# Critical analysis of a multicriteria decision-aid method for the choice of urban drainage Systems

Analyse critique d'un jeu d'indicateurs pour le choix de systèmes d'assainissement pluvial urbain

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## RESUME

Nombreuses sont les possibilités de conception des systèmes de drainage urbain ayant recours à des techniques alternatives en assainissement pluvial. Castro et Baptista (2004) ont proposé un jeu d'indicateurs de performance basé sur des critères sociaux, environnementaux, sanitaires et hydrologiques, pour l'évaluation des systèmes de drainage urbain. Cet article présente les résultats de l'analyse critique accomplie pendant la validation du jeu d'indicateurs. Elle est basée sur deux approches : l'une concerne l'évaluation de la qualité du jeu d'indicateurs et l'autre la vérification de la méthodologie de pondération. L'analyse critique s'est montrée un outil important pour la validation du jeu d'indicateurs apportant une information précieuse pour supprimer, relier ou améliorer les indicateurs.

## ABSTRACT

There are various possibilities for the design of urban stormwater systems, using best management practices. Castro and Baptista (2004) have proposed a set of performance indicators, based social, environmental, sanitary and hydrologic aspects. During the validation process, a critical analysis of the indicators was done. The aim of this paper is to present the results of this analysis which is based on two approaches: one concerning the evaluation of the quality of the indicators set and the other verifying the methodology of the weighting. The critical analysis showed to be a good tool to validate the indicators set bringing interesting information to suppress, join or improve indicators.

## KEYWORDS

Indicators ; multicriteria methods ; urban stormwater.

## 1 INTRODUCTION

In the last years, the researchers are studying new technologies for urban drainage, as best management practices (BMPs) in order to reach different objectives: quality of life and environmental preservation at the same time. These technologies are mainly based on retention and infiltration of the stormwater. They aim to reduce floods by limiting peak flows or volumes and pollution discharges in surface waters. They allow possible recharge of the groundwater and other benefits, as landscape enhancement, possibility to be used for other activities (squares, parks, reservoirs, etc.).

The BMPs can assume different forms as trenches, swales, porous pavements, pits and retention or infiltration basins. Different arrangements can also be integrated using the potential of a situation, project or landscape. According to Barraud et al. (2004a), even being indispensable and rich in possibilities, these technologies are, sometimes, not used, or used in the wrong way, due to the difficulty to choose the best arrangement that fits each area.

Based on this difficulty, Castro and Baptista (2004) proposed a methodology to aid in the choice of best drainage solutions according to a set of indicators used in multicriteria methods. They defined three objectives related to technical goals, impacts and integration of the drainage systems. For each objective, performance indicators were proposed. These indicators and the analysis methodology were applied to case studies by Castro (2002) and Moura (2004) using three multicriteria methods: Compromise Programming, Electre III and TOPSIS.

According to Barraud et al. (2004b), few studies deal with the evaluation of the quality and credibility of results obtained through estimation of performance indicators in a decision process. In this context, to validate and consolidate the method, it was considered necessary to carry out a critical analysis of the set of indicators. The main objective of this paper is to present the results of the critical analysis done during the evaluation process of the set of indicators.

## 2 SET OF INDICATORS

The performance indicators were proposed on the basis of three objectives and twelve indicators (Castro and Baptista, 2004) dealing with:

- Technical objective :
  - Ability of the system to drain an area in safe conditions (low flooding) (IO);
- Impacts :
  - Hydrologic impacts to the downstream flow ($I_{H1}$) and aquifer recharge ($I_{H2}$);
  - Sanitary impacts on the possibility of disease transmission ($I_{S1}$) and on the possibility of insects' proliferation ($I_{S2}$);
  - Impacts on the quality of surface waters ($I_{Q1}$) and/or groundwater ($I_{Q2}$);
- Integration :
  - Environmental integration with the creation and preservation of habitats ($I_{A1}$) and landscape enhancement ($I_{A2}$);
  - Social integration with of the possibility of leisure and recreation areas ($I_{SC1}$), traffic conditions ($I_{SC2}$), possibility of using the drainage technique to other technical functions ($I_{SC3}$) and, finally with expropriated areas ($I_{SC4}$).

