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Methodology for Selecting Best Management Practices Integrating Multiple Stakeholders and Criteria. Part 1: Methodology

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Academic Editor: Kelly Morgan

Received: 16 December 2015; Accepted: 28 January 2016; Published: 6 February 2016

Abstract: The implementation of stormwater Best Management Practices (BMPs) could help re-establish the natural hydrological cycle of watersheds after urbanization, with each BMP presenting a different performance across a range of criteria (flood prevention, pollutant removal, *etc.*). Additionally, conflicting views from the relevant stakeholders may arise, resulting in a complex selection process. This paper proposes a methodology for BMP selection based on the application of multi-criteria decision aid (MCDA) methods, integrating multiple stakeholder priorities and BMP combinations. First, in the problem definition, the MCDA methods, relevant criteria and design guidelines are selected. Next, information from the preliminary analysis of the watershed is used to obtain a list of relevant BMPs. The third step comprises the watershed modeling and analysis of the BMP alternatives to obtain performance values across purely objective criteria. Afterwards, a stakeholder analysis based on survey applications is carried out to obtain social performance values and criteria priorities. Then, the MCDA methods are applied to obtain the final BMP rankings. The last step considers the sensitivity analysis and rank comparisons in order to draw the final conclusions and recommendations. Future improvements to the methodology could explore inclusion of multiple objective analysis, and alternative means for obtaining social performance values.

Keywords: BMPs; drainage network; SWMM; multi-criteria decision analysis; Analytical Hierarchy Process; Elimination et Choix Traduisant la Réalité; Preference Ranking Organization Method for Enrichment of Evaluation; Modified Technique for Order Preference by Similarity to Ideal Solutions

1. Introduction

The disturbance of natural landscapes, as a result of urbanization, has direct impacts on the hydrological cycle and water quality, disrupting processes like infiltration, interception, among others. The traditional stormwater management approach based on peak runoff discharge further deteriorates the cycle and the receiving water bodies [1]. The implementation of Best Management Practices (BMPs), like rain gardens, detention ponds and green roofs, aims to mitigate these negative effects, trying to mimic as much as possible the natural hydrology of the watershed, while also treating a wide range of pollutants through physical, chemical and biological processes [2].

However, BMPs vary significantly in performance across different criteria, including the level of water quantity and quality control provided, their physical constraints, the economic costs, and even social perception. As such, their selection process in a given watershed becomes a fairly complicated process. Additionally, the stakeholders involved in land-development projects could present different views and priorities, adding to the complexity of the situation.

These kinds of problems are not new in civil and environmental engineering, and the use of Multi-Criteria Decision Aid (MCDA) methods has been the subject of different studies. These methods are characterized by aiming to evaluate complex systems while recognizing that different criteria are at work (often at odds with each other) and that the decision ultimately leads to compromise or arbitrary choices [3,4].

As each MCDA method could present a different approach to the problem, final results may vary, with none giving a single undisputed answer. As such, decision makers are also faced with choosing which method(s) to apply and retain. Complete aggregation methods, like the Analytical Hierarchy Process (AHP), seek to loosen incomparability between alternatives, adding up performances to obtain a single global score. This could result in easier analysis and interpretation, but may not faithfully represent all aspects of the decision making process, especially if there are criteria completely at odds with each other. On the other hand, partial aggregation methods, like Élection et Choix Traduisant la Réalité (ELECTRE), can take better account of this, but conclusions and recommendations are harder to make, as incomparability between alternatives is possible [4].

Nevertheless, direct application of MCDA for selecting BMPs has been relatively rare, with most of the research being done on optimization through multiple objective constraints, as done by Chen *et al.* [5], Zou *et al.* [6] or Efta and Chung [7]. Concerning the selection of BMPs through MCDA methods, Fuamba *et al.* [8], and Young *et al.* [9] presented an application of AHP to rank the performance of a variety of different BMPs, though the criteria analyzed were different in both works. The first work included social acceptability issues, while the latter included more specific pollutants. Expert consultation was required to establish performance indicators for the BMPs, which were difficult to quantify for some criteria (*i.e.*, aesthetic benefits). Jia *et al.* [10] developed a new set of normalized two-level indexes for ranking the performance of BMPs by calculating an aggregate score. However, the weighting of the criteria remained an obstacle and was done in a relatively subjective manner. This situation was addressed in part by Martin *et al.* [11], who applied the ELECTRE III method to select BMPs and compared different scenarios considering varying interests of stakeholders. However, the weighting itself remained relatively simple, as all criteria within the same "area of interest" of the stakeholders were granted the same weight, while all other areas of interest were given a minimum weight. Most recently, Chitsaz and Banihabib [12], in a different branch of water management, performed an extensive comparison of the results obtained from 8 different MCDA methods, including AHP and ELECTRE III, to select flood mitigation techniques.

Additionally, in the work previously mentioned, the methods tended to be applied to evaluate each technique or practice individually. Due to the differences in BMP characteristics and performances, it could be inferred that it is highly unlikely that a single one will lead to the best solution, but rather a combination of practices complementing each other's strengths and weaknesses. Therefore, including BMP combinations in the analysis would be highly relevant.

The present work seeks to continue with the research established by Fuamba *et al.* [8], aiming to present a methodology for selecting BMPs for urban watersheds by comparing the result of different MCDA methods under different stakeholder scenarios, and also considering possible combinations of BMPs.

2. Methodology

The proposed methodology comprises a step of problem definition, plus 5 main steps, consisting of the preliminary site analysis, analysis of alternatives, stakeholder analysis, application of the MCDA methods, and the final analysis and recommendations. The following sections discuss in further detail the suggested approach and the main points that should be kept in mind when applying the methodology.

2.1. Problem Definition

In the problem definition step, the site, MCDA methods, criteria and technical guidelines are selected. The amount of available information should dictate most of the choices in this step. For instance, the various MCDA methods may call for different input parameters, including various thresholds (in some cases), or information on how to treat and consider the criteria analyzed. For example, multi-attribute utility theory requires the estimation of the "utility" derived from each performance value of the criteria analyzed [13]; if such determination is not possible with the available resources and information, there is no point in choosing it as one of the MCDA methods. Each method may present different axiomatic bases, leading it to treat the input data differently, or requiring additional information. Considering these differences, MCDA methods could be classified into the groups summarized in Table 1.

Table 1. Multi-criteria decision aid (MCDA) method classification [4].

Classification	Description	Examples
Complete or total aggregation (American school of thought)	Seeking to loosen all incomparability, a single, comprehensive and definitive answer is obtained when adding the performances of the alternatives.	• Weighted Averages • Multi-attribute Utility Theory • Additive Utility Function • AHP
Partial aggregation (French-speaking school of thought)	Accepting situations that are incomparable, it is based on "outranking relationships" between alternatives when adding the performances of the alternatