UNIVERSITAT POLITÈCNICA DE VALÈNCIA

máster en ingeniería hidráulica y medio ambiente mihma

Título del Trabajo Fin de Máster:

SUSTAINABLE STORMWATER MANAGEMENT: DEVELOPMENT OF A DECISION-MAKING TOOL TO HELP IN BEST MANAGEMENT PRACTICES SELECTION. CASE STUDY IN LAVAL (CANADA).

DESARROLLO DE UNA HERRAMIENTA DE APOYO PARA LA TOMA DE DECISIONES EN LA SELECCIÓN DE SISTEMAS SOSTENIBLES DE DRENAJE URBANO: APLICACIÓN EN LA CIUDAD DE LAVAL (CANADA)

Intensificación:

ORDENACIÓN, RESTAURACIÓN Y GESTIÓN DE CUENCAS

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Fecha: **JULIO, 2012**

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Abstract:

The use of Best Management Practices (BMPs) has increased significantly in the past decades as an efficient alternative to traditional drainage systems and practices. However, the huge variety of BMP types, the insufficient experience in this field of some stormwater managers and the little existing regulatory texts or guidelines, often make the selection of a BMP installation a complex decision-making problem. The main objective of this study was to develop a decision-making tool to assist stormwater managers in BMPs selection problems. The proposed methodology consisted in ranking 14 different BMPs according to 4 main criteria and specific site conditions. Innovating tools were used to evaluate some criteria indicators. The developed ranking program was based on two multicriteria decision-aid (MCDA) well-known methods: AHP and ELECTRE III. Besides, different simulated scenarios were studied: 3 design storms were considered and management preferences were in accord with 3 different stakeholders' points of view. The developed methodology was applied in a demonstration site in Canada. Results issued from both MCDA methods were compared. Despite some evident differences, the best and worst ranking positions were occupied in general by the same BMPs in both rankings. It was also observed that the different considered rainfall inputs didn't affect the ranking results. In addition, AHP method was found to be more sensitive to criteria weights variations than ELECTRE III. Finally, sensitivity analyses were made to evaluate the methodology robustness. Results didn't seem sensitive to some parameters and input data so methodology could be considered robust. In spite of the promising and satisfactory results, recommendations for future researchers were also established at the end of this study.

Keywords:

BMP, SUDS, AHP, ELECTRE III

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Resumen:

El uso de Best Management Practices (BMPs), o Sistemas de Drenaje Sostenible (SUDS) en español, ha aumentado significativamente en las últimas décadas como una alternativa eficaz a los sistemas de drenaje tradicionales. Sin embargo, la enorme variedad de tipos de BMPs, la insuficiente experiencia en este campo de algunos gestores de aguas pluviales y la poca normativa y guías técnicas existentes, a menudo hacen que la selección de una BMP para su instalación en un lugar determinado se convierta en un problema complejo de la toma de decisiones. El objetivo principal de este estudio fue desarrollar una herramienta de toma de decisiones para ayudar a los gestores de aguas pluviales en los problemas de selección de BMPs. La metodología propuesta consiste en clasificar 14 BMPs diferentes en función de 4 criterios principales y de las condiciones específicas del lugar de instalación. Se utilizaron herramientas innovadoras para evaluar los indicadores de algunos criterios. El programa de clasificación de BMPs se desarrolló basándose en dos métodos multicriterio de ayuda a la decisión ampliamente conocidos: AHP y ELECTRE III. Además, se estudiaron diferentes escenarios simulados: se consideraron 3 tormentas de diseño distintas y las preferencias en cuanto a objetivos de gestión se establecieron en función de los puntos de vista de 3 actores diferentes. La metodología desarrollada se aplicó en una cuenca residencial urbana en Canadá. Los resultados obtenidos con ambos métodos fueron comparados. A pesar de algunas diferencias evidentes, las mejores y peores posiciones en la clasificación fueron ocupadas en general por las mismas BMPs en ambos rankings. También se observó que las diferentes lluvias consideradas no afectan a los resultados de la clasificación. Además, el método AHP resultó ser más sensible a las variaciones en los pesos de los criterios que ELECTRE III. Por último, se realizaron análisis de sensibilidad para evaluar la solidez de la metodología. Los resultados no parecieron sensibles a algunos de los parámetros y datos de entrada evaluados por lo que la metodología podría considerarse robusta. A pesar de los prometedores y satisfactorios resultados se hicieron algunas recomendaciones para los futuros investigadores al final del estudio.

Palabras clave:
BMP, SUDS, AHP, ELECTRE III

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Resum:

L'ús de Best Management Practices (BMPs), o Sistemes de Drenatge Urbà Sostenible (SUDS) en valencià, ha augmentat significativament en les últimes dècades com una alternativa eficaç als sistemes de drenatge tradicionals. No obstant això, l'enorme varietat de tipus de BMPs, la insuficient experiència en aquest camp d'alguns gestors d'aigües pluvials i la poca normativa i guies tècniques existents, sovint fan que la selecció d'una BMP per instal·lar-la en un lloc determinat es convertisca en un problema complex de la presa de decisions. L'objectiu principal d'aquest estudi va ser desenvolupar una eina de presa de decisions per ajudar els gestors d'aigües pluvials en els problemes de selecció de BMPs. La metodologia proposada consisteix en classificar 14 BMPs diferents en funció de 4 criteris principals i de les condicions específiques del lloc d'instal·lació. Es van utilitzar eines innovadores per avaluar els indicadors d'alguns criteris. El programa de classificació de BMPs es va desenvolupar basant-se en dos mètodes multi criteri d'ajuda a la decisió àmpliament coneguts: AHP i ELECTRE III. A més, diferents escenaris simulats van ser estudiats: 3 tempestes de disseny van ser considerades i les preferències pel que fa a objectius de gestió es van establir en funció dels punts de vista de 3 actors diferents. La metodologia desenvolupada es va aplicar en una conca residencial urbana a Canadà. Els resultats obtinguts amb els dos mètodes van ser comparats. Malgrat algunes diferències evidents, les millors i pitjors posicions en la classificació van ser ocupades en general per les mateixes BMPs en ambdós rànquings. També es va observar que les diferents pluges considerades no afecten els resultats de la classificació. A més, el mètode AHP va resultar ser més sensible a les variacions en els pesos dels criteris que ELECTRE III. Finalment, es van realitzar anàlisis de sensibilitat per avaluar la solidesa de la metodologia. Els resultats no van semblar sensibles a alguns dels paràmetres i dades d'entrada avaluats, de manera que la metodologia es podria considerar robusta. Malgrat els prometedors i satisfactoris resultats es van fer algunes recomanacions per als futurs investigadors al final de l'estudi.

Paraules Clau:
BMP, SUDS, AHP, ELECTRE III

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor from the Ecole Polytechnique de Montréal, Dr. Musandji Fuamba, whose expertise, understanding and patience were decisive to develop a satisfying and promising project.

I must also acknowledge Dr. Rafael Luis García Bartual and Dr. Ignacio Andrés Doménech, the co-supervisors of this project in the Universidad Politécnica de Valencia. Their institutional support and multiple advices, even in the distance, were enormously helpful.

A very special thanks goes to all my Master's colleagues who brought happiness to my last years in university and have become really good friends. Thank you for these lovely years.

I would also like to thank Sebastian for his love, patience and support during all these months. Thank you for helping me in all the difficult moments and make me smile every day.

Lastly, and most importantly, this study would not have been possible without my parents' support. Pilar and Jose have borne me, raised me, supported me, taught me and loved me unconditionally. Thank you for all the encouragement and, particularly in this case, for the editing assistance and advice.

INDEX

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Watersheds urbanization and, as a result, soils impermeabilization have consequences in terms of stormwater management. On the one hand, they cause an increase in runoff rates often resulting in a rise of the number and frequency of overflows and flooding. On the other hand, these uncontrolled overflows lead to increased pollution of receiving waters. If we observe the expected future trends of the climate for the coming decades, this problem is likely to worsen. Indeed, climate change may entail in certain areas of the planet, such as in the Quebec region, higher temperatures and precipitations. The combined effect of these two phenomena would accelerate the winter snow melting and, in general, it would increase runoff in watersheds of these areas.

Traditionally, stormwater management in urban areas has been based on the idea of a rapid evacuation of runoff waters into the drainage and treatment systems. During the past decade, a new approach is being established as the traditional one has become in somewhat obsolete due to the increasing runoff volumes in urban catchments. This new approach promotes rainfall control especially in the watersheds' source by constructing retention and infiltration systems. Thus, we reduce inputs to the drainage network and we help restoring the hydrologic cycle, highly disrupted due to soils impermeabilization. In addition, this new approach takes into account not only exceptionally large events but also the smaller and regular ones which are mainly responsible for the first flush pollution.

Within this context, these recent stormwater control strategies, commonly known as Best Management Practices (BMP), emerge as plausible and recommended solutions in view of the issues outlined above. These practices aim to (1) restore the hydrologic cycle, (2) improve the water quality of the flows, (3) decrease runoff erosive potential, and (4) control peak discharges so as to reduce flooding.

There are currently several types of BMPs. In addition, there is a huge set of selection criteria related to the site's physical constraints, the type of pollution source, the percentage of pollutant removal targeted, the type of receiving waters, the control objectives, the available budget, etc. Due to the lack of experience in the subject and in view of the vast number of criteria involved, it is sometimes difficult for managers to decide which type of BMPs, or combination of several ones, is the most appropriated for their specific case. Besides, in some countries or regions, there is also a regulatory vacuum in this regard which increases the level of uncertainty and the degrees of freedom to solve this kind of problems.

For this reason, the development of decision-support tools becomes highly interesting in urban water management, particularly for sustainable stormwater managers. The following study deals with this question by applying a multicriteria analysis approach to urban stormwater management in Quebec (Canada). Different Multicriteria Decision Aid (MCDA) methods have been adapted to BMPs analysis in order to guide users in their choice of the best stormwater solution. Main objectives and the study methodology are described in detail in sections 1.2 and 1.3.

1.1. BACKGROUND

MCDA methods have been widely used in civil engineering decision-making problems (Rogers & Bruen, 1998) and in environmental studies (Martin, et al., 2007).

According to stormwater management, and particularly in relation to BMPs selection, the use of mathematically-based algorithms to assist in BMP decision-making problems is an evolving area of research, with a number of approaches recently attempted (Young, et al., 2010). First studies were mostly based on a cost-benefit approach and guided by an optimization principle. Efforts have been under way by the U.S. Environmental Protection Agency (EPA) since 2003 to develop a decision-support tool to place best management practices at strategic locations in urban watersheds. The tool, called the **S**ystem for **U**rban **S**tormwater **T**reatment and **A**nalysis **IN**tegration (*SUSTAIN*), is designed to use by watershed and stormwater practitioners in order to develop, evaluate and select optimal BMP options for various watershed scales based on cost and effectiveness (Lai, et al., 2010).

Other studies have attempted to create BMP decision support tools for optimization of BMP placement and design using linear programming (Hipp, et al., 2006), genetic algorithms ((Zhen, et al., 2004); (Carter, et al., 2008); (Veith, et al., 2004)) and a variation of genetic algorithms called species conserving genetic algorithms ((Artita, et al., 2007); (Kaini, et al., 2008)). These promising works combined the algorithms with other hydrological or soils models.

Precedent studies were based on a unicriterion approach usually related to the economical aspect. However, engineering decision-making processes are nowadays based not only on economical and technical objectives but also on social and environmental ones. As a result, researchers have started to adapt MCDA methods to BMPs decision-making scenarios taking into account both, economical and technical factors as well as socio-environmental ones.

In this way, the Analytic Hierarchy Process (AHP) has been successfully used in different studies to assist in BMPs selection problems. Young et al. (2010) developed a decision support software based on this MCDA method for selecting stormwater management BMPs. Supported with input from a geographic information system, they applied the AHP algorithm to evaluate and rank BMP options in the Town of Blacksburg (Virginia, U.S.A). Next, SWMM models were built to provide a comparative analysis of those BMPs recommended by the software against a traditional, detention-based stormwater management approach (Young, et al., 2010).

Fuamba et al. (2011) also used the AHP method to develop a computer program to asses BMPs performance and rank them according to four major criteria: technical, economical, social and environmental. The methodology was applied in a city area of Laval (Quebec, Canada). The satisfactory results obtained in this study showed that AHP method can be efficiently applied in the selection of BMPs.

Other MCDA methods as *ELimination Et Choix Traduisant la REalité* family methods, established by Roy (1978), have also been applied in BMPs selection problems. Thus, Martin et al. (2007) utilized ELECTRE III to help in the decision-making process from the point of view of different stakeholders. Assessment of BMPs performances was determined by combining data issued from a national survey to BMPs users in France and literature and previous studies review.

The present study continues the line of research of Fuamba et al. (2011) as it is developed in the same research project framework. In addition, it takes into account some of the most interesting characteristics and conclusions of the abovementioned methodologies in order to create a new one, better adapted to the actual research group needs.

1.1.1. ORIGINALITY

There is a huge variety of MCDA methods which, applied to the same problem, can lead to different results. Besides, nowadays there is an increasing tendency to mix methodologies and create hybrid methods that take advantage of the best characteristics of each original method. In view of these circumstances, comparison and analysis of results obtained from different MCDA techniques becomes really interesting. Nevertheless, there are only a small number of papers on this subject, especially with regard to BMPs selection.

Zanakis et al. (1998) developed a simulation experiment to investigate the performance of eight different MCDA methods: ELECTRE, TOPSIS, Multiplicative Exponential Weighting (MEW), Simple Additive Weighting (SAW), and four versions of AHP (original vs. geometric scale and right eigenvector vs. mean transformation solution). The simulation parameters considered in the study were the number of alternatives, the number of criteria and their distribution. Solutions were analyzed using twelve measures of similarity of performance. Results were interesting but remained too theoretical.

Concerning AHP and ELECTRE III, two of the best well known techniques among these numerous MCDA methods, Banar et al. (2010) studied a recycling system selection problem with both ANP (the general form of the AHP) and ELECTRE III methods. Other studies (Ho & Sherris, 2012) have used these two techniques in financial and insurance field applications. Obtained rankings have been compared and important conclusions were established, especially for the case studies analyzed.

The originality of the present work lies on the following points:

- it adapts two different methods, AHP and ELECRE III, to BMPs selection problems using the same methodology framework and, as a result, allowing comparison between ranking results from both MCDA techniques;
- it takes into account three different stakeholders, in order to analyze the same BMP selection problem from different points of view and, in addition, evaluate the program robustness according to criteria weighting;
- it considers new and more specific criteria and improves the assessment of BMPs performance related to them;
- it applies and compares different MCDA methods for the first time in Quebec region to assist in BMPs selection problems.

1.2. OBJECTIVES

The development of decision-making methods to help managers in BMP selection has already been discussed in other studies initiated at the Ecole Polytechnique de Montreal: Coulais (2010) and Tisba (2011) worked on the development of two BMPs selection tools based on the multicriteria AHP and Pareto methods respectively. Coulais' (2010) AHP-based methodology concluded that different points, mainly related to the calculation of the criteria indicators, should be reviewed and maybe modified to improve its performance. The present research group decided to take Coulais' (2010) work as the starting point of this study.

Furthermore, in view of the little scientific papers about MCDA methods comparison, it seemed interesting to compare the results from two of the most well know MCDA methods, AHP and ELECTRE III, and give the manager the opportunity to choose between the obtained solutions or even a combination of both.

Thus, the main objectives of this study are:

- to develop a multicriteria decision-making program to select the most appropriate BMPs in order to achieve a sustainable stormwater management in urban areas. The developed tool will allow the manager to choose between two multicriteria decision aid methods: AHP and ELECTRE III;

- to compare the AHP and ELECTRE III methods by analyzing the two ranking results issued from the application of the developed program in a demonstration site.

Secondary objectives could then be described as follows:

- Modification of the AHP-based methodology already developed by Coulais (2010).
- Adaptation and implementation of ELECTRE III method to BMPs selection problems.
- Adaptation of the BMP ranking program to the Quebec stormwater management guide (MDDEP and MAMROT, 2012) so as to apply it for the first time a case study in Quebec.
- Evaluation of the program robustness and the results' coherence according to different scenarios.

1.3. METHODOLOGY

In order to achieve the objectives abovementioned a specific and well-defined methodology must be followed. Two different methodologies may be differenced: the decision-making methodology and the global methodology. The former, which is the same in all decision-making problems, provides the results needed for the next analysis, i.e. the BMPs rankings issued from the program application to the demonstration site. The latter, which includes the decision-making process itself, compares the results from the two MCDA methods.

1.3.1. THE GLOBAL METHODOLOGY

A schema of the global methodology is presented in figure 1.

First step of the global methodology consisted in identifying the multicriteria decision-making BMPs problem and defining the objectives of the study. Introduction of section 1 and section 1.2 describe in detail the problem and the study objectives respectively.

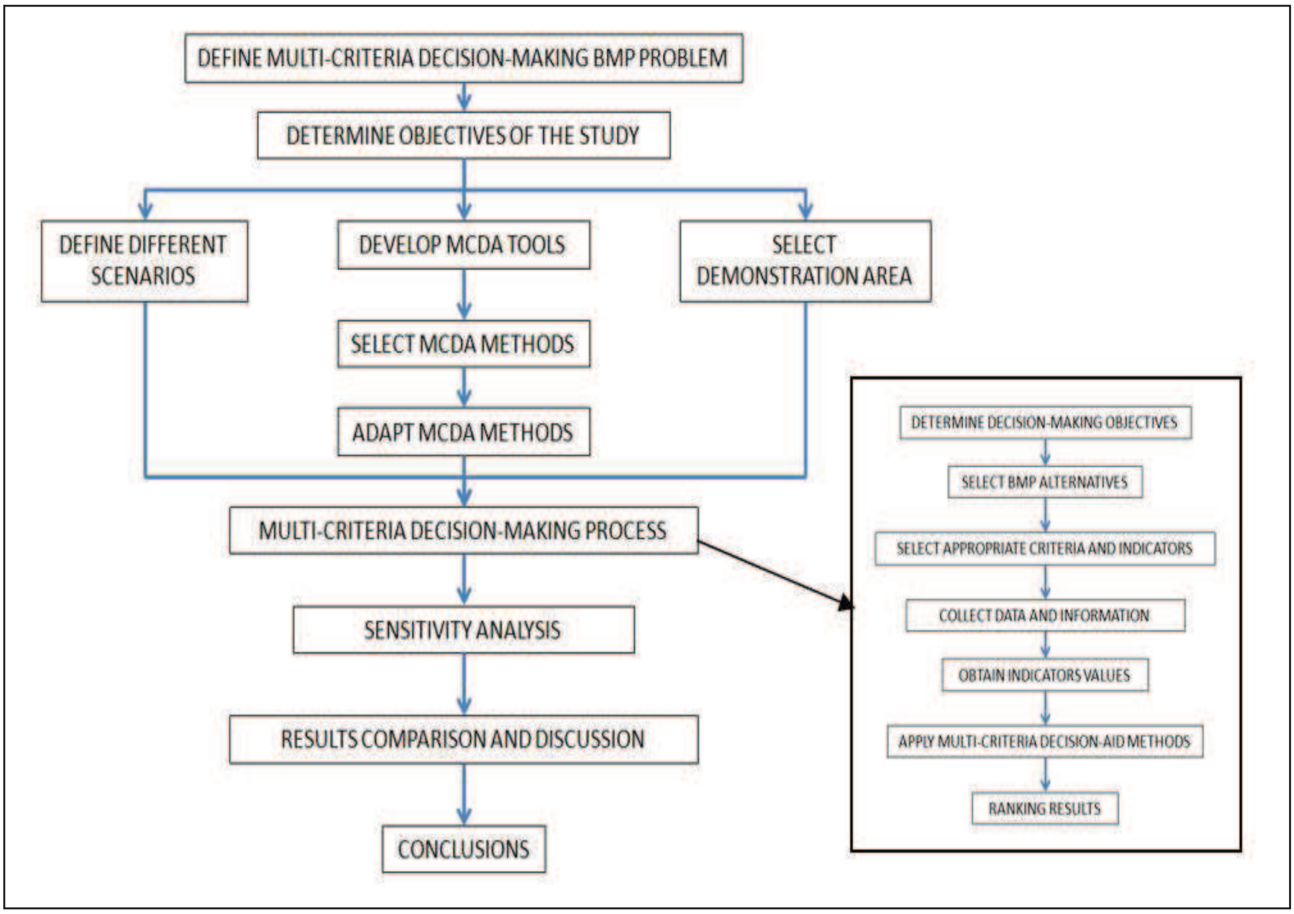

Figure 1.- Schema of the global methodology.

Once these two aspects had been determined, MCDA tools were developed. This step implies the selection of MCDA methods, AHP and ELECTRE III in this case, and their adaptation to the BMPs field. An adjustment of Coulais' (2010) AHP-based methodology was made in order to improve its performance and adapt some of its parameters to the Quebec stormwater management guide (MDDEP and MAMROT, 2012). Further details of the adaptation of both MCDA methods to BMPs problems and a schema of the global structure of the developed tool and are given in sections 3.3 and 4.1 respectively.

At the same time, a demonstration area was chosen so as to obtain the needed data to run the program. As it was said in the introduction of this Chapter, the selected demonstration site in this study was located in the city of Laval (Quebec, Canada). Besides, different scenarios were determined in order to evaluate the program robustness and applicability. A detailed description of these scenarios is presented at the end of this section.

The next step of the global procedure is the multicriteria decision-making procedure, which is described in section 1.3.2. At the end of this step, BMP rankings are obtained and different sensitive analyses were made in order to evaluate the methodology robustness. Four sensitivity analyses were carried out: a sensitivity analysis of the ELECTRE III thresholds, a sensitivity analysis of the socio-environmental criteria inputs, a sensitivity analysis of the quality criteria inputs and a sensitivity analysis of the initial infiltration rate input. Results and conclusions are presented in section 5.3.

To conclude this study, results of the decision-making process are analyzed, compared and discussed in order to draw conclusions. These latter are presented in Chapter 6.

Scenarios description

Eighteen different scenarios have been considered in the present study. Each scenario corresponds to a different stakeholder involved in the BMPs decision-making process and a different type of precipitation, according to different return periods.

Three stakeholders have been selected. The first stakeholder is an engineer or a developer whose aim is to minimize the costs induced by stormwater management. The second stakeholder is local authorities, politicians or regulatory bodies. Their aim is to improve the level of amenity and contribution to sustainable urban development policies. The last stakeholder is public, pressure groups or residents associations, whose aim is to prevent against adverse environmental impacts from stormwater BMPs.

Furthermore, three design storms have been considered in this study. These storms correspond to precipitations inputs of 2, 10 and 100 years of return period obtained from the IDF curves of the pluviometer of Dorval, near Montreal city. Duration of the storms has been settled at 3 hours, as it is the value established by the local authorities of the demonstration site of this study for doing urban drainage studies.

Scenarios influence the weighting criteria step of the decision-making methodology described in section 1.3.2 and the evaluation of the alternatives, as different input values (precipitation) are introduce to the program. Table 1 presents the scenario characteristics and its nomenclature. First letter corresponds to the type of stakeholder (E: engineer; P: politician; R: resident), the second correspond to the type of MCDA method used (A: AHP; E: ELECTRE III) and the final number corresponds to the return period of precipitation (2, 10 or 100 years).

SCENARIO	STAKEHOLDER	RAINFALL	METHOD
EA-2	Engineer, developer	T=2 years	AHP
EA-10	Engineer, developer	T=10 years	AHP
EA-100	Engineer, developer	T=100 years	AHP
PA-2	Politician, local authority	T=2 years	AHP
PA-10	Politician, local authority	T=10 years	AHP
PA-100	Politician, local authority	T=100 years	AHP
RA-2	Residents	T=2 years	AHP
RA-10	Residents	T=10 years	AHP
RA-100	Residents	T=100 years	AHP
EE-2	Engineer, developer	T=2 years	ELECTRE III
EE-10	Engineer, developer	T=10 years	ELECTRE III
EE-100	Engineer, developer	T=100 years	ELECTRE III
PE-2	Politician, local authority	T=2 years	ELECTRE III
PE-10	Politician, local authority	T=10 years	ELECTRE III
PE-100	Politician, local authority	T=100 years	ELECTRE III
RE-2	Residents	T=2 years	ELECTRE III
RE-10	Residents	T=10 years	ELECTRE III
RE-100	Residents	T=100 years	ELECTRE III

Table 1.- Scenario characteristics and nomenclature.

1.3.2. THE MULTICRITERIA DECISION-MAKING METHODOLOGY

A schema of the multicriteria decision-making methodology is presented in figure 2.

The first step to solve a multicriteria decision-making problem of stormwater management it’s to determine the objectives for decision-making and, then, select the BMPs options. In this study, the decision-making objectives were:

- to reduce runoff flows
- to reduce BMPs costs
- to improve runoff water quality
- to improve community welfare and reduce environmental impacts

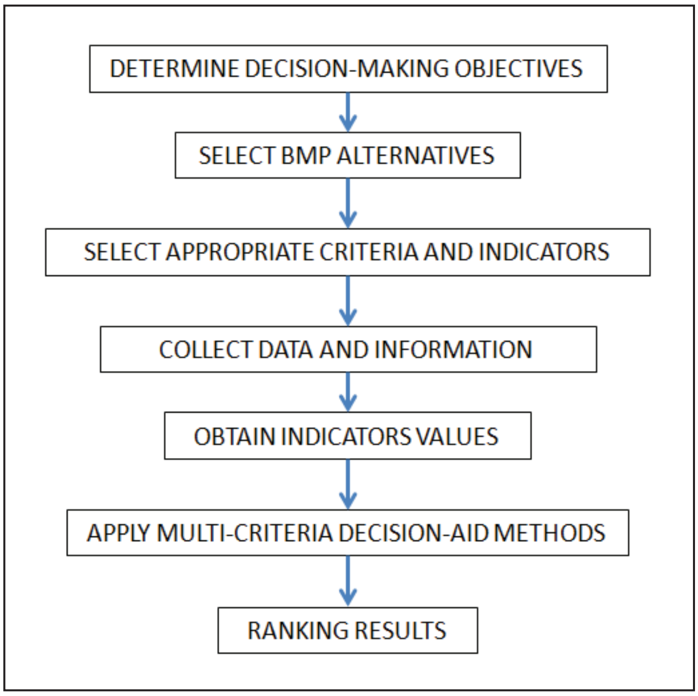

Figure 2.- schema of the multicriteria decision-making methodology.

The BMPs selected for this study are only structural BMPs. The following 14 different types of BMPs have been chosen:

1. Extensive green roof
2. Intensive green roof
3. Rainwater harvesting
4. Filter drain
5. Permeable pavement
6. Filter strip
7. Bioretention system
8. Infiltration trench
9. Shallow swale
10. Deep swale
11. Perforated pipe system
12. Detention basin
13. Retention pond
14. Wetland

Detailed description of the general characteristics and design criteria of these BMPs is given in Chapter 2 and Annex A.

Next step of the decision-making process is to select appropriate criteria and indicators in order to evaluate each BMP performance. In this study, 4 main criteria were chosen and 2 of them were divided into different sub-criteria. Table 2 shows the different criteria and sub-criteria and the indicators used to evaluate each one. Annex A gives further information about the sub-criteria senses.

TABLE 1.3.2

CRITERIA	SUB-CRITERIA	INDICATOR
Technical performance	No	Total treated volume (m^3)
Economical performance	No	Net Present Value (CAD $)
Quality performance	Suspended sediment removal Nitrogen removal Phosphorus removal	Average percentage of pollutant removal (%) or Total mass of removed pollutant (Kg)
Socio-environmental performance	Residents acceptability Society life quality improvement Environment protection and sustainable development contribution Health and safety risks	Qualitative evaluation (1-9 scale)

Table 2.- Criteria, sub-criteria and indicators used to evaluate them.

As well as criteria selection, technical constraints should be taken into account in the decision-making analysis so as to identify the BMPs which are not pertinent to conceive and that, as a result, could be eliminated of the decision-making process. Values for these technical constraints are specified in almost every stormwater management guide. In this study, as the demonstration site was located in Canada, both Quebec and Ontario region stormwater management guides where considered to obtain these values. Table 50 in Annex A shows which technical constraints have been considered, the values of these variables and the guide from which they were obtained.

Once the criteria and indicators are defined, data and information to calculate or obtain the indicator values must be collected. The demonstration site of this study will be situated in the city of Laval, in the Canadian region of Quebec (see location map in figure 44). Data were collected from different sources: previous studies ((Coulais, 2010); (Tisba, 2011)), technical field reports of the site (Doutetien & D., 2007) and literature (Rivard, 2005).

Next step in this methodology is to obtain the values of each criterion for each BMP considered. In this study, evaluation of each criterion was done in the following way:

- Technical performance was evaluated by the "total treated volume" of each BMP. Calculation of this value implied sizing each BMP and estimating the runoff discharge of the studied watershed. Processes, formulas and sizing values are described in detail in Annex A.
- Economical performance was evaluated by the "net present value" of each BMP. Construction costs and maintenance cost were considered. Lifetime was supposed according to usual values determined by the BMP management experts. Processes, formulas, costs and lifetime values are described in detail in Annex A.
- Quality performance was evaluated by the "average percentage of pollutant removal" of each BMP. The developed program allows the user to choose between two different indicators as it is presented in table 2. "Average percentage of pollutant removal" was selected as there were no enough data to calculate the "total mass of removed pollutant" (pollutant concentrations in the stormwater to be treated by the BMPs were unknown). The quality performance indicator values, presented in Annex A, were taken from different stormwater management guides.
- Socio-environmental performance was evaluated by a "qualitative scale" going from 1 to 9. The values for each BMP, which are presented in Annex A, were determined by experts in BMPs management from the city of Laval.

The final step of the decision-making methodology is to apply the multicriteria decision aid methods in order to obtain a ranking of the BMPs considered. As it has been said at the beginning of this report, AHP and ELECTRE III are the selected methods to apply in the present study. The reasons for this choice are explained in section 3.2.

2. STORMWATER BEST MANAGEMENT PRACTICES

Stormwater Best Management Practices (BMP), also called Sustainable Urban Drainage Systems (SUDS) or Low Impact Development practices (LID), can be defined as a diverse range of source control procedures which integrate stormwater quality and quantity control as well as enabling social and amenity perspectives to be incorporated into stormwater management approaches (Scholes, et al., 2008).

The principle of these procedures is to manage rainwater at its source, instead of discharge into conventional combined or separated sewer systems (Martin, et al., 2007). The traditional approach in stormwater management was to evacuate runoff volumes as soon as possible and convey them through the sewer conduits to finally discharge directly into the receiving water bodies. On the contrary, the sustainable stormwater management approach is concerned not only with runoff quantity aspects but also with the quality ones, as well as dealing with downstream erosion and aquifer recharge. In this case, runoff water is considered mostly a source rather than a nuisance (MAMROT, 2010).

The two main aims when developing a BMP are:

- to prevent from flooding, by reducing runoff volumes or retarding runoff peaks.
- to reduce pollutant loads, by applying different mechanisms.

The different mechanisms taking place in stormwater BMPs are filtration, infiltration, biologic assimilation, settling, evaporation and vegetation uptake.

Other benefits of stormwater BMPs implementation are the following:

- to reduce incidence of combined sewer overflow events
- to reduce size and extent of drainage infrastructures
- to reduce overall water consumption
- to reduce erosion of water bodies
- to contribute to the livability of a community
- to improve environment conditions

2.1. CLASSIFICATION

BMPs can be classified in many different ways (MDDEP and MAMROT, 2012). The most common classification is to categorize BMPs into two groups: structural and non-structural. Structural BMPs include engineered and built systems designed to provide water quantity and/or quality control; these are based on either rainwater retention or infiltration into the soil. Non-structural BMPs include a range of pollution prevention, education, management and development practices designed to limit the conversion of rainfall into runoff (Martin, et al., 2007). They are linked to urban zoning, landscape planning, education and legislation fields so that they prevent rather than fix runoff problems.

Another interesting classification is based on the BMP location in relation to the water path. It is linked with the control mechanisms chain presented in figure 3.

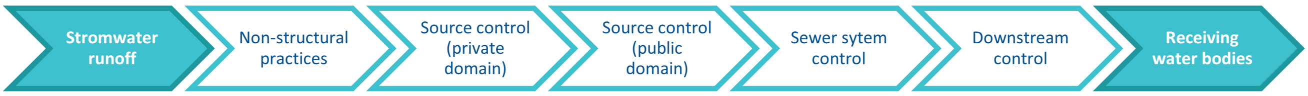

Figure 3.- The control mechanisms chain in stormwater management.

We can divide the BMPs into 5 groups: the non-structural practices developed firstly, the ones located at the source in private land, those located at the public land source, the ones located along the sewer system and finally, those situated just before the outflow.

Table 3 shows the different BMPs considered in the stormwater management guide of Quebec, (MDDEP and MAMROT, 2012), classified into structural and non-structural according to their situation along the system.

Finally, it must be said that not all BMPs are able to achieve the objectives listed above. Table 4 shows which goals each BMPs would reach.

		BEST MANAGEMENT PRACTICES	
NON-STRUCTURAL	SOURCE CONTROL	- Public education, awareness and participation - Landscape planning and management of areas under development - Integrated planning of stormwater management - Changed use, discharges and chemicals elimination - Development and application of sewer systems regulations - Maintenance practices - Control of construction activities	
STRUCTURAL	SOURCE CONTROL	- Green roofs - Rainwater harvesting - Bioretention systems - Permeable pavement - Filter drains	Private land
STRUCTURAL	SOURCE CONTROL	- Infiltration trenches - Filter strips - Bioretention systems - Permeable pavement - Swales	Public land
STRUCTURAL	CONVEYANCE CONTROL	- Perforated pipes - Swales	Public land
STRUCTURAL	END-OF-PIPE CONTROL	- Retention ponds - Detention basin - Wetland	Public land

Table 3.- BMP classification according to the type of control. **(MDDEP and MAMROT, 2012)**

	RUNOFF VOLUME REDUCTION	QUALITY CONTROL	EROSION CONTROL	AQUIFER RECHARGE
Bioretention	X	X	X	X
Filter strip		X	X	X
Rainwater Harvesting	X			
Green roof	X	X		
Filter drain	X			X
Permeable pavement	X			X
Swale	X	X	X	X
Retention pond	X		X	
Wetland	X	X	X	

Table 4.- Objectives achieved by the different BMPs. **(MAMROT, 2010)**

2.2. CHARACTERISTICS

In this section, the different structural BMPs will be presented, pointing out the most important characteristics of each one of them.

2.2.1. GREEN ROOFS

Green roofs, also known as vegetated roofs, eco-roofs, or nature roofs, are structural components that help to mitigate the effects of urbanization on water quality by filtering, absorbing or detaining rainfall. Besides, they have other environmental benefits: they reduce the urban heat island effect, improve the air quality and limit the smog phenomena. Furthermore, they isolate the buildings so that less energy would be needed to acclimate the inside spaces.

These practices are becoming more and more usual in Quebec but they are mostly used in vast flat roofs, as those from industrial and commercial buildings, as their slopes allow a bigger water storage.

Drawbacks for this BMP are the regular inspections needed and the necessity of sealing the roof effectively. Besides, careful attention should be paid not to exceed roof bearing capacity.

An example of the different components of a green roof is shown in figure 4.

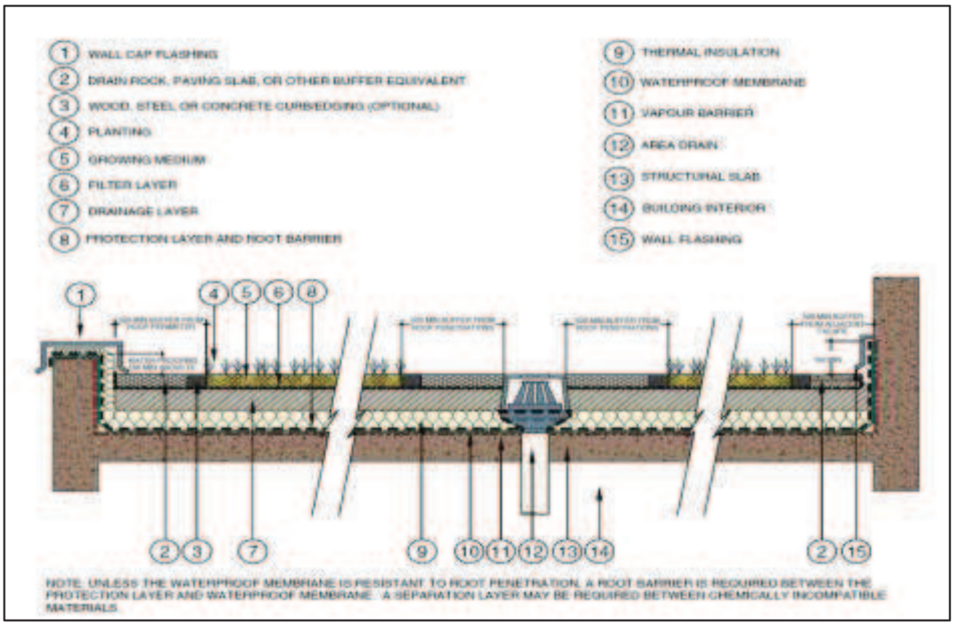

Figure 4.- Components of an extensive green roof. (GVRD, 2005)

Design Variations

Modern vegetated roofs can be categorized as "intensive" or "extensive" systems depending on the plant material and planned usage for the roof area. Intensive vegetated roofs (figure 5) utilize a wide variety of plant species that may include trees and shrubs, require deeper substrate layers (usually > 10 cm (4 in)), are generally limited to flat roofs, require 'intense' maintenance, and are often park-like areas accessible to the general public. In contrast, extensive roofs (figure 6) are limited to herbs, grasses, mosses, and drought tolerant succulents such as Sedum, and can be sustained in a shallow substrate layer (< 10 cm (4 in)), require minimal maintenance, and are generally not accessible to the public. An additional variation is the possibility of designing vegetated roofs as urban gardens capable of providing a local food supply. Soil depth and plant suitability should be considered when exploring this option.

Figure 5.- Intensive green roof in the CEGEP of Limoilou, Quebec. (www.climoilou.qc.ca)

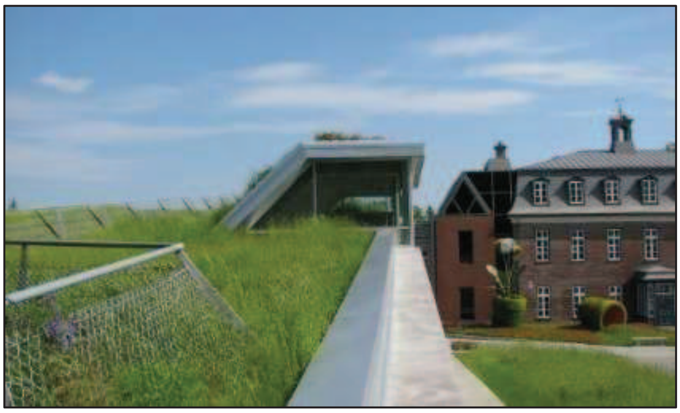

Figure 6.- Extensive green roof of the Charlesbourg Library, Quebec. (www.trait-carre.org)

2.2.2. RAINFALL HARVESTING

Rain barrels (figure 7) and cisterns (figure 8) collect building runoff from roof downspouts and store it for later reuse for non-potable applications such as irrigation or toilets. These practices are the basis of water reuse in houses.

Figure 7.- Rain barrel. (TRC and CVC, 2010)

Figure 8.- Above-ground plastic cistern. (TRC and CVC, 2010)

Design Variations

Rain barrels and cisterns are low-cost water conservation devices that reduce runoff volume and, for very small storm events, delay and reduce the peak runoff flow rates. However, attention must be paid to the barrel drainage so that storage can be effective. Besides, additional attention is required in winter in order to avoid that conduits and even the barrel water freeze.

Rain barrels are easy to install, especially in already developed areas. Schemas of a typical rain barrel and cistern systems are shown in figures 9 and 10.

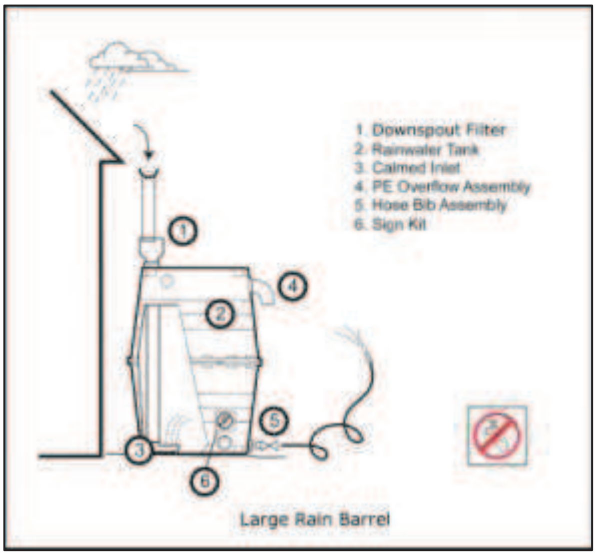

Figure 9.- Rain barrel schema. (www.caes.uga.edu)

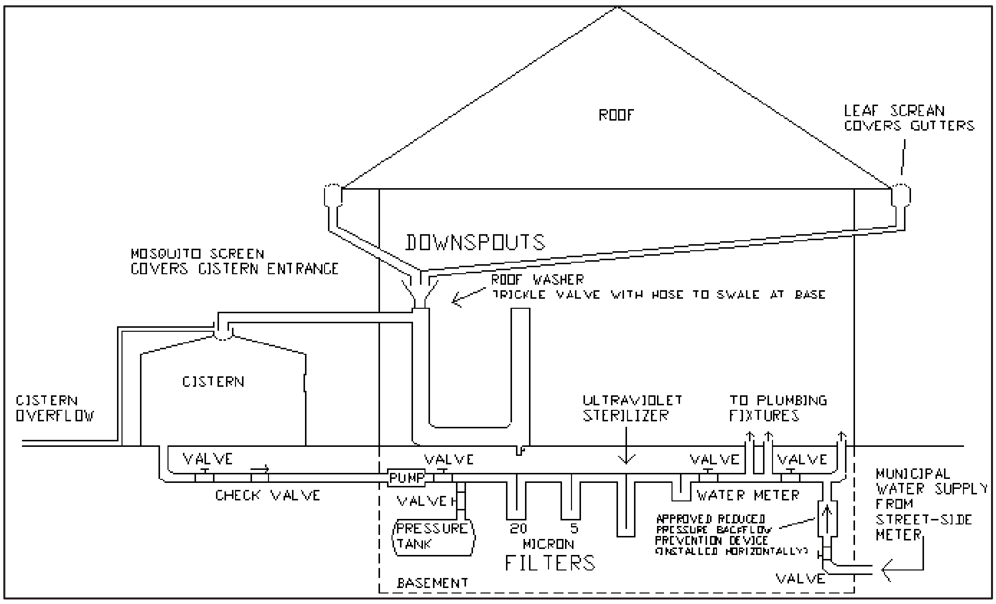

Figure 10.- Cistern schema. (www.lid-stormwater.net)

2.2.3. DOWNSPOUT DISCONNECTION

In urban areas, downspouts are commonly connected to drain tiles that feed the sewer system, and the cumulative effect of thousands of connected downspouts can greatly increase the annual number, magnitude, and duration of CSO events. Downspout disconnection (figure 11) is the process of separating roof downspouts from the sewer system and redirecting roof runoff onto permeable surfaces, most commonly a lawn. This reduces the amount of directly connected impermeable area in a drainage area.

Figure 11.- Downspout disconnection. (www.centurywaterproofing.com)

Design Variations

Ideally, a downspout disconnection plan will work with the existing downspouts on a building. In some cases, however, downspouts can be relocated if the new position would drain to a more appropriate receiving area (e.g., a hedge). Re-pitching the gutters in order to direct the flow to another corner of the roof is another option. For buildings with internal drainage, disconnecting internal downspouts may be difficult or impractical. Other BMPs such as cisterns or vegetated roofs may be more appropriate in such a case.

For disconnection to be safe and effective, each downspout must discharge into a suitable receiving area. Runoff must not flow toward building foundations or onto adjacent property. Typical receiving areas for disconnected roof runoff include lawns, gardens, and other existing landscaping such as shrubs. Soil amendments can be used to increase soil permeability if necessary. However, site constraints such as small or non-existent lawns may dictate runoff to be directed into a rain garden or, most commonly, an infiltration practice.

Figure 12 shows the schema of a typical downspout disconnection.

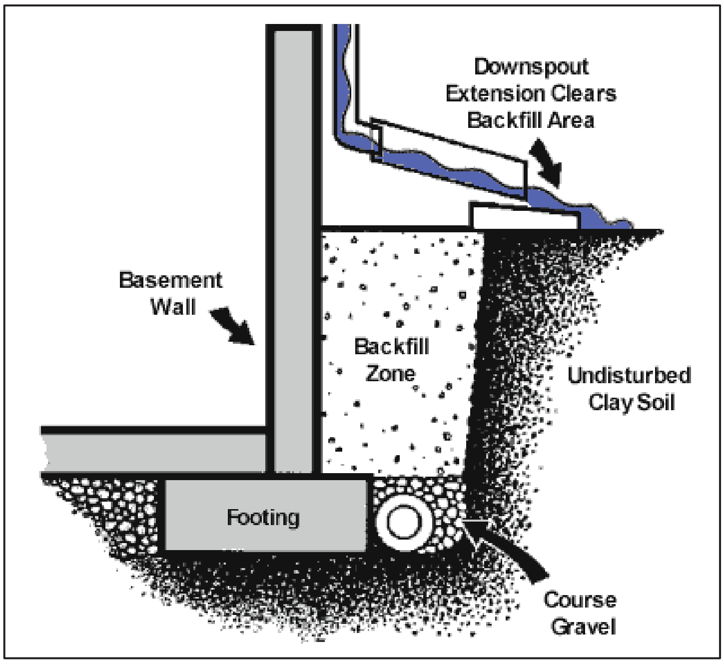

Figure 12.- Schema of a typical downspout disconnection. (www.enermac.com)

2.2.4. INFILTRATION PRACTICES

Infiltration practices are designs that enhance water percolation through a media matrix that slows and partially holds stormwater runoff and facilitates pollutant removal.

Design Variations

INFILTRATION TRENCH

Infiltration trenches (figure 13) are stone-filled excavated trenches that allow stormwater runoff to infiltrate into surrounding soils through the bottom and sides of the trench. Captured stormwater generally exfiltrates to surrounding soils within 48 hours and serves to recharge groundwater. Designs must include filter strips or other filtering mechanisms to prevent sediment from reaching and clogging the trench.

Figure 13.- Infiltration trench under construction. (TRC and CVC, 2010)

DRY WELL/FILTER DRAINS

Dry wells (figure 14) typically are gravel or stone aggregate-filled pits located to catch stormwater from roof downspouts or paved areas. Most often used to treat stormwater from small impermeable surfaces, dry wells act as an alternative to infiltration trenches and can be used on steep slopes where other infiltration practices are not as well-suited. Dry wells should not be installed in areas of high sediment loading. This BMP can include a drain at the bottom of the trench (then called filter drains) and is especially useful when available surface for BMP implementation is not very extent.

Figure 14.- Dry well under construction. (www.agry.purdue.edu)

Schemas of both types of BMPs are presented in figures 15 and 16.

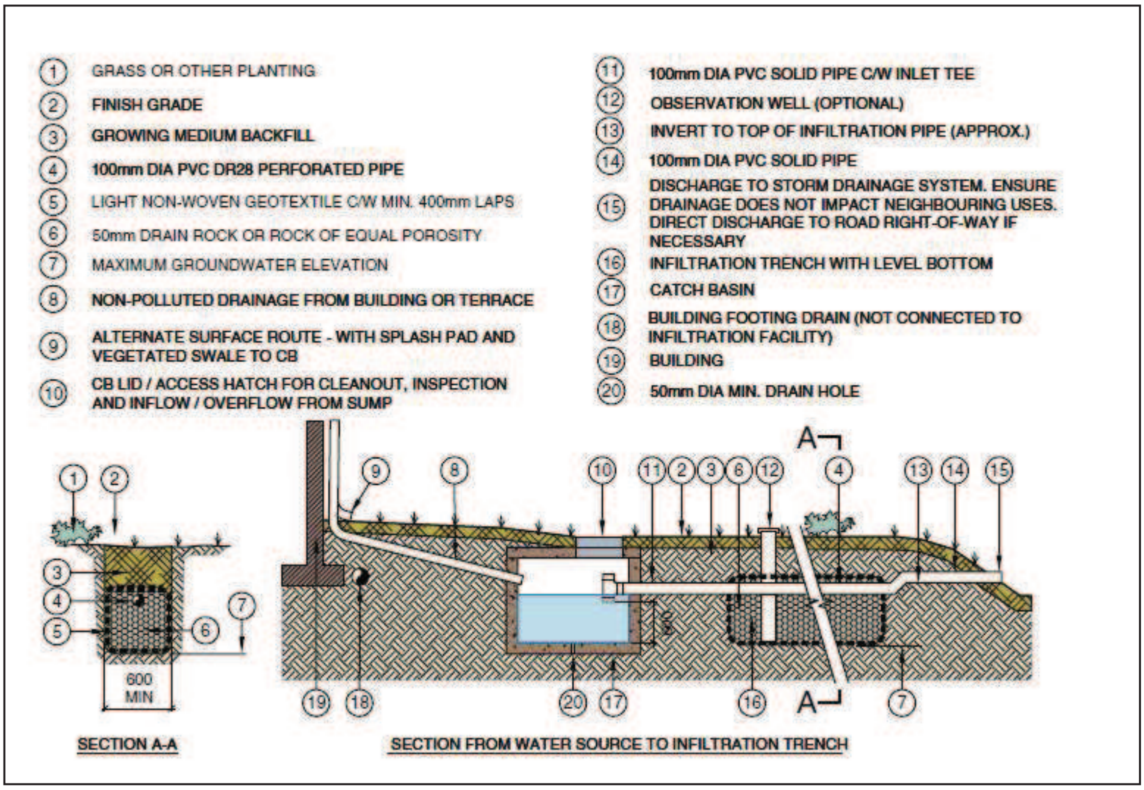

Figure 15.- Schema of an infiltration trench. (GVRD, 2005)

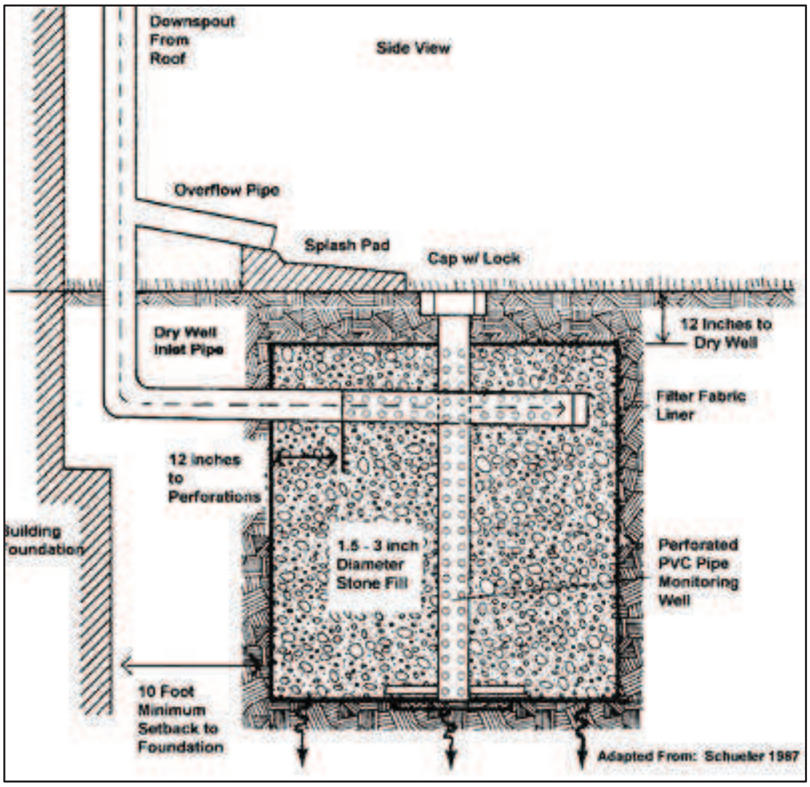

Figure 16.- Schema of a dry well. (TRC and CVC, 2010)

2.2.5. PERMEABLE PAVEMENTS

Porous pavement (figure 17) allows stormwater and snow melt to pass through voids in the paved surface and infiltrate into the sub-base. In open (unlined) systems, infiltration into the underlying soil may also be possible.

Figure 17.- Permeable pavement. (www.jesuispauvre.com)

This practice is not very used in Quebec due to winter climate, although this BMP has an acceptable performance in winter conditions. On the contrary, it is not recommended in areas with a lot of traffic and where heavy vehicles circulate regularly.

Design Variations

Porous pavements may be constructed of four basic material types:

- Porous asphalt
- Porous concrete
- Interlocking paver blocks
- Plastic grid

Porous asphalt and concrete often look the same as their conventional counterparts but are mixed with a low proportion of fine aggregates, leaving void spaces that allow for infiltration. Interlocking paver blocks themselves are impermeable, but gravel- or grass-filled voids in between the blocks allow stormwater to enter the sub-base. Plastic grid systems provide a stable structure in which each cell in the grid contains grass or gravel. Figures 18a, 18b and 18c show these different porous pavements.

Figure 18 a,b,c.- Different types of porous pavements. From left to right and from top to bottom: plastic grid, porous asphalt and porous concrete (Sources: www.giteco.unican.es and Dr. Ignacio Andres Domenech).

Drainage in porous pavements may be one of three types:

- Full exfiltration
- Partial exfiltration
- No exfiltration or tanked systems

The amount of exfiltration depends on the permeability of the existing soil. Regardless of which approach is used, overflow devices are usually provided to prevent ponding. In full exfiltration systems, all stormwater is expected to exfiltrate into the underlying subsoil. Pipes at the top of the sub-base provide overflow and secondary drainage in case the base becomes clogged or loses capacity over time. Partial exfiltration systems are designed so that some water exfiltrates into the underlying soil while the remainder is drained by the overflow devices. No exfiltration occurs when the sub-base is lined with an impermeable membrane and water is removed at a controlled rate through the overflow device. Tanked systems are essentially underground detention systems and are used in cases where the underlying soil has low permeability and low strength, there is a high water table, or there are water quality limitations.

A schema of a typical porous pavement is shown in figure 19.

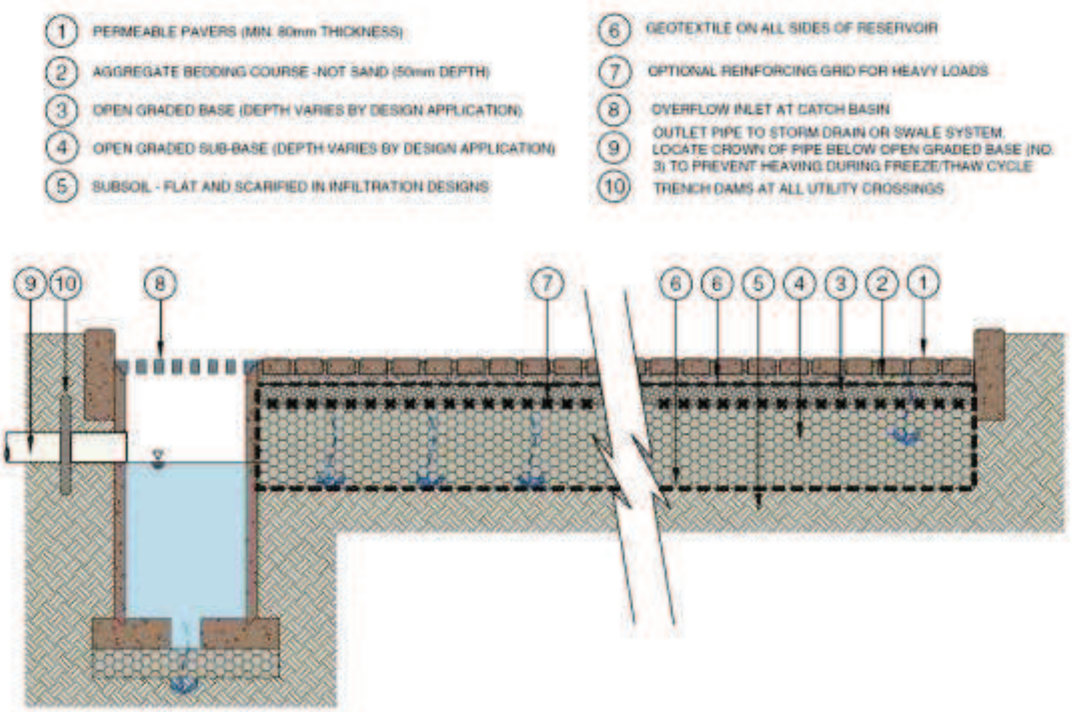

Figure 19.- Permeable pavement with full infiltration. **(GVRD, 2005)**

2.2.6. FILTER STRIPS

Filter strips (figure 20) are bands of dense, permanent vegetation with a uniform slope, primarily designed to provide water quality pretreatment between a runoff source (i.e., impermeable area) and another BMP. Filter strips are important components of a BMP treatment train.

This practice is commonly used when in small watersheds. It is not recommended for already developed areas or very dense developed areas because it needs space to be implemented. It is neither recommended downstream sensible areas, such as industries or petrol stations cause aquifers could be polluted due to infiltration.

Figure 20.- Filter strip in a road area. (MDDEP and MAMROT, 2012)

On the other hand, this BMP is relatively easy to build and it doesn't need too much maintenance, which is a clear advantage.

Design Variations

A filter strip may be constructed with or without a permeable berm at the downstream end. The maximum berm height should be no more than one foot and may be used to contain the water quality volume (WQV). Because it increases the contact time with runoff, a berm will reduce the required filter strip width.

Besides, this BMP requires non concentrated flow at its entrance so flux distributor elements are often used to spread the flow.

A schema of a typical filter strip is shown in figure 21.

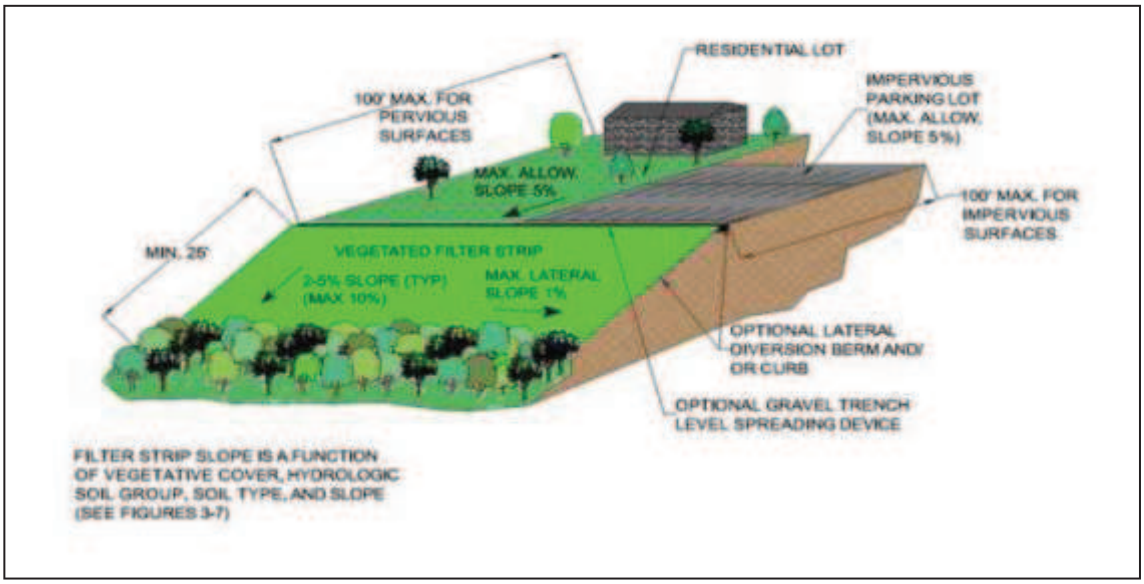

Figure 21.- Schema of a filter strip. (DEP, 2006)

2.2.7. RAIN GARDENS

Rain gardens (figure 22), also known as bioretention cells, are vegetated depressions that store and infiltrate runoff. Uptake into plants reduces runoff volume and pollutant concentrations. The soil media is engineered to maximize infiltration and pollutant removal. Rain gardens are typically designed to avoid ponding for longer than 24 hours.

Figure 22.- Rain garden in Germany. (Emanuel, et al., 2010)

Rain gardens are practices well adapted to Quebec's winter climate and they are one of the most aesthetic among all the BMPs. On the contrary, attention must be paid to avoid clogging. Other BMPs can be implemented upstream as a pretreatment in order to avoid it.

Design Variations

Rain gardens function as soil and plant-based filtration devices that remove pollutants through a variety of physical, biological, and chemical treatment processes. They can resemble miniature ponds or long strips, and may be lined or unlined, depending on site requirements. Rain gardens are used to treat stormwater that has run over impermeable surfaces in commercial, residential, and industrial areas. Use of rain gardens for stormwater management is ideal for median strips, parking lot islands, and swales.

A schema of a bioretention system can be observed in figure 23.

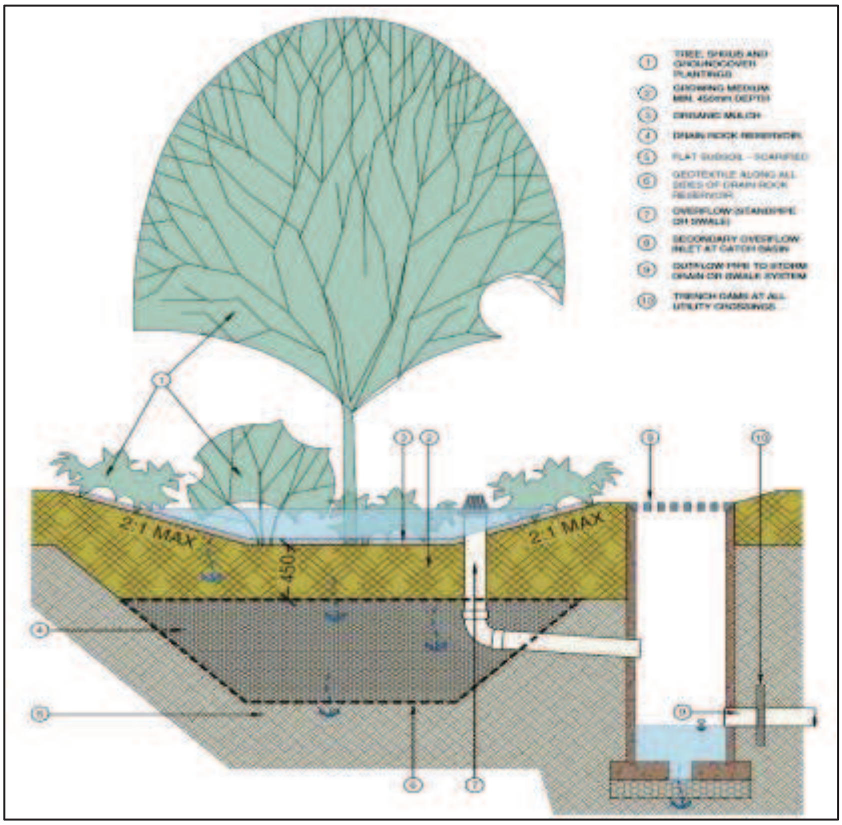

Figure 23.- Schema of a bioretention system. (GVRD, 2005)

2.2.8. VEGETATED SWALES

Vegetated swales (figures 24 and 25) are broad, shallow channels designed to convey and infiltrate stormwater runoff. The swales are vegetated along the bottom and sides of the channel, with side vegetation at a height greater than the maximum design stormwater volume. The design of swales seeks to reduce stormwater volume through infiltration, improve water quality through infiltration and vegetative filtering, and reduce runoff velocity by increasing flow path lengths and channel roughness.

Figure 24.- Shallow swale. (GVRD, 2005)

Figure 25.- Deep swale. (MAMROT, 2010)

These BMPs are commonly used as pretreatment practices, in parking areas and as road shoulders. In this last case, vehicles and activities to remove snow in winter can damage the swales. Besides, these practices need a regular maintenance and attention must be paid to erosion downstream.

Design Variations

Two primary vegetated swale design variations exist. Dry swales are designed with highly permeable soils and an underdrain to allow the entire stormwater volume to convey or infiltrate away from the surface of the swale shortly after storm events. Dry swales may be designed with check dams that act as flow spreaders and encourage sheet flow along the swale. Check dams also retain stormwater. Wet swales are designed to retain water and maintain marshy conditions for the support of aquatic vegetation. Because of their highly permeable soil and conveyance capability, dry swales are more applicable for urban environments.

A schema of this type of BMP is presented in figure 26.

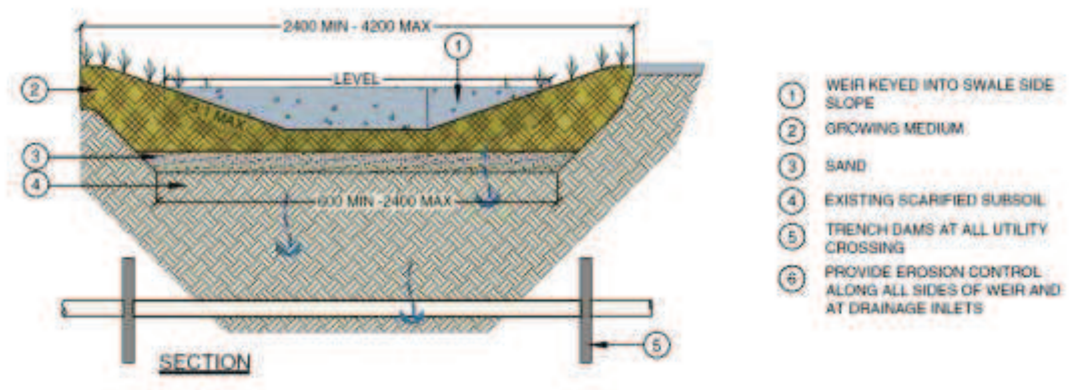

Figure 26.- Schema of a swale section. (GVRD, 2005)

2.2.9. PERFORATED PIPE SYSTEMS

Perforated pipe systems (figure 27) can be thought of as long infiltration trenches or linear soakaways that are designed for both conveyance and infiltration of stormwater runoff. They are underground stormwater conveyance systems designed to attenuate runoff volume and thereby, reduce contaminant loads to receiving waters.

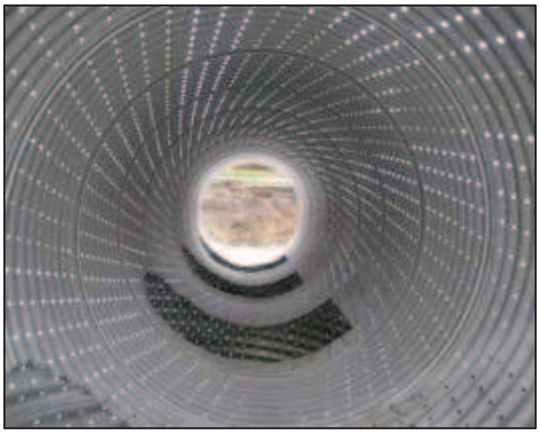

Figure 27.- Perforated pipe. (www.conteches.com)

They can be used in place of conventional storm sewer pipes, where topography, water table depth, and runoff quality conditions are suitable. They are suitable for treating runoff from roofs, walkways, parking lots and low to medium traffic roads, with adequate pretreatment. By contrast, as a general rule, conveyance perforated pipe systems should not be used in areas that are vulnerable to spills of chemicals or hazardous materials, as industrial or commercial zones.

Design Variations

Perforated systems pipe are composed of perforated pipes installed in gently sloping granular stone beds that are lined with geotextile fabric that allow infiltration of runoff into the gravel bed and underlying native soil while it is being conveyed from source areas or other BMPs to an end-of-pipe facility or receiving water body.

A design variation can include perforated catch basins, where the catch basin sump is perforated to allow runoff to infiltrate into the underlying native soil. Perforated pipe systems can also be referred to as permeable pipe systems, exfiltration systems, clean water collector systems and percolation drainage systems.

Schemas of perforated pipe systems can be observed in figure 28.

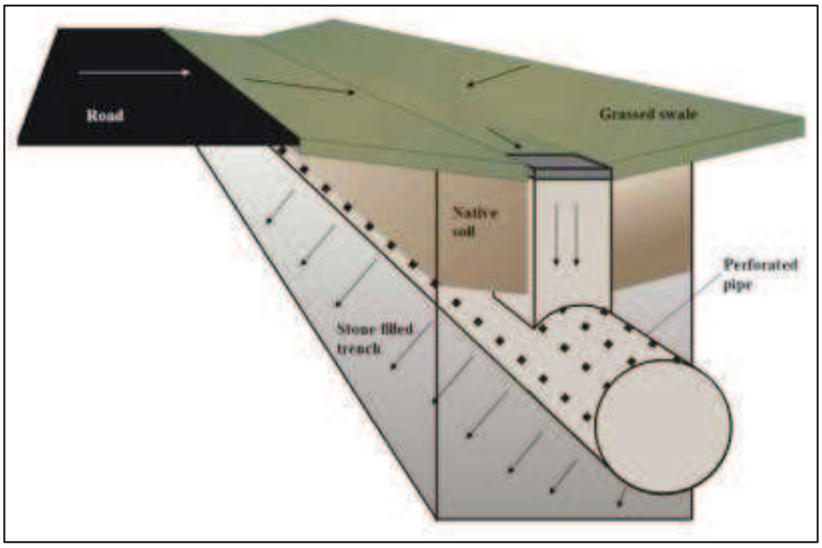

Figure 28.- Schema of a simple perforated pipe system combine with a swale. (www.sustainabletechnologies.ca)

2.2.10. DETENTION BASIN/DRY POND

Dry extended detention basins (figure 29) are surface stormwater structures which provide for the temporary storage of stormwater runoff to prevent downstream flooding impacts. Water quality benefits may be achieved with extended detention of the runoff volume from the water quality design storm.

Figure 29.- Detention basin in a residential area. (www.stormwaterpartners.com)

The primary purpose of the detention basin is the attenuation of stormwater runoff peaks. Detention basins should be designed to control runoff peak flow rates of discharge for the 1 year through 100 year events. Inflow and discharge hydrographs should be calculated for each selected design storm. These hydrographs should be based on the 24-hour rainfall event.

Basins should be designed to provide water quality treatment storage to capture the computed runoff volume of the water quality design storm. Detention basins should have a sediment forebay or equivalent upstream pretreatment. The forebay should consist of a separate cell that is offline so as to not re-suspend sediment, formed by an acceptable barrier and will need periodic sediment removal. A micropool storage area should be designed where feasible for the extended detention of runoff volume from the water quality design storm. Flow paths from inflow points to outlets should be maximized.

Design Variations

Extended detention storage can also be provided in a variety of sub-surface structural elements, such as underground vaults, tanks, large pipes or other structural media placed in an aggregate filled bed in the soil mantle. All such systems are designed to provide runoff peak rate mitigation as their primary function, but some pollutant removal may be included. Regular maintenance is needed, since the structure must be drained within a design period and cleaned to assure detention capacity for subsequent rainfall events. These facilities are usually intended for space-limited applications and are not intended to provide significant water quality treatment.

- Underground vaults are typically box shaped underground stormwater storage facilities constructed of reinforced concrete, while tanks are usually constructed of large diameter metal or plastic pipe. They may be situated within a building, but the use of internal space is frequently not cost beneficial.
- Storage design and routing methods are the same as for surface detention basins.
- Underground vaults and tanks do not provide water quality treatment and should be used in combination with a pretreatment BMP.
- Underground detention beds can be constructed by excavating a subsurface area and filling with uniformly graded aggregate for support of overlying land uses.
- This approach may be used where space is limited but subsurface infiltration is not feasible due to high water table conditions or shallow soil mantle.

- As with detention vaults and tanks, this facility provides minimal water quality treatment and should be used in combination with a pretreatment BMP.
- It is recommended that underground detention facilities not be lined to allow for even minimal infiltration, except in the case where toxic contamination is possible.

A schema of a typical detention pond is presented in figure 30.

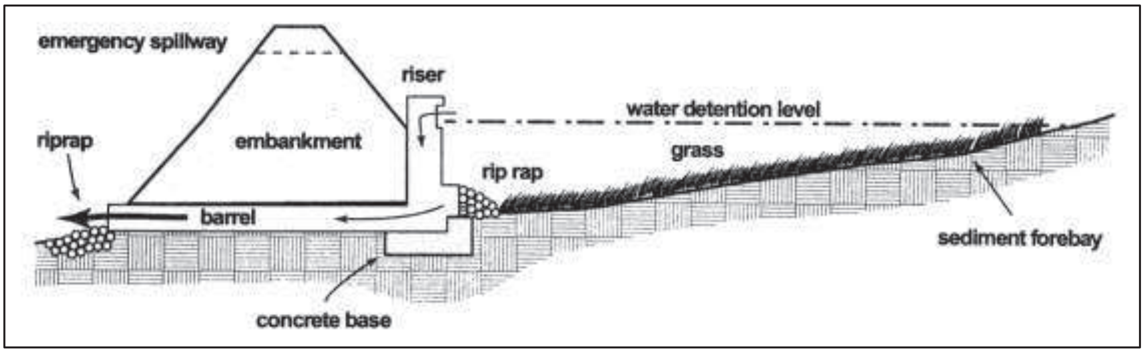

Figure 30.- Schema of a dry pond. (www.cfpub.epa.gov)

2.2.11. RETENTION POND/WET POND

Wet detention ponds (figure 31) are stormwater basins that include a permanent pool for water quality treatment and additional capacity above the permanent pool for temporary storage. Wet Ponds should include one or more forebays that trap course sediment, prevent short-circuiting, and facilitate maintenance.

Figure 31.- Retention pond. (www.winnipeg.ca)

The pond perimeter should generally be covered by a dense stand of emergent wetland vegetation.

While they do not achieve significant groundwater recharge or volume reduction, they can be effective for pollutant removal and peak rate mitigation. Wet Ponds (WPs) can also provide aesthetic and wildlife benefits. WPs require an adequate source of inflow to maintain the permanent water surface.

Due to the potential to discharge warm water, wet ponds should be used with caution near temperature sensitive water bodies. Properly designed and maintained WPs generally do not support significant mosquito populations.

Design Variations

Wet Ponds can be designed as either an online or offline facilities. They can also be used effectively in series with other sediment reducing BMPs that reduce the sediment load such as vegetated filter strips, swales, and filters. Wet Ponds may be a good option for retrofitting existing dry detention basins. WPs are often organized into three groups:

- Wet Ponds primarily accomplish water quality improvement through displacement of the permanent pool and are generally only effective for small inflow volumes (often they are placed offline to regulate inflow).
- Wet Detention Ponds are similar to Wet Ponds but use extended detention as another mechanism for water quality and peak rate control.
- Pocket Wet Ponds are smaller WPs that serve drainage areas between approximately 5 and 10 acres and are constructed near the water table to help maintain the permanent pool. They often include extended detention as well.

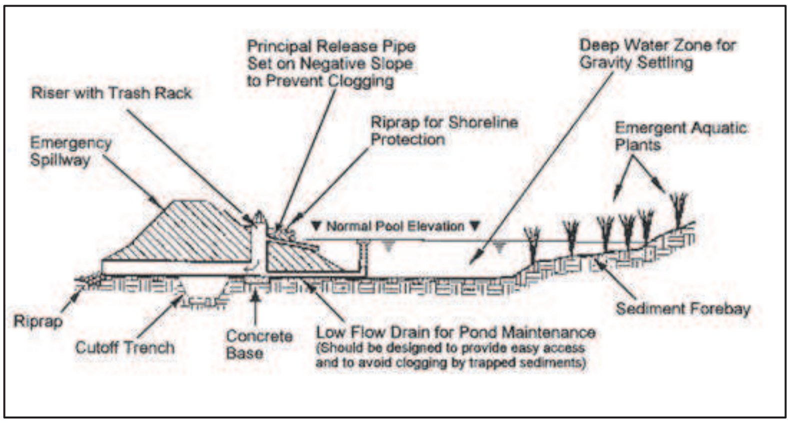

Figure 32.- Schema of a retention pond. (www.myweb.wit.edu)

This BMP focuses on Wet Detention Ponds as described above because this tends to be the most common and effective type of Wet Pond.

A schema of a retention pond section is presented in figure 32.

2.2.12. CONSTRUCTED WETLAND

Constructed wetlands (figure 33) are shallow marsh systems planted with emergent vegetation that are designed to treat stormwater runoff. While they are one of the best BMPs for pollutant removal, Constructed Wetlands (CWs) can also mitigate peak rates and even reduce runoff volume to a certain degree. They also can provide considerable aesthetic and wildlife benefits. CWs use a relatively large amount of space and require an adequate source of inflow to maintain the permanent water surface.

Figure 33.- Constructed wetland in Quebec. (MAMROT, 2010)

Design Variations

Constructed Wetlands can be designed as either an online or offline facilities. They can also be used effectively in series with other flow/sediment reducing BMPs that reduce the sediment load and equalize incoming flows to the CWs. Constructed Wetlands are a good option for retrofitting existing detention basins. CWs are often organized into four groups:

- Shallow Wetlands are large surface area CWs that primarily accomplish water quality improvement through displacement of the permanent pool.

- Extended Detention Shallow Wetlands are similar to Shallow Wetlands but use extended detention as another mechanism for water quality and peak rate control.
- Pocket Wetlands are smaller CWs that serve drainage areas between approximately 5 and 10 acres and are constructed near the water table.
- Pond/Wetland systems are a combination of a wet pond and a constructed wetland.

Although this BMP focuses on surface flow Constructed Wetlands as described above, subsurface flow CWs can also be used to treat stormwater runoff. While typically used for wastewater treatment, subsurface flow CWs for stormwater may offer some advantages over surface flow wetlands, such as improved reduction of total suspended solids and oxygen demand. They also can reduce the risk of vectors (especially mosquitoes) and safety risks associated with open water. However, nitrogen removal may be deficient. Perhaps the biggest disadvantage is the relatively low treatment capacities of subsurface flow CWs – they are generally only able to treat small flows.

A schema of a wetland typical design is presented in figure 34

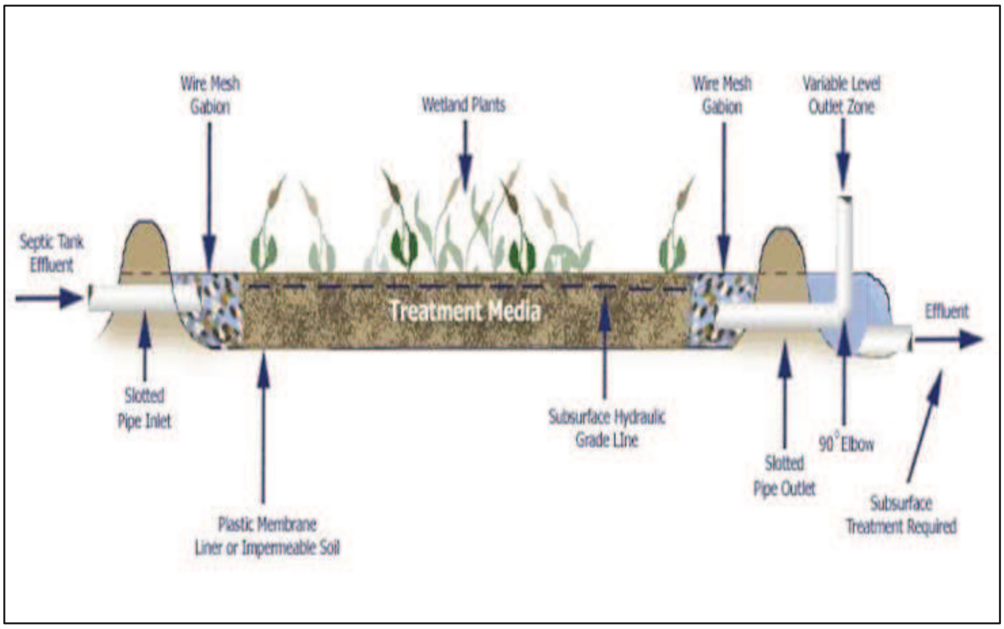

Figure 34.- Schema of a constructed wetland. (www.pgoforth.myweb.uga.edu)

3. MULTICRITERIA DECISION AID METHODS

The proper planning of large engineering projects requires a set of procedures to be devised which ensures that available resources are allocated as efficiently as possible in its subsequent design and construction (Rogers, et al., 2000). These procedures must take into account all the factors relevant to the project's design and construction as well as all the different possible ways to achieve the desired objectives of the project. The fundamental steps that constitute the foundation of an engineering system planning are:

1. Definition of objectives
2. Formulation of criteria or measures of effectiveness
3. Generation of alternatives
4. Evaluation of alternatives
5. Selection of preferred alternative or group of alternatives

Selection of alternatives is often one of the most difficult steps in the planning process. In order to help decision makers in choosing the most appropriate option, a set of rules is required to interpret the criterion valuations for each alternative considered. This set of rules, called evaluation methods, represents one of the most important tools to guide engineers in selection problems.

Optimization versus compromise: types of evaluation methods

If the principle of optimization is at the basis of the decision rules used, it can be assumed that different objectives, as stated through their relevant measures of performance, can be expressed in a common denominator by means of trade-offs, so that the loss in one objective can be evaluated against the gain in another. This idea of compensatory changes underlies the traditional cost-benefit analysis.

Cost-Benefit Analysis (CBA) constitutes the first formal model utilized in the planning of major engineering projects. This model is based on the traditional economic theory where evaluating effects of a given project option involves making a distinction between the purely technical and physical effects, i.e. those related to technical and socio-environmental criteria, and the economic evaluation of these effects. Hence it requires the transformation of all project option effects into one single monetary dimension. This severe restriction is responsible for many difficulties in the practical application of CBA.

Therefore, as the optimizing principle seems to be rather limiting in finding solutions to real life problems, the so-called compromise principle is often considered. This principle assumes the existence of a variety of decision criteria and states that any viable solution has to reflect a compromise between various priorities while the various discrepancies between actual outcomes and aspiration level are traded off against each other by means of preference weights. The compromise principle is particularly relevant for option evaluation or choice problems leading to multicriteria analyses. Given the potential complexity of the planning process for major engineering projects, such multicriteria methodologies can provide a useful resource for decision makers in the completion of their task. Engineering problems often have to take into account conflicting and opposite points of view so that in many cases no single option exists which is the best in economic, technical and socio-environmental terms. Hence, optimization becomes not applicable to these problems. On the contrary, multicriteria methods, issue from Multicriteria Decision Aid, do not yield a single, “objectively best” solution but rather yield a kernel of preferred solutions or a general ranking of all options. As a result, this type of evaluating methods are most readily applicable models to problems of option choice within civil engineering where it is virtually impossible to provide a scientific basis for an optimal solution.

The major advantage of a multicriteria analysis is its capacity to take account of an entire range of differing yet relevant criteria, even if these criteria cannot be related to monetary outcomes. On the basis of this concept of a multidimensional compromise, a series of alternative multicriteria decision methods have been developed.

3.1. TYPES OF MCDA METHODS AND MAJOR CHARACTERISTICS

It could be said that multicriteria methods were born in the fifties. At the beginning of this decade, the systematic study of the theoretical and methodological issues of multicriteria decision emerged in American academic Medias of the novel field of operations research ((Koopmans, 1951); (Kuhn & Tucker, 1951)). From the beginning of the seventies, where the 1st. World Conference on Multiple Criteria Decision Making took place in South Carolina University in 1972, until nowadays there has been a continued increase of the interest and the theoretical and practical development of the MCDA methods.

MCDA methods consist of rational and consistent evaluation procedures that a decision maker will use for choosing between a set of feasible alternatives, simultaneously optimizing them according to several objective functions or influent criteria.

There are two main types of MCDA methods: the discrete methods and the continuous or multi-objective ones. Discrete MCDA methods are used for evaluation and decision on issues that, due to its nature or design, only admit a finite number of alternative solutions. By contrast, multi-objective MCDA methods are used to perform an evaluation and decision on issues that may have an infinite set of alternative solutions. The objective functions or criteria can take an infinite number of values, i.e. a continuum.

MCDA methods do not consider the possibility of finding an optimal solution. Depending on the decision maker preferences and the pre-defined goals, usually conflicting, the main problem of MCDA methods consists in: (1) selecting the "best" alternative(s) (α problem type), (2) accepting alternatives that seem “good” and reject those that seem “bad” (β problem type) or (3) generating a ranking of the alternatives considered from the “best” to “worst” (γ problem type). A number of approaches, methods and solutions have been developed to solve all these different types of problems.

Main discrete MCDA methods are described below.

Linear Programming or Scoring Method

It is a method with an orthodox and direct theoretical basis appropriated to deal with situations of uncertainty or with modest levels of information. It consists of building a "value function" for each alternative. Linear Programming method assumes transitivity of preferences or comparability. The method is fully compensatory and may be dependent on and easy manipulated by the criteria weighting or the measurement scale of assessments. It is an intuitive and easy-to-use method and, as a result, it is highly widespread.

Multi-Attribute Utility Theory (MAUT)

In this method, a "utility function" (a partial function) is determined for each attribute and then they are aggregated in a "multi-attribute utility function", either additively or multiplicatively. By determining the utility of each of the alternatives a complete organization of the finite set of alternatives is obtained. The multi-attribute utility method assumes transitivity of preferences or comparability; it uses "interval scales" and accepts the principle of "rank preservation". The condition of mutual preferential independence between attributes is generally accepted almost axiomatically and, implicitly, the non-interaction between preferences, a fact that it is often questionable and does not reflect the preference structure of the decision maker. The rigor and rigidity of the theoretical assumptions of this method, often controversial and difficult to check in practice, requires a high level of information for the decision maker in order to construct the multi-attribute utility functions. However, it allows dealing fluently with uncertainty and risk issues. Despite the difficulties in using this method, it is has been used in a variety of practical experiences in the Anglo-Saxon countries as the USA and England.

Analytic Hierarchy Process (AHP)

The AHP decomposes a complex, unstructured situation into its components and it organizes them into a hierarchy. Then, it executes binary comparisons attributing numerical values to subjective judgments (related to the relative importance of each variable) and synthesizes the judgments adding the partial solutions into a single one. The AHP uses "ratio scales", does not fulfill the principle of "rank preservation" (undesirable effects of "rank-reversal" may be caused, although it is possible to avoid them using the Absolute Measurement or the Mode Ideal Relative Measurement Mode) and allows an attractive sensitivity analysis. Normally, objectives or criteria are arranged from the most general and less controllable to the most specific and more controllable. It is an intuitive method and not easy-to-manipulate. Besides, it has an attractive and robust software (the Expert Choice) and is probably the most widespread method and the one with the broadest range of practical experience in both the U.S. and the rest of world.

Overcoming or Outranking Relations methods (Elimination Et Choix Traduisant la Réalité (ELECTRE) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE))

These methods are relatively simple tools to obtain a pre-selection of large groups of alternatives or choices. The size of the set of efficient solutions is reduced by a partition on a subset (also called a kernel) of "favorable" and "less favorable" alternatives. An overcoming relationship is a preference aggregation model which takes into account the particular case of two alternatives that are "incomparable". Building overcoming relationships does not absolutely need to carry out binary comparisons of alternatives. Besides, these methods do not necessarily assume transitivity of preferences or comparability, they use ordinal scales, they are indifferent to the principle of "rank preservation" and they are not easily manipulated. The best known approaches of this kind of methods, as it is ELECTRE, are based on the concepts of "concordance" and "discordance". Other methods are based on the "replacement rates" concept or in a family of utility functions. The overcoming relationship model consists of admitting, to any pair of alternatives, that one alternative "exceeds" the other when they satisfy both, concordance and discordance conditions. The concordance quantifies the "degree of dominance" of the alternative *A* over alternative *B*, the discordance quantifies the "degree of non-domination" of the alternative *B* over *A*. Regarding the level of uncertainty, there are deterministic and fuzzy overcoming relationships. The outranking methods have emerged from the French School and its use is also favored in Belgium, the Netherlands and the rest of Europe.

3.2. AHP AND ELECTRE III

In this study, AHP and ELECTRE III methods have been chosen to rank BMPs and analyze and compare their results. The reasons for selecting these two methods are mainly that they are two of the most well know MCDA methods (Ho & Sherris, 2012) and, as it has been showed in section 1.2, they have already been used successfully to assist in BMPs selection problems ((Young, et al., 2010); (Fuamba, et al., 2011); (Martin, et al., 2007)).

Besides, these two methods have some advantages compared to the rest of MCDA techniques. AHP is characterized by its simplicity and effectiveness: it can be satisfactory applied without requiring the user to possess an in-depth knowledge of MCDA theory (Young, et al., 2010). Its hierarchic structure makes it ideal for problems based on a complex situation with elements difficult to quantify because it groups them according to their characteristics and puts them in order from the most general to the most specific one. On the other hand, ELECTRE III is an interesting method to use as it is based in fuzzy logic. Two other original and remarkable features are that it introduces the possibility to declare two alternatives "incomparable" and that it also considers the possibility of "veto" when the degree of discordance between two alternatives is extremely high.

The main differences between both methods in relation to some key characteristics are presented in table 5. According to transitivity, if alternative A outranks alternative B and alternative B outranks alternative C, AHP considers that A outranks C while ELECTRE III doesn't. In AHP method, criteria are weighted making pairwise comparisons while in ELECTRE III criteria are weighted all together considering all at the same time. This fact may become an advantage for AHP method when the number of criteria is high because, in this case, it may be difficult to consider and evaluate all the criteria at the same time as ELECTRE III does. While weight values are determined by a specific scale in AHP method (a ration scale going from 1 to 9), ELECTRE III uses scalar numbers selected by the decision-maker. Besides, ELECTRE III, contrary to AHP, is a non-compensatory method, which means that a very bad score on a criterion cannot be compensated by good scores on other criteria. Concerning the rank reversal problems, which consists basically of changes in the final ranking when a new alternative is added to the set of study or when an alternative from the set is deleted, different studies have proved that AHP is affected by this phenomenon (Triantaphyllou, 2001) while few studies have obtained similar conclusions for ELECTRE III (Wang & Triantaphyllou, 2008). Finally, normalization of criteria values is highly recommended for AHP method but it is not necessary for ELECTRE III.

CHARACTERISTIC	AHP	ELECTRE III
Transitivity	implicit	not necessarily implicit
Criteria weighting	pairwise	all together
Criteria weights scales	ratio scale (from 1 to 9)	scalar numbers scale
Rank reversal problems	affected	little affected
Compensatory method	yes	no
Normalization need	yes	not indispensable
Axiomatic base	yes	no

Table 5.- Main differences between AHP and ELECTRE III methods.

3.2.1. THE AHP ALGORITHM

The AHP method was first proposed by Thomas Saaty (1980). A schema of the algorithm is presented in figure 35. As it can be observed, AHP procedure can be divided in the following five steps:

1. Decompose the problem in a hierarchical structure
2. Make pairwise comparisons
3. Determine priorities for each level
4. Synthesize priorities for each alternative
5. Assess coherence of the performed judgments

First of all, the problem is decomposed in a hierarchical structure. The top level of the hierarchy considers the general objective of the problem. The second level includes all the evaluation criteria. Each criterion is analyzed in the subsequent levels into sub-criteria. Finally, the last level of the hierarchy involves the objects to be evaluated.

Secondly, the decision-maker performs pairwise comparisons of all elements at each level of the hierarchy. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.

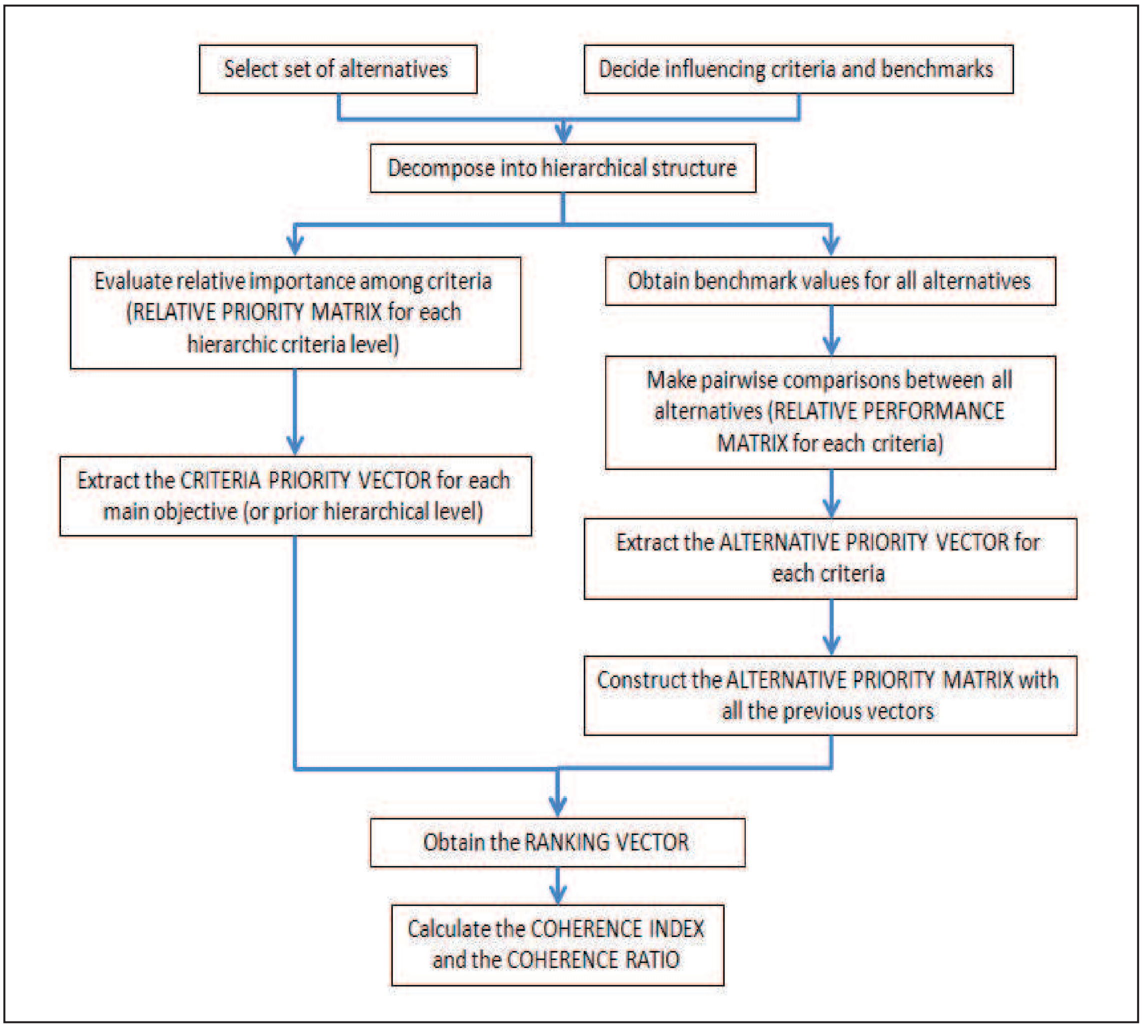

Figure 35.- Schema of the AHP algorithm.

To make comparisons, a scale of numbers is needed to indicate how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared. This scale was proposed by Saaty (1980) and is presented in table 6.

SCALE	DEFINITION	INTERPRETATION
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	One element is slightly favored over the other
5	Strong importance	One element is strongly favored over the other
7	Very strong importance	One element is very strongly favored over the other
9	Extreme importance	One element is absolutely favored over the other
2,4,6,8	Intermediate values	When compromise is needed

Table 6.- Saaty scale for AHP method.

The results of the comparisons made are used to form an *nxn* matrix (*W*) for each level *k* of the hierarchy, where *n* denotes the number of elements in level *k*.

$$W_k = \begin{bmatrix} w_{k,1}/w_{k,1} & w_{k,1}/w_{k,2} & \cdots & w_{k,1}/w_{k,n} \\ w_{k,2}/w_{k,1} & w_{k,2}/w_{k,2} & \cdots & w_{k,2}/w_{k,n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{k,n}/w_{k,1} & w_{k,n}/w_{k,2} & \cdots & w_{k,n}/w_{k,n} \end{bmatrix} \quad (1)$$

Each row of the matrix represents the actual weights assigned to each element included at level *k* of the hierarchy as opposed to a specific element of the level *k-1*. Assuming that all comparison are consistent, the weights, or priorities, can be estimated through the solution of the following eigenvalue problem for each level *k*:

$$Ax = \lambda x \quad (2)$$

There are different possibilities to solve this eigenvalue problem. In this study, the simplest methodology has been utilized to obtain the solution. Considering $A = W_k$, vector *B* is firstly formed as the addition of the *A* matrix rows:

$$B = \begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix} \text{ where } b_t = \sum_{s=1}^{n} a_{t,s} \quad (3)$$

Secondly, vector *C*, called the priority vector, is obtained by normalizing vector *B*:

$$C = \begin{pmatrix} c_1 \\ \vdots \\ c_n \end{pmatrix} \text{ where } c_t = \frac{b_t}{\sum_{s=1}^{n} b_s} \quad (4)$$

Then, vector *D* is calculated as the product of matrix *A* and vector *C*:

$$d_t = \sum_{s=1}^{n} \left(a_{t,s} \times c_s \right) \quad (5)$$

Finally, vector *E*, which is used to calculate the eigenvalue, is formed dividing the elements of vector *D* by those of vector *C*.

$$E = \begin{pmatrix} d_1/c_1 \\ \vdots \\ d_n/c_n \end{pmatrix} \qquad (6)$$

The eigenvalue is calculated as follows:

$$\lambda = \frac{\sum_{t=1}^{n} e_t}{n} \qquad (7)$$

The next step of the AHP procedure consists in combining the priorities defined in the previous step so that an overall evaluation of elements belonging to the final level of the hierarchy is performed on the basis of the initial objective of the analysis. Being *M* the squared matrix composed by the priority vectors of each level *k*, to calculate the final ranking vector *V*, matrix *M* is firstly normalized:

$$M = (C_1 \quad \cdots \quad C_P) \text{ where } p \text{ is the number of levels} \qquad (8)$$

$$Q = \begin{bmatrix} m_{1,1}/S & \cdots & m_{1,p}/S \\ \vdots & \ddots & \vdots \\ m_{n,1}/S & \cdots & m_{n,p}/S \end{bmatrix} \text{ where } S = \sum_{t=1}^{n}\sum_{s=1}^{p} m_{t,s} \qquad (9)$$

Secondly, *Q* matrix is multiplied by vector *C* from the upper level *k-1* obtaining *Z* matrix.

$$Z = \begin{bmatrix} q_{1,1} \times c_1 & \cdots & q_{1,p} \times c_p \\ \vdots & \ddots & \vdots \\ q_{n,1} \times c_1 & \cdots & q_{n,p} \times c_p \end{bmatrix} \qquad (10)$$

The addition of the rows of this new matrix provides vector *X* which is normalized to obtain the final vector *V*.

$$V = \begin{pmatrix} x_1/R \\ \vdots \\ x_n/R \end{pmatrix} \text{ where } x_t = \sum_{s=1}^{p} z_{t,s} \text{ and } R = \sum_{t=1}^{n} x_t \qquad (11)$$

Vector *V* gives the ranking of the alternatives where the highest number corresponds to the best alternative.

The final step of the AHP methods involves assessing coherence of the judgments performed by the decision-maker. These judgments present often a certain degree of incoherence. Saaty defined a coherence index which is calculated as follows:

$$CI = \frac{\lambda - K}{K - 1} \text{ where } K \text{ is the number of compared elements} \quad (12)$$

The higher the index is, the more incoherent the judgments from the decision-maker are. This index is then compared to critical values obtained by simulation. Saaty defined a coherence ratio as the relation between the calculated index and a random index issue from a matrix of the same dimension (formula 13). These random indexes were obtained by Saaty by experimentation and are presented in table 7.

$$CR = \frac{CI}{RI} \text{ where } CI \text{ is the Coherence Index and } RI \text{ the random index} \quad (13)$$

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Table 7.- Random coherence indexes obtained by Saaty by experimentation.

where *N* is the number of criteria.

The coherence ratio can be interpreted as the probability that the matrix of the performed judgments is complemented randomly. The overall coherence of the assessment is evaluated using this coherence ratio. According to Saaty, the value of the latter must be at most equal to 10%. If this value exceeds 10%, performed judgments may require some revisions.

3.2.2. THE ELECTRE III ALGORITHM

The first version of ELECTRE methods was devised by Bernard Roy (1978). ELECTRE family methods are based on the concept of outranking. The outranking relation *S* is a binary relation defined on the set of alternatives by using pairwise comparison under each criterion. Alternative *a* outranks *b*, (*aSb)*, if on most of the criteria *a* performs at least as good as *b* (concordance condition), and for those criteria where *a* has worse performance than *b*, it is still considered acceptable (non-discordance condition).

ELECTRE versions differ according to the nature of the procedure, the type of criteria utilized and the nature of the outranking relationship derived. Characteristics of the different ELECTRE methods are presented in table 8.

		PROCEDURE		
OUTRANKING	**CRITERIA**	**Selection**	**Allocation**	**Ranking**
crisp	true	I		II
fuzzy	pseudo	IS	Tri	III, IV

Table 8.- Characteristics of the different ELECTRE methods.

ELECTRE III method was chosen because, within the planning of civil and environmental engineering projects, where the uncertainties inherent in criterion estimates can be significant, the choice of a fuzzy decision model was a clear recognition of the nature of the problems being confronted. Besides, as a comparison with AHP method was pursued, criteria weighting and a ranking procedure were desired characteristics that determine the III version better than the IV one.

ELECTRE III comprises two distinct phases:

1. Construct the outranking relation, which comprises the creation of the Concordance, Discordance and Credibility matrices.
2. Exploit the outranking relation, which comprises the Qualification and Distillation procedures.

A schema of the algorithm is presented in figure 36. To construct the outranking relationship, preference relations must be made between the alternatives. Consider comparing a set of alternatives *A* under a predefined set of criteria $G = g_1, \ldots, g_m$. ELECTRE III allows for imprecision and uncertainty in judgments by making use of the concept of an indifference threshold *q* and preference thresholds *p*.

Preference relations under a single criterion *g* are defined as follows (assuming an increasing performance scale):

- *a* is strictly preferred to *b*: $g(a) - g(b) \geq p$
- *a* is weakly preferred to *b*: $q < g(a) - g(b) < p$
- *a* is indifferent to *b*: $|g(a) - g(b)| \leq q$

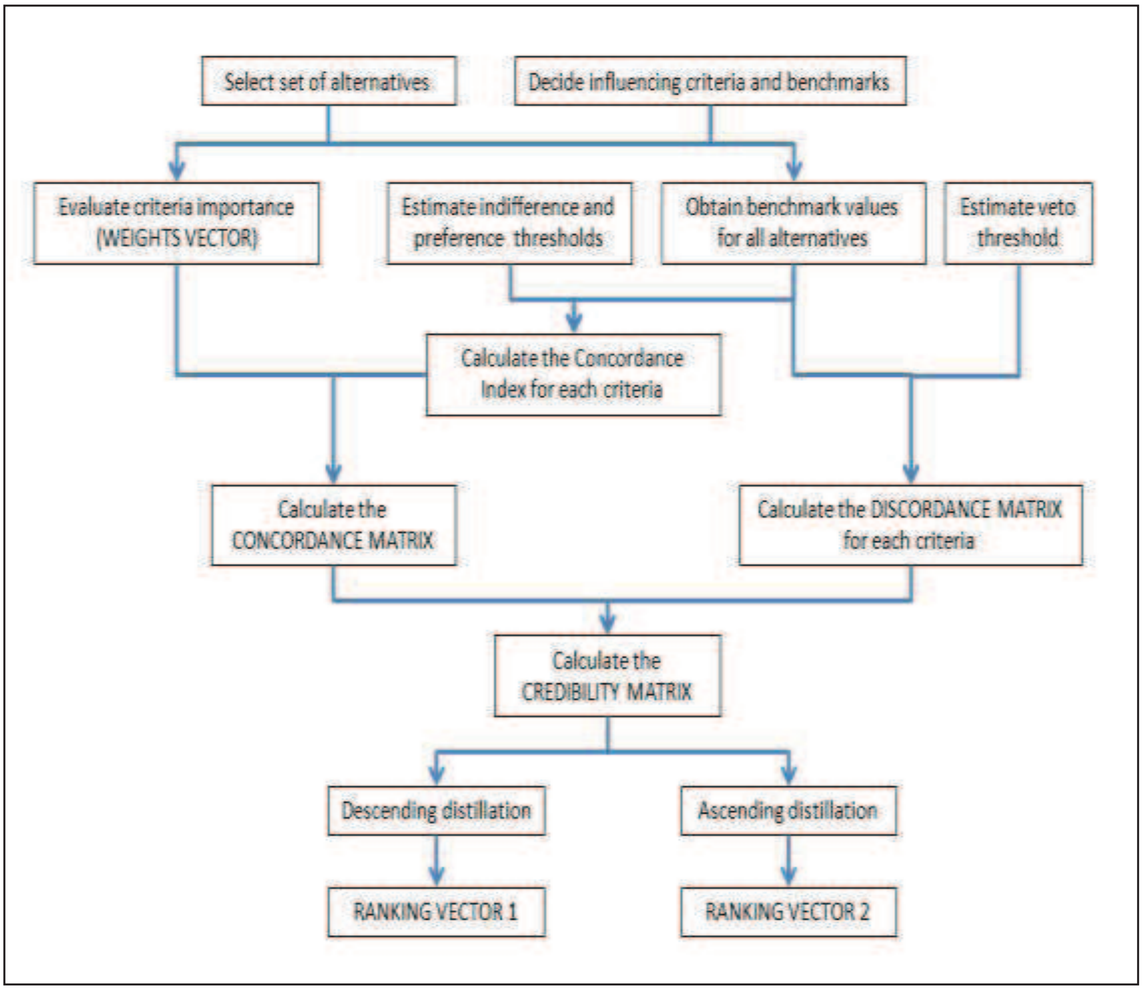

Figure 36.- Schema of the ELECTRE III algorithm.

This double threshold avoids the need for a clear distinction between indifference and strict preference.

Another threshold, the veto threshold *v*, can be introduced (not necessarily for each criterion *g*) in order to define the outranking relation *S* that incorporates all of the criteria considered. More precisely, when veto *v* is defined for criterion *g*, this leads to refusing the outranking of *b* by *a* when *b* appears sharply better than *a* on *g*, even if *a* outranks *b* according to all other criteria:

$$\text{If } g(b) - g(a) > v \rightarrow \text{no } (aSb)$$

The first step when constructing the outranking relationship is to calculate the Concordance matrix. The elements of this matrix are the Concordance Indexes computed for each ordered pair of alternatives. Concordance index is calculated as follows:

$$C(a,b)=\frac{1}{W}\sum_{j=1}^{n}w_j c_j(a,b) \text{ where } W=\sum_{j=1}^{n}w_j \quad (14)$$

$c_j(a,b)$ is calculated as follows (assuming an increasing performance scale):

If g(a) + q ≥ g(b) → c_j(a,b) = 1 **(15)**

If g(a) + p ≥ g(b) → c_j(a,b) = 1 **(16)**

Otherwise $c_j(a,b)=\dfrac{g(a)-g(b)+p}{p-q}$ **(17)**

Then, a Discordance matrix is calculated for each criterion as follows:

If g(b) ≤ g(a) + p → D_j(a,b) = 0 **(18)**

If g(b) > g(a) + v → D_j(a,b)= 1 **(19)**

Otherwise $D_j(a,b)=\dfrac{g(b)-g(a)-p}{v-p}$ **(20)**

Finally, the degree of credibility, collected in the Credibility matrix, is defined as follows:

If $D_j(a,b)\leq C(a,b), \forall j$ → S(a,b) = C(a,b) **(21)**

Otherwise $S(a,b)=C(a,b)\prod_{j\in J(a,b)}\dfrac{1-D_j(a,b)}{1-C(a,b)}$ **(22)**

where J(a,b) is the set of criteria for which D_j(a,b)>C(a,b)

The second phase of the ELECTRE III method is exploiting the outranking relationship. The algorithm for ranking all options yields two pre-orders, each constructed in a different way. The first pre-order is obtained in a descending manner, selecting the best-rated options initially and finishing with the worst. This procedure is called Descending Distillation. On the other hand, the second pre-order is obtained in an ascending manner, selecting firstly the worst rated options and finishing with the assignment of the best. This procedure is called Ascending Distillation.

The construction of these two pre-orders requires the qualification score for each option. The procedure to calculate this score as well as the descending distillation process are stated below:

1. A minimum acceptable value of the credibility index is defined and used to determine if the credibility index is compatible with the assertion *aSb*. Denoting by

$$\lambda_0 = Max\{S(a,b), a \neq b\} \quad \textbf{(23)}$$

the smallest value of *S(a,b)* that is still considered acceptable must be sufficiently close to λ_0. A cut-off level is defined λ_1 as:

$$\lambda_1 = Max\{S(a,b), S(a,b) < (\lambda_0 - s(\lambda_0)), a \neq b\} \quad \textbf{(24)}$$

s(λ) is known as the discrimination threshold. In ELECTRE III, s(λ) is usually set at $s(\lambda) = 0.3 - 0.15\lambda$.

2. At cut-off level λ_1, *a* outranks *b* if and only if *S(a,b)* exceeds the cut off level and *S(a,b)* is greater than *S(b,a)* by more than the discrimination threshold. The credibility matrix *S* is converted into an outranking relation matrix *T* with entries as follows:

   If S(a,b) > λ_1 and S(a,b) - S(b,a) > s(S(a,b)) → T(a,b) = 1 **(25)**

   Otherwise T(a,b) = 0 **(26)**

3. Each alternative is assigned a qualification *Q(a),* defined as the difference between number of alternatives outranked by *a* and number of alternatives outrank *a*. Q(a) is the row sum minus the column sum of *T* for alternative *a*.
4. The set of alternatives having the largest *Q* is the first distillation D_1 of *A.*
5. If D_1 has more than one member, process is repeated inside D_1 until D_1 has only one member or if it still has more than one member but is no longer reducible.

A schema of the descending distillation process is presented in figure 37. As we proceed, λ_0 is subsequently reduced from maximum of *S(a,b)* to λ_1 of the previous step. Thus the cut off level is reduced accordingly toward 0. Once D_1 is reduced to only one member or becomes irreducible, we then repeat the process with the original set of alternatives *A* excluding D_1, until all alternatives are ranked.

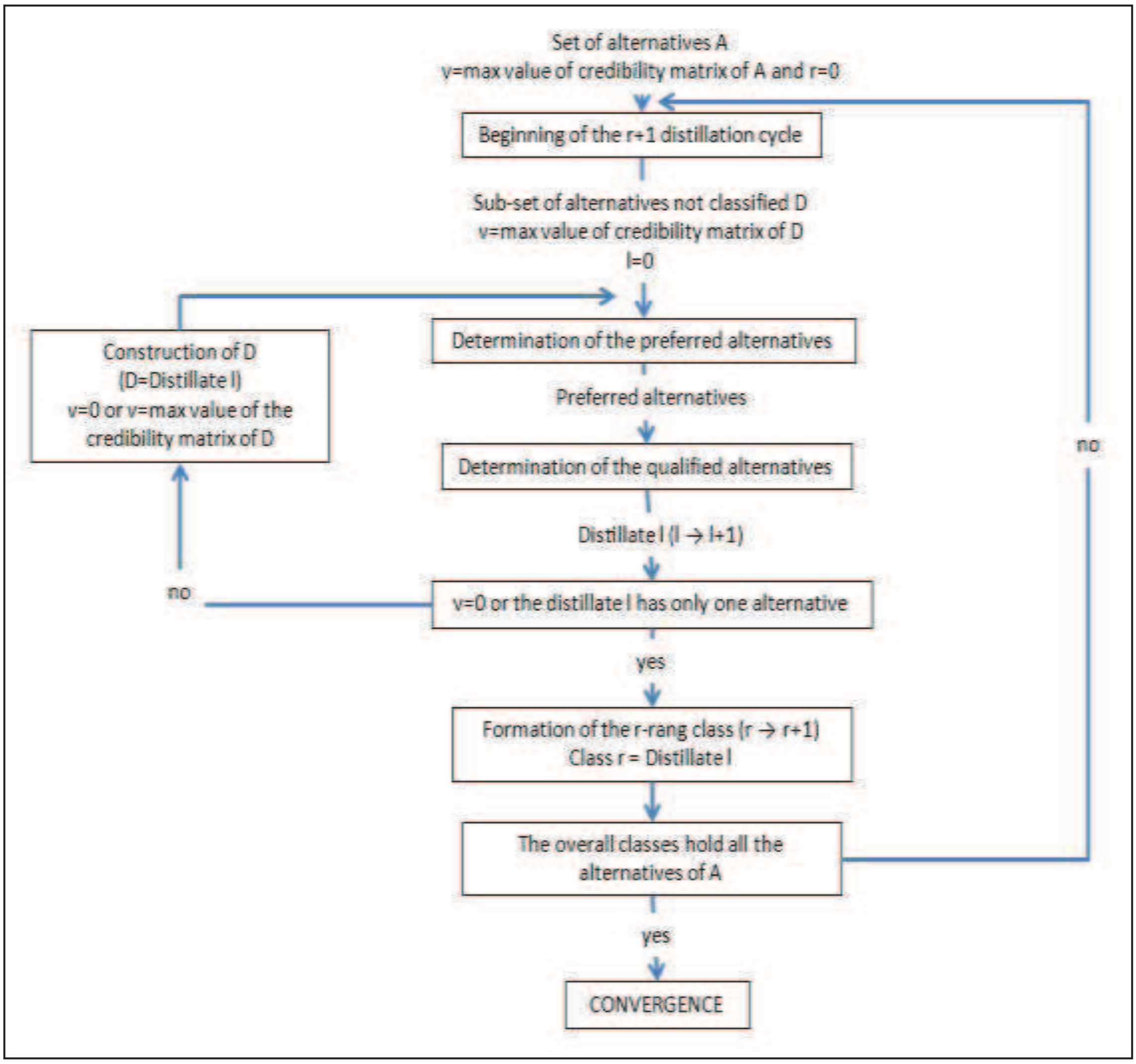

Figure 37.- Schema of the ELECTRE III descending distillation process.

The ascending distillation process is similar to descending distillation except in step 4 where the alternative(s) with the smallest qualification Q is retained first.

The rankings from both distillations are then combined to get a final overall ranking for all alternatives.

3.3. AHP AND ELECTRE III ADAPTATION TO BMP PROBLEM

As it has been explained in Chapter 1, the problem contemplated in the present study is related to the selection of BMPs. 14 different alternatives, each one corresponding to a different structural BMPs, were considered and they were evaluated and compared according to 4 different criteria: technical performance of the BMP, economical performance, quality performance and socio-environmental performance.

The last 2 criteria were divided into other sub-criteria as it was described in table 1. In both, AHP and ELECTRE III methods, criteria must be weighted according to the decision-maker preferences. Besides, in ELECTRE III method, thresholds values must be also determined.

In this section, the structure of the problem adapted to AHP and ELECTRE III methods is presented as well as the weighting methodology and the thresholds values selection for ELECTRE III.

3.3.1. AHP APPLICATION TO BMPs PROBLEM

The first step in the AHP method is to decompose the problem into a hierarchical structure. In this study the main objective is to assess the global performance of different BMPs according to four criteria. Two of these criteria are also based on several sub-criteria. Finally, 14 BMPs have been taken into account. The hierarchical structure of the problem is represented in figure 38.

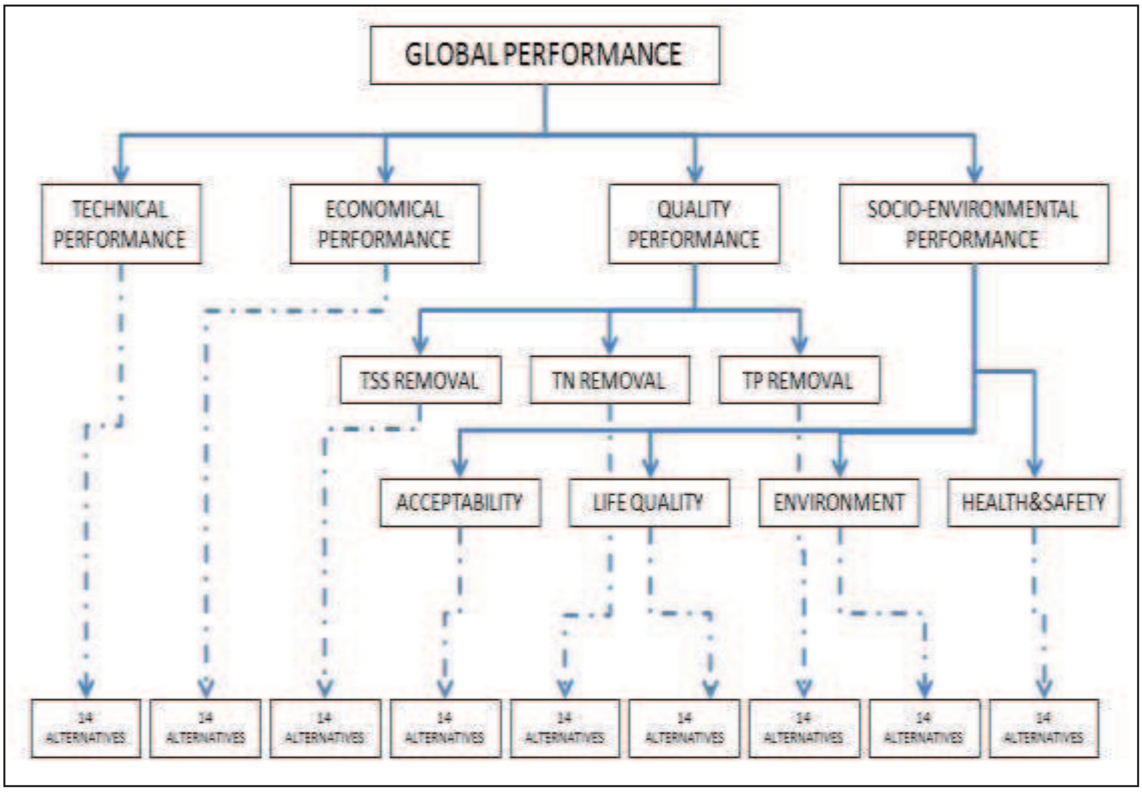

Figure 38.- Hierarchical structure of the problem.

The second and third steps in the AHP method are to make pairwise comparisons and to determine priorities for each level. In this study, there are 3 hierarchic levels: the first one corresponding to the main criteria, the second one corresponding to the sub-criteria and the third and last one corresponding to the alternatives. The relative priority matrices for the first and second levels are related to the weights assigned to each criterion. Their construction is explained in detail in section 3.3.3. Three matrices are obtained, one for the first level and two for the second level, corresponding to quality and socio-environmental criteria.

Concerning the relative priority matrices of the last level, a total number of nine matrices are obtained, each one corresponding to one sub-criteria of the second level (quality and socio-environmental cases) or, if the main criteria is not based on sub-criteria, directly to one of the main criteria (technical and economical cases). These matrices are obtained from the pairwise comparisons. Their construction is made as follows:

1. Given two alternatives *a* and *b*, and their corresponding values of performance according to the criterion *g* (indicator values), firstly these values are normalized and scaled according to a linear relation and Saaty's scale values (from 1 to 9) presented in table 6.

$$G_a = m \cdot g_a + n \tag{27}$$

$$\left.\begin{aligned} m \cdot \max_{a=1 to 14} g_a + n = 9 \\ m \cdot \min_{a=1 to 14} g_a + n = 0 \end{aligned}\right\} \quad \begin{aligned} m &= \frac{8}{g_{\max} - g_{\min}} \\ n &= \frac{g_{\max} - 9 g_{\min}}{g_{\max} - g_{\min}} \end{aligned} \tag{28}$$

   where g_a is the criterion indicator value for alternative a and G_a is the same value but normalized.

2. The relative priority between alternative *a* and alternative *b* regarding the criterion *g* is then calculated as follows:

$$r_{a,b} = \frac{G_a}{G_b} \tag{29}$$

The different indicators for each criteria or sub-criteria were briefly described in section 1.3.2. Further information about the calculation and obtaining procedures of these values is presented in Annex A.

3.3.2. ELECTRE III APPLICATION TO BMPs PROBLEM

Contrary to the AHP method, the ELECTRE III method does not have a hierarchical structure. All criteria and sub-criteria are compared at the same level simultaneously. In this study, 9 criteria were considered for the ELECTRE III method (2 main criteria and 3+4 sub-criteria). Only one performance matrix is created, where the rows represent the indicator values of each alternative for each of the nine criteria, represented by the columns. Thus, the performance matrix dimension for this study is 14x9. The values of the different indicators were obtained the same way as for the AHP method (see Annex A). However, no normalization is needed with this method and no relative priority is calculated between alternatives. The performance matrix is presented in section 5.2 (tables 32 and 33).

The weights vector is obtained from the same criteria weighting methodology as for the AHP method described in section 3.3.3. The weights vector is presented in that section.

Finally, the pseudo-criterion used in ELECTRE III requires specified indifference, preference and veto thresholds. Fixing the thresholds involves not only the estimation of error in a physical sense, but also a significant subjective input by the decision-makers themselves (Rogers & Bruen, 1998). Maystre et al. (1994) interpreted the indifference threshold *q* as the minimum margin of imprecision associated with a given criterion and the preference threshold *p* as the maximum margin of error associated with criterion in question. The veto threshold *v* characterizes the situation where a discordant criterion can, on its own, exert a veto on an entire outranking relationship. In this study, indifference threshold was estimated by the authors and its values are presented in table 9. Preference thresholds can be set at twice the indifference thresholds, and veto thresholds are usually set between 3 to 10 times preference thresholds (Rogers, et al., 2000). In this study, veto thresholds have been established at 8 times preference thresholds. Preference and veto threshold values for each criterion are also presented in table 9.

	THRESHOLDS		
CRITERION	**Indifference (q)**	**Preference (p)**	**Veto (v)**
Technical - T	10 %	20 %	160 %
Economical - E	10 %	20 %	160 %
Quality - TSS	20	40	320
Quality - TN	20	40	320
Quality - TP	20	40	320
Socio-env - RA	1	2	16
Socio-env LQ	1	2	16
Socio-env - EP	1	2	16
Socio-env - HS	1	2	16

Table 9.- Threshold matrix for ELECTRE III method.

3.3.3. THE CRITERIA WEIGHTING METHODOLOGY

The assignment of importance weightings to each criterion is a crucial step in the application of AHP and ELECTRE III methods. The interpretation of weights is, however, different in both methods as the former is compensatory and the latter non-compensatory. In a compensatory method, weights amount to being substitution rates, allowing differences in preferences, as they relate to different criteria, to be expressed on the same scale. Within ELECTRE III, weights used are not constants of scale, but are simply a measure of the relative importance of the criteria involved.

Nevertheless, in this study a common methodology was created and then used in order to be able to compare results from both methods. This common methodology is, however, adapted to each method but keeps relative importance among criteria similar. The criteria weighting procedure is defined as follows:

1. A 3-grade qualitative scale to assess the different criteria has been created:
    - Very Important - V
    - Important - I
    - Slightly important - S
2. Each set of criteria belonging to a hierarchic level has been evaluated according to this scale and from the point of view of one stakeholder (tables 10 and 11).

STAKEHOLDER	Technical	Economical	Quality	Socio-environmental
Engineer	I	V	S	S
Politician	V	I	V	S
Resident	S	I	S	V

Table 10.- Evaluation of the main criteria according to the different stakeholders.

STAKEHOLDER	Quality TSS	Quality TN	Quality TP	Socio-env RA	Socio-env LQ	Socio-env EP	Socio-env HS
Engineer	S	S	S	I	S	I	V
Politician	V	V	V	V	I	I	V
Resident	S	S	S	I	V	I	V

Table 11.- Evaluation of the quality and socio-environmental sub-criteria according to the different stakeholders.

3. Then, the scale has been translated into a quantitative one. Difference between each grade has been established at 4 points and it has been determine that the scale goes from 1 to 9, so that the possible grades are 1, 5 or 9.
4. For AHP method: criteria are compared pairwise. If a criterion is equal to another, they get 1 point. If a criterion is one grade more important than another, it gets 5 points. If a criterion is two grades more important than another, it gets 9 points. The opposite criterion gets the inverse points, i.e. 1/5 for the second case and 1/9 for the third one. Tables 12 to 20 present the relative priority matrices for levels 2 and 3 (criteria and sub-criteria) for the 3 considered stakeholders.

	DEVELOPMENT COMPANY / ENGINEER				
	RELATIVE PRIORITY MATRIX (AHP)				WEIGHTS VECTOR (ELECTRE)
MAIN CRITERIA	Technological	Economical	Quality	Socio-environmental	
Technological	1	0.2	5	5	0.281
Economical	5	1	9	9	0.603
Quality	0.2	0.11	1	1	0.058
Socio-environmental	0.2	0.11	1	1	0.058

Table 12.- Relative priority matrix and weights vector of the main criteria for the Development Company/Engineer stakeholder.

	LOCAL AUTHORITIES / POLITICIANS / PLANNING BODY				
	RELATIVE PRIORITY MATRIX (AHP)				WEIGHTS VECTOR (ELECTRE)
MAIN CRITERIA	Technological	Economical	Quality	Socio-environmental	
Technological	1	5	1	9	0.402
Economical	0.2	1	0.2	5	0.161
Quality	1	5	1	9	0.402
Socio-environmental	0.11	0.2	0.11	1	0.036

Table 13.- Relative priority matrix and weights vector of the main criteria for the Local Authorities/Politicians/Planning Body stakeholder.

	RESIDENTS				
	RELATIVE PRIORITY MATRIX (AHP)				WEIGHTS VECTOR (ELECTRE)
MAIN CRITERIA	**Technological**	**Economical**	**Quality**	**Socio-environmental**	
Technological	1	0.2	1	0.11	0.058
Economical	5	1	5	0.2	0.281
Quality	1	0.2	1	0.11	0.058
Socio-environmental	9	5	9	1	0.603

Table 14.- Relative priority matrix and weights vector of the main criteria for the Residents stakeholder.

	DEVELOPMENT COMPANY					
	RELATIVE PRIORITY MATRIX (AHP)				WEIGHTS VECTOR (ELECTRE)	
SOCIO-ENVIRONMENTAL SUB-CRITERIA	**Acceptability**	**Life quality**	**Environment**	**Health&Safety risks**	**Partial weights**	**Global weights**
Acceptability	1	5	1	0.2	*0.20*	0.012
Life quality	0.2	1	0.2	0.11	*0.04*	0.002
Environment	1	5	1	0.2	*0.20*	0.012
Health&Safety risks	5	9	5	1	*0.56*	0.032

Table 15.- Relative priority matrix and weights vector of the socio-environmental sub-criteria for the Development Company/Engineer stakeholder.

	LOCAL AUTHORITIES / POLITICIANS / PLANNING BODY					
	RELATIVE PRIORITY MATRIX (AHP)				WEIGHTS VECTOR (ELECTRE)	
SOCIO-ENVIRONMENTAL SUB-CRITERIA	**Acceptability**	**Life quality**	**Environment**	**Health&Safety risks**	**Partial weights**	**Global weights**
Acceptability	1	5	5	1	0.42	0.015
Life quality	0.2	1	1	0.2	0.08	0.003
Environment	0.2	1	1	0.2	0.08	0.003
Health&Safety risks	1	5	5	1	0.42	0.015

Table 16.- Relative priority matrix and weights vector of the socio-environmental sub-criteria for the Local Authorities/Politicians/Planning Body stakeholder.

	RESIDENTS					
	RELATIVE PRIORITY MATRIX (AHP)				WEIGHTS VECTOR (ELECTRE)	
SOCIO-ENVIRONMENTAL SUB-CRITERIA	**Acceptability**	**Life quality**	**Environment**	**Health&Safety risks**	**Partial weights**	**Global weights**
Acceptability	1	0.2	1	0.2	0.08	0.050
Life quality	5	1	5	1	0.42	0.251
Environment	1	0.2	1	0.2	0.08	0.050
Health&Safety risks	5	1	5	1	0.42	0.251

Table 17.- Relative priority matrix and weights vector of the socio-environmental sub-criteria for the Residents stakeholder.

	DEVELOPMENT COMPANY				
	RELATIVE PRIORITY MATRIX (AHP)			WEIGHTS VECTOR (ELECTRE)	
QUALITY SUB-CRITERIA	**Total suspended sediments**	**Total nitrogen**	**Total phosphorus**	**Partial weights**	**Global weights**
Total suspended sediments	1	1	1	0.33	0.019
Total nitrogen	1	1	1	0.33	0.019
Total phosphorus	1	1	1	0.33	0.019

Table 18.- Relative priority matrix and weights vector of the quality sub-criteria for the Development Company/Engineer stakeholder.

	LOCAL AUTHORITIES / POLITICIANS / PLANNING BODY				
	RELATIVE PRIORITY MATRIX (AHP)			WEIGHTS VECTOR (ELECTRE)	
QUALITY SUB-CRITERIA	**Total suspended sediments**	**Total nitrogen**	**Total phosphorus**	**Partial weights**	**Global weights**
Total suspended sediments	1	1	1	0.33	0.134
Total nitrogen	1	1	1	0.33	0.134
Total phosphorus	1	1	1	0.33	0.134

Table 19.- Relative priority matrix and weights vector of the quality sub-criteria for the Local Authorities/Politicians/Planning Body stakeholder.

	RESIDENTS				
	RELATIVE PRIORITY MATRIX (AHP)			WEIGHTS VECTOR (ELECTRE)	
QUALITY SUB-CRITERIA	**Total suspended sediments**	**Total nitrogen**	**Total phosphorus**	**Partial weights**	**Global weights**
Total suspended sediments	1	1	1	0.33	0.019
Total nitrogen	1	1	1	0.33	0.019
Total phosphorus	1	1	1	0.33	0.019

Table 20.- Relative priority matrix and weights vector of the quality sub-criteria for the Residents stakeholder.

5. For ELECTRE III: weights established for AHP method have been adapted to ELECTRE III structure following the Weighted Goal Programming procedure. Thus, relative weights have been translated in absolute weights. Weights are obtained in a percentage form and sub-criteria weights have been multiplied by the percentage of their associated main criteria to keep the relative importance between criteria and sub-criteria. Tables 12 to 20 present these results.

This methodology establishes equivalent weights for all criteria and sub-criteria of both MCDA methods so that their results can be compared.

To conclude with the criteria weighting issue, it has to be said that different methodologies exist to weight criteria in ELECTRE III and AHP methods, as the ones for ELECTRE method called “The Pack of Cards Technique” from Simos (1990) or “The Resistance to Change Grid” from Rogers & Bruen (1998). These methods try to weight criteria in a more objective way than it is made by the decision-maker directly. However, these methods are not used in this study. On the one hand, this study aims to evaluate 3 different scenarios regarding to 3 different stakeholders. These scenarios are not real but simulated scenarios, in order to study better differences between results in three different situations. Thus, it has no sense to try to make the weighting process more objective as subjectivity is exactly what it is pursued. On the other hand, these methods are usually conceived to weight criteria of a particular type of MCDA method so it is not guaranteed that they could be used in other type of MCDA method.

4. THE BMP RANKING PROGRAM

The main objective of the present study was to create a program to assist in BMP decision-making problems. This program aim is to rank different types of structural BMPs, 14 in this case, within a multicriteria approach.

The BMP ranking program was developed with MATLAB. MATLAB is both a programming language and a development environment created and commercialized by The MathWorks American Company, a developer of mathematical computing software for engineers and scientists.

In this chapter, the program's structure, its inputs and outputs as well as the main functions, variables, vectors and matrices utilized in it are described. In addition, at the end of the chapter some tips or advices are presented for future users.

4.1. GLOBAL STRUCTURE

The developed BMP ranking program consists of a chain of functions where a function calls other functions until a last one is called and it develops an action. This action can be a calculation or a data collection. A general schema of the program is presented in figure 39. Note that the names of the functions are in French as the program was developed in a French spoken university.

As it can be observed, the program first calls the "*localisation*" function, which asks the user where the study is going to be applied. The selection of one placement or another influences the economical evaluation as prices change from one continent to another. Then, the program calls the "*dimensionnement*" function, which asks the user the problem inputs and then calculates the indicator values of the criteria. Finally, the program asks the user whether he wants to utilize the AHP method or the ELECTRE III to obtain the BMP ranking. Depending on the user's choice, the program calls then the "*AHP*" function or the "*ELECTRE III*" function. A detailed description of all functions and the principal vectors and matrices used is described in sections 4.3 and 4.4 respectively.

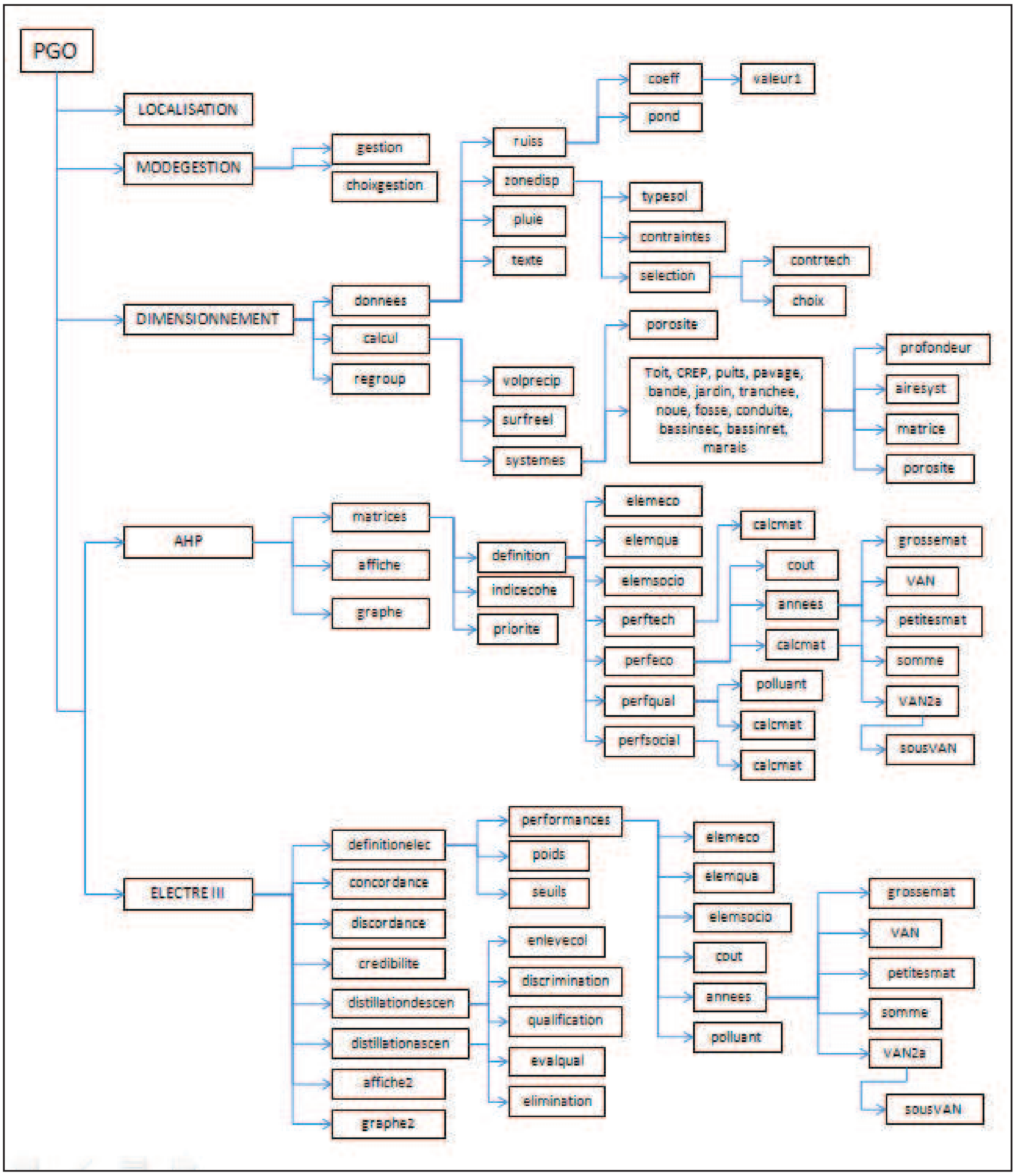

Figure 39.- General schema of the BMP ranking program.

4.2. INPUTS AND OUTPUTS

Most of the input data needed to build the BMP rankings is asked directly to the user by the program. The asked inputs, presented in order as the program asks them, are the following ones:

- Localization of the problem

→ The program gives 3 possible answers to this question: 1) North America, 2) Europe and 3) base system. The localization influences the prices to evaluate the construction and maintenance BMP costs. The base system is a mix of the other 2 localizations. Further information about considered prices is given in Annex B or table 52.

- Pre-selection of the type of management.

→ The program gives the option to the user to choose one specific type of management. The type of management is related to the main action of the BMPs. The options are: 1) Infiltration, 2) Storage and 3) Conveyance. If the user chose one type of management, only these BMPs will be considered in the analysis. Table 21 classifies the 14 BMPs into the 3 different types of management.

BMP	INFILTRATION	STORAGE	CONVEYANCE
Extensive green roof	•	•	•
Intensive green roof	•	•	•
Rainwater harvesting			•
Filter drain	•	•	
Permeable pavement	•		
Filter strip	•	•	•
Bioretention system	•		
Infiltration trench	•	•	
Shallow swale	•	•	
Deep swale	•	•	
Perforated pipe system	•		•
Detention basin	•	•	
Retention pond	•	•	
Wetland	•	•	

Table 21.- BMP classification according to the type of management.

- Number of permeable areas with different runoff coefficients.
- Number of impermeable areas with different runoff coefficients.
- For each permeable area: surface (m^2) and runoff coefficient.
- For each impermeable area: surface (m^2) and runoff coefficient.
- Soil permeability (mm/h)

→ The program asks the user if he knows the initial soil permeability. If he knows it, he can introduce this value (mm/h). If the user doesn't know this data, the program takes a value by default. This value, fixed at 75 mm/h, corresponds to an average value of initial soil permeability (see table 22, an adaptation of (Musy & Soutter, 1991) permeability table).

K(m/s)	10^{-1} 10^{-2} 10^{-3}	10^{-4} 10^{-5}	10^{-6} 10^{-7} 10^{-8}	10^{-9} 10^{-10} 10^{-11}
Soil type	gravel without either sand nor fine elements	gravel with sand, coarse sand to fine sand	very fine sand, coarse silt to clayey silt	homogeneous clay, silty clay
Infiltration possibilities	excellent	good	medium to poor	poor to useless

Table 22.- Soils permeability. **(Musy & Soutter, 1991)**

- Available surface for BMP construction (m^2)
- Site slope (%)
- Depth to high water table (m)
- Length of the building walls surrounding the BMP construction surface (m)
- Maximal length for infiltration trenches and swales (m)
- Maximal length for perforated pipes (m)
- Roof surface to be replaced by green roofs (m^2)
- Roof surface to be disconnected and transformed in rainwater harvesting (m^2)
- Pollution hot spots
  - → The program asks the user if there are pollution hot spots near the BMP construction area.
- Land Use
  - → The program asks the user which is the land use of the site. There are 4 possibilities: 1) Houses residential area, 2) Apartment blocks residential area, 3) Industrial or commercial area and 4) Other land use.
- Rainfall event data: rain intensity (mm/h) and event duration (min)
- Type of MCDA method
  - → The program asks which MCDA method the user wants to use for the analysis. There are 2 possible options: AHP and ELECTRE III. If AHP is selected, the program will ask for the following inputs: T, U, V, W. If ELECTRE III is chosen, the program will ask for the following inputs: W, X, Y, Z.
- Relative priority values for main criteria
  - → The program asks the user if he wants to introduce the relative priority values for the main criteria (technical, economical, quality and socio-

environmental). What it is asked is the relative priorities, i.e. the elements of the relative priority matrix for the first hierarchical level. Only a half of the matrix is asked as the other half is the inverse numbers of the introduced values. If the user does not want to introduce these values, the program takes them by default. The default values correspond to the engineer point or view, i.e. the engineer stakeholder scenario. It has been decided this way because it is supposed that this program will be mainly used by engineers and developers. They are presented in tables 12 to 14 of section 3.3.

- Relative priority values for socio-environmental sub-criteria
  → The program asks the user if he wants to introduce the relative priority values for socio-environmental sub-criteria (Stakeholder acceptability, Social inclusion and multifunctional use, Environmental impacts and sustainable development and Health and safety risks). What it is asked is the relative priorities, i.e. the elements of the relative priority matrix for the second hierarchical level associated to the socio-environmental criterion. If the user does not want to introduce these values, the program takes them by default. The default values correspond to the engineer point or view, i.e. the engineer stakeholder scenario values, as the default relative priority values for the main criteria. They are presented in tables 15 to 17 of section 3.3.
- Relative priority values for quality sub-criteria
  → The program asks the user if he wants to introduce the relative priority values for quality sub-criteria (Total suspended sediment removal, Total nitrogen removal and Total phosphorus removal). What it is asked is the relative priorities, i.e. the elements of the relative priority matrix for the second hierarchical level associated to the quality criterion. If the user does not want to introduce these values, the program takes them by default. The default relative priority values have been established at 1, i.e. the program gives equal importance to all quality sub-criteria.
- Pollutants concentration in the runoff water that must be treated by the BMP

→ The program asks the user if he knows the concentration of the 3 considered pollutants in the runoff water that will be treated by the BMP. This data is used to calculate the total quantity of removed pollutant (kg) in order to assess the quality performance of each BMP. If the user does not know these data, the indicator used to assess the quality criterion changes to "Average percentage of pollutant removal" (%). The program takes then these values by default. They are presented in table 53 of Annex A.

- Weights vector
  → The program asks the user if he wants to introduce the weight vector values. If he does not want, the program takes these values by default. The default values correspond to the engineer point or view, i.e. the engineer stakeholder scenario. They are presented in tables 12 to 20 in section 3.3.
- Thresholds matrix
  → The program asks the user if he wants to introduce the thresholds matrix values. If he does not want, the program takes these values by default. The default values correspond to the engineer point of view, i.e. the engineer stakeholder scenario. They are presented in table 9 in section 3.3.

All program inputs have been presented in this section. Some of these data are used to calculate the BMPs different performances or indicator values of the different criteria. Other inputs are needed to verify that the construction area fulfill the site constraints. And other ones are used in the decision-making algorithms. Table 23 classifies the abovementioned inputs in these 3 categories according to their purpose.

Finally, the program outputs are the BMP rankings, ranked from the best to the worst. For the AHP-based analysis the program gives one unique ranking while for the ELECTRE III-based analysis the program gives two rankings, one for descending distillation process and another for ascending distillation process. User should decide which aggregation methodology is the most appropriated to obtain a final BMP ranking.

INPUT	INPUT FUNCTION		
	INDICATOR CALCULATION	**TECHNICAL CONSTRAINTS VERIFICATION**	**DECISION-MAKING ALGORITHMS**
Localization	X	X	
Management mode			X
Number of permeable zones	X		
Number of impermeable zones	X		
Surface permeable area	X		
Runoff coefficient for permeable area	X		
Surface impermeable area	X		
Runoff coefficient for impermeable area	X		
Infiltration rate	X	X	
Available construction area	X	X	
Site slope	X	X	
Soil surface - water table depth	X	X	
Surrounding buildings walls length		X	
Maximal length for swales and infiltration trenches	X		
Maximal length for perforated pipes	X		
Roof surface to be replaced by green roof	X		
Roof surface to be disconnected	X		
Pollution hot spots		X	
Land use		X	
Rainfall intensity	X		
Rainfall duration	X		
Main criteria weights			X
Socio-environmental sub-criteria weights			X
Quality sub-criteria weights			X
ELECTRE III thresholds			X
Pollutant concentrations			X

Table 23.- Classification of the program inputs according to their function in the global algorithm.

4.3. PRINCIPAL FUNCTIONS, VECTORS AND MATRICES

The BMP ranking program is developed in a MATLAB environment where functions form a function chain so as to execute different calculations or evaluations. The developed program has a total number of 80 functions. These functions are listed in table 24 where it is also described their action and their input and output variables. Some of these variables have been listed and described in table 25.

FUNCTION	DESCRIPTION	OUTPUT VARIABLES	INPUT VARIABLES
affiche	Shows the matrices CoutTotal, Mvan, Mvan2 in MATLAB screen, the Rc vector as well as the final ranking vectors PfinAHP, PclassD, PclassA	(-)	Pfinale, Rc, CoutTotal, Mvan, Mvan2
AHP	Main function for processing data by the AHP method	PfinAHP, Rc, CoutTotal	Mat, x
airesyst	Calculates the surface of the PGO as it will be located in site	Ss	Sr, i, As
annees	Calculates the real costs, taking into account the sizing of BMPs	CoutTotal, Mvan, Mvan2	Mat, Mc, F
bande	Calculates the total treated volume of a filter strip	Mat	K, t, Vt, Sr, Mat, k
bassinret	Calculates the total treated volume of a retention pond	Mat	K, H, t, M, Vt, Sr, Mat, k
bassinsec	Calculates the total treated volume of a detention basin	Mat	K, H, t, M, Vt, Sr, Mat, k
calcmat	Determines the priorities for the matrices by limiting element "X" between elements 1 and 9	S	X
calcul	Calculates the volume treated by the various BMPs and gives the sizing of BMPs	Mat	N, M
choix	Identifies the BMPs that fulfills the site constraints of the land on which we will implement the BMPs	V2, pq	X, c, G, M, D
choixgestion	Asks whether to do a pre-selection of the systems and, if so does the user, makes this selection	V1	G
coeff	Collects data of the different areas with different runoff coefficients	S, Cr	k, x
concordance	Calculates the correlation matrix for the ELECTRE III method	Mcon	Vpoids, Mseuils, Mperf
conduite	Calculates the total treated volume of a perforated pipe	Mat	Lc, t, Vt, Mat, k
contraintes	Collects the site constraints from where you want to implement the work	Sd, P, H, D, L, Lc, St, Screp, Pp, U	(-)
contrtech	Creates the matrix of technical constraints of each BMP	M	Sa, Stimp
cout	Calculates the real costs, taking into account the sizing of BMPs	F	Mat, Mc, x
credibilite	Calculates the credibility matrix for the ELECTRE III method	Mcred	Mcon, Mdis1, Mdis2, Mdis3, Mdis4, Mdis5, Mdis6, Mdis7, Mdis8, Mdis9
CREP	Calculates the total treated volume of a rainwater harvesting system	Mat	S, Screp, i, t , Mat, k
definition	Defines the priority matrices	M1, M2, M3, S1, S2, SQ1, SQ2, SQ3, SS1, SS2, SS3, SS4, CoutTotal, Mvan, Mvan2	Mat, x
definitionelec	Defines the performance matrix, the weights vector for the different criteria and the threshold matrix for ELECTRE III method	Vpoids, Mseuils, Mperf	Mat, x
dimensionnement	Main function of sizing calculation of BMPs	V, Mat	V1
discordance	Calculates the discordance matrices for the ELECTRE III method	Mdis1, Mdis2, Mdis3, Mdis4, Mdis5, Mdis6, Mdis7, Mdis8, Mdis9	Mseuils, Mperf
discrimination	Calculates the discrimination threshold	lambda1	A, lambda0
distillationascen	Builds the second ELECTRE III ranking, le upward pre-order	Pclass2	Mcred
distillationdescen	Builds the first ELECTRE III ranking, le downward pre-order	Pclass1	Mcred

FUNCTION	DESCRIPTION	OUTPUT VARIABLES	INPUT VARIABLES
donnees	Collects the problem data	M, N, V2	(-)
ELECTREIII	Main function for processing data by the ELECTRE III method	PclassD, PclassA	Mat, x
elemeco	Defines the matrix containing the economic elements values	Mc	x
elemqua	Defines the matrix containing the quality sub-criteria elements values	Mq	x
elemsocio	Defines the matrix containing the socio-environmental sub-criteria elements values	Ms	x
elimination	Eliminates the alternative "x" from the "d" matrix (eliminates the corresponding row and column)	d1	d, x
enlevecol	Removes the first column of the "D" matrix	A	D
evalqual	Counts the number of alternatives that have the maximum qualification in ELECTRE III method	k	q, a
fosse	Calculates the total treated volume of a deep swale	Mat	K, H, L, t, M, Vt, Mat, k
gestion	Classes BMPs according to their type of water management		
graphe	Shows the resulting graphs	(-)	Pfinale, CoutTotal, Mat
grossemat	Calculates the Mg matrix containing the data of the costs per year for all BMPs	Mg, i, P	Mat, Mc, F
indicecohe	Calculates the coherence index of the matrices and brings out the priority vector	C, RC	A
jardin	Calculates the total treated volume of a bioretention system	Mat	K, t, Vt, Sr, Mat, k
localisation	Asks the user the location of the BMP construction area	x	(-)
marais	Calculates the total treated volume of a wetland	Mat	K, H, t, M, Vt, Sr, Mat, k
matrice	Inserts the parameters of the BMP in the "Mat" matrix	Mat	Vg, Mat, q
matrices	Calculates and defines the priority matrices and vectors	PfinAHP, Rc, CoutTotal, Mvan, Mvan2	Mat, x
modegestion	Main function of the stormwater management mode	V1	(-)
noue	Calculates the total treated volume of a shallow swale	Mat	K, H, L, t, M, Vt, Mat, k
pavage	Calculates the total treated volume of a permeable pavement	Mat	t, Vt, Sr, Mat, k
perfeco	Determines the priority matrix for the economic criterion of the BMPs	S2, CoutTotal, Mvan, Mvan2	Mat, Mc, x
performances	Calculates the performance matrix for ELECTRE III method	Mperf	Mat, x
perfqual	Determines the priority matrix for the quality criterion of the BMPs	SQ1,SQ2, SQ3	Mat, Mq
perfsocial	Determines the priority matrix for the socio-environmental criterion of the BMPs	SS1,SS2, SS3, SS4	Ms
perftech	Determines the priority matrix for the technical criterion of the BMPs	S1	Mat
petitesmat	Separates the large Mg matrix into small matrices for each BMP	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14	Mc, Mg
PGO	Main function of the BMP ranking program	(-)	(-)
pluie	Collects the rainfall data	i, t	(-)
poids	Asks the user the criteria weights for ELECTRE III method	Vpoids	(-)
polluant	Calculates the amount of pollutant removed by a BMP	P	Mat, Mq, Ctss, Ctn, Ctp

FUNCTION	DESCRIPTION	OUTPUT VARIABLES	INPUT VARIABLES
pond	Calculates the surface area and weighted runoff coefficient	Sa, Ca	Sper, Crp, kp, Simp, Cri, ki
porosite	Calculates the soils permeability according to the time	K	t, f0
priorite	Calculates the vector allowing the BMP ranking	P	M, C
profondeur	Calculates the maximal soil depth	Prof	M, H, i
puits	Calculates the total treated volume of a filter drain	Mat	K, H, t, M, Vt, Sr, Mat, k
qualification	Calculates the qualification vector for the alternatives in matrix "D" of the ELECTRE III method	q, m	D, lambda1
regroup	Combines the vectors V1 and V2 to know the system that fulfills the constraints	V	V1, V2
ruiss	Calculates the variables Crper, Crimp, Sper, Simp, S, Ca and Sa	S, Ca, Sa, Stimp	(-)
selection	Selects BMPs to be considered according to the site constraints	V2, M	Sd, P, H, D, K, Sa, Pp, U, Stimp
seuils	Asks the user the criteria thresholds for ELECTRE III method	Mseuils	(-)
somme	Calculates the total cost for each small matrix and groups them all in the CoutTotal matrix	CoutTotal	Mc, M1, M2, M3, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14
sousVAN	Calculates the NPV per year of the "x" BMP	Mx	P, Mx
surfreel	Calculates the real construction area of the BMP	Sr	N, M
systemes	Groups all the sizing data for the BMPs	Mat	N, M, Vt, Sr
texte	Shows all collected data	(-)	N, Pp, U
toit	Calculates the total treated volume of a green roof	Mat	S, St, i, t
tranchee	Calculates the total treated volume of a infiltration trench	Mat	K, H, L, t, M, Vt, Mat, k
typesol	Asks or calculates the initial soils infiltration rate	K	(-)
valeur1	Identifies if there is a correct value in the variable "a" which must be between "b" and "c"	a	a, b, c
VAN	Calculates the net present value per year of each BMP, and adds that value to the matrix Mg	Mg	Mg, i
VAN2	Adds the NPV of each year for each BMP to each BMP matrix and creates a matrix that contains these values	Mvan, Mvan2	Mc,P,M1,M2,M3,M4,M5,M6,M7,M8,M9,M10, M11,M12,M13, M14
volprecip	Calculates the overall stormwater volume to be taken into account for the BMPs design	Vt	N
zonedisp	Collects data of the available construction area of the BMPs	C, V2, M, Pp, U	Sa, STimp

Table 24.- Main BMP ranking program functions.

VARIABLE	UNITS	DESCRIPTION
x	(-)	Localization
S	m^2	Total surface
Cr	(-)	Runoff coefficient
Ca	(-)	Weighted runoff coefficient
Sa	m^2	Active surface
Sper	m^2	Permeable surface
Simp	m^2	Impermeable surface
Crper	(-)	Permeable runoff coefficient
Crimp	(-)	Impermeable runoff coefficient
kp	(-)	Number of permeable zones
ki	(-)	Number of impermeable zones
K	mm/h	Soil infiltration rate

VARIABLE	UNITS	DESCRIPTION
Sd	m^2	Construction surface
P	%	Site slope
H	m	Water table depth
D	m	Building foundation distance from PGO
L, Lc	m	Maximal BMP length
St	m^2	Roof surface to be changed by green roof
Screp	m^2	Roof surface to be disconnected to rainwater harvesting systems
Pp	(-)	Pollution hot spots
U	(-)	Land use
t	min	Rainfall duration
i	mm/h	Rainfall intensity
Vt	m^3	Runoff volume to be treated by the BMP
Prof	m	Maximal depth
As	m^2	Needed surface for the BMP to treat all the rainfall
Ss	m^2	BMP in-site real surface
Ctss	Kg/m^3	Total suspended sediments concentration
Ctn	Kg/m^3	Total nitrogen concentration
Ctp	Kg/m^3	Total phosphorus concentration
lambda0 lambda1	(-)	Discrimination thresholds

Table 25.- Main BMP ranking program variables.

VECTOR MATRIX	DESCRIPTION	ORGANIZATION
V	This vector determines the BMPs that fulfill the constraints of the study area. It contains the number of the BMPs meeting the constraints.	
M	This matrix contains the technical constraints of BMPs.	• Column 1: Number of the BMP • Column 2: minimum construction surface • Column 3: minimum acceptable slope • Column 4: maximum acceptable slope • Column 5: minimum height of the structure • Column 6: maximum height of the structure • Column 7: height required between the water table and the BMP base • Column 8: distance between the building foundations nearby and the BMP • Column 9: minimum acceptable permeability • Column 10: minimum active surface • Column 11: maximum active surface • Column 12: acceptability (0) or not (1) pollution hot spots near the construction zone • Column 13: acceptability (0) or not (1,2,3, according to type of BMP) of the type of land use
N	This vector is composed of the data entered in the program during the running process.	
Mat	This matrix shows the values processed by each BMP.	• Column 1: number of the BMP • Column 2: volume processed by the BMP • Column 3: area used by the BMP • Column 4: depth of the BMP • Column 5: length of the BMP
Mc	This matrix contains the values of the elements to calculate the economic performance.	• Column 1: number of the BMP • Column 2: installation/construction cost • Column 3: maintenance cost • Column 4: lifetime

VECTOR MATRIX	DESCRIPTION	ORGANIZATION
Mq	This matrix contains the values of the elements of quality performance.	• Column 1: number of the BMP • Column 2: average percentage of pollutant removal ("Total suspended solids" (TSS)) • Column 3: average percentage of pollutant removal ("Total nitrogen (Kjeldahl)" (TN)) • Column 4: average percentage of pollutant removal ("Total phosphorus" (TP))
Ms	This matrix contains the values of elements of socio-environmental performance.	• Column 1: number of the BMP • Column 2: value, "Residents acceptability" • Column 3: value, "Society life quality" • Column 4: value, "Environment protection and sustainable development contribution" • Column 5: value, "Health and safety risks for population"
M1	This matrix contains the values of relative priorities between the main criteria.	
M2	This matrix contains the values of relative priorities between the socio-environmental performance sub-criteria.	
M3	This matrix contains the values of relative priorities between quality performance sub-criteria.	
F	This matrix gives the BMPs cost considering its design.	
Mg	This matrix contains the costs per year of various BMPs.	
PfinAHP	This vector gives the classification of BMPs relative to their performance according to the AHP method.	
PclassD	This vector gives the first rank of BMPs relative to their performance according to the ELECTRE III method	
PclassA	This vector gives the second ranking of BMPs relative to their performance according to the ELECTRE III method	
Mperf	This matrix shows all the performance values for every BMP	• Column 1: Technical performance • Column 2: Economic Performance • Column 3: Qualitative Performance: sub-criterion "Total suspended solids" (TSS) • Column 4: Qualitative Performance: sub-criterion "Total nitrogen (Kjeldahl)" (TN) • Column 5: Qualitative Performance: sub-criterion "Total phosphorus" (TP) • Column 6: Socio-Environmental Performance: sub-criterion "Residents acceptability" • Column 7: Socio-Environmental Performance: sub-criterion "Society life quality" • Column 8: Socio-Environmental Performance: sub-criterion " Environment protection and sustainable development contribution " • Column 9: Socio-Environmental Performance: sub-criterion " Health and safety risks "

VECTOR MATRIX	DESCRIPTION	ORGANIZATION
Vpoids	This vector contains weights given to each criterion for the ELECTRE III method	• Element 1: weight of the criterion "Technical Performance" • Element 2: weight of the criterion "Economic Performance" • Element 3: weight of the sub-criterion "Total suspended solids" of the qualitative performance • Element 4: weight of the sub-criterion "d'' Total nitrogen (Kjeldahl)" of the qualitative performance • Element 5: weight of the sub- criterion "Total phosphorus" qualitative performance Element 6: weight of the sub-criterion "Acceptance of the local community" of socio-environmental performance • Element 7: weight of the sub-criterion "Quality of life of the local community" of socio-environmental performance • Element 8: weight of the sub-criterion "Environment" of the socio-environmental performance • Element 9: weight of the sub-criterion "Risks and nuisance for the people" of socio-environmental performance
Mseuils	This matrix contains the values of the ELECTRE III thresholds for each criterion.	• Column 1: Indifference threshold • Column 2: Preference threshold • Column 3: Veto threshold
Mvan, Mvan2	These two matrices give the NPV of each BMP based on the total of years of use of the BMPs.	The first line corresponds to the numbers of BMPs. The first column is the number of years. The last column is the sum of the NPV of each BMP annually. The Mvan matrix contains all BMP while the Mvan2 matrix contains all BMPs except intensive green roof which is the most expensive BMP. This results often in getting a negative overall NPV.
Mcon	This matrix is the correlation matrix of ELECTRE III method.	
MdisX (“X” from 1 to 9)	These matrices are the discordance matrices of the ELECTRE III method for each criterion.	
Mcred	This matrix is the credibility matrix of the ELECTRE III method.	
q	This vector contains the qualification value of each alternative in the ELECTRE III method.	• Column 1: BMP number • Column 2: qualifying value
Rc	This vector contains the value of the coherence ratio for the AHP method.	
CoutTotal	This matrix contains the BMPs costs over 10 years and their NPV.	• Column 1: BMP number • Column 2: total cost of the BMP on n years • Column 3: Net present value of the BMP at the end of its life
Sr	This vector contains the values of the real BMP construction surfaces	
V1	This vector contains the valid BMPs according to the type of management.	
V2	This vector contains the valid BMPs according to the technical constraints.	
Vg	This vector contains the values of the volumes treated by the BMPs	
P	This matrix contains the values of the quantity of pollutant removed by the BMPs	• Column 1: number of the book • Column 2: amount of suspended material removed (Kg) • Column 3: amount of nitrogen removed (Kg) • Column 4: amount of phosphorus removed (Kg)

Table 26.- Main BMP ranking program vectors and matrices.

4.4. TIPS AND ADVICES FOR USERS

Two types of users will be considered, the non-expert users and the expert users (Coulais, 2010).

The first type of users, not experts ones, do not known how to use the programming tool MATLAB. Firstly the user must be in the folder where all functions are registered. To do this, either he has to double click a function, if the software is closed, or, if he is already in the software, he must select the folder in the address bar at the top of the software in the main window (“*Current folder*”, figure 40).

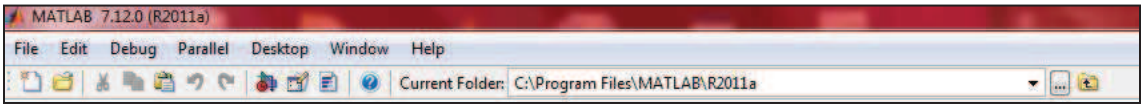

Figure 40.- MATLAB address bar.

Once this is done, the program is run. To perform this task, user must call the main function of the program which is "*PGO*". "*PGO*" must be typed in the MATLAB command window (figure 42). The program will then ask the user all the inputs. They have been described in detail in section 4.2.

Figure 41.- MATLAB command window.

Once these values have been entered into the program, it shows at first a summary of the data, then, after making "entry" on the computer, the program obtains the ranking results and shows the outputs.

If user forgets to fill a value during the above operation, an error message will appear in the MATLAB command window. He will then have to restart the program. In the case where the user realizes before the end that he forgot a value or that he set a bad value, it can interrupt the process by pressing "*Ctrl + C*".

To improve readability of *Mvan* and *Mvan2* matrices, the program creates two Excel files in which these two matrices are collected. These files are located in the folder where all functions are registered.

The second type of user, the expert one, can change certain values in the functions of the program, in addition to the input data.

- The expert user can change the values of permeability constants of the Horton formula (38) in the "*porosite*" and the "*systemes*" functions.
- The values of the design elements as well as the values of the technical constraints can be changed in "*systemes*" and "*contrtech*" functions.
- Users can also change the interest rate and the inflation rate in "*grossemat*" function.
- Other economical data as costs and BMPs lifetime can be modified in "*elemeco*".
- Finally, expert users would be able to modify the "average percentage of pollutant removal" values to adapt them to specific case studies as well as the qualitative values obtained for socio-environmental sub-criteria assessment issued from the BMPs socio-environmental performance survey presented in section A.4. These values are found in functions "*elemqua*" and "*elemsocio*" program functions respectively.

5. CASE STUDY

In order to apply the developed BMP ranking program, a demonstration area has been chosen to obtain specific results and discuss them. As explained in section 1.2, one of the secondary objectives of this study was to apply a MCDA tool in the Canadian region of Quebec, where these kinds of practices are still relatively recent. Therefore, the selected demonstration site was an urban watershed located in the district of Fabreville, in the city of Laval (Quebec, Canada). Figures 42 and 43 show the location of this catchment.

Figure 42.- Laval location in North America.

Figure 43.- Location of Fabreville city area in Laval, Quebec, Canada.

5.1. DEMONSTRATION SITE DATA

The study area is a residential zone with a total drainage surface of 7.88 ha, from which a 30% is considered impermeable. The average slope of the demonstration site is 2% and the maximum length (measured from the existing site maps) is 355m. The BMP construction area is situated at the north part of the catchment (figure 44) and its total surface, keeping a security strip of land, has been estimated at 2300m^2. All these data have been taken from technical reports made at the same location (Doutetien & D., 2007).

Figure 44.- BMP construction area location in the Fabreville catchment.

No soil or rainfall data of the area where available in the technical reports so the following data where obtained from literature for urban drainage design of the region of Montreal (Rivard, 2005). The runoff coefficients where estimated according to the type of soil and the return period of the rainfalls. Table 27, adapted from Rivard (2005), in turn adapted from Wright & McLaughlin (1968/1991), presents these values.

LAND USE	C for T=2 years	C for T=5 years	C for T=10 years	C for T=100 years
Residential with houses (30% of impermeable surface)	0.4	0.45	0.5	0.6

Corresponding values of $C_{permeable}$ and $C_{impermeable}$ for 30% of impermeable surface and 70% of permeable surface:

$$C_{permeable} = \frac{C_{global} - 0.3 \cdot C_{impermeable}}{0.7}$$

T	C(T)	$C_{permeable}$	$C_{impermeable}$
2	0.4	0.23	0.8
10	0.5	0.35	0.85
100	0.6	0.47	0.9

Table 27.- Runoff coefficients. (Rivard, 2005)

According to the Quebec's soils map presented in figure 45 and its legend in figure 46, it has been considered that the soils of the demonstration site were clayey soils (type C according to SCS classification). Thus, Horton Infiltration parameters where estimated from literature for C-type wet (drained but not sec) clayed soils as it is presented in tables 28 and 29, adapted from Rivard (2005), in turn adapted from Huber & Dickinson (1988).

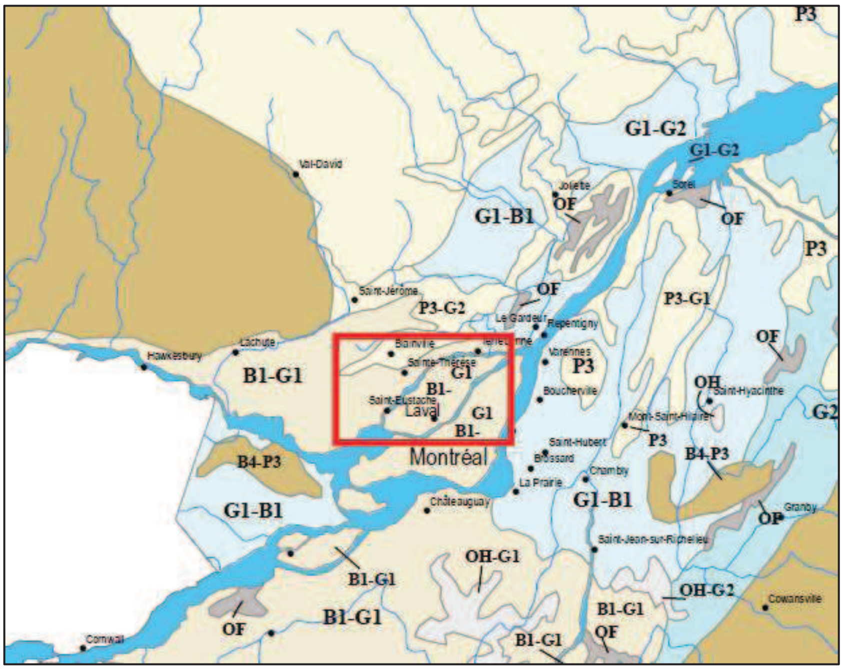

Figure 45.- Quebec's soils map. (IRDA, 2008)

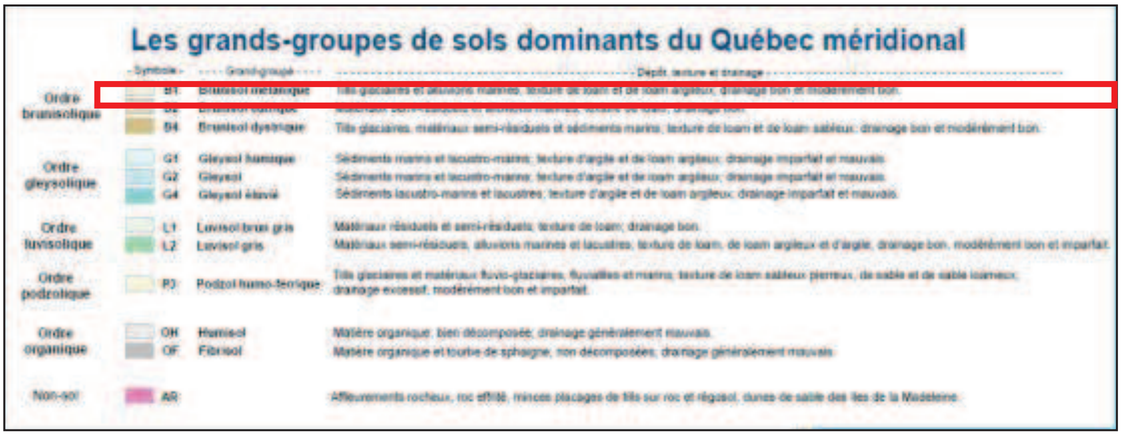

Figure 46.- Quebec's soils map legend. Soil type B1 consists of "glacial tills and marine alluvium; loam and clayey loam texture; from moderately good to good drainage". (IRDA, 2008)

SOIL TYPE	f_c (mm/h)
A	11.43 - 7.62
B	7.62 - 3.81
C	3.81 - 1.27
D	1.27 - 0

Table 28.- Final infiltration capacity values for Horton Infiltration model according to the SCS soil type. (Rivard, 2005)

SOIL TYPE	f_0 (mm/h)
Dry soils (little or no vegetated)	Sandy soils: 125 Loam: 76 Clayey soils: 25
Dry soils (dense vegetation)	Multiply precedent values by 2
Wet soils	Drained soils but not sec: divide precedent values by 3 Saturated soils: Take values close to f_c Partial saturated soils: divide precedent values by 1.5 to 2.5.

Table 29.- Initial infiltration capacity values for Horton Infiltration model according to the SCS soil type. (Rivard, 2005)

In relation to the rainfall data, Chicago-type rainfall was considered. The IDF curves where obtained again from the Quebec stormwater management guide (MDDEP and MAMROT, 2012) (figure 47).

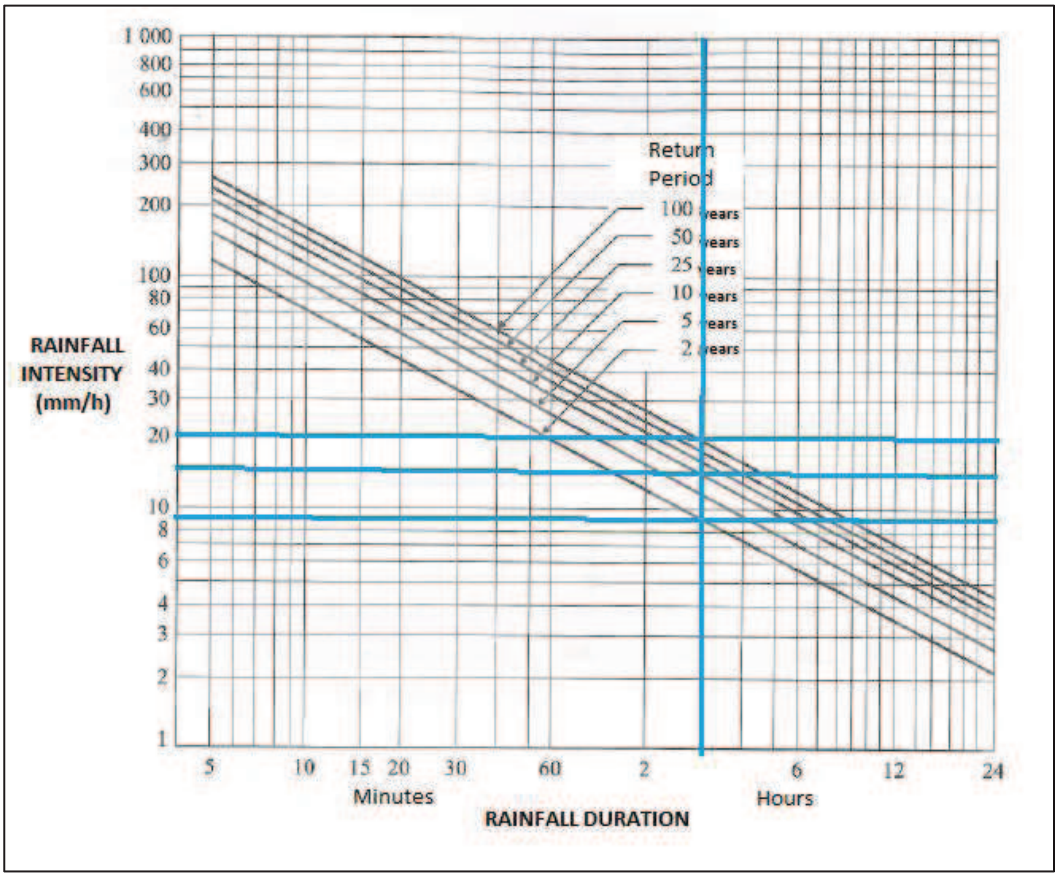

Figure 47.- IDF curves from Dorval pluviometer. (MDDEP and MAMROT, 2012)

These curves correspond to a pluviometer situated in Dorval, a location 20 Km away from the demonstration area. As explained in section 1.3.1, the considered return periods were 2, 10 and 100 years. In view of a rainfall event duration of 180 min, the corresponding design rainfall intensities for these return period values were 9, 16 and 20 mm/h respectively.

Finally, some design values must also been determined, as the maximal length of the longitudinal BMPs (infiltration trenches, filter strips, perforated systems and swales) and the total roof surface to be replaced by green roof or to be disconnected to be part of a rainfall harvesting system. In this study it has been considered that the maximal length for longitudinal BMPs corresponded to the 50% of the total length of the existing streets. This value was around 1200m (measured from the existing site maps) so the maximal length was established at 600m. On the other hand, the number of lots in the urban catchment was approximately 120. Considering an average roof surface of 100m^2 and considering that only 10% of the residents will accept to change their roofs, a total roof area of 1200m^2 was estimated to be changed or disconnected.

Table 30 presents a summary of the inputs values to be introduced in the program for the present case study.

INPUT VARIABLE	VARIABLE UNITS	ENTERED VALUE
Localization	(-)	1
Management mode?	(-)	no
Number of permeable zones	(-)	1
Number of impermeable zones	(-)	1
Surface permeable area	(m^2)	55160
Runoff coefficient for permeable area	(-)	0.23 (T=2) 0.35 (T=10) 0.47 (T=100)
Surface impermeable area	(m^2)	23640
Runoff coefficient for impermeable area	(-)	0.8 (T=2) 0.85 (T=10) 0.9 (T=100)
Infiltration rate known?	(mm/h)	yes: 75
Available construction area	(m^2)	2300
Site slope	(%)	2
Soil surface - water table depth	(m)	4.5
Surrounding buildings walls length	(m)	0
Maximal length for swales and infiltration trenches	(m)	600
Maximal length for perforated pipes	(m)	600
Roof surface to be replaced by green roof	(m^2)	1200
Roof surface to be disconnected	(m^2)	1200
Pollution hot spots?	(-)	no
Land use	(-)	1
Rainfall intensity	(mm/h)	9 (T=2) 16 (T=10) 20 (T=100)
Rainfall duration	(min)	180
Main criteria weights?	(-)	(see tables 12 to 14)
Socio-environmental sub-criteria weights?	(-)	(see tables 15 to 17)
Quality sub-criteria weights?	(-)	(see tables 18 to 20)
ELECTRE III thresholds?	(-)	(see table 9)
Pollutant concentrations?	(Kg/m^3)	non

Table 30.- Summary of the inputs values to be introduced in the BMP Ranking program.

5.2. RESULTS

After running the BMP ranking program for the 18 scenarios described in section 1.3, a BMP ranking was obtained for each of the 18 cases. Besides, the technical and economical performance indicators were calculated for each type of rainfall. Quality and socio-environmental performance indicators are the same for all the cases. In this section, the most important results related to the performance values, the rankings and the program coherence will be presented.

Performance values

Table 31 presents technical and economical values and table 32 presents the quality and socio-environmental results (also introduced in tables 53 and 55). These values are in fact the elements of the "performance matrix" used in the MCDA methods to obtain the rankings. Finally, total runoff volume of each rainfall is indicated in table 33. It can be observed that several BMPs have the same treated volume, equal to the maximum runoff volume for that rainfall. In fact, these BMPs, even if they have a higher treatment capacity, they only can obviously treat the maximum runoff volume. Other BMPs treat the same volume for the 3 considered rainfalls. That means that they always treat their maximum capacity volume. Just BMP 1, extensive green roof, which does not consider a retention capacity, treats a different volume each time. According to the NPV, it can be observed that there are several negative values, which means that these BMPs will not still be profitable in the investment refund period considered (10 years).

	TECHNICAL AND ECONOMICAL PERFORMANCES INDICATORS					
	T=2 years		T=10 years		T=100 years	
BMP	Vt (m^3)	NPV ($)	Vt (m^3)	NPV ($)	Vt (m^3)	NPV ($)
1	22.68	-3.16E+05	40.32	-3.16E+05	50.4	-3.16E+05
2	96	-2.24E+06	96	-2.24E+06	96	-2.24E+06
3	5	92513	5	92513	5	92513
4	8.0432	77403	8.0432	77403	8.0432	77403
5	342.12	93704	945.6	52219	1696.4	605.97
6	73.295	-29625	73.295	-29625	73.295	-29625
7	73.295	-1.91E+05	73.295	-1.91E+05	73.295	-1.91E+05
8	342.12	-21396	945.6	-2.03E+05	1696.4	-4.29E+05
9	342.12	65993	797.8	45255	797.8	45255
10	342.12	45812	469.12	32542	469.12	32542
11	260.2	61236	719.19	61236	1290.2	61236
12	342.12	74018	945.6	60711	1696.4	44155
13	342.12	66631	945.6	40293	1696.4	7525.2
14	342.12	66631	945.6	40293	1696.4	7525.2

Table 31.- Technical and economical performance indicators. Vt.- Treated volume; NPR.- Net Present Value

	QUALITY AND SOCIO-ENVIRONMENTAL PERFORMANCES INDICATORS						
	All rainfall						
BMP	% TSS	% TN	% TP	Acceptability	Life quality	Environment	Heal&Safety
1	89	0	0	4	4	3	0
2	89	0	0	3	4	3	0
3	43	43	43	4	2	2	0
4	80	46	65	6	2	2	2
5	50	65	83	5	2	2	-1
6	50	40	40	5	4	4	0
7	60	5	28	7	8	5	-2
8	89	65	55	3	2	3	2
9	80	34	34	6	4	4	0
10	80	34	34	6	4	3	0
11	89	87	83	2	1	2	0
12	60	20	30	5	4	4	0
13	80	52	24	7	8	4	1
14	70	45	30	7	9	5	2

Table 32.- Quality and socio-environmental performance indicators. % TSS, %TN and %TP.- Average percentage of removed suspended sediments, nitrogen and phosphorus respectively.

RETURN PERIOD (years)	TOTAL RUNOFF VOLUME (m^3)
2	342.12
10	945.6
100	1696.41

Table 33.- Total runoff volumes for the 3 rainfall analyzed in this case study.

BMPs rankings

According to the obtained rankings, two aspects related to the ELECTRE ones must be highlighted. On the one hand, in the scenarios where ELECTRE III was used, 2 BMP pre-rankings were obtained, one issued from the descending distillation process and another from the ascending distillation one. In order to better present, analyze, understand and compare the results, an “average ranking” or “final ranking” was calculated for those cases by calculating the average value of the 2 positions given to each BMP. Thus, ranking values for ELECTRE III final ranking can present decimals numbers. On the other hand, ELECTRE III allows “incomparability” of alternatives, which means that two alternatives can be placed at the same ranking position and are considered equal in importance.

Firstly, table 34 shows the rankings for the 9 scenarios which utilize the AHP method and table 35 show the average rankings for the other 9 scenarios which use ELECTRE III method. It can be observed that the first 3 positions (cells highlighted in blue) are mainly occupied by BMPs 5, 9, 11, 12, 13 and 14 which are respectively the permeable pavement, the shallow swale, the perforated pipe, the detention basin, the retention pond and the wetland. In contrast, the last 3 positions (cells highlighted in green) are mainly occupied by BMPs 1, 2 and 7 which are respectively the extensive and intensive green roofs and the bioretention systems.

If rankings are analyzed by MCDA method, AHP best ranked BMP is, in general, the wetland, while for ELECTRE III is the detention basin (almost equalized with permeable pavement). The worst ranked BMP for AHP is unanimously the intensive green roof, while for ELECTRE III both extensive and intensive green roofs are in general the worst ranked.

		SCENARIOS WITH AHP METHOD								
	BMP	**EA-2**	**EA-10**	**EA-100**	**PA-2**	**PA-10**	**PA-100**	**RA-2**	**RA-10**	**RA-100**
1	**Extensive green roof**	13	13	13	13	13	13	10	10	10
2	**Intensive green roof**	14	14	14	14	14	14	14	14	14
3	**Rain harvesting**	12	11	11	12	11	11	13	13	13
4	**Filter drain**	10	9	9	9	9	9	8	7	7
5	**Permeable pavement**	5	3	4	4	3	3	11	11	12
6	**Filter strips**	9	10	10	10	10	10	9	9	9
7	**Bioretention system**	11	12	12	11	12	12	5	5	5
8	**Infiltration trench**	4	5	5	2	1	1	4	4	6
9	**Shallow swale**	2	6	7	1	4	7	3	3	3
10	**Deep swale**	6	8	8	7	8	8	7	8	8
11	**Perforated pipe**	8	7	6	3	2	2	12	12	11
12	**Detention basin**	7	4	3	8	7	6	6	6	4
13	**Retention pond**	3	2	2	5	5	4	2	2	2
14	**Wetland**	1	1	1	6	6	5	1	1	1

Table 34.- Rankings for the 9 scenarios which utilize the AHP method.

BMP		SCENARIOS WITH ELECTRE III METHOD								
		EE-2	EE-10	EE-100	PE-2	PE-10	PE-100	RE-2	RE-10	RE-100
1	**Extensive green roof**	10.5	11	10.5	10.5	10	9.5	10	9.5	8.5
2	**Intensive green roof**	9.5	11	10.5	9.5	9.5	9.5	10	11.5	10
3	**Rain harvesting**	6	5.5	5.5	6	6	6.5	6.5	6	6
4	**Filter drain**	7	7	7	7	5	5	8.5	8.5	7.5
5	**Permeable pavement**	1	3	6	1	1	5	2.5	6	7
6	**Filter strips**	7.5	8	8	8	7.5	7	6.5	7	6
7	**Bioretention system**	9	9	9	9.5	8.5	8	4	5	4
8	**Infiltration trench**	6.5	7	8	7	6	7	10	10.5	9
9	**Shallow swale**	2.5	5.5	5	1.5	5.5	4	3	5	1
10	**Deep swale**	5	7	6.5	5.5	6.5	6	4.5	6	4
11	**Perforated pipe**	5	3.5	1.5	5	2	1.5	7	6	2.5
12	**Detention basin**	2	1	2	3.5	2.5	1	2.5	1	1
13	**Retention pond**	2.5	4.5	4	2.5	3	3.5	1	1.5	1.5
14	**Wetland**	2.5	4.5	4	3	3	3.5	4.5	5	4

Table 35.- Average rankings for the other 9 scenarios which use ELECTRE III method.

In order to compare ranking results issued from the different scenarios, correlation coefficients were calculated. Comparison was made among (1) the different rainfall types, (2) the different MCDA methods and (3) the different stakeholders. Table 36 presents correlation coefficients for case 1, table 37 for case 2 and table 38 for case 3.

		CORRELATION COEFFICIENT BETWEEN RAINFALLS		
STAKEHOLDER	**METHOD**	**2 vs 10**	**2 vs 100**	**10 vs 100**
Engineer	AHP	0.91	0.88	0.99
	ELECTRE III	0.90	0.80	0.92
Politician	AHP	0.96	0.89	0.97
	ELECTRE III	0.86	0.77	0.88
Resident	AHP	1.00	0.97	0.98
	ELECTRE III	0.91	0.80	0.90

Table 36.- Correlation coefficient between rankings according to different rainfall events.

	CORRELATION COEFFICIENT BETWEEN METHODS		
RAINFALL	**Engineer**	**Politician**	**Resident**
T=2 years	0.81	0.74	0.48
T=10 years	0.80	0.77	0.46
T=100 years	0.76	0.70	0.61

Table 37.- Correlation coefficient between rankings according to different MCDA methods.

RAINFALL	METHOD	CORRELATION COEFFICIENT BETWEEN STAKEHOLDERS		
		E vs P	E vs R	P vs R
T=2 years	AHP	0.86	0.77	0.51
	ELECTRE III	0.98	0.78	0.76
T=10 years	AHP	0.81	0.63	0.39
	ELECTRE III	0.94	0.74	0.60
T=100 years	AHP	0.86	0.62	0.35
	ELECTRE III	0.97	0.78	0.77

Table 38.- Correlation coefficient between rankings according to different stakeholders.

Table 36 shows that correlation coefficients are relatively high between rankings from different rainfall events. There are no tendencies when comparing coefficients by stakeholder. In contrast, it could be said that coefficients for AHP method cases are slightly higher than ELECTRE III ones.

Table 37 shows that correlation coefficients between rankings from different MCDA methods are moderate. However, this could be explained by the "incomparability" characteristic of the ELECTRE III method that is not considered in AHP.

Table 38 shows significant differences between correlation coefficients between rankings regarding the different stakeholders. Correlation coefficients between the "Engineer" and the "Politician" are high, while those between the "Engineer" and the "Resident" are slightly lower. Finally, coefficients between the "Politician" and the "Resident" are the lowest of the table, significantly small in some cases ("AHP and 100 years" or "AHP and 10 years" scenarios). There are no tendencies when comparing coefficients by rainfall. In contrast, it can be observed that coefficients for AHP method cases are always lower than ELECTRE III ones, reaching significant differences in some cases. This result leads to an interesting hypothesis which is that it seems that AHP could be more sensitive to weights modifications than ELECTRE III. This hypothesis should be analyzed in detail by a sensitivity analysis of the BMP ranking program weights and relative priority matrices.

One of the main problems when comparing the obtained results is that ELECTRE III allows incomparability and thus, it ranks several BMPs at the same position. As a result, it is sometimes difficult to compare AHP and ELECTRE III rankings by analyzing the BMPs position number. In fact, correlation coefficients presented in the tables above present sometimes low values, probably due to this fact and, as it can be observed in figure 48, ELECTRE III tends always to give lower position numbers (so higher importance) to BMPs than AHP. This aspect should be taken into account when drawing explanations or conclusions for the obtained results.

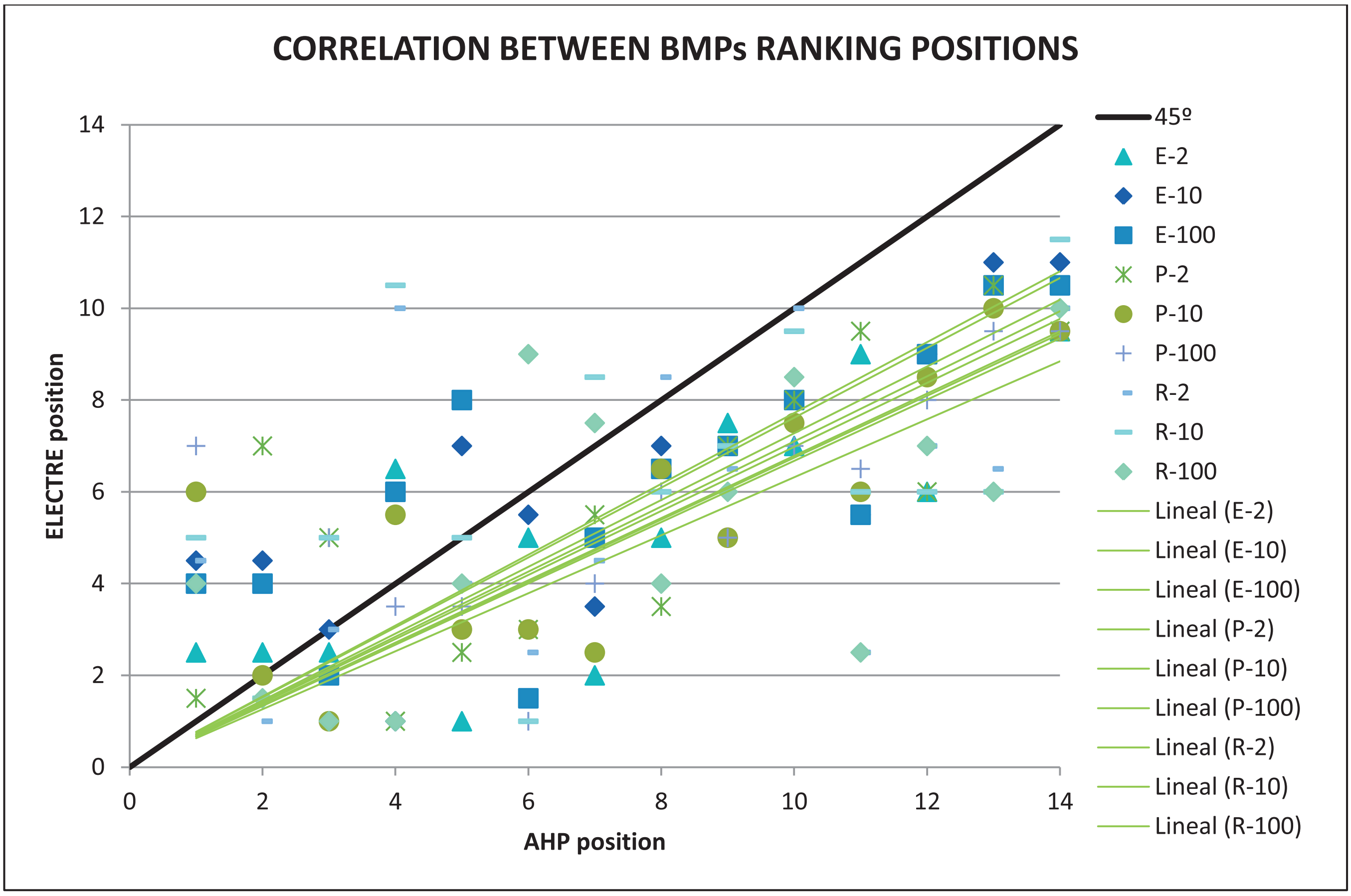

Figure 48.- Correlation between BMPs ranking positions.

Coherence of the program regarding the relative importance of the criteria

In order to evaluate the results coherence, unicriterion rankings were also calculated by ranking BMPs in relation to the performance values of each criteria or sub-criteria isolated. Results are presented in tables 39 to 42.

Then, unicriterion rankings (tables 39 to 42) were compared to the multicriteria rankings (tables 34 and 35) in view of the stakeholders' preferences.

For the "resident" stakeholder, the most important criterion was the socio-environmental performance and secondly, the economical one. It can be observed that the best BMPs classified in residents multicriteria rankings are, in general, numbers 9, 12, 14 and 5 while the first ranked BMPs in unicriterion rankings related to socio-environmental and economical criteria are, more or less, the same BMPs. In technical unicriterion ranking these BMPs are also among the best ranked. On the contrary, in technical and quality unicriterion rankings, these BMPs are worse ranked. According to the worst ranked BMPs, multicriteria rankings select BMPs 2, 3, 8 and 11 while only BMPs 2 and 11 from these 4 are selected in unicriterion rankings related to the most important criteria.

For the “politician” stakeholder, the most important criteria were the quality and the technical performances. It can be observed that the best BMPs classified in politician multicriteria rankings are, in general, numbers 5, 8, 9, 11, 12, 13 and 14 while the first ranked BMPs in unicriterion rankings related to technical and quality criteria are, more or less, the same BMPs. In socio-environmental unicriterion ranking BMPs 12, 13, 14 are also among the best ranked but not 5, 8, 9 and 11 BMPs. According to the worst ranked BMPs, multicriteria rankings select BMPs 1, 2 and 7 while only BMPs 1 and 2 from these 3 are selected in unicriterion rankings related to the most important criteria. In contrast, BMP 3 is ranked among the worst BMPs in the unicriterion rankings.

For the “engineer” stakeholder, the most important criterion was the economical performance and secondly, the technical one. It can be observed that the best BMPs classified in residents multicriteria rankings are, in general, numbers 5, 9, 12, 13 and 14 while the first ranked BMPs in unicriterion rankings related to economical and technical criteria are, more or less, the same BMPs but they include BMPs 3 and 4 among the best ranked. In socio-environmental and quality unicriterion rankings these BMPs are worse ranked. According to the worst ranked BMPs, multicriteria rankings select BMPs 1, 2 and 7 while only BMP 1 from these 3 is selected in unicriterion rankings related to the most important criteria. In contrast, BMP 3 is again ranked among the worst BMPs in the unicriterion rankings.

Regarding the previous results, a slightly coherence can be drawn between the criteria relative importance and the ranking results. However, MCDA methods are obviously made to identify the best BMPs among a set of possible alternatives.

Finally, it must be indicated that the AHP method calculates coherence ratio for each of its relative priority matrices and, as it was said in section 3.2.1, Saaty (1980) considered the matrices coherent if this ratio was lower than 10%. In this study, coherence ratios of all matrices were always lower than 10% except from the relative priority matrix of the main performances for the politician stakeholder. However, the coherence ratio was 10.1% so, even if its values should maybe be revised, the authors of this study considered them as acceptable as the purpose of the study was clearly differentiate the 3 stakeholders preferences by choosing “extreme” relative priority values.

	RANKINGS ACCORDING TO TECHNICAL PERFORMANCE		
BMP	T=2 years	T=10 years	T=100 years
1	5	7	7
2	3	5	5
3	7	9	9
4	6	8	8
5	1	1	1
6	4	6	6
7	4	6	6
8	1	1	1
9	1	2	3
10	1	4	4
11	2	3	2
12	1	1	1
13	1	1	1
14	1	1	1

Table 39.- Unicriterion rankings according to technical performance.

	RANKINGS ACCORDING TO ECONOMICAL PERFORMANCE		
BMP	T=2 years	T=10 years	T=100 years
1	12	12	11
2	13	13	13
3	2	1	1
4	3	2	2
5	1	5	8
6	10	9	9
7	11	10	10
8	9	11	12
9	6	6	4
10	8	8	6
11	7	3	3
12	4	4	5
13	5	7	7
14	5	7	7

Table 40.- Unicriterion rankings according to economical performance

	RANKINGS ACCORDING TO QUALITY PERFORMANCE SUB-CRITERIA		
BMP	% TSS	% TN	% TP
1	1	11	10
2	1	11	10
3	6	6	4
4	2	4	2
5	5	2	1
6	5	7	5
7	4	10	8
8	1	2	3
9	2	8	6
10	2	8	6
11	1	1	1
12	4	9	7
13	2	3	9
14	3	5	7

Table 41.- Unicriterion rankings according to quality performance sub-criteria.

	RANKINGS ACCORDING TO SOCIO-ENVIRONMENTAL PERFORMANCE SUB-CRITERAI			
BMP	Acceptability	Life quality	Environment	Heal&Safety
1	4	3	3	3
2	5	3	3	3
3	4	4	4	3
4	2	4	4	1
5	3	4	4	4
6	3	3	2	3
7	1	2	1	5
8	5	4	3	1
9	2	3	2	3
10	2	3	3	3
11	6	5	4	3
12	3	3	2	3
13	1	2	2	2
14	1	1	1	1

Table 42.- Unicriterion rankings according to socio-environmental performance sub-criteria.

5.3. SENSITIVITY ANALYSIS

In order to evaluate the BMP ranking program robustness 4 sensitivity analysis were made:

1. Sensitivity analysis of the ELECTRE III thresholds.
2. Sensitivity analysis of the socio-environmental criteria inputs.
3. Sensitivity analysis of the quality criteria inputs.
4. Sensitivity analysis of the initial infiltration rate.

The reason for choosing these 4 sensitivity analysis is that values of these parameters or inputs present higher difficulties to be obtained accurately. Results are presented and discussed in the following sections.

5.3.1. SENSITIVITY ANALYSIS OF THE ELECTRE III THRESHOLDS.

A sensitivity analysis was made to the ELECTRE III thresholds to assess the method robustness in view of these parameters. This is an important test because thresholds values are often difficult to determine so it is suitable that the method won't be sensitive to their modification. To develop the analysis, the 3 thresholds (indifference, preference and veto) values were all increased a 20% of their value. Results of the sensitivity analysis are presented in Annex C.

It seems that BMPs rankings haven not changed significantly. In order to better evaluate differences between the original rankings and the ones issued from the sensitivity analysis, correlation coefficients were calculated. Results are presented in table 43.

		CORRELATION PRE-RANKINGS 1			CORRELATION PRE-RANKINGS 2		
RAINFALL	CORRELATION	Engineer	Politician	Resident	Engineer	Politician	Resident
T=2	original vs +20 %	0.99	0.99	0.96	1	0.99	0.97
	original vs - 20%	1	0.99	1.00	0.98	0.95	0.99
T=10	original vs +20 %	0.99	0.99	1.00	0.99	0.97	0.99
	original vs - 20%	1.00	0.98	0.98	1.00	0.99	0.98
T=100	original vs +20 %	1.00	1	1	0.98	0.98	0.99
	original vs - 20%	1	0.99	0.98	1	0.98	0.98

Table 43.- Correlation coefficients between original ELECTRE pre-rankings and the ones issued from the sensitivity analysis of ELECTRE III thresholds.

It can be observed that all correlation coefficients are higher than 0.95 and in general close to 1. In view of the problem characteristics, it was considered that these are relatively high values and that it could be said that ELECTRE III seems robust according to the thresholds. This conclusion has also been drawn by other researchers in precedent studies ((Martin, et al., 2007); (Ho & Sherris, 2012); (García Cebrián, et al., 2009); (Raju, et al., 2004); (Mena, 2001)).

5.3.2. SENSITIVITY ANALYSIS OF THE PROGRAM INPUTS.

Three inputs were analyzed in a sensitivity analysis: quality indicators "average percentage of removed pollutant" for each of the 3 pollutant studied (suspended sediments, nitrogen and phosphorus), socio-environmental indicators "residents acceptability", "society life quality", "environment and sustainable development" and "health and safety risks" and the initial infiltration rate input. Values of the quality and socio-environmental inputs were firstly increased a 50% and then decreased a 50%. The initial infiltration rate value was increased and decreased a 20 %. The reason for this difference is that incertitude for the initial infiltration ratio value is lower than the values for the other inputs so a 20 % of variability was found to be enough for this test.

Resulting rankings for both inputs are presented and discussed in the following subsections.

Quality inputs sensitivity analysis

Rankings issued from this sensitivity analysis are presented in Annex C. Table 44 presents the correlation coefficients between the original rankings and the ones issued from the analysis for ELECTRE III and table 45 presents equivalent results for AHP method.

		CORRELATION ELECTRE III					
		CORRELATION PRE-RANKINGS 1			CORRELATION PRE-RANKINGS 2		
RAINFALL	CORRELATION	Engineer	Politician	Resident	Engineer	Politician	Resident
T=2	original vs +50 %	1	0.95	1	1	0.92	1
	original vs - 50%	1	0.99	1	1	0.97	1
T=10	original vs +50 %	1	0.81	1	1	0.90	1
	original vs - 50%	1	0.96	1	1	0.93	1
T=100	original vs +50 %	1	0.97	1	1	0.97	1
	original vs - 50%	1	1	1	1	0.99	1

Table 44.- Correlation coefficients between the original pre-rankings and the ones issued from the sensitivity analysis for ELECTRE III. Pre-ranking 1 corresponds to the descending distillation and pre-ranking 2 corresponds to ascending distillation.

		CORRELATION AHP		
RAINFALL	CORRELATION	Engineer	Politician	Resident
T=2	original vs +50 %	0.99	0.93	1
	original vs - 50%	0.99	0.93	1
T=10	original vs +50 %	1	0.99	1
	original vs - 50%	1	0.99	1
T=100	original vs +50 %	1	1	0.97
	original vs - 50%	1	1	0.97

Table 45.- Correlation coefficients between the original rankings and the ones issued from the sensitivity analysis for AHP.

As for the thresholds sensitivity analysis, it seems that BMPs rankings haven not changed significantly as correlation coefficients are always higher than 0.93 for AHP and 0.81 for ELECTRE III. Besides, it can be observed that the most variable rankings are the ones related to the “politician” stakeholder, which is the scenario where quality criterion is the most important.

Socio-environmental inputs sensitivity analysis

Rankings issued from this sensitivity analysis are presented in Annex C. Table 46 presents the correlation coefficients between the original rankings and the ones issued from the analysis for ELECTRE III and table 47 presents equivalent results for AHP method.

		CORRELATION ELECTRE III					
		CORRELATION PRE-RANKINGS 1			CORRELATION PRE-RANKINGS 2		
RAINFALL	CORRELATION	Engineer	Politician	Resident	Engineer	Politician	Resident
T=2	original vs +50 %	1	1	0.97	1	1	0.96
	original vs - 50%	1	1	0.77	1	1	0.94
T=10	original vs +50 %	0.89	1	0.97	0.88	0.97	0.98
	original vs - 50%	1	1	0.78	1	0.97	0.95
T=100	original vs +50 %	1	1	0.91	1	1	0.97
	original vs - 50%	1	1	0.85	1	1	0.98

Table 46.- Correlation coefficients between the original pre-rankings and the ones issued from the sensitivity analysis for ELECTRE III. Pre-ranking 1 corresponds to the descending distillation and pre-ranking 2 corresponds to ascending distillation.

		CORRELATION AHP		
RAINFALL	CORRELATION	Engineer	Politician	Resident
T=2	original vs +50 %	1	1	1
	original vs - 50%	1	1	1
T=10	original vs +50 %	1	1	1
	original vs - 50%	1	1	1
T=100	original vs +50 %	1	1	1
	original vs - 50%	1	1	1

Table 47.- Correlation coefficients between the original rankings and the ones issued from the sensitivity analysis for AHP.

As for the thresholds and the quality inputs sensitivity analysis, it seems that BMPs rankings still do not change significantly as correlation coefficients are always 1 for AHP and higher than 0.85 for ELECTRE III. Besides, it can be observed that the most variable rankings are the ones related to the “residents” stakeholder, which is the scenario where socio-environmental criterion is the most important. This result reinforces the idea that the BMP ranking program operates coherently.

Initial infiltration rate sensitivity analysis

Rankings issued from this sensitivity analysis are presented in Annex C. Table 48 presents the correlation coefficients between the original rankings and the ones issued from the analysis for ELECTRE III and table 49 presents equivalent results for AHP method.

		CORRELATION ELECTRE III					
		CORRELATION PRE-RANKINGS 1			CORRELATION PRE-RANKINGS 2		
RAINFALL	CORRELATION	Engineer	Politician	Resident	Engineer	Politician	Resident
T=2	original vs +20 %	1	0,99	1	0,99	0,97	1
	original vs - 20%	1	0,99	1	1	0,97	1
T=10	original vs +20 %	1,00	0,98	1	0,99	1	1,00
	original vs - 20%	1	1,00	1	1	1	1
T=100	original vs +20 %	1,00	1,00	1	0,99	1,00	1
	original vs - 20%	1	1,00	1	1	1,00	1

Table 48.-Correlation coefficients between the original pre-rankings and the ones issued from the sensitivity analysis for ELECTRE III. Pre-ranking 1 corresponds to the descending distillation and pre-ranking 2 corresponds to ascending distillation.

		CORRELATION AHP		
RAINFALL	CORRELATION	Engineer	Politician	Resident
T=2	original vs +20 %	0,99	0,93	1,00
	original vs - 20%	0,98	0,93	1,00
T=10	original vs +20 %	1	0,99	1
	original vs - 20%	1	0,99	1,00
T=100	original vs +20 %	1,00	1	0,97
	original vs - 20%	1	1,00	0,97

Table 49.- Correlation coefficients between the original rankings and the ones issued from the sensitivity analysis for AHP.

As for the precedent sensitivity analysis, it seems that BMPs rankings still do not change significantly as correlation coefficients are always higher than 0.93 for AHP and 0.98 for ELECTRE III. Besides, it can be observed that the most variable rankings are the ones related to the 2-years return period rainfall and the most stable are the ones for 100-years return period rainfall. Furthermore, it seems that AHP is more sensitive than ELECTRE III to this input.

6. CONCLUSIONS AND RECOMMENDATIONS

Interesting and promising conclusions were drawn in the present study. They are all going to be presented and discussed in the following subsections, organized by the objective to which they are related.

Main objective 1

The main objective of this study was to develop a MCDA tool in order to assist in BMP selection problems. An innovating methodology, based on AHP and ELECTRE III MCDA methods, has been developed. It provides the stormwater managers a coherent ranking according to their specific case study and criteria preferences. Besides, two different MCDA methods can be used in the decision-making process: AHP and ELECTRE III. This tool represents an important contribution to decision-making problems involving BMPs as, to date, only few research projects have deal with this issue and obtained promising results. This tool is really useful to medium-to-small-size towns where BMPs information and engineers experience may be insufficient.

Main objective 2

The second main objective was to compare the results issued from both MCDA methods used in this study. The developed methodology was applied to a demonstration site in Canada. Both MCDA methods ranking results were then compared. In general, the first 3 positions were occupied in both cases by BMPs 5, 9, 11, 12, 13 and 14 which are respectively the permeable pavement, the shallow swale, the perforated pipe, the detention basin, the retention pond and the wetland. In contrast, the last 3 positions were occupied by BMPs 1, 2 and 7 which are respectively the extensive and intensive green roofs and the bioretention systems.

It can be conclude that even though the 2 methods have a different structure and follow different ranking methodologies and calculations, best and worst ranked BMPs may be, in general, the same ones in both cases. As the purpose of the MCDA methods is not to select the best and optimal BMP but to identify the group of the best BMPs and the group of the worst ones, so that to reduce the alternatives for the decision maker, this result becomes positive.

However, it must be reminded that ELECTRE III method allows incomparability of alternatives and thus, it can give the same position to several BMPs. That makes the comparison process between ELECTRE III and AHP methods more difficult so critical view of the results must be taken into account by the user.

In addition, the decision of whether to use AHP or ELECTRE III is made by the user. Future research in this area may try to find more general or objective conditions to direct the user through which MCDA method is more appropriated in its particular case.

Secondary objective 1

First secondary objective was to modify the last version of the BMP ranking program developed by Coulais (2010) in the same research group as the present study. The modifications consisted in dividing the quality criteria into 3 different sub-criteria related to the type of pollutant removed by the BMP. The socio-environmental sub-criteria selected by Coulais (2010) were replaced by other 4 sub-criteria. The author of the present study thought that the new sub-criteria represented better the different aspects of the socio-environmental performance of a BMP.

Furthermore, both quality and socio-environmental performance indicators were better evaluated. For the first one, data from North American stormwater guides were utilized to calculate the “total mass of removed pollutant” of each BMP. For the second one, a survey was developed in order to be filled by the BMP experts of each study case.

Finally, an important modification of the precedent program version is that in the new version the user can introduce the relative criteria preferences or weights. That makes the program more flexible and adaptable to different management objectives.

Secondary objective 2

Second secondary objective was to adapt and implement ELECTRE III method to BMP selection problems. Adaptation and implementation were successfully made and thus, comparison between results issued from both methods was possible.

Secondary objective 3

Third secondary objective was to adapt the developed methodology to Quebec's Canadian region. Data and recommendation issued from the recent published Quebec stormwater management guide (MDDEP and MAMROT, 2012) were collected and implemented in the developed computer program. The most important adaptation aspects were related to the technical constraints. According to this aspect, all BMPs fulfilled the constraints related to the distance between the water table and the BMP's base (as it was higher than 1.2m), the site slope (as it was higher than 1 and lower than 5), the pollution hot spots (as there weren't in the present study area) and minimal drainage surface (as it was 7.88ha). However, BMPs 1 and 2 would not be recommended in the present case study as it is located in a residential area with houses and not with blocks (so roofs are not flat). Furthermore, BMPs do not fulfill the maximal drainage area constraint. This is due to the fact that these BMPs which have a restriction in the maximal drainage area are BMPs that are usually combined with other BMPs and thus the total drainage area is divided into all of them. In this study they have been considered isolated to simplify the methodology but in real projects they should probably be considered in combination with others. Finally, BMPs did neither fulfill the minimal construction area constraint. As these technical constraints are compulsory recommendations and not obligatory rules, after a critical analysis of the situation, the author of this study considered the constraints too restrictive and thus it was not to taken into account.

Secondary objective 4

Forth secondary objective was to evaluate the program robustness and the methodology results' coherence according to different scenarios.

To evaluate the program robustness, sensitivity analysis were made. The following conclusions were drawn:

- ELECTRE III is not significantly sensitive to the thresholds values. This conclusion has also been drawn by other researchers in precedent studies ((Martin, et al., 2007); (Ho & Sherris, 2012); (García Cebrián, et al., 2009); (Raju, et al., 2004); (Mena, 2001)).
- In relation to the inputs, quality and socio-environmental inputs as well as initial infiltration rate input were subjected to sensitivity analysis. Only these inputs were evaluated because they are the most difficult to obtain. Besides, for quality and socio-environmental inputs, they are also the ones which have been modified from the last version of the methodology developed by Coulais (2010). The results conclude that the program was not significantly sensitive to either of the inputs analyzed. In the quality and socio-environmental case, this could mean that finally it is maybe not necessary to better evaluate these performances as their input values changes do not apparently affect the final results. However, this result could also be due to the type of sensitivity analysis. In fact, the sensitivity analysis made was a “global” sensitivity analysis where all parameters or inputs are modified at the same time. As our results are based in the relative importance of the BMPs performances, if they all change at the same time in the same way, results are likely to be similar to the original ones. Maybe, a “local” sensitivity analysis, where inputs are modified one by one, would be more appropriated.
- For the rate infiltration case, it is positive that the developed methodology seems not sensitive to it because it is an input really difficult to obtain in hydrological projects.

According to the methodology coherence, two aspects lead to think that the results given by the program are coherent. Firstly, the coherence ratio defined by Saaty for the AHP method was in all cases (except from the relative priority matrix of the politician stakeholder) within the allowed limits. The matrix that didn’t fulfill the recommended values should maybe be revised even though the differences with the permitted values were minimal.

Secondly, for each stakeholder, multicriteria rankings were compared with the unicriterion rankings of the preferred criteria according to that stakeholder. There were no strong tendencies to prove that both rankings were related but the best ranked BMPs often matched.

Furthermore, results changes in the sensitivity analysis of quality and socio-environmental inputs were coherent as they mainly affected the stakeholders with higher preferences in these performances.

Finally, other conclusions were also identified from secondary tests. It was observed that the type of rainfall, in relation to the return period, did not influence the final ranking results. Besides, according to the weights, AHP seems more sensitive to changes in the criteria weights than ELECTRE III as the differences between the different stakeholders' rankings were bigger with AHP than with ELECTRE III. Furthermore, AHP seemed also more sensitive to changes in the infiltration rate input while, in the case of socio-environmental inputs, it is apparently more robust than ELECTRE III. However, more robust sensitivity analysis, maybe with Montecarlo simulations, should be done to better prove these facts.

Recommendations for future projects developed in this area of research

Even though the conclusions of this study were satisfactory, there are some aspects that could be modified or improved by future researchers. Some of them have already been introduced above as (1) the need of finding general conditions to help the users decide between AHP or ELECTRE III and (2) the need of developing more robust sensitivity analysis of the weights, relative priority matrices of the MCDA methods and methodology inputs. Other recommendations are:

- Some data used for the indicators calculation as the BMPs lifetime are hypothetic values that should be better estimated. Another example is the benefice value taken to calculate the NPV of the BMPs. This study has taken a fixed value issue from a precedent study of Fuamba et al. (2010) but this study only takes into account 3 of the 14 considered BMPs. Future studies should estimate a variable benefice according to the type of BMP.

- Even though the quality and socio-environmental criteria indicators have been better evaluated and their calculation methodology has been improved, performance calculation can still be better studied. For example, the design of the different BMPs to evaluate the technical performance is relatively simple. A hybrid methodology combining this BMP ranking program with other commercial drainage design programs as SWMM could be developed. Or even try to introduce an optimization module in order to avoid oversizing of some BMPs.
- In relation to the precipitation-runoff model, rainfall was considered as a total runoff volume that would be all absorbed by the BMP. But some BMPs, particularly those whose main function is infiltration, could not absorb all the runoff discharge as their infiltration capacity could be reached.
- Continuing with the precipitation-runoff model, different design storms were considered in this study. Their differences lied in the rainfall intensity as the type of design storm and the duration were the same. However, it was observed that they did not influence the final ranking results. Maybe, other aspects related to precipitations should be taken into account as, for example, the time between events, called “dry periods”. These periods of time influence not only the runoff quantity but especially the quality of it as pollutants tend to be accumulated in the catchment surfaces.
- Other aspect that must be highlighted is that rainfall data was obtained from a unique pluviometer so that the rainfall inputs correspond to punctual precipitations. Spatial distribution of the rainfall was not considered as this project is a preliminary study where performances and runoff volumes are calculated in a simple and easy way. Nevertheless, future and more detailed studies should take into account spatial of the rainfall events using, for example, the Thiessen methodology.
- According to the weights values, in this study simulated scenarios related to 3 different stakeholders have been used to evaluate the program robustness and coherence. However, in real project, a combination of all stakeholders’ preferences should be considered, according to the specific project management objectives. To do so, local authorities or developers should not

only evaluate their preferences but also those from the residents. Surveys could be done in order to obtain the local community opinion.

- In relation to the sensitivity analysis, an important aspect that should be studied is the rank reversal phenomenon. This phenomenon occurs when the ranking results of a MCDA method change because one (or more) of the considered alternatives have been removed from the set or when one (or more) new alternatives are added. These ranking irregularities are well known for the additive variants of the AHP method and some studies have already identified them when the ELECTRE methods are used (Wang & Triantaphyllou, 2008). This type of sensitivity analysis helps evaluating and comparing MCDA methods.
- Local authorities of the demonstration area selected in this study highlighted that maintenance costs (not only in terms of material costs but also in terms of time, planning and specialized personnel) should be given higher importance in the criteria definition. Maybe the economical criteria should also be divided into several sub-criteria, as, for example, construction costs, maintenance costs and investment refund.
- Other possible socio-environmental sub-criteria were identified in the course of the study. It seems that nowadays it is found important to take into account energy criteria for energy saving. Another possible sub-criterion could be creation of the called Green Jobs, i.e. jobs or businesses that are considered to be environmentally conscious. As local authorities from Laval pointed out, qualified personnel are needed to assure a proper performance of the BMPs and their maintenance. These could be other sub-criteria related to the socio-environmental performance.
- Finally, in view of the difficulties to obtain water quality data, BMPs monitoring should be promoted in the main BMP studies to increase the actual database.

Methodology applicability and limitations

The most important methodology limitations are related to the lack of information. In fact, performance indicators calculation is an essential step in this methodology. For that purpose, quite a lot of inputs are required. Technical and site data are indispensable and asked values are the basic and usual one for any hydrologic study of urban drainage. As it has been said in the precedent paragraph, economical data is already provided for North America and Europe but should be collected for other places. Socio-environmental inputs are not easy to obtain but this study has developed a survey that facilitates this task. The most difficult data to be obtained are maybe the average percentage of pollutant removal of each BMP. These values are issued from previous BMPs monitoring and, unfortunately, to date there are not too many BMPs where water quality is monitored.

Other limitations should be pointed out to future users:

- The number of alternatives that are taken into account in this methodology is fixed and restrained to 14.
- Even if the criteria weights and the relative priority matrices are justified by the experts' opinions, they are still subjective elements.
- As only one unit of some little BMPs, as filter drains or rain harvesting barrels, is taken into account, these BMPs are always at a disadvantage in relation to BMPs with high storage and infiltration/filtration capacities, as basins. These types of little BMPs are typically considered in combination with other BMPs. In fact, one of the most important recommendations for future researchers is that combination of several BMPs should be studied.

Finally, in relation to the tool's applicability to other urban sites, it must be said that this methodology has been conceived to be used at a district scale, i.e. for urban planning in medium-to-small city areas or urban sectors renovations. Apart from that, it is possible to use the methodology in other sites always adapting the program code to the new inputs. The most important modifications will be related to the average percentage of pollutant removal, technical constraints and BMP design considerations as specific regulations related to stormwater management may exist in that region. Costs considered in this study have been evaluated for North America and Europe. If the program is used elsewhere, these data should be reviewed. According to the methodology structure, no other adaptations are needed. The 4 criteria taken into account are the usual considered ones in all problems of this kind and the 14 selected

BMPs are also the most popular ones. Obviously, this methodology has been developed for the template zone of the Earth; extreme weather conditions may require further modifications.

ANNEX A: Methodologies for Indicators Evaluation

In order to assess the criteria and sub-criteria utilized in the BMP ranking program, different indicators were selected. Section 1.3.2 summarizes how these indicators were calculated. As it is presented in table 1.3.2, the Technical Performance indicator is the “total treated volume” of each BMP. Economical Performance indicator is the “net present value” of each BMP. To evaluate the Quality Performance, the program allows the user to choose between two different indicators, the “average percentage of pollutant removal” or the “total mass of removed pollutant”. Finally, the Socio-environmental Performance is evaluated by a qualitative scale issue from the results of a public survey. This annex aims to explain with further details the indicator calculations.

A.1. TECHNICAL PERFORMANCE INDICATOR

As it has been indicated in the introduction of this annex, the Technical Performance indicator considered in this methodology is the “total treated volume” of each BMP. The calculation methodology to obtain these values depends on the type of management that the BMP does. As it is explained in section 4.2, three different types of BMP management can be identified: 1) Infiltration, 2) Storage and 3) Conveyance. In general, the 14 BMPs considered in this study could be classified into three different categories: 1) BMPs that stock and infiltrate, 2) BMPs that convey water to other drainage systems and 3) BMPs that cannot be classified in the precedent categories.

The calculation methodologies for each BMP category are described in section A.1.1. To calculate these values, different formulas (based on the literature related to BMP design ((Ecovégétal, 2008a); (Ecovégétal, 2008b); (MOE, 2003); (Grand Lyon, 2008b); (Grand Lyon, 2008)) and the Quebec stormwater management guide recommendations (MDDEP and MAMROT, 2012) have been established and adapted to the present case study. Besides, some design variable ranges must be taken into account when designing the BMPs. These values are collected in table A.1.2. They have been estimated from the expert’s opinion and recommendations.

Moreover, to obtain the treated volume values, it is necessary to estimate the rainfall volumes and runoff discharges in the study catchment. Section A.1.2 describes the calculation methods used for this purpose.

Furthermore, to evaluate the infiltrated water in the infiltration-management BMPs, an infiltration model must be utilized in order to calculate the variation of the soils permeability during the storm event. Section A.1.3 explains this aspect.

Finally, as it was mention in section 1.3.4, BMP must obey some technical constraints included in most of the stormwater management guides. These technical constraints are presented in section A.1.4.

A.1.1. METHODOLOGY USED TO CALCULATE THE TREATED VOLUMES

As it was mentioned above, the calculation methodology to obtain the treated volume values depends on the type of management that the BMP does.

BMPs that stock and infiltrate the runoff water are the filter drains, the permeable pavements, the filter strips, the bioretention systems, the infiltration trenches, the shallow an deep swales, the detention basins, the retention ponds and the wetlands. For these BMPs, the general equation to calculate the treated volume values is the following one:

$$V_{global} = V_{stored} + V_{\inf iltrated} = V_{capacity} + Q_{leaked} \times t \tag{30}$$

where V_{sotred} (m^3) is the stored volume in the BMP, which corresponds to its maximal capacity, and $V_{infiltrated}$ (m^3) is the infiltrated volume, which corresponds to the multiplication of the leaked discharge of the BMP (m^3/s) by the duration (s) of the rainfall event.

Storage in some of these BMPs, in particular in permeable pavements and bioretention systems, is negligible so for these two BMPs only infiltration volumes will be considered. Furthermore, filter strips main function is to filter the stormwater discharges. Different methodologies exist to calculate the volume discharged by the BMP when filtering but, in the present study, filter strips will be treated as an infiltration BMP and thus infiltration volumes will be calculated as for the other infiltration BMPs. Equations utilized for each BMP are presented in table 50.

PGO	EQUATION	VARIABLES
Filter drains	$V_{global} = 0.7 \cdot V_{stored} + Q_{leaked} \cdot t$ $Q_{leaked} = 0.5 \cdot S_{vertical\_walls} \cdot K$ $S_{vertical\_walls} = 2\pi \cdot \frac{D}{2} \cdot H$ $V_{stored} = \pi \frac{D^2}{4} \cdot H$	▪ K: infiltration rate (mm/h) ▪ H: BMP depth (m) ▪ D: drain diameter (m) ▪ t: duration of the rainfall event (h) ▪ We consider 0.7 of the stored volume because of the space occupied by gravels in the drain volume
Permeable pavements Filter strips Bioretention systems	$V_{global} = K \cdot Ss \cdot t$	▪ K: infiltration rate (mm/h) ▪ Ss: BMP surface (m^2) ▪ t: duration of the rainfall event (h)
Infiltration trenches	$V_{global} = 0.7 \cdot V_{stored} + Q_{leaked} \cdot t$ $Q_{leaked} = 0.5 \cdot S_{vertical\_walls} \cdot K$ $S_{vertical\_walls} = L \cdot H$ $V_{stored} = L \cdot l \cdot H$ $l = 0.6 \cdot H + 0.2$	▪ K: infiltration rate (mm/h) ▪ H: BMP depth (m) ▪ L: trench length (m) ▪ l: trench wide (m) ▪ t: duration of the rainfall event (h) ▪ We consider 0.7 of the stored volume because of the space occupied by gravels in the trench volume
Shallow and deep swales	$V_{global} = V_{stored} + Q_{leaked} \cdot t$ $Q_{leaked} = S_{mirror} \cdot K$ $S_{mirror} = L \cdot l$ $V_{stored} = 0.5 \cdot L \cdot l \cdot H$	▪ K: infiltration rate (mm/h) ▪ H: BMP depth (m) ▪ L: trench length (m) ▪ l: trench wide (m) ▪ t: duration of the rainfall event (h) ▪ S_{mirror}: surface of the horizontal projection of the BMP (m^2)
Detention basin Retention pond Wetland	$V_{global} = V_{stored} + Q_{leaked} \cdot t$ $Q_{leaked} = S_{basin\_bottom} \cdot K$ $S_{basin\_bottom} = Ss$ $V_{stored} = Ss \cdot H$	▪ K: infiltration rate (mm/h) ▪ Ss: BMP surface (m^2) ▪ t: duration of the rainfall event (h) ▪ H: BMP depth (m)

Table 50.- Equations utilized to calculate the treated volume of each BMP.

In all formula, BMP depth is calculated as follows:

$$H = \begin{cases} WT - M \; if\,(WT - M) < N \\ N \quad if\,(WT - M) \geq N \end{cases} \tag{31}$$

where *H* (m) is the BMP depth, *WT* (m) is the minimal distance between the BMP base and the water table and *N* (m) is the maximal height of the BMP.

In the same way, the BMP surface is calculated as follows:

$$Ss = \begin{cases} S_d - D \cdot d & if A_s \geq Ss \\ A_s = \dfrac{V_t}{H + K \cdot t} & if A_s < Ss \end{cases} \tag{32}$$

where Ss (m^2) is the BMP surface, S_d (m^2) is the available construction surface, D (m) is the legth of the the walls of the surrounding buildings, d (m) is the minimal distance between the BMP and the building foundations, V_t (m^3) is the treated volume and A_s (m^2) is the active surface.

As it has been indicated above, all design values that have been considered are presented in table 51. Active surface calculation is based on the rational method and its calculation is explained in detail in section A.1.2. Infiltration rates are based on Horton's Infiltration model and its calculation is also explained in detail in section A.1.3.

PGO	VARIABLE	RECOMMENDED RANGE	SELECTED VALUE
Extensive green roof	roof slope	0 - 30%	not applicable
Intensive green roof	roof slope	0 - 3 %	not applicable
Filter drains	diameter	0.8 - 2 m	2 m
Filter drains	depth	2.5 - 5 m	min and max values
Permeable pavement	initial infiltration rate for permeable pavement		3600 mm/h
Permeable pavement	depth	0.2 - 1.5 m	min and max values
Filter strips	depth	0 - 0.2 m	min and max values
Bioretention systems	depth	0.5 - 1 m	min and max values
Infiltration trenches	depth	0.3 - 5 m	min and max values
Shallow swale	wide	1 - 5 m	2.5 m
Shallow swale	depth	0.2 - 1 m	min and max values
Deep swale	wide	0.2 - 1.5 m	1 m
Deep swale	depth	0.2 - 1.5 m	min and max values
Perforated pipe	diameter	≥ 200 mm	300 mm
Perforated pipe	depth	0.5 - 1 m	min and max values
Detention basin	depth	1 - 3 m	min and max values
Retention pond	depth	1 - 3 m	min and max values
Wetland	depth	1 - 3 m	min and max values

Table 51.- Values considered to design the BMPs.

The second category of BMPs consists in the two different green roof BMPs and the rainwater harvesting. For the green roofs, the treated volume will be estimated as the difference between the volume discharged by a normal roof and the one discharged by a green one. Both volumes are determined by the rational method. The equations utilized for the calculation are the following ones:

$$V_{global}Extensive = \frac{(1-C_e)\cdot i\cdot A}{360}\cdot 10^{-4}\cdot t \quad \textbf{(33)}$$

$$V_{global}Intensive = \begin{cases} \frac{i \cdot t \cdot A}{1000} & if\,(i \cdot t) \leq Cap \\ \frac{Cap \cdot A}{1000} & if\,(i \cdot t) > Cap \end{cases}$$

(34)

where C_e is the runoff coefficient for an extensive green roof, A (m^2) is the green roof surface, Cap (mm) is the retention capacity of the intensive green roof, i (mm/h) is the average rainfall intensity and t (h) the duration of the rainfall event.

The runoff coefficient for extensive green roofs formula was estimated at 0.3 according to the literature (Ecovégétal, 2008a). On the other hand, the retention capacity in the intensive green roof formula was estimated at 80mm (Ecovégétal, 2008b). In both calculations total surface of normal roof that will be replaced by the green roof must be estimated by the user.

According to rainwater harvesting, the treated volume depends on the size of the tank or cistern used to collect the rainwater. In this study a $5m^3$ tank has been considered so that treated volume is calculated as follows:

$$V_{stored} = \begin{cases} \frac{A \cdot i}{360} \cdot 10^{-4} \cdot t & if\,(\frac{A \cdot i}{360} \cdot 10^{-4} \cdot t) < G \\ G & if\,(\frac{A \cdot i}{360} \cdot 10^{-4} \cdot t) \geq G \end{cases}$$

(35)

where G (m^3) is the tank volume and A (m^2) the total disconnected roof surface.

Finally, the perforated pipe systems cannot be included in neither of the categories abovementioned. Thus, the volume treated by this type of BMPs is calculated as follows (MOE, 2003):

$$V_{global} = L \cdot t \cdot (15 \cdot A - 0.06 \cdot slope + 0.33) \frac{V_t}{L\max \cdot t}$$

(36)

where L (m) is the pipe length, t (h) the duration of the rainfall event, A (m^2) the perforation area per pipe length, *slope* (%) is the pipe slope, *Lmax* (m) is the maximal length of the study site and V_t (m^3) is the treated volume.

The above formula is for perforated conduits with a 300 mm diameter which are the ones considered in this study.

In order to calculate this treated volume, a hypothesis has been made: the longitudinal discharge in the pipe has been considered equal to the pick discharge of the catchment divided by the maximal length of the demonstration site.

A.1.2. THE RATIONAL METHOD: CALCULATION OF THE ACTIVE SURFACE

The active surface is a hydrological variable issue from the Rational Method. This method is recommended for estimating the design storm peak runoff, especially in urban areas (Brière, 2000). The Rational Method, while first introduced in North America in 1889 by Kuichling (1889), is still used in many engineering offices in Canada and particularly in stormwater management and drainage design practices. Even though it has frequently come under criticism for its simplistic approach, no other drainage design method has received such widespread use (ConnDOT, 2000).

The utilization of the Rational Method implies the assumption of the following hypothesis:

- Rainfall intensity is uniform in time and space.
- Runoff velocity is stationary: the maximal runoff is produced for a rainfall duration at equal to the time of concentration.
- Frequency of occurrence of Q is identical to that of the rain.
- Runoff coefficient is considered constant and independent of the rainfall intensity.

The rational formula estimates the peak rate of runoff at any location in a watershed as a function of the drainage area, runoff coefficient and mean rainfall intensity corresponding to a rainfall duration at least equal to the time of concentration (the time required for water to flow from the most remote point of the basin to the location being analyzed). The rational formula is expressed as follows:

$$Q = \frac{C \cdot i \cdot A}{360} \qquad (37)$$

where Q (m^3/s) is the maximum rate of runoff, C (dimensionless) is the runoff coefficient, i (mm/h) average rainfall intensity for a duration at least equal to the time of the concentration, for a selected return period and *A* (ha) is the drainage area tributary to the design location.

The runoff coefficient can be estimated according to land use and the percentage of impermeable surface in the drainage area. If the drainage area is formed by different types of lands, a weighted runoff coefficient can be calculated. In this study, runoff coefficients where taken from the literature (Rivard, 2005). The active surface is then calculated as the multiplication of the runoff coefficient by the drainage area.

Average rainfall intensity can be calculated with the IDF curves of the study area. In this study, these curves were also taken from the literature (Rivard, 2005). In order to obtain these values, a return period and duration of the rainfall event must be determined. As it was explained in section 1.3.1, in this study 3 different rainfall events have been considered, each one corresponding to a different return period. The selected return periods were 2, 10 and 100 years and the rainfall duration was 3 hours, as it is established by the local authorities of Laval for drainage practices designs (Mailhot, et al., 2008).

A.1.3. CALCULATION OF THE SOILS INFILTRATION RATE

In order to calculate the values of the soils permeability, the Horton's Infiltration model has been considered. The model's main equation is:

$$f(t) = f_c + (f_o - f_c) \cdot e^{-kt} \tag{38}$$

where f (mm/h) is the infiltration capacity, f_c (mm/h) is the final or equilibrium infiltration capacity, f_0 (mm/h) is the initial infiltration capacity, t (s) is the time after the beginning of the rainfall event and k (s^{-1}) is a constant representing the decline of the infiltration capacity.

This equation indicates the infiltration rate at a given time. To obtain the average infiltration during the rainfall event, overall infiltration (I) must be calculated first by integrating this formula within the rainfall duration, i.e. between the beginning (t=0) and the end (t=τ) of the rainfall event, as follows:

$$I = \int_0^{\tau} f_c + (f_o - f_c) \cdot e^{-kt} dt \qquad (39)$$

$$I = \left[f_c \cdot t + (\frac{f_o - f_c}{-k}) \cdot e^{-kt} \right]_0^{\tau} \qquad (40)$$

$$I = \left[f_c \cdot \tau + (\frac{f_o - f_c}{-k}) \cdot e^{-k\tau} \right] - \left[f_c \cdot 0 + (\frac{f_o - f_c}{-k}) \cdot e^{-k0} \right] \qquad (41)$$

$$I = f_c \cdot \tau + (\frac{f_o - f_c}{-k}) \cdot \left(e^{-k\tau} - 1\right) \qquad (42)$$

Then, overall infiltration is divided into the duration of the rainfall event to obtain the average infiltration rate of the event:

$$K = \frac{I}{\tau} \qquad (43)$$

where K (mm/h) is the soils average permeability of the rainfall event.

A.1.3. TECHNICAL CONSTRAINTS TO EVALUATE BMPs PERTINENCE

There are some technical constraints that restrict the installation of a BMP in a specific site. These technical constraints are related to the BMP construction area localization and with some watershed and soils characteristics and they are defined in almost every stormwater management guide and it is recommended to satisfy them. The program developed in this study takes into account the technical constraints determined by the Ontario and Quebec stormwater management guides ((MDDEP and MAMROT, 2012); (TRC and CVC, 2010)). These values are presented in table 52 and table 53 resumes which BMPs should not been taken into account in the analysis because of the non satisfaction of the limiting criteria values.

		CRITERIA IN BOTH GUIDES: QUEBEC'S AND ONTARIO'S							EXCLUSIVE CRITERIA FROM ONTARIO'S GUIDE		ADDED CRITERIA
	BMP	**MIN distance from BMP base to water table level (m)**	**MIN Slope (%)**	**MAX Slope (%)**	**MIN Soil infiltration rate (mm/h)**	**MIN Drainage area (ha)**	**MAX Drainage area (ha)**	**MIN Required area for construction (% of impermeable area) *(% of drainage area)**	**Suitable in pollution hot spots**	**MIN Building foundation distance (m)**	**Unsuitable land uses**
1	Extensive green roof	NA	NA	NA	NA	X	X	NA	YES	0	Residential (houses)
2	Intensive green roof	NA	NA	NA	NA	X	X	NA	YES	0	Residential (houses)
3	Rainwater harvesting	NA	NA	NA	NA	X	X	0	YES	0	None
4	Filter drain	1	0	X	15	X	0.5	NA	X	4	None
5	Permeable pavement	1	1	5	15	X	X	NA	NO	4	None
6	Filter strip	0.5	1	5	0	X	2	variable	NO	0	None
7	Bioretention system	1.2	0	20	0	X	2	7	NO	4	None
8	Infiltration trench	1	X	15	15	X	2	2	NO	4	None
9	Shallow swale	1	0.5	5	0	X	2	10	NO	4	None
10	Deep swale	1	0.5	5	0	X	2	10	NO	4	None
11	Perforated pipe system	1	0	15	15	0	X	variable	NO	4	Industrial, commercial
12	Detention basin	0	X	25	0	5	X	1*	X	X	None
13	Retention pond	0	X	25	0	5	X	2*	X	X	None
14	Wetland	0	X	25	0	5	X	2*	X	X	None

NA= Not applicable

***Table 52.- BMP design technical constraints determined by the Ontario and Quebec stormwater management guides (* **(MDDEP and MAMROT, 2012); (TRC and CVC, 2010)).**

CRITERION VARIABLE	LIMITING VALUE (if)	UNSUITABLE BMPs
Water table depth FROM BMP BASE (m)	< 0.5	6
	< 1	4, 5, 8, 9, 10, 11
	< 1.2	7
Slope (%)	> 5	5, 6, 9, 10
	> 15	8, 11
	> 20	7
	> 25	12, 13, 14
	< 0.5	9, 10
	< 1	5, 6
Soil infiltration rate (mm/h)	< 15	4, 5, 8, 11
Drainage area (ha)	> 0.5	4
	> 2	6, 7, 8, 9, 10
	< 5	12, 13, 14
Pollution hot spots	No	5, 6, 7, 8, 9, 10, 11
Building foundations distance (m)	< 4	5, 7, 8, 9, 10, 11
Land use	Residential (houses)	1, 2
	Residential (blocks)	x
	Industrial	11
	Commercial	11
Required area for construction *(% of the drainage area) (% of the impermeable area)	<2	8
	<7	7
	<10	9,10
	<1*	12
	<2*	13,14

Table 53.- Unsuitable BMPs according BMP design technical constraints.

The program does not eliminate the BMPs that don't satisfy the technical constraints as these constraints are recommendations but not obligated characteristics to achieve. However, it outputs a vector that presents which BMPs don't satisfy the technical constraints as well as which technical constraints are they in order to let the user identify them and decide whether to eliminate them from the study or not.

A.2. ECONOMICAL PERFORMANCE INDICATOR

The economical performance is evaluated by the "net present value" (NPV) of each BMP. As for some BMPs this value was negative, the following indicator, still based on NPV, has been considered to assess the economical performance of an alternative *i*:

$$I_i = NPV_i + \max\left(\left|NPV_i\right|\right) \quad (44)$$

The NPV is calculated as follows:

$$NPV_i = \sum_{k=1}^{n} (B_k - C_k) \quad (45)$$

$$B_k = \frac{R_k}{(1+i)^k} \quad (46)$$

$$C_k = \frac{D_k + OM_k}{(1+i)^k} \quad (47)$$

where NPV_i ($) is the net present value for an interest rate *i (%)*, R_k ($) and B_k ($) are the benefice and the updated benefice at year *k*, D_k ($) and OM_k ($) are the construction and maintenance costs at year *k* and C_k ($) is the updated cost at year *k* and *n* (years) the BMP lifetime.

In this study, BMPs construction and maintenance costs have been taken from Coulais (2010) study as well as the BMP lifetimes. Table 54 presents all these values for each BMP.

BMP	CONSTRUCTION COST		MAINTENANCE COST		LIFETIME (years)
	North-America	Europe	North-America	Europe	
Extensive green roof	350 $/m^2	70 $/m^2	1 $/m^2/year	1 $/m^2/year	30
Intensive green roof	1500 $/m^2	250 $/m^2	20 $/m^2/year	20 $/m^2/year	30
Rainwater harvesting	2100 $/m^3	2000 $/m^3	1.26 $/m^3/year	1.26 $/m^3/year	15
Filter drain	320 $	1600 $	190 $/year	190 $/year	10
Permeable pavement	75 $/m^2	38 $/m^2	0.5 $/m^2/year	2.5 $/m^2/year	20
Filter strip	40 $/m^2	40 $/m^2	1 $/m^2/year	1 $/m^2/year	10
Bioretention system	110 $/m^2	110 $/m^2	1 $/m^2/year	1 $/m^2/year	10
Infiltration trench	340 $/m^3	250 $/m^3	35 $/m^3/year	0.9 $/m^3/year	10
Shallow swale	50 $/m^3	25 $/m^3	1.26 $/m^3/year	1.26 $/m^3/year	10
Deep swale	50 $/m^3	50 $/m^3	3.8 $/m^3/year	3.8 $/m^3/year	10
Perforated pipe	90 $/m	90 $/m	0.2 $/m/year	0.2 $/m/year	20
Detention basin	46 $/m^3	126 $/m^3	2.5 $/m^3/year	1.26 $/m^3/year	10
Retention pond	46 $/m^3	100 $/m^3	2.5 $/m^3/year	0.6 $/m^3/year	10
Wetland	46 $/m^3	90 $/m^3	2.5 $/m^3/year	0.6 $/m^3/year	10

Table 54.- Construction and maintenance costs and BMPs lifetime to calculate the economical indicator.

Some hypotheses have also been considered to simplify the calculations. Firstly, the investment refund has been established at 10 years. Interest rate has been established at 0.08625 and inflation rate at 0.0725 (Coulais, 2010). Moreover, according to Fuamba's et al. (2011) study, a fixed benefice of 12500 $/year has been considered.

As it was explained in section 4.4, expert users will be able to change or update these values by modifying the program code.

A.3. QUALITY PERFORMANCE INDICATOR

To evaluate the Quality Performance sub-criteria, two different types of indicators can be considered for each type of the three considered pollutant: total suspended sediments, total nitrogen and total phosphorus.

The first indicator, "total mass of removed pollutant", is calculated as follows:

$$TM = C \cdot V \cdot E \quad (48)$$

where *C* (Kg/m^3) is the pollutant concentration in the runoff water that is going to be treated by the BMPs, *E* is the average percentage of removed pollutant (%) of the treated water and *V* is the treated volume (m^3) calculated as explained in section A.1.

The average percentage of pollutant removal values have been estimated from several North-American stormwater management guides. If these values were available in Quebec stormwater management guide (MDDEP and MAMROT, 2012), these were the selected values. If not, Ontario stormwater management guide (TRC and CVC, 2010) values were taken and if this guide did not recommend them, then other guides where considered. Table 55 presents the final considered values and the guide from which they were estimated.

BMP	TSS	TP	TN
Extensive green roof	89[2]	0[1]	0
Intensive green roof	89	0	0
Rainwater harvesting	43[2]	43[2]	43[2]
Filter drain	80[3]	46[4]	65[6]
Permeable pavement	50[2]	65[5]	83[6]
Filter strip	50[2]	40[2]	40[2]
Bioretention system	60[1]	5[1]	28[1]
Infiltration trench	89[1]	65[1]	55[2]
Shallow swale	80	34	34
Deep swale	80[1]	34[1]	34[1]
Perforated pipe system	89[2]	87[2]	83[2]
Detention basin	60[1]	20[1]	30[1]
Retention pond	80[1]	52[1]	24[1]
Wetland	70[1]	45[1]	30[1]

Table 55.- Average percentage of removed pollutant for each BMP. Data come from the following stormwater management guides: 1.- Quebec **(MDDEP and MAMROT, 2012)*****; 2.- Ontario*** **(TRC and CVC, 2010)*****; 3.- Georgia*** **(ARC, 2001)*****; 4.- Minnesota*** **(MPCA, 2005)*****; 5.- New York*** **(NYSDEC, 2010)*****; 6.- Pennsylvania*** **(DEP, 2006)*****. Values without number mean that were not found in any of the consulted guides so were estimated from similar BMPs.***

As concentration values of the pollutants in the runoff waters are often difficult data to obtain for the urban drainage managers, if these values are unknown, the program considers a second Quality Performance indicator: the "average percentage of pollutant removal" presented in table 55. Some research groups or organisms (WWEGC, 2007) do not recommend utilizing this indicator but when concentration data are not available, it becomes an appropriate option. Thus, these values will be the default quality performance values utilized by the BMP ranking program. As it was indicated in section 4.4, expert users would be able to modify them.

A.4. SOCIO-ENVIRONMENTAL PERFORMANCE INDICATOR

The Socio-Environmental Performance sub-criteria are evaluated with a qualitative scale issue from the results of a survey made by some experts in sustainable urban drainage. An example of the survey questions is presented in table 58. Each question is related to the sub-criteria sense in order to assess it. It can be observed that the survey questions have 6 possible responses. These responses correspond to a numerical scale as it is presented in table 56. The final qualification for each sub-criterion corresponds to the weighted average of all the responses corresponding to this sub-criterion. It must be taken into account that questions 3.5, 3.9, 3.10, 4.2 and 4.3 have negative value as they are opposite to the sub-criterion sign. In fact, if their responses receive a high qualification, negative performance values for the related criteria may appear for some BMPs. Furthermore, it should be highlighted that sub-criterion "Health and Risks for Population" is the only criterion to minimize so the higher its value is, the worse is the socio-environmental performance of that BMP (more health and safety risks are expected). The rest sub-criteria are to be maximized.

REPONSE	NUMERICAL SCALE (WEIGHT)
Not at all	1
Rather not	3
More or less	5
Rather yes	7
Absolutely	9
Unknown	0

Table 56.- Numerical scale to evaluate questions of the survey for socio-environmental performance assessment.

The survey final results, i.e. the socio-environmental performance values, are presented in table 57. These values will be the default socio-environmental performance values utilized by the BMP ranking program. As it was indicated in section 4.4, expert users would be able to modify them.

	SOCIO-ENVIRONMENTAL SUB-CRITERIA			
BMP	**Acceptability**	**Life quality**	**Environment**	**Health&Safety risks**
1	4	4	3	0
2	3	4	3	0
3	4	2	2	0
4	6	2	2	2
5	5	2	2	-1
6	5	4	4	0
7	7	8	5	-2
8	3	2	3	2
9	6	4	4	0
10	6	4	3	0
11	2	1	2	0
12	5	4	4	0
13	7	8	4	1
14	7	9	5	2

Table 57.- Socio-environmental sub-criteria qualitative values issued from the survey results.

Questions about the sub-criterion 1: Residents acceptability of the BMP project

Do you think the local community …	RESPONSE					
	Not at all	Rather not	More or less	Rather yes	Absolutely	Unknown
1.1) … would be willing to contribute to the cost of BMPs?						
1.2) … prefers BMPs, which will treat water in their living spaces, the traditional approach to treatment of sewage?						
1.3) … show the will to participate in the development and proper implementation of BMPs in operation?						

Questions about the sub-criterion 2: Society life quality improvement

Do you think that BMPs contribute to…	RESPONSE					
	Not at all	Rather not	More or less	Rather yes	Absolutely	Unknown
2.1) … the improvement of the urban landscape?						
2.2) … the increment of the level of equipment and facilities available to citizens (fishing, navigation, recreation, ...)?						
2.3) … the increment of community participation in environmental activities (educational activities about nature, environmental organization, ...)?						
2.4) … the increment of number of visitors to the site?						
2.5) … improving the health of residents (decrease urban heat island effect, improved water quality, ...)?						

Questions about the sub-criterion 3: Environment protection and sustainable development contribution	RESPONSE					
Do you think that BMPs contribute to…	**Not at all**	**Rather not**	**More or less**	**Rather yes**	**Absolutely**	**Unknown**
3.1) … the reduction of down time water level of rainwater?						
3.2) … the reduction of erosion of river downstream from its location?						
3.3) … the increase in recharge of ground water?						
3.4) … the retention of stormwater pollution?						
3.5) … the degradation of groundwater quality?						
3.6) … the conservation status of species that were in place before being put into operation?						
3.7) … the regulations or principles of sustainable urban development?						
3.8) Are the materials used for construction, maintenance and management BMPs are reusable?						
3.9) Do you think that the BMPs are most significant spas in the treated water?						
3.10) Do you think that the BMPs introduce non-native species (plant or animal) in the area?						

Questions about the sub-criterion 4: Health and safety risks for the population	RESPONSE					
Do you think that BMPs…	**Not at all**	**Rather not**	**More or less**	**Rather yes**	**Absolutely**	**Unknown**
4.1) … contribute to reducing flood risk?						
4.2) … increase the danger for the community safety (grids as obstacles, falls in the works, drowning, ...)?						
4.3) … increase the danger for the community health (diseases due to mosquitoes in stagnant water, groundwater pollution, ...)?						

Table 58.- Survey questions for socio-environmental performance assessment.

ANNEX B: BMPs Stormwater Management Objectives

In this annex further details related to each BMP stormwater management objectives are presented. It is a complement of the general description given in Chapter 2.

B.1. GREEN ROOFS

Through a variety of physical, biological, and chemical treatment processes that filter pollutants and reduce the volume of runoff, vegetated roofs reduce the amount of pollution delivered to the local drainage system and, ultimately, to receiving waters. In addition, vegetated roofs have a longer life span than standard roofs because they protect the roof structure from ultraviolet radiation and the extreme fluctuations in temperature that cause roof membranes to deteriorate. Furthermore, the construction and maintenance of vegetated roofs provide business opportunities for nurseries, landscape contractors, irrigation specialists, and other green industry members while addressing the issues of environmental stewardship.

Volume

A major benefit of vegetated roofs is their ability to absorb stormwater and release it slowly over a period of several hours. Vegetated roof systems have been shown to retain 60-100% of the stormwater they receive. They can provide substantial stormwater retention in urban areas especially when the soil matrix has sufficient opportunity to dewater between discrete rain events. Generally, vegetated roofs treat only the rainfall that falls directly on that particular surface area.

Peak Discharge

Peak flow reductions of as much as 80% have been observed in the U.S. from extensively vegetated roofs. Water retention rates are known to be higher in the summer than in the winter due to higher evapotranspiration rates.

Water Quality

The selection of the soil material will impact the effluent quality. While materials such as compost will provide excellent volume reduction, the concentrations of nutrients in vegetated roof effluent may increase because of nutrients present in the soil. Typically, non-organic, high-mineral content substrates are recommended for the soil matrix. From a combined sewer overflow (CSO) perspective, however, green roofs will provide water quality improvements in receiving waters by reducing the volume and peak rate of stormwater entering the sewer system.

B.2. RAINFALL HARVESTING

Rain barrels are most often used for individual residences while cisterns have both residential and commercial applications. Both storage devices act to decrease the volume and flow rate of rooftop generated stormwater runoff. Rain barrels and cisterns can provide a source of chemically untreated 'soft water' for gardens and compost and other non-potable needs, free of most sediment and dissolved salts.

Volume

Rain barrels are most effective when collected rainwater is emptied from the barrel prior to the next storm event. Rain barrel water is most commonly used for residential landscaping purposes.

Peak Discharge

Peak discharge is minimally impacted by the use of rain barrels and cisterns. An initial runoff volume is retained by the storage devices, ranging from approximately 50 gallons to several thousand for each device, prior to the remaining runoff bypassing the systems. When used throughout a watershed or stormwater collection basin, rain barrels and cisterns will modestly impact the peak stormwater flow rate.

Water Quality

Modest water quality improvements will be gained by using rain barrels and cisterns to reduce the volume of stormwater available to convey pollutants.

B.3. DOWNSPOUT DISCONNECTION

Volume

Volume reductions occur through infiltration and evapotranspiration in the receiving area. The potential exists for disconnected roof runoff to be completely taken "out of the system" by spreading out and infiltrating over permeable surfaces and BMPs.

Stormwater that eventually flows onto an impermeable surface and then into the sewer will at least be initially detained by flowing over rough, permeable surfaces such as grass.

Peak Discharge

Downspout disconnection decreases the peak discharge by reducing the volume of roof runoff that enters the sewer and by increasing the discharge time over which it enters. Also, roofs are inherently distributed over a drainage area. Connected downspouts concentrate and centralize roof runoff, causing peak discharges from individual roofs to accumulate in a relatively small number of manmade conveyances. By contrast, downspout disconnection helps to keep separate the peak discharge from each individual roof.

Water Quality

Roof runoff contains deposited atmospheric pollutants, particles of roofing material, and nutrients and BOD loading from bird droppings. The concentrations of these pollutants will be reduced as the stormwater infiltrates and is taken up into plant roots. Also, receiving water quality will improve because CSOs will occur less frequently and with less magnitude as a result of the water quantity benefits of downspout disconnection.

B.4. INFILTRATION PRACTICES

Volume

Diverting runoff to the soil and encouraging infiltration has the ability to largely control volume from small storm events and reduce the overall volume of larger events. Infiltration retention volumes are typically equal to the first flush stormwater volume. The captured volume serves to recharge groundwater and help to maintain regional baseflows.

Peak Discharge

Infiltration practices have a small effect on peak discharge. Dependent upon the storage volume of the infiltration area and the permeability of surrounding soils, discharge stormwater flow rates will be modestly diminished with the use of infiltration techniques.

Water Quality

The filtering properties of the media and surrounding soils allow infiltration techniques to improve water quality. A wide suite of pollutants may be removed by various mechanisms: sorption, precipitation, filtering, and bacterial and chemical degradation. Pollutant removals can reach values of 60 % for nitrogen and phosphorus, 80 % for TSS, and 90 % for metals and pathogens.

B.5. PERMEABLE PAVEMENTS

Volume

Potentially 70-80 % of the annual rainfall can be returned to groundwater through the use of porous pavement if underlying soils have a permeability of between 0.5 and 3.0 inches per hour. In lined systems, stormwater will be detained in the sub-base and slowly pass through the underdrains into the sewer.

Peak Discharge

As a design rule, if the sub-base can provide a storage volume equal to the volume of increased runoff during a local two-year storm event (that is, the difference between the pre- and post-development runoff volumes), this will provide sufficient storage to mitigate the peak rate of runoff during larger storm events (25-year to 100-year). For small events, the peak discharge is attenuated by stormwater movement through the sub-base.

Water Quality

Porous pavements intercept TSS and larger sediment particles in the pavement structure and the sub-base; annual vacuuming is required to preserve permeability. Cooper, Zinc and motor oil concentrations can also be reduced to below detection limits.

In open systems, pollutants that are not easily trapped or adsorbed, such as nitrates and chlorides, may continue to move through the soil profile and into groundwater. Further scientific data is necessary before porous pavement is constructed near drinking water supplies. Porous pavements simultaneously serve as hardscape and as stormwater infrastructure, and are therefore especially practicable where space constraints preclude the use of other water quality BMPs. They are often used as parking in commercial areas.

B.6. FILTER STRIPS

Volume

Filter strips can significantly reduce the volume of runoff from small, frequently-occurring storms if:

- the soils are sufficiently permeable;
- sheet flow is maintained through the entire length and width of the strip; and
- contact time is long enough for infiltration to occur.

Infiltration and evapotranspiration are the means by which water is retained. Soil amendments can be used to enhance permeability if the existing soils are compacted.

Peak Discharge

Filter strips decrease the peak discharge by reducing the volume of runoff through ponding and infiltration and by reducing the velocity because of surface roughness.

Water Quality

As a general guideline, a filter strip can be expected to reduce TSS concentrations by 50 %, total Phosphorus by 20 %, total Nitrogen by 20 %, and heavy metals by 40 %. Essentially, filter strips are designed to fill with sediment. Filter strips achieve water quality improvements through infiltration and vegetative filtering and their effectiveness increases with runoff contact time and density of vegetation.

B.7. RAIN GARDENS

Volume

Rain gardens allow for high-rate infiltration of stormwater runoff and provide storage and exfiltration capacity to surrounding soils. These mechanisms result in substantial volume reduction of generated stormwater. Volume reductions are also realized through plant uptake and evapotranspiration facilitated by the rain gardens.

Peak Discharge

Rain gardens effectively both reduce stormwater volume and increase the duration of stormwater discharge. Controlling these two hydrologic functions serves to diminish the peak discharge of the storm event. Volume reduction decreases the total amount of stormwater discharged and duration extension decreases the energy of the discharge.

Water Quality

Rain gardens are among the best BMPs for stormwater quality control incorporating physical and microbiological remediation processes. Bioretention can effectively remove 90 % of bacteria, 90 % of organics, 90 % of total suspended solids, 70-80 % of Total Kjeldahl nitrogen, 93-98 % of metals, and 70-83 % of total phosphorus.

B.8. VEGETATED SWALES

Volume

Infiltration into the underlying and surrounding soils is the mechanism through which vegetated swales reduce stormwater volume. Evapotranspiration further reduces the stormwater volume. Reductions in discharge volume will be most apparent in moderate to small storms. Soils in vegetated swales can be amended to enhance permeability and increase volume reductions.

Peak Discharge

Peak discharge is decreased because of a decrease in volume and an increase in runoff duration. Dry swales should be sized to store and infiltrate the determined water quality volume of runoff within 24-48 hours.

Water Quality

Vegetated swales improve water quality through two main mechanisms. The vegetation in the channel removes large and course particulate matter from stormwater. Pollutant removal is also facilitated by the infiltration process encouraged through the use of swales. Estimated removal efficiencies are 80 % for TSS, 50 % for phosphorus and nitrogen, and 40 % for metals.

B.9. PERFORATED PIPE SYSTEMS

Volume

Infiltration into the underlying and surrounding soils is the mechanism through which vegetated swales reduce stormwater volume.

Peak Discharge

Peak discharge is decreased because of a decrease in volume and an increase in runoff duration.

Water Quality

Perforated pipes can successfully reduce sediment, nutrients, metals and organic substances loads.

B.10. DETENTION BASIN/DRY POND

Peak Discharge

Inflow and discharge hydrographs should be calculated and routed for each design storm.

Hydrographs should be based on a 24-hour rainfall event.

Water Quality

Water quality mitigation is partially achieved by retaining the runoff volume from the water quality design storm for a minimum prescribed period. Sediment forebays should be incorporated into the design to improve sediment removal. The storage volume of the forebay may be included in the calculated storage of the water quality design volume.

B.11. RETENTION PONDS/WETLANDS

Volume

Although not typically considered a volume-reducing BMP, Wet Ponds can achieve some volume reduction through infiltration and evapotranspiration, especially during small storms. According to the International Stormwater BMP Database, wet ponds have an average annual volume reduction of 7 %. Hydrologic calculations that should be performed to verify that the WP will have a viable amount of inflow can also predict the water surface elevation under varying conditions. The volume stored between the predicted water level and the lowest outlet elevation will be removed from the design storm.

Peak Discharge

Peak rate is primarily controlled in Wet Ponds through the transient storage above the normal water surface.