The indicators were defined with a numerical evaluation. However, as it was sometimes difficult to assess them, so some of them had evaluations estimated in a subjective way, using direct expertise or expertise rules defined by the decision team. Anyway, all of them were evaluated on the same basis i.e. with values ranging from 1 to 7.

## 3 CRITICAL ANALYSIS

The use of decision support systems is nowadays applied to diverse domains and consequently, the estimation of performance indicators is increasing. However, as said before, few researches and studies deal with the evaluation of the quality and credibility of results obtained (Barraud et al., 2004), despite the existence of diverse methods, with different approaches.

The quality of the decision aid process depends on the quality of each indicator, of the quality of the global set of indicators and at last on the method used to select, to rank or to sort good solutions.

For the evaluation of the quality of each indicator, we globally found two approaches (Kastner, 2003). The first is funded on the definition of a list of *a priori* general quality criteria (Labouze & Labouze (1995), Personne (1998), Hart (1999), Bellagio (1996) or Pastille (2002)). The other approach is based on *a posteriori* analysis of errors made during application of performance estimation (Perrin (1998) and Riley (2001)).

Taking into account the main ideas of these authors, the quality of an indicator has to be evaluated by their:

- Accessibility : Are they easy to calculate and the data for the calculation available ?
- Objectivity : Aren't they ambiguous? Can they be evaluated in the same way by different appraisers ?
- Relevance : Is the performance relevant ?
- Robustness : Do they give stable results according to the variation of uncertain parameters ?
- Sensitivity : Do they discriminate different strategies ?
- Fidelity : Can they be estimated with a constant bias ?

For the quality of the global set of indicators, the number of indicators has to be considered. In effect the indicators have to be exhaustive, but their number must not be excessive, because a large number of indicators can bring difficulties in the methodology application. Therefore their independence or redundancy has to be examined.

The quality of the method depends on different aspects: the weighting procedure, the way uncertainties are taken into account and at last the sensitivity of the global method and its robustness.

The weight of each indicator was defined as the relative importance of a particular aspect compared to the others in a given decision context. In the present work reference values of weights were defined by means of interviews with representatives of technical municipal services, designers of urban stormwater systems, environmental regulatory bodies and researchers. Concerning the verification of the weighting methodology, different methods were tested in order to verify the changes in the final decision. The aim was to conclude if the weighting methodology applied was adequate and if it influences the final result.

The weighting factors were compared with the entropy weighting method (Pomerol & Barba-Romero, 1993). In this method the weights are defined apart from the decision maker. The main idea is that the indicator weight will be greater if the dispersion of the evaluations of the different scenarios is important. In other words, the wider the dispersion of performances on an indicator for the various solutions, the more important is the indicator weight.

In the present work the set of indicators proposed by Castro and Baptista (2004) is evaluated considering a particular case study selected because of the diversity of solutions involved. It is an industrial and services area, named Technopolis, located in south-western France, with total drainage surface of about 23 ha, being about 6 ha occupied by buildings and other 6 ha corresponding to streets and parks (Baptista & Barraud, 2001). Four drainage scenarios were evaluated: a separate pipe system without any restrictions in terms of maximum downstream flow; an intermediate system: a separate pipe system with a downstream detention basin implemented in order to respect a fixed downstream flow limit; an alternative system, with the use of porous pavements, ditches and a detention basin, respecting the fixed downstream flow limit and an alternative system with the use of infiltration systems with no downstream flow. Each of the four scenarios was studied with 3 return periods : 10, 30 and 100 years, giving twelve alternatives.

The selection method used for the test of the method has been ELECTRE III.

## 4 RESULTS

The critical analysis was done by means of :

- The verification of each aspect related to the quality of each indicator : accessibility, objectivity, relevance, robustness, sensibility and fidelity ;
- The verification of the global quality of the set (number, potential redundancy and dependence of the different indicators) ;
- The verification of the quality of the methods (relevance of the weighting procedure, sensitivity and robustness of the method).

### 4.1 Quality of each indicator

The accessibility was verified during their estimation realized by Castro (2002) and Moura (2004), it was tested together with the objectivity, the fidelity. The main aspect to test was the difficulty to calculate or estimate the value of some indicators, the subjectivity or the possible errors while assessing some of them.

Some indicators were assessed by means of mathematical expressions with parameters as return period, downstream flows, infiltration volumes that could be calculated by hydrological models. Despite the uncertainties in their estimation due to hydrological information and models, they were found “accessible”. The necessary parameters could be calculated and the errors estimated and in the same range for all the alternatives.

The indicators relating to sanitary and quality impacts on surface waters or groundwater could not be calculated with expressions because their parameters weren’t quantifiable. As the necessary factors for their evaluation couldn’t be quantifiable, some would think that they weren’t accessible. However, the results of the case studies showed that, as the relevant factors could be enumerated, the indicators values could finally be estimated without a high level of subjectivity.

To analyze the environmental and social aspects some indicators were calculated with mathematical expressions and others with subjective factors. The ones that were calculated by expressions used parameters such as the surface to preserve natural habitats or to create leisure and recreation areas. These surfaces could be defined with a good accuracy and was mainly based on the project analysis so that the indicators finally present a good accessibility. For the others, they depended on subjective approach, it was necessary to determinate all the factors to obtain the indicators values. However, during the estimation process of the landscape impact a high difference of interpretation of the decision maker was observed.

This showed that this estimation was too much subjective and did not fulfill accessibility requirements.

The sensitivity and robustness of each indicator has been tested and integrated in parameters of the decision aid method. When using ELECTRE III method to select the best solution according to the set of indicators, indifference and preference thresholds were defined with the range of uncertainties obtained by sensitivity and robustness analysis.

## 4.2 Quality of the set of indicators

The number of indicators was considered adequate as all the aspects were evaluated and none of them by more than one indicator. 12 indicators is a reasonable number.

The dependence of indicators has been verified by analyzing the correlation of indicators taken in pairs. The results of this test were important to show which indicators could be gathered and the ones that were not related. The determination matrix of the indicators is presented below, in Table 1**.**

| Coefficient of Determination ($R_2$) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Io | 0.000 | 0.034 | 0.290 | 0.290 | 0.018 | 0.034 | 0.412 | 0.290 | 0.392 | 0.000 | 0.290 | 0.404 |
| | IH1 | 0.088 | 0.360 | 0.360 | 0.526 | 0.095 | 0.325 | 0.360 | 0.217 | 0.333 | 0.360 | 0.328 |
| | | IH2 | 0.179 | 0.179 | 0.002 | 0.878 | 0.173 | 0.179 | 0.010 | 0.263 | 0.179 | 0.181 |
| | | | IS1 | 1.000 | 0.324 | 0.137 | 0.958 | 1.000 | 0.596 | 0.120 | 1.000 | 0.961 |
| | | | | IS2 | 0.324 | 0.137 | 0.958 | 1.000 | 0.596 | 0.120 | 1.000 | 0.961 |
| | | | | | IQ1 | 0.003 | 0.311 | 0.324 | 0.112 | 0.458 | 0.324 | 0.316 |
| | | | | | | IQ2 | 0.140 | 0.137 | 0.019 | 0.286 | 0.137 | 0.144 |
| | | | | | | | IA1 | 0.958 | 0.669 | 0.119 | 0.958 | 0.999 |
| | | | | | | | | IA2 | 0.596 | 0.120 | 1.000 | 0.961 |
| | | | | | | | | | ISC1 | 0.009 | 0.596 | 0.647 |
| | | | | | | | | | | ISC2 | 0.120 | 0.128 |
| | | | | | | | | | | | ISC3 | 0.961 |
| | | | | | | | | | | | | ISC4 |

Table 1 - Determination matrix of the indicators

High values of the Coefficient of Determination don't mean that the indicators are redundant, but that their definitions have to be verified to allow a conclusion. Otherwise, the low value of the $R^2$ directly means that the indicators are not redundant.

The Coefficient of Determination ($R^2$) between the indicator $I_{S1}$ and $I_{S2}$ is equal to 1, which means that a possible redundancy exists. Analyzing the indicators definition and the way the values were obtained, it could be concluded that the two indicators were really redundant and could be joined. The Coefficient of Determination of $I_{S1}$ and $I_{A2}$, $R^2$ was also equal to 1, but regarding their sources, they don't depend on the same factors and so they are not redundant, as each one considers a different aspect on the global analysis. Many indicators present a low value of $R^2$, meaning a non redundancy.

### 4.3 Some aspects of the quality of the method

The robustness and the sensibility of the method were studied with the same case study. It consisted in performing variations in the indifference and preference thresholds in ELECTRE III method, variations in the indicators weights and variations in the indicators values, according to parameter uncertainties. The complete results can be found in Castro (2002) and Moura (2004). The methodology was found robust as small variations in the parameters did not change the ranking of the three first alternatives and so did not change the trends on the results.

Variations of the thresholds, values and weights of the indicators were done according to the parameter uncertainties. The results obtained showed that the expected errors did not make difference on the results of the three first and the last three alternatives. However, the alternatives in the intermediate level had important differences. So, the methodology was considered to be robust.

The validation of the weighting procedure has also be carried out by means of interviews of experts. The results obtained by the multicriteria method were compared to the results using two approaches: the weights of the entropy method, that do not consider the decision makers opinion, and a variant of the of the entropy method which consists in a multiplication of the weights obtained by the entropy method and the weights obtained by the interviews. In Figure 1, the dispersion between the weights obtained by the different methodologies can be seen.

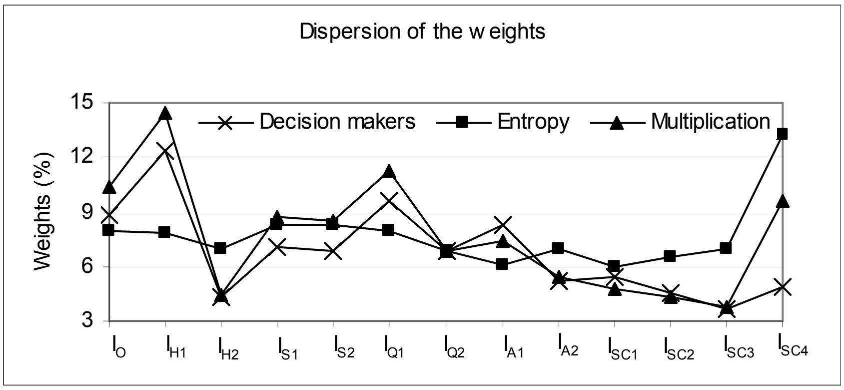


Figure 1 – Dispersion of the obtained weights

The results of the multicriteria method ELECTRE III using the three different weights presented differences. Comparing the original solution (weights obtained by interviews) and the entropy method, it could be observed that the first and the second solutions ranked was the same. The worst solution was also the same. However, the entropy method has a higher discriminating power (less equivalent solutions) in the ranking process. It is interesting to see that some indicators (i.e. IH1) are important according to the decision maker but in fact are not very discriminating (low weight with the entropy method).

## 5 CONCLUSION

The critical analysis showed to be a strong tool to validate the indicators set, checking some aspects related to their quality. It was important to define the indicators that could be suppressed, the ones that could be joined and even some which expressions and parameters had to be improved. The tests performed could verify that all the indicators were relevant to the proposal, but it was also important to bring the necessary information to consolidate them.

The expression proposed to the indicator to attendance of the main objective was verified and needed to be improved in function of the lack of sensibility of its results. The indicators that concern sanitary aspects are being joined, as they were seen as redundant. Concerning the impacts on the quality of the superficial or groundwater, it was verified the necessity to change the indicators expressions, because of the accessibility of their basic parameters. Some of the indicators to evaluate the environmental and social impacts had parameters of subjective analysis that could take to unknown errors, which was verified as a result of the fidelity analysis. Actual studies are being done now to consolidate these indicators.

The interviews with decision makers showed to be the best weighting methodology, as it could consider different opinions of specialists used to deal with this kind of analysis. However, for the proposed multicriteria methodology, the entropy method is interesting and could be used as an alternative for the weighting process when the opinions of the decision makers are extremely divergent or when the interviews are not possible. It can also be used just as a comparison with the weights given by the decision makers.

It's important to say that the validated indicators were made for the Brazilian conditions. Anyway, after this analysis, it was verified that they offer the opportunity of use in other tropical developing countries without substantial modifications.

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