria analysis, ELECTRE, waste water sewerage

Jérôme Le Gouévec
Olivier Blanpain (corresponding author)
Laboratoire de Mécanique de Lille, EUDIL, Dpt
GTGC, Cité scientifique,
59655 Villeneuve D'ascq, France
Tel: +33 3 20 43 46 10;
Fax: +33 3 20 43 46 10;
E-mail: *olivier.blanpian@eudil.fr*

INTRODUCTION

Due to the French water law of 1992, each community is compelled to install appropriate wastewater sewerage systems before 31 December 2005. Within this context, a preliminary zoning study (which is a part of a sewerage master plan) is generally carried out. Its principle is based on the analysis of the existing infrastructure (in terms of performance towards purification of the effluents), followed by the division of the territory into sub-areas to be sewered by suitable collective and non-collective systems. These systems have to be well adapted to the local context of a community and to the constraints present in each sub-area. Yet the zoning study does not have an overall approach to the wastewater sewerage of an entire territory. Each sub-area is often considered independently from the others. The main consequence is a lack of coherence between the different solutions carried out, as well as doubts about the methodology of the study by several communities. Moreover, it is well known that choosing a wastewater sewerage solution requires consideration of different fields (hydraulics, legislation, safeguarding of the environment, etc.), but they are rarely all taken into account. A solution is very often justified on purely economic grounds.

Starting from these limits, we propose to redefine the methodological process of zoning studies. We seek a new modelling approach to the wastewater sewerage problem by means of the systemic approach. This modelling allows us to build a methodological decision-making support tool to help the decision-maker to choose the most acceptable solution to be carried out in each sub-area. This support is able to take into account the complexity of the process expressed through various selection criteria and interactions between sub-areas.

THE CURRENT PROCESS OF ZONING STUDIES

The objective of zoning studies is the definition of the needs in sewerage equipment. Given the diagnostic of the existing systems, this process can be synthesized into four main steps:

- The division of the studied area into sub-areas, taking into account population distribution, topographical constraints (slope, etc.), hydrogeological constraints (existence of ground water), geology, its ability to purify wastewater and constraints relating to the existence of a collective network close to the area (in the form of the connecting length).
- The study of the autonomous sewerage solutions (individual collection and purification of wastewater) on the basis of these constraints and on the basis of existing devices.
- The study of a collective sewerage solution (gravity-based) on sub-areas where an individual device cannot be installed.
- The economic comparison between autonomous and collective solutions if neither of these two approaches is applicable in its basic form (e.g. due to the need for a pumping station for the collective sewerage or the need for an appropriate ground for a specific individual device, for example).

The current process thus leads to an adjustment of the area, as Figure 1 illustrates.

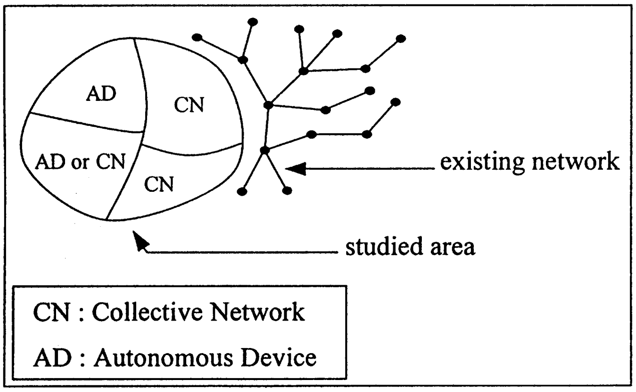

Figure 1 | Example of adjustment of an area by various sewerage types.

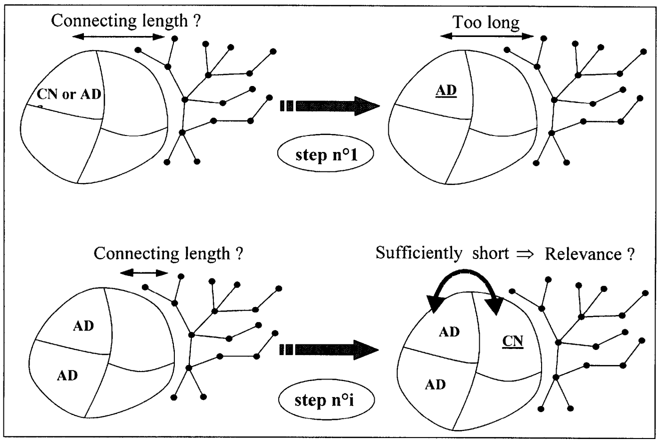

Figure 2 | How the relevance of some solutions can be called into question.

LIMITATIONS OF THE PROCESS

Deciding on the sewerage solutions sub-area by sub-area can call their relevance at the territory scale into question, as Figure 2 illustrates (Le Gouévec & Blanpain, 2001).

Let us first choose a sub-area taken at random, for which the implementation of an autonomous device or a collective network is proposed (see Figure 2). The connecting length is then evaluated (step 1). As the suggested length is too long (a value greater than 25 or 30 m is generally not allowed), the autonomous device will consequently be chosen. During a subsequent step (step i), if the same scenario is met in a sub-area closer to the existing network than the previous one, the connecting length can be considered to be sufficiently short to carry out a collective network. But, if at this point of reasoning we examine the choices of the sewerage solutions, we can notice that the autonomous device is not relevant any more, considering the distance to a network. Initially supposed too long, the connecting length is reduced because of the development of the collective infrastructures in a neighbouring sub-area. From now on, this kind of system could consequently be preferred in the sub-area characterized by an autonomous system.

Besides, the objective of the zoning study is to seek the best solution on each sub-area. This is possible to achieve when the reasoning is based on a single criterion, such as the economic one, for example. But in the case of an evaluation of different solutions requiring various criteria, the current methodology fails, particularly when some of them are in opposition.

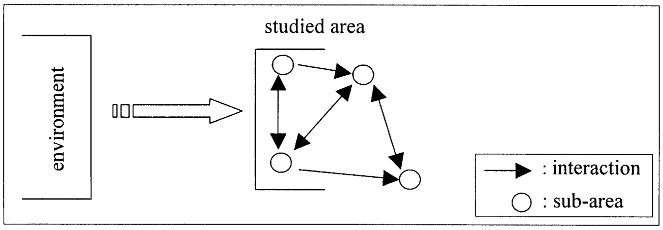

Figure 3 | Modelling of the system represented by the studied area.

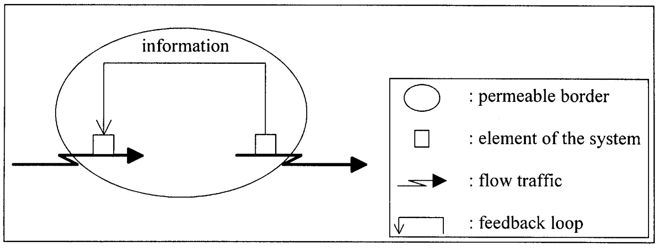

Figure 4 | Organization of the complex system based on the fourth level of the nine level model archetype.

Finally, if some solution proposals coming from the zoning study are different from those of the decision-maker, the methodology is not structured to solve conflicting choices. Which proposition is a good one or a bad one? Such an analytical process cannot answer these questions.

MODELLING OF THE SEWERAGE PROBLEM

Given the division of the territory into sub-areas, we want to describe the way it works with respect to its environment. The area is represented like a system. Based on the systemic approach, this system is characterized by four aspects (Durand 1998):

- Its *complexity*, due to the particular relationship between the elements of the system (interactions between sub-areas).
- Its *opening*, that is to say its relationship with the environment.
- Its *entirety*: priority is given to the description of the interactions between its elements more than to the structural description of each of them.
- Its *organization*, which expresses the way the interactions are organized.

The complex system shows properties not present in the elements (the sub-areas) from which it is build (Clergue 1997). The concepts of opening and entirety can be represented as shown in Figure 3.

The modelling of the organization is based on the fourth level of the nine level model archetype developed by Le Moigne (1999), related to the category of 'machine type systems' (Figure 4).

According to Figure 4, the choice of a solution is not a linear process. Due to feedback connections between sub-areas (i.e. the elements of the system), the systemic modelling of the studied area involves a methodology for choosing relevant sewerage solutions which has to take into account choices that can be called into question.

METHODOLOGY

Presentation

Figure 5 illustrates the decision-making support (Le Gouévec 2001). At each sub-area scale, three wastewater sewerage types are taken into account (Berland 1999). Firstly, we can find the Autonomous Device (AD) which individually collects and purifies the effluents (each dwelling uses its underground area for purification). Secondly, we find the Semi-Autonomous device (SA) where the effluents are separately collected from each dwelling and treated with a common treatment device (a part of the collective underground is used for this). Thirdly, the last sewerage type is the Collective Network (CN) which separately collects the effluents into a treatment device which involves chemical processes instead of the capacity of the underground.

The *first stage* consists of determining the technical feasibility of each wastewater sewerage type in each sub-area considered independently from other sub-areas. This stage does not take into account any interaction between the sub-areas. Each technical feasibility is evaluated by means of a set of conditional instructions noted as (1), (2) and (3) in Figure 5.

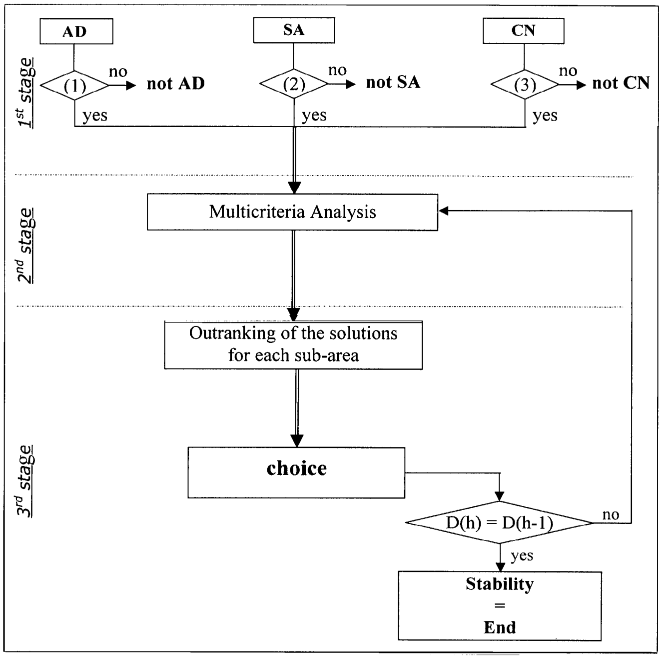

Figure 5 | Synoptic of the decision-making support.

Table 1 | Constraints related to the autonomous device (AD)

Constraints
Surface available
Adjustment of private space
Use of private space
General slope
Permeability coefficient
Depth of permeable substratum
Depth of impermeable substratum
Depth of ground water

Table 2 | Constraints related to the semi-autonomous device (SA)

Constraints
Surface available
Adjustment of private space
General slope
Permeability coefficient
Depth of permeable substratum
Depth of impermeable substratum
Depth of ground water

Table 3 | Constraints related to the collective network (CN)

Constraints
Residual capacity of the existing network
Residual capacity of the existing treatment device

Once a sewerage type is considered technically feasible, it becomes a potential solution. The *second stage* consists of the evaluation of different solutions in a sub-area using a multicriteria analysis. The relevance of each solution is evaluated with the help of a set of criteria and by additionally taking potential interactions between some sub-areas into account.

On the basis of these evaluations, the *third stage* consists of outranking the potential solutions. They are sorted from the best to the worst, according to the decision-maker's preferences. Once the decision-maker is given each outranking (one per sub-area), he has to make his own choice. Either he can choose the solution coming first (the outranking is validated) or not (the outranking is rejected). This stage is interactive and iterative.

The individual stages are outlined below.

First stage: definition of potential solutions for each sub-area

This stage of the methodology must be able to create a well-codified structure of reasoning, in contrast to the variability often observed in practice. It does not yet imply an intervention of the decision-maker and does not take into account economic constraints. The reasoning mechanism is funded on proposals {IF . . . THEN . . . ELSE}. Given a specific sewerage type, we must know if the statutory constraints presented in Tables 1, 2 and 3 (STU 85) can be enforced with regard to the corresponding data collected on each sub-area. If so, the solution can potentially be carried out. Otherwise, it will not be evaluated in the following stages.

For example, let us consider the autonomous device:

- if the surface available is greater than 600 m^2 (for one dwelling),

- if the adjustment of private space is correct (the dwelling was built such as there is enough place to install this device),
- but if the use of private space is such that a part of it cannot be devoted to the purification of the effluents (in the case that the private space could be taken up by a garden or trees, for example),

then this solution could not be potentially carried out because of this lack, even if the general slope and the ground conditions should have been respected.

Second stage: evaluation of the potential solutions on each sub-area

Once the sewerage solutions (AD, SA and CN) are considered to be potentially feasible for each sub-area, they have to be evaluated in order to choose which one will be effectively carried out. A proper method of evaluation, including a set of different criteria, has to be chosen.

Choice of method

Two families of methods are usually distinguished (Mareschal 2000):

- the monocriterion methods, in which a mathematical function synthesizes the multidimensional aspect of the problem. A parametric function $U = F(g_1, \ldots, g_i, \ldots g_n)$ is built, where g_j $(h = 1 \ldots n)$ represents the different criteria. For example, we can quote the weighted sum;
- the multicriteria methods, based on taking into account all the dimensions of the problem. In this case, the chosen solution is considered as the most acceptable.

Regarding the evaluation of two solutions, the monocriterion methods are often unable to translate hesitation or uncertainty, which generally characterize the real decision-making situations with which a decision-maker is faced. Moreover, this family of methods is unable to take into account both quantitative and qualitative criteria (Belton & Pictet 1997).

Conversely, multicriteria methods were originally conceived in order to assist a decision-maker when he has to evaluate various alternatives in the presence of multiple criteria, even if they are conflicting (Ruscassier-Chadirat & Deutsch 2000). These methods completely lie within our sewerage problem. That is the reason why we chose to evaluate the potential solutions on each sub-area with multicriteria analysis.

Among the multicriteria procedures, ELECTRE is a family of methods relying on the concept of outranking (Maystre *et al.* 1994). Within the framework of an aid for choosing sewerage solutions, our aim was to provide the decision-maker with an outranking of these solutions from the best to the worst. For this kind of problem, three methods are relevant: ELECTRE II, ELECTRE III and ELECTRE IV.

Moreover, considering that each criterion does not have the same importance to the decision-maker (an environmental criterion can be more important than an economic one), weighting coefficients have to be allocated to the criteria used for the analysis. Since the ranking procedure developed by ELECTRE IV considers every weighting coefficient equal to 1, this method was not adopted. Furthermore, we must keep in mind that a multicriteria approach is still not in widespread use among decision-makers. This is the reason why we did not want to use a multicriteria method which could be too complex. Because of the use of fuzzy logic, ELECTRE III reaches a level of complexity to such an extent that this method is not justified for a decision-maker who wants to learn to model his preferences by multicriteria reasoning. For all these reasons, ELECTRE II was preferred.

Outranking of potential solutions using ELECTRE II

ELECTRE II is a method that allows an outranking of the solutions from the best to the worst according to a set of criteria $\{g_j\}$. Table 4 lists those criteria that we have formalized. They are, in detail:

- $\{g_1\}$: choosing a relevant sewerage solution must take into account how the urbanization will be developed in the sub-area. For example, the choice of the AD is not relevant in the case of a short term increase in population density.
- $\{g_2\}$: the choice of a solution has a large influence on the current uses and vocations of the environment,

Table 4 | Outranking criteria for each potential solution

Criteria {g_j}
Adequacy with the housing expansion of the sub-area {g_1}
Safeguarding of the environment {g_2}
Financial cost {g_3}
Adequacy with the policy of sewerage management {g_4}
Adequacy with the sewerage of other sub-areas {g_5}

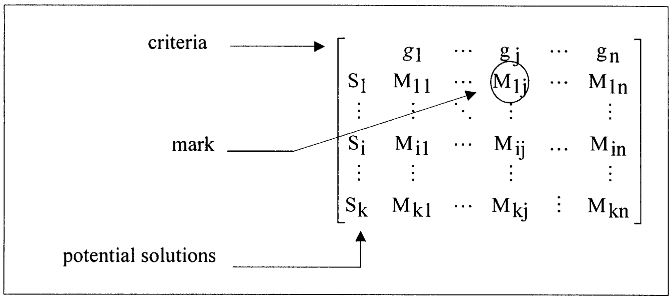

Figure 6 | General form of the decision matrix.

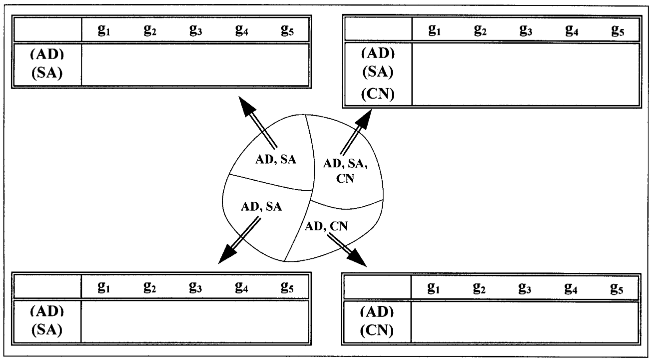

Figure 7 | Set of decision matrices for the studied area.

like fishing or swimming (Leon *et al.* 2000). But this choice also has to take into account wider purposes defined by legislation (e.g. a decrease in polluting flows).

- {g_3}: the financial cost is one of the most important constraints for a community. This cost must also include those for investment and operating (Jacquemin & Tulkens 1987).
- {g_4}: in practice, each sewerage type involves different constraints (relationship with the inhabitants, human and technical means of providing, etc.). The decision-maker has to make a choice in accordance with these factors if he wants to produce a relevant policy of sewerage management.
- {g_5}: with respect to the systemic modelling of the studied area (interactions between sub-areas), the choice of a sewerage solution has to take into account those solutions already selected for neighbouring sub-areas.

For each pair of potential solutions (S_i, S_k), ELECTRE II evaluates up to which level of certainty (weak or strong), the hypothesis 'S_i outranks S_k' is true in relation to all the criteria considered.

Firstly, a mark is allocated to each solution S_i ($i = 1 \ldots k$) in relation to each criterion g_j ($j = 1 \ldots n$), leading to a decision matrix (Figure 6).

In practice, if we look back at Figure 1, each sub-area will be characterized by a decision matrix as in the example given in Figure 7.

Secondly, the decision-maker has to express his/her preferences for some criteria with respect to the others by allocating (subjective) weighting coefficients wc_j to them.

Thirdly, the hypothesis 'S_i outranks S_k' is evaluated. It will be accepted if a condition of agreement and a condition of non-discordance are satisfied. Three thresholds c^-, c^0, c^+ ($c^+ > c^0 > c^-$), an index of agreement C_{ik} and two thresholds of discordance D_1 and D_2 ($D_1 > D_2$) have to be defined. C_{ik} expresses how much the hypothesis 'S_i outranks S_k' agrees with reality (where reality is expressed by the evaluation of each solution with respect to each criterion). In other words, we first want to know if the importance of the criteria for which S_i is preferred to S_k is sufficiently strong, and secondly if the importance of the other criteria (those for which S_i is not preferred to S_k) is sufficiently weak in order to keep the hypothesis acceptable: this is the role of D_1 and D_2.

The outranking is then constructed as following:

- The hypothesis 'S_i outranks S_k' is false if $C_{ik} < c^-$ or if there is not a weak certainty that some criteria {g_j} do not present a major opposition to the hypothesis ($M_{kj} - M_{ij} > D_1$).
- The hypothesis 'S_i outranks S_k' is true with a weak certainty if $C_{ik} > c^-$ and if there is a weak certainty

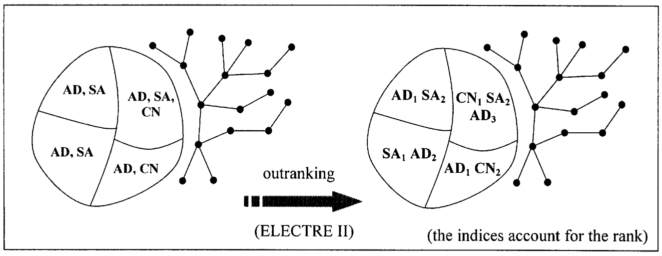

Figure 8 | Example of outranking in each sub-area provided by ELECTRE II.

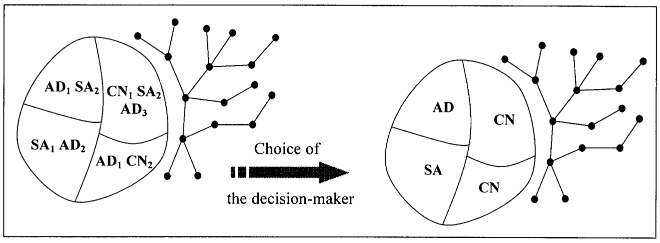

Figure 9 | Example of choices in the sub-areas.

that some criteria do not present a major opposition to the hypothesis ($D_2 < M_{kj} - M_{ij} \leq D_1$).

- The hypothesis 'S_i outranks S_k' is true with a strong certainty if $C_{ik} > c^+$ and if there is a strong certainty that some criteria do not present a major opposition to the hypothesis ($M_{kj} - M_{ij} \leq D_2$).

Finally, ELECTRE II provides a proposal, as Figure 8 illustrates.

Third stage: stability of the process at a large scale: the studied area

The outranking provided by ELECTRE II is not the result of the decision-making support. It only constitutes one step of the outranking process. Each proposal must be confirmed by the decision-maker, as we must keep in mind that the support we build remains a decision-making aid.

At a first step, the outranking is presented to the decision-maker. He has to choose only one solution for each sub-area. Two cases are possible:

- he chooses the solution outranked as the first and consequently validates the outranking;
- he rejects the proposal and keeps a solution not outranked as the best.

Whatever the case, the outranking provided by ELECTRE II is then substituted by the choice of the decision-maker (Figure 9).

The second step consists of studying the potential interactions between sub-areas. If the decision-maker chooses a collective network for a sub-area, then we assume the existence of an interaction between this sub-area and the neighbouring ones not equipped with this kind of system.

As a consequence, the solutions which have been chosen for the neighbouring sub-areas (AD or SA) are not potentially relevant anymore. A collective network could be more appropriate in certain sub-areas due to the existence of another one close to them. Their decision-matrix is thus modified. The evaluation of the solution 'CN' compared to the criterion 'Adequacy with the sewerage of other sub-areas' has to be reformulated. The outranking provided by ELECTRE II is thus called into question and a new one has to be proposed to the decision-maker so that he/she can judge if each choice made relies on a proposal (the outranking) not influenced by interactions between sub-areas.

The process will stop when the choice coming from the decision-maker at a step ($h + 1$) in each sub-area is the same as the one made at the step (h). In this way, the sewerage solutions chosen to be carried out are considered stable and final.

CONCLUSIONS

The current methodology used by the zoning studies shows several limitations. Their success is measured by the relevance and the coherence of the chosen solutions regarding the choice of wastewater sewerage systems. The process we formalized is not in opposition to this method. We simply sought to adopt another point of view by considering a studied area as a complex system. This system consists of a set of interacting sub-areas in relation to their environment. The choice of wastewater solutions has been divided into three stages: elaboration of potential solutions in each sub-area with rule-based systems, outranking of the solutions with multicriteria analysis (ELECTRE II), and finally, choice of the most acceptable one. The results allow the decision-maker to choose whether he/she wants to follow the solutions proposed by the methodology. More generally, taking support on this method does not involve any lack of coherence between solutions thanks to the iterative process that examines the stability of the choices. On the contrary, of the common approach of the choice (e.g. the weighted sum), the use of multicriteria analysis allows the decision-maker to justify their decision and to know the strength and the weakness of their choices. This must be underlined, because usually the decision-maker does not play a role in the elaboration of the solutions. The decision support we built seems to be essential to the current zoning studies, since the complexity of the sewerage problem often leads to a simplified approach which generates a gap between the needs and the solutions. But the methodology based on a complex approach of the problem is not specific to this kind of study. This approach can be adapted to other ones, as far as a general point of view is required and as far as the different elements of the problem can interact in the final decision (e.g. a planning problem).

ACKNOWLEDGEMENTS

The authors would like to thank the Artois-Picardie Water Agency, the Artois-Lys and SACRA communities for their financial support and for providing important interest in this research.

NOTATION

(1)	set of conditional instructions relating to AD
(2)	set of conditional instructions relating to SA
(3)	set of conditional instructions relating to CN
AD	Autonomous Device
CN	Collective Network
c^-, c^0, c^+	thresholds of agreement
C_{ik}	index of agreement
D_1, D_2	thresholds of discordance
$D(h)$	choice of the decision-maker at step (h)
g_j	criterion j
M_{ij}	evaluation of S_i to g_j
M_{kj}	evaluation of S_k to g_j
S_i, S_k	wastewater sewerage solution i, k
SA	Semi-Autonomous device
U	general parametric function.

REFERENCES

Belton, V. & Pictet, J. 1997 A framework for a group decision using a MCDA model: sharing, aggregating or comparing individual information? *J. Dec. Syst.* **6**(3), 283–303.

Berland, J. M. 1999 Normes: quelle influence sur les choix techniques dans les domaines de l'assainissement et de l'épuration? Comparaison France/Allemagne. *PhD thesis*, ENPC, France.

Clergue, G. 1997 *L'apprentissage de la complexité*. Hermès, Paris.

Durand, D. 1998 *La systémique*, *Que sais-je?* PUF, Paris.

Jacquemin, A. & Tulkens, H. 1987 *Fondements d'économie politique*. Universitaires, Paris.

Le Gouévec, J. 2001 Méthodologie d'aide à la décision: application à la mise en conformité des systèmes d'assainissement des collectivités de faible taille. *PhD thesis*, University of Lille I, Lille.

Le Gouévec, J. & Blanpain, O. 2001 Choosing technological solutions of waste water sewerage: a methodological tool based on expert systems and multicriteria analysis. *Adv. Design Sci. Technol.* Europia, Paris.

Le Moigne, J. L. 1999 *La modélisation des systèmes complexes*. Dunod, Paris.

Leon, C., Martin S., Elena, J. M. & Luque, J. 2000 Explore-hybrid system for water networks management. *J. Wat. Res. Plan. Mngnt.* **126**(2), 65–74.

Mareschal, B. 2000 A multicriteria approach to decision aid: new tools and applications. *Proc. 2nd Int. Conf. on Decision Making in Urban and Civil Engineering*, *Lyon, France* pp. 35–43.

Maystre, L. Y., Pictet, J. & Simos, J. 1994 *Méthodes multicritères ELECTRE*. Presses Polytechniques et Universitaires romandes, Lausanne.

Ruscassier-Chadirat, G. & Deutsch, J-Cl. 2000 Development and implementation of sewerage programmes: proposal of a methodology for the decision process. *Proc. 2nd Int. Conf. on Decision Making in Urban and Civil Engineering, Lyon, France*, pp. 639–642.

STU 1985 *Assainissement autonome eaux usées et eaux pluviales. Eléments pour un bilan technico-économique*. Report, Paris, France.