Water Quality

Wet Ponds improve runoff quality through settling, filtration, uptake, chemical and biological decomposition, volatilization, and adsorption. WPs are relatively effective at removing many common stormwater pollutants including suspended solids, heavy metals, total phosphorus, total nitrogen, and pathogens. The pollutant removal effectiveness varies by season and may be affected by the age of the WP. It has been suggested that this type of BMP does not provide significant nutrient removal in the long term unless vegetation is harvested because captured nutrients are released back into the water by decaying plant material. Even if this is true, nutrients are usually released gradually and during the non-growing season when downstream susceptibility is generally low.

ANNEX C: BMP Ranking Program Results

As results obtained in this study represent sometimes a huge number of information they have been presented in this annex. Thus, it contains:

1. Rankings of the sensitivity analysis of the ELECTRE III thresholds.
2. Rankings of the sensitivity analysis of the quality inputs.
3. Rankings of the sensitivity analysis of the socio-environmental inputs.
4. Rankings of the sensitivity analysis of the initial infiltration rate input.

C.1. SENSITIVITY ANALYSIS RANKINGS FOR THE ELECTRE III THRESHOLDS

Tables 59 and 60 present the rankings for the T=2 years rainfall. Table 59 presents the pre-rankings for descending distillation and table 60 for ascending distillation.

T=2 years RAINFALL									
	Original pre-ranking 1			+20% pre-ranking 1			-20% pre-ranking 1		
BMP	E	P	R	E	P	R	E	P	R
1	10	9	11	9	10	10	10	9	11
2	10	9	11	9	10	10	10	9	11
3	9	9	9	9	10	8	9	9	9
4	10	8	11	9	9	10	10	8	11
5	1	1	4	1	1	3	1	1	3
6	7	7	5	7	8	5	7	7	5
7	8	8	6	8	9	6	8	8	6
8	6	6	10	6	7	9	6	6	10
9	3	2	3	3	2	2	3	2	2
10	4	4	4	4	5	3	4	4	4
11	5	5	7	5	6	7	5	5	7
12	2	3	2	2	4	2	2	4	1
13	3	3	1	3	4	1	3	3	1
14	3	4	8	3	3	4	3	3	8

Table 59.- Rankings issued from the sensibility analysis of the ELECTRE III thresholds. Pre-rankings for descending distillation process and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

T=2 years RAINFALL									
	Original pre-ranking 2			+20% pre-ranking 2			-20% pre-ranking 2		
BMP	E	P	R	E	P	R	E	P	R
1	11	12	9	11	11	9	12	11	9
2	9	10	9	9	9	9	10	9	9
3	3	3	4	3	3	5	3	4	4
4	4	6	6	4	5	9	5	3	6
5	1	1	1	1	1	1	1	1	1
6	8	9	8	8	8	8	9	8	8
7	10	11	2	10	10	3	11	10	2
8	7	8	10	7	7	10	8	7	10
9	2	1	3	2	1	4	4	1	3
10	6	7	5	6	6	6	7	6	5
11	5	5	7	5	4	7	6	2	7
12	2	4	3	2	2	4	2	5	1
13	2	2	1	2	2	1	4	2	1
14	2	2	1	2	2	2	4	2	1

Table 60.- Rankings issued from the sensibility analysis of the ELECTRE III thresholds. Pre-rankings for ascending distillation process and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

Tables 61 and 62 present the rankings for the T=10 years rainfall. Table 61 presents the pre-rankings for descending distillation and table 62 for ascending distillation.

T=10 years RAINFALL									
	Original pre-ranking 1			+20% pre-ranking 1			-20% pre-ranking 1		
BMP	E	P	R	E	P	R	E	P	R
1	10	9	9	9	9	10	10	8	9
2	11	9	11	10	10	12	10	8	9
3	9	9	9	10	10	10	9	8	7
4	11	8	11	10	8	12	10	7	9
5	2	1	7	2	1	7	2	1	6
6	7	7	5	7	7	5	7	6	4
7	8	8	6	8	8	6	8	7	5
8	7	7	10	7	7	11	7	6	8
9	5	5	3	5	5	3	5	4	2
10	6	6	4	6	6	4	6	5	3
11	3	3	7	3	3	8	3	4	6
12	1	4	1	1	4	1	1	3	1
13	4	2	2	4	2	2	4	2	2
14	4	2	8	4	2	9	4	2	7

Table 61.- Rankings issued from the sensibility analysis of the ELECTRE III thresholds. Pre-rankings for descending distillation process and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

T=10 years RAINFALL									
	Original pre-ranking 2			+20% pre-ranking 2			-20% pre-ranking 2		
BMP	E	P	R	E	P	R	E	P	R
1	12	11	10	10	12	8	13	11	8
2	11	10	12	9	11	10	12	10	8
3	2	3	3	1	5	2	2	3	2
4	3	2	6	1	3	4	3	2	5
5	4	1	5	2	1	3	5	1	4
6	9	8	9	7	9	7	10	8	7
7	10	9	4	8	10	2	11	9	3
8	7	5	11	5	6	9	8	6	9
9	6	6	7	4	7	5	7	5	4
10	8	7	8	6	8	6	9	7	6
11	4	1	5	2	2	3	4	1	4
12	1	1	1	1	4	1	1	1	1
13	5	4	1	3	4	1	6	4	1
14	5	4	2	3	4	1	6	4	2

Table 62.- Rankings issued from the sensibility analysis of the ELECTRE III thresholds. Pre-rankings for ascending distillation process and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

Tables 63 and 64 present the rankings for the T=100 years rainfall. Table 63 presents the pre-rankings for descending distillation and table 64 for ascending distillation.

T=100 years RAINFALL									
	Original pre-ranking 1			+20% pre-ranking 1			-20% pre-ranking 1		
BMP	E	P	R	E	P	R	E	P	R
1	9	9	9	9	9	9	9	10	9
2	10	10	11	10	10	11	10	11	11
3	9	10	9	10	10	9	9	11	9
4	10	8	11	10	8	11	10	9	11
5	5	5	8	5	5	8	5	5	8
6	7	7	5	7	7	5	7	7	4
7	8	8	6	8	8	6	8	8	5
8	8	8	10	8	8	10	8	8	10
9	4	4	1	4	4	1	4	5	1
10	6	6	3	6	6	3	6	6	3
11	2	2	4	2	2	4	2	2	6
12	1	1	1	1	1	1	1	1	1
13	3	3	2	3	3	2	3	3	2
14	3	3	7	3	3	7	3	4	7

Table 63.- Rankings issued from the sensibility analysis of the ELECTRE III thresholds. Pre-rankings for descending distillation process and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.

T=100 years RAINFALL									
	Original pre-ranking 2			+20% pre-ranking 2			-20% pre-ranking 2		
BMP	E	P	R	E	P	R	E	P	R
1	12	10	8	10	10	7	12	10	7
2	11	9	9	9	9	8	11	9	8
3	2	3	3	1	4	2	2	3	2
4	4	2	4	1	2	3	4	2	4
5	7	5	6	5	5	5	7	5	5
6	9	7	7	7	7	6	9	7	6
7	10	8	2	8	8	2	10	8	3
8	8	6	8	6	6	7	8	6	7
9	6	4	1	4	3	1	6	4	1
10	7	6	5	5	6	4	7	6	5
11	1	1	1	1	1	1	1	1	1
12	3	1	1	2	1	1	3	1	1
13	5	4	1	3	3	1	5	2	2
14	5	4	1	3	3	1	5	4	2

Table 64.- Rankings issued from the sensibility analysis of the ELECTRE III thresholds. Pre-rankings for ascending distillation process and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.

C.2. SENSITIVITY ANALYSIS RANKINGS FOR THE QUALITY INPUTS.

Tables 65, 66 and 67 present the rankings for the T=2 years rainfall. Table 65 presents the AHP rankings, table 66 presents the ELECTRE III pre-rankings for descending distillation and table 67 the ones for ascending distillation.

T=2 years RAINFALL									
	Original AHP ranking			+ 50% AHP ranking			- 50% AHP ranking		
BMP	E	P	R	E	P	R	E	P	R
1	13	13	10	13	14	10	13	13	10
2	14	14	14	14	12	14	14	14	14
3	12	12	13	12	13	13	12	12	13
4	10	9	8	10	9	8	10	9	8
5	5	4	11	5	3	11	5	3	11
6	9	10	9	9	10	9	9	10	9
7	11	11	5	11	11	5	11	11	5
8	4	2	4	3	1	3	3	1	3
9	2	1	3	4	6	4	4	6	4
10	6	7	7	6	7	7	6	7	7
11	8	3	12	8	2	12	8	2	12
12	7	8	6	7	8	6	7	8	6
13	3	5	2	2	4	2	2	4	2
14	1	6	1	1	5	1	1	5	1

Table 65.- Rankings issued from the sensibility analysis of the quality inputs. Pre-rankings for AHP method and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

T=2 years RAINFALL									
	Original pre-ranking 1			+50% pre-ranking 1			-50% pre-ranking 1		
BMP	E	P	R	E	P	R	E	P	R
1	10	9	11	10	8	11	10	10	11
2	10	9	11	10	8	11	10	10	11
3	9	9	9	9	8	9	9	10	9
4	10	8	11	10	7	11	10	9	11
5	1	1	4	1	1	4	1	1	4
6	7	7	5	7	6	5	7	7	5
7	8	8	6	8	7	6	8	8	6
8	6	6	10	6	5	10	6	6	10
9	3	2	3	3	3	3	3	2	3
10	4	4	4	4	4	4	4	4	4
11	5	5	7	5	5	7	5	5	7
12	2	3	2	2	5	2	2	2	2
13	3	3	1	3	2	1	3	2	1
14	3	4	8	3	4	8	3	3	8

Table 66.- Rankings issued from the sensibility analysis of the quality inputs. ELECTRE III pre-rankings for descending distillation process and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

T=2 years RAINFALL									
	Original pre-ranking 2			+50% pre-ranking 2			-50% pre-ranking 2		
BMP	E	P	R	E	P	R	E	P	R
1	11	12	9	11	12	9	11	11	9
2	9	10	9	9	10	9	9	9	9
3	3	3	4	3	5	4	3	3	4
4	4	6	6	4	4	6	4	6	6
5	1	1	1	1	1	1	1	1	1
6	8	9	8	8	9	8	8	8	8
7	10	11	2	10	11	2	10	10	2
8	7	8	10	7	7	10	7	7	10
9	2	1	3	2	3	3	2	2	3
10	6	7	5	6	8	5	6	4	5
11	5	5	7	5	2	7	5	5	7
12	2	4	3	2	6	3	2	2	3
13	2	2	1	2	1	1	2	2	1
14	2	2	1	2	3	1	2	2	1

Table 67.- Rankings issued from the sensibility analysis of the quality inputs. ELECTRE III pre-rankings for ascending distillation process and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

Tables 68, 69 and 70 present the rankings for the T=10 years rainfall. Table 68 presents the AHP rankings, table 69 presents the ELECTRE III pre-rankings for descending distillation and table 70 the ones for ascending distillation.

T=10 years RAINFALL									
	Original AHP ranking			+ 50% AHP ranking			- 50% AHP ranking		
BMP	E	P	R	E	P	R	E	P	R
1	13	13	10	13	13	10	13	13	10
2	14	14	14	14	14	14	14	14	14
3	11	11	13	11	11	13	11	11	13
4	9	9	7	9	9	7	9	9	7
5	3	3	11	3	3	11	3	3	11
6	10	10	9	10	10	9	10	10	9
7	12	12	5	12	12	5	12	12	5
8	5	1	4	5	1	4	5	1	4
9	6	4	3	6	6	3	6	6	3
10	8	8	8	8	8	8	8	8	8
11	7	2	12	7	2	12	7	2	12
12	4	7	6	4	7	6	4	7	6
13	2	5	2	2	4	2	2	4	2
14	1	6	1	1	5	1	1	5	1

Table 68.- Rankings issued from the sensibility analysis of the quality inputs. Pre-rankings for AHP method and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

T=10 years RAINFALL									
	Original pre-ranking 1			+50% pre-ranking 1			-50% pre-ranking 1		
BMP	E	P	R	E	P	R	E	P	R
1	10	9	9	10	7	9	10	10	9
2	11	9	11	11	7	11	11	10	11
3	9	9	9	9	7	9	9	10	9
4	11	8	11	11	6	11	11	9	11
5	2	1	7	2	3	7	2	1	7
6	7	7	5	7	5	5	7	7	5
7	8	8	6	8	6	6	8	8	6
8	7	7	10	7	6	10	7	7	10
9	5	5	3	5	2	3	5	5	3
10	6	6	4	6	3	4	6	6	4
11	3	3	7	3	1	7	3	4	7
12	1	4	1	1	4	1	1	2	1
13	4	2	2	4	3	2	4	3	2
14	4	2	8	4	4	8	4	3	8

Table 69.- Rankings issued from the sensibility analysis of the quality inputs. ELECTRE III pre-rankings for descending distillation process and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

T=10 years RAINFALL									
	Original pre-ranking 2			+50% pre-ranking 2			-50% pre-ranking 2		
BMP	E	P	R	E	P	R	E	P	R
1	12	11	10	12	9	10	12	13	10
2	11	10	12	11	8	12	11	12	12
3	2	3	3	2	4	3	2	4	3
4	3	2	6	3	2	6	3	3	6
5	4	1	5	4	4	5	4	1	5
6	9	8	9	9	6	9	9	10	9
7	10	9	4	10	7	4	10	11	4
8	7	5	11	7	6	11	7	7	11
9	6	6	7	6	3	7	6	8	7
10	8	7	8	8	5	8	8	9	8
11	4	1	5	4	1	5	4	6	5
12	1	1	1	1	2	1	1	1	1
13	5	4	1	5	4	1	5	2	1
14	5	4	2	5	4	2	5	5	2

Table 70.- Rankings issued from the sensibility analysis of the quality inputs. ELECTRE III pre-rankings for ascending distillation process and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

Tables 71, 72 and 73 present the rankings for the T=100 years rainfall. Table 71 presents the AHP rankings, table 72 presents the ELECTRE III pre-rankings for descending distillation and table 73 the ones for ascending distillation.

T=100 years RAINFALL									
	Original AHP ranking			+ 50% AHP ranking			- 50% AHP ranking		
BMP	E	P	R	E	P	R	E	P	R
1	13	13	10	13	13	10	13	13	10
2	14	14	14	14	14	14	14	14	14
3	11	11	13	11	11	13	11	11	13
4	9	9	7	9	9	7	9	9	7
5	4	3	12	4	3	12	4	3	12
6	10	10	9	10	10	9	10	10	9
7	12	12	5	12	12	4	12	12	4
8	5	1	6	6	1	5	6	1	5
9	7	7	3	7	7	6	7	7	6
10	8	8	8	8	8	8	8	8	8
11	6	2	11	5	2	11	5	2	11
12	3	6	4	3	6	3	3	6	3
13	2	4	2	2	4	2	2	4	2
14	1	5	1	1	5	1	1	5	1

Table 71.- Rankings issued from the sensibility analysis of the quality inputs. Pre-rankings for AHP method and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.

T=100 years RAINFALL									
	Original pre-ranking 1			+50% pre-ranking 1			-50% pre-ranking 1		
BMP	E	P	R	E	P	R	E	P	R
1	9	9	9	9	8	9	9	10	9
2	10	10	11	10	9	11	10	11	11
3	9	10	9	9	9	9	9	11	9
4	10	8	11	10	7	11	10	9	11
5	5	5	8	5	4	8	5	5	8
6	7	7	5	7	6	5	7	7	5
7	8	8	6	8	7	6	8	8	6
8	8	8	10	8	7	10	8	8	10
9	4	4	1	4	4	1	4	4	1
10	6	6	3	6	5	3	6	6	3
11	2	2	4	2	2	4	2	2	4
12	1	1	1	1	1	1	1	1	1
13	3	3	2	3	3	2	3	3	2
14	3	3	7	3	5	7	3	3	7

Table 72.- Rankings issued from the sensibility analysis of the quality inputs. ELECTRE III pre-rankings for descending distillation process and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.

T=100 years RAINFALL									
	Original pre-ranking 2			+50% pre-ranking 2			-50% pre-ranking 2		
BMP	E	P	R	E	P	R	E	P	R
1	12	10	8	12	11	8	12	11	8
2	11	9	9	11	10	9	11	10	9
3	2	3	3	2	3	3	2	3	3
4	4	2	4	4	2	4	4	2	4
5	7	5	6	7	5	6	7	6	6
6	9	7	7	9	8	7	9	8	7
7	10	8	2	10	9	2	10	9	2
8	8	6	8	8	6	8	8	7	8
9	6	4	1	6	6	1	6	5	1
10	7	6	5	7	7	5	7	6	5
11	1	1	1	1	1	1	1	1	1
12	3	1	1	3	1	1	3	1	1
13	5	4	1	5	2	1	5	4	1
14	5	4	1	5	4	1	5	4	1

*Table 73.- Rankings issued from the sensibility analysis of the quality inputs. ELECTRE III pre-rankings for ascending distillation process and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.*C.3. SENSITIVITY ANALYSIS RANKINGS FOR THE SOCIO-ENVIRONMENTAL INPUTS.

C.3. SENSITIVITY ANALYSIS RANKINGS FOR THE SOCIO-ENVIRONMENTAL INPUTS.

Tables 74, 75 and 76 present the rankings for the T=2 years rainfall. Table 74 presents the AHP rankings, table 75 presents the ELECTRE III pre-rankings for descending distillation and table 76 the ones for ascending distillation.

T=2 years RAINFALL									
	Original AHP ranking			+ 50% AHP ranking			- 50% AHP ranking		
BMP	E	P	R	E	P	R	E	P	R
1	13	13	10	13	13	10	13	13	10
2	14	14	14	14	14	14	14	14	14
3	12	12	13	12	12	13	12	12	13
4	10	9	8	10	9	8	10	9	8
5	5	4	11	5	4	11	5	4	11
6	9	10	9	9	10	9	9	10	9
7	11	11	5	11	11	5	11	11	5
8	4	2	4	4	2	4	4	2	4
9	2	1	3	2	1	3	2	1	3
10	6	7	7	6	7	7	6	7	7
11	8	3	12	8	3	12	8	3	12
12	7	8	6	7	8	6	7	8	6
13	3	5	2	3	5	2	3	5	2
14	1	6	1	1	6	1	1	6	1

Table 74.- Rankings issued from the sensibility analysis of the socio-environmental inputs. Pre-rankings for AHP method and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

T=2 years RAINFALL									
	Original pre-ranking 1			+50% pre-ranking 1			-50% pre-ranking 1		
BMP	E	P	R	E	P	R	E	P	R
1	10	9	11	10	9	11	10	9	12
2	10	9	11	10	9	11	10	9	12
3	9	9	9	9	9	9	9	9	11
4	10	8	11	10	8	11	10	8	12
5	1	1	4	1	1	4	1	1	1
6	7	7	5	7	7	5	7	7	9
7	8	8	6	8	8	6	8	8	10
8	6	6	10	6	6	10	6	6	8
9	3	2	3	3	2	2	3	2	5
10	4	4	4	4	4	4	4	4	6
11	5	5	7	5	5	8	5	5	7
12	2	3	2	2	3	1	2	3	4
13	3	3	1	3	3	3	3	3	2
14	3	4	8	3	3	7	3	3	3

Table 75.- Rankings issued from the sensibility analysis of the socio-environmental inputs. ELECTRE III pre-rankings for descending distillation process and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

T=2 years RAINFALL									
	Original pre-ranking 2			+50% pre-ranking 2			-50% pre-ranking 2		
BMP	E	P	R	E	P	R	E	P	R
1	11	12	9	11	12	7	11	12	8
2	9	10	9	9	10	7	9	10	8
3	3	3	4	3	3	3	3	3	2
4	4	6	6	4	6	5	4	6	4
5	1	1	1	1	1	1	1	1	1
6	8	9	8	8	9	6	8	9	7
7	10	11	2	10	11	2	10	11	2
8	7	8	10	7	8	7	7	8	6
9	2	1	3	2	1	1	2	1	3
10	6	7	5	6	7	4	6	7	5
11	5	5	7	5	5	4	5	5	5
12	2	4	3	2	4	1	2	4	3
13	2	2	1	2	2	1	2	2	1
14	2	2	1	2	2	1	2	2	1

Table 76.- Rankings issued from the sensibility analysis of the socio-environmental inputs. ELECTRE III pre-rankings for ascending distillation process and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

Tables 77, 78 and 79 present the rankings for the T=10 years rainfall. Table 77 presents the AHP rankings, table 78 presents the ELECTRE III pre-rankings for descending distillation and table 79 the ones for ascending distillation.

T=10 years RAINFALL									
	Original AHP ranking			+ 50% AHP ranking			- 50% AHP ranking		
BMP	E	P	R	E	P	R	E	P	R
1	13	13	10	13	13	10	13	13	10
2	14	14	14	14	14	14	14	14	14
3	11	11	13	11	11	13	11	11	13
4	9	9	7	9	9	7	9	9	7
5	3	3	11	3	3	11	3	3	11
6	10	10	9	10	10	9	10	10	9
7	12	12	5	12	12	5	12	12	5
8	5	1	4	5	1	4	5	1	4
9	6	4	3	6	4	3	6	4	3
10	8	8	8	8	8	8	8	8	8
11	7	2	12	7	2	12	7	2	12
12	4	7	6	4	7	6	4	7	6
13	2	5	2	2	5	2	2	5	2
14	1	6	1	1	6	1	1	6	1

Table 77.- Rankings issued from the sensibility analysis of the socio-environmental inputs. Pre-rankings for AHP method and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

T=10 years RAINFALL									
	Original pre-ranking 1			+50% pre-ranking 1			-50% pre-ranking 1		
BMP	**E**	**P**	**R**	**E**	**P**	**R**	**E**	**P**	**R**
1	10	9	9	7	9	8	10	9	8
2	11	9	11	8	9	11	11	9	9
3	9	9	9	6	9	8	9	9	8
4	11	8	11	8	8	11	11	8	9
5	2	1	7	3	1	6	2	1	2
6	7	7	5	4	7	4	7	7	6
7	8	8	6	5	8	5	8	8	7
8	7	7	10	5	7	10	7	7	7
9	5	5	3	2	5	2	5	5	3
10	6	6	4	3	6	3	6	6	4
11	3	3	7	1	3	9	3	3	5
12	1	4	1	3	4	1	1	4	1
13	4	2	2	3	2	2	4	2	1
14	4	2	8	3	2	7	4	2	2

Table 78.- Rankings issued from the sensibility analysis of the socio-environmental inputs. ELECTRE III pre-rankings for descending distillation process and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

T=10 years RAINFALL									
	Original pre-ranking 2			+50% pre-ranking 2			-50% pre-ranking 2		
BMP	**E**	**P**	**R**	**E**	**P**	**R**	**E**	**P**	**R**
1	12	11	10	10	11	10	12	11	8
2	11	10	12	9	10	11	11	10	9
3	2	3	3	2	3	3	2	3	2
4	3	2	6	3	2	6	3	2	3
5	4	1	5	4	1	5	4	1	1
6	9	8	9	6	8	8	9	8	6
7	10	9	4	8	9	4	10	9	3
8	7	5	11	7	5	9	7	5	7
9	6	6	7	4	6	5	6	6	4
10	8	7	8	5	7	7	8	7	5
11	4	1	5	1	1	5	4	1	3
12	1	1	1	4	4	1	1	4	1
13	5	4	1	4	4	1	5	4	1
14	5	4	2	4	4	2	5	4	1

Table 79.- Rankings issued from the sensibility analysis of the socio-environmental inputs. ELECTRE III pre-rankings for ascending distillation process and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

Tables 80, 81 and 82 present the rankings for the T=100 years rainfall. Table 80 presents the AHP rankings, table 81 presents the ELECTRE III pre-rankings for descending distillation and table 82 the ones for ascending distillation.

T=100 years RAINFALL									
	Original AHP ranking			+ 50% AHP ranking			- 50% AHP ranking		
BMP	E	P	R	E	P	R	E	P	R
1	13	13	10	13	13	10	13	13	10
2	14	14	14	14	14	14	14	14	14
3	11	11	13	11	11	13	11	11	13
4	9	9	7	9	9	7	9	9	7
5	4	3	12	4	3	12	4	3	12
6	10	10	9	10	10	9	10	10	9
7	12	12	5	12	12	5	12	12	5
8	5	1	6	5	1	6	5	1	6
9	7	7	3	7	7	3	7	7	3
10	8	8	8	8	8	8	8	8	8
11	6	2	11	6	2	11	6	2	11
12	3	6	4	3	6	4	3	6	4
13	2	4	2	2	4	2	2	4	2
14	1	5	1	1	5	1	1	5	1

Table 80.- Rankings issued from the sensibility analysis of the socio-environmental inputs. Pre-rankings for AHP method and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.

T=100 years RAINFALL									
	Original pre-ranking 1			+50% pre-ranking 1			-50% pre-ranking 1		
BMP	E	P	R	E	P	R	E	P	R
1	9	9	9	9	9	8	9	10	8
2	10	10	11	10	10	11	10	11	9
3	9	10	9	9	10	8	9	11	8
4	10	8	11	10	8	11	10	9	9
5	5	5	8	5	5	7	5	5	4
6	7	7	5	7	7	4	7	7	6
7	8	8	6	8	8	5	8	8	7
8	8	8	10	8	8	10	8	8	8
9	4	4	1	4	4	1	4	4	1
10	6	6	3	6	6	3	6	6	5
11	2	2	4	2	2	9	2	2	3
12	1	1	1	1	1	1	1	1	1
13	3	3	2	3	3	2	3	3	1
14	3	3	7	3	3	6	3	3	2

Table 81.- Rankings issued from the sensibility analysis of the socio-environmental inputs. ELECTRE III pre-rankings for descending distillation process and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.

T=100 years RAINFALL									
	Original pre-ranking 2			+50% pre-ranking 2			-50% pre-ranking 2		
BMP	E	P	R	E	P	R	E	P	R
1	12	10	8	12	10	10	12	10	8
2	11	9	9	11	9	11	11	9	9
3	2	3	3	2	3	3	2	3	3
4	4	2	4	4	2	5	4	2	4
5	7	5	6	7	5	6	7	5	6
6	9	7	7	9	7	8	9	7	7
7	10	8	2	10	8	4	10	8	4
8	8	6	8	8	6	9	8	6	7
9	6	4	1	6	4	1	6	4	1
10	7	6	5	7	6	7	7	6	5
11	1	1	1	1	1	1	1	1	1
12	3	1	1	3	1	1	3	1	1
13	5	4	1	5	4	3	5	4	2
14	5	4	1	5	4	2	5	4	2

Table 82.- Rankings issued from the sensibility analysis of the socio-environmental inputs. ELECTRE III pre-rankings for ascending distillation process and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.

C.4. SENSITIVITY ANALYSIS RANKINGS FOR THE INITIAL INFILTRATION RATE INPUT.

Tables 83, 84 and 85 present the rankings for the T=2 years rainfall. Table 83 presents the AHP rankings, table 84 presents the ELECTRE III pre-rankings for descending distillation and table 85 the ones for ascending distillation.

T=2 years RAINFALL									
	Original AHP ranking			+ 20% AHP ranking			- 20% AHP ranking		
BMP	E	P	R	E	P	R	E	P	R
1	13	13	10	13	13	10	13	13	10
2	14	14	14	14	14	14	14	14	14
3	12	12	13	12	12	13	11	12	13
4	10	9	8	10	9	8	9	9	8
5	5	4	11	5	3	11	5	3	11
6	9	10	9	9	10	9	10	10	9
7	11	11	5	11	11	5	12	11	5
8	4	2	4	3	1	3	3	1	3
9	2	1	3	4	6	4	4	6	4
10	6	7	7	6	7	7	6	7	7
11	8	3	12	8	2	12	8	2	12
12	7	8	6	7	8	6	7	8	6
13	3	5	2	2	4	2	2	4	2
14	1	6	1	1	5	1	1	5	1

Table 83.- Rankings issued from the sensibility analysis of the initial infiltration rate input. Pre-rankings for AHP method and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

T=2 years RAINFALL									
	Original pre-ranking 1			+20% pre-ranking 1			-20% pre-ranking 1		
BMP	E	P	R	E	P	R	E	P	R
1	10	9	11	10	9	11	10	8	11
2	10	9	11	10	9	11	10	8	11
3	9	9	9	9	9	9	9	8	9
4	10	8	11	10	8	11	10	7	11
5	1	1	4	1	1	4	1	1	4
6	7	7	5	7	6	5	7	6	5
7	8	8	6	8	7	6	8	7	6
8	6	6	10	6	5	10	6	5	10
9	3	2	3	3	2	3	3	2	3
10	4	4	4	4	3	4	4	3	4
11	5	5	7	5	4	7	5	4	7
12	2	3	2	2	2	2	2	2	2
13	3	3	1	3	2	1	3	2	1
14	3	4	8	3	3	8	3	3	8

Table 84.- Rankings issued from the sensibility analysis of the initial infiltration rate input. ELECTRE III pre-rankings for descending distillation process and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

T=2 years RAINFALL									
	Original pre-ranking 2			+20% pre-ranking 2			-20% pre-ranking 2		
BMP	E	P	R	E	P	R	E	P	R
1	11	12	9	10	11	9	11	11	9
2	9	10	9	10	9	9	9	9	9
3	3	3	4	3	4	4	3	4	4
4	4	6	6	4	5	6	4	5	6
5	1	1	1	1	1	1	1	1	1
6	8	9	8	8	8	8	8	8	8
7	10	11	2	9	10	2	10	10	2
8	7	8	10	7	7	10	7	7	10
9	2	1	3	2	2	3	2	2	3
10	6	7	5	6	6	5	6	6	5
11	5	5	7	5	3	7	5	3	7
12	2	4	3	2	2	3	2	2	3
13	2	2	1	2	2	1	2	2	1
14	2	2	1	2	2	1	2	2	1

Table 85.- Rankings issued from the sensibility analysis of the initial infiltration rate input. ELECTRE III pre-rankings for ascending distillation process and T=2 years rainfall. E.- engineer, P.- politician and R.- resident.

Tables 86, 87 and 88 present the rankings for the T=10 years rainfall. Table 86 presents the AHP rankings, table 87 presents the ELECTRE III pre-rankings for descending distillation and table 88 the ones for ascending distillation.

T=10 years RAINFALL									
	Original AHP ranking			+ 20% AHP ranking			- 20% AHP ranking		
BMP	E	P	R	E	P	R	E	P	R
1	13	13	10	13	13	10	13	13	10
2	14	14	14	14	14	14	14	14	14
3	11	11	13	11	11	13	11	11	13
4	9	9	7	9	9	7	9	9	7
5	3	3	11	3	3	11	3	3	11
6	10	10	9	10	10	9	10	10	9
7	12	12	5	12	12	5	12	12	6
8	5	1	4	5	1	4	5	1	4
9	6	4	3	6	6	3	6	6	3
10	8	8	8	8	8	8	8	8	8
11	7	2	12	7	2	12	7	2	12
12	4	7	6	4	7	6	4	7	5
13	2	5	2	2	4	2	2	4	2
14	1	6	1	1	5	1	1	5	1

Table 86.- Rankings issued from the sensibility analysis of the initial infiltration rate input. Pre-rankings for AHP method and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

T=10 years RAINFALL									
	Original pre-ranking 1			+20% pre-ranking 1			-20% pre-ranking 1		
BMP	E	P	R	E	P	R	E	P	R
1	10	9	9	10	9	9	10	8	9
2	11	9	11	11	9	11	11	8	11
3	9	9	9	9	9	9	9	8	9
4	11	8	11	11	8	11	11	7	11
5	2	1	7	2	1	7	2	1	7
6	7	7	5	7	6	5	7	6	5
7	8	8	6	8	7	6	8	7	6
8	7	7	10	8	6	10	7	6	10
9	5	5	3	5	4	3	5	4	3
10	6	6	4	6	5	4	6	5	4
11	3	3	7	3	3	7	3	3	7
12	1	4	1	1	3	1	1	3	1
13	4	2	2	4	2	2	4	2	2
14	4	2	8	4	2	8	4	2	8

Table 87.- Rankings issued from the sensibility analysis of the initial infiltration rate input. ELECTRE III pre-rankings for descending distillation process and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

T=10 years RAINFALL									
	Original pre-ranking 2			+20% pre-ranking 2			-20% pre-ranking 2		
BMP	**E**	**P**	**R**	**E**	**P**	**R**	**E**	**P**	**R**
1	12	11	10	11	11	9	12	11	10
2	11	10	12	12	10	11	11	10	12
3	2	3	3	2	3	3	2	3	3
4	3	2	6	3	2	5	3	2	6
5	4	1	5	4	1	4	4	1	5
6	9	8	9	9	8	8	9	8	9
7	10	9	4	10	9	3	10	9	4
8	7	5	11	7	5	10	7	5	11
9	6	6	7	6	6	6	6	6	7
10	8	7	8	8	7	7	8	7	8
11	4	1	5	4	1	4	4	1	5
12	1	1	1	1	1	1	1	1	1
13	5	4	1	5	4	1	5	4	1
14	5	4	2	5	4	2	5	4	2

Table 88.- Rankings issued from the sensibility analysis of the initial infiltration rate input. ELECTRE III pre-rankings for ascending distillation process and T=10 years rainfall. E.- engineer, P.- politician and R.- resident.

Tables 89, 90 and 91 present the rankings for the T=100 years rainfall. Table 89 presents the AHP rankings, table 90 presents the ELECTRE III pre-rankings for descending distillation and table 91 the ones for ascending distillation.

T=100 years RAINFALL									
	Original AHP ranking			+ 20% AHP ranking			- 20% AHP ranking		
BMP	**E**	**P**	**R**	**E**	**P**	**R**	**E**	**P**	**R**
1	13	13	10	13	13	10	13	12	10
2	14	14	14	14	14	14	14	14	14
3	11	11	13	11	11	13	11	11	13
4	9	9	7	9	9	7	9	9	7
5	4	3	12	4	3	12	4	3	12
6	10	10	9	10	10	9	10	10	9
7	12	12	5	12	12	4	12	13	4
8	5	1	6	6	1	5	5	1	5
9	7	7	3	7	7	6	7	7	6
10	8	8	8	8	8	8	8	8	8
11	6	2	11	5	2	11	6	2	11
12	3	6	4	3	6	3	3	6	3
13	2	4	2	2	4	2	2	4	2
14	1	5	1	1	5	1	1	5	1

Table 89.- Rankings issued from the sensibility analysis of the initial infiltration rate input. Pre-rankings for AHP method and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.

T=100 years RAINFALL									
	Original pre-ranking 1			+20% pre-ranking 1			-20% pre-ranking 1		
BMP	**E**	**P**	**R**	**E**	**P**	**R**	**E**	**P**	**R**
1	9	9	9	10	8	9	9	8	9
2	10	10	11	11	9	11	10	9	11
3	9	10	9	10	9	9	9	9	9
4	10	8	11	11	7	11	10	7	11
5	5	5	8	5	4	8	5	4	8
6	7	7	5	7	6	5	7	6	5
7	8	8	6	8	7	6	8	7	6
8	8	8	10	9	7	10	8	7	10
9	4	4	1	4	4	1	4	4	1
10	6	6	3	6	5	3	6	5	3
11	2	2	4	2	2	4	2	2	4
12	1	1	1	1	1	1	1	1	1
13	3	3	2	3	3	2	3	3	2
14	3	3	7	3	3	7	3	3	7

Table 90.- Rankings issued from the sensibility analysis of the initial infiltration rate input. ELECTRE III pre-rankings for descending distillation process and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.

T=100 years RAINFALL									
	Original pre-ranking 2			+20% pre-ranking 2			-20% pre-ranking 2		
BMP	**E**	**P**	**R**	**E**	**P**	**R**	**E**	**P**	**R**
1	12	10	8	11	10	8	12	10	8
2	11	9	9	12	9	9	11	9	9
3	2	3	3	2	3	3	2	3	3
4	4	2	4	4	2	4	4	2	4
5	7	5	6	7	5	6	7	5	6
6	9	7	7	9	7	7	9	7	7
7	10	8	2	10	8	2	10	8	2
8	8	6	8	8	6	8	8	6	8
9	6	4	1	6	5	1	6	5	1
10	7	6	5	7	6	5	7	6	5
11	1	1	1	1	1	1	1	1	1
12	3	1	1	3	1	1	3	1	1
13	5	4	1	5	4	1	5	4	1
14	5	4	1	5	4	1	5	4	1

Table 91.- Rankings issued from the sensibility analysis of the initial infiltration rate input. ELECTRE III pre-rankings for ascending distillation process and T=100 years rainfall. E.- engineer, P.- politician and R.- resident.

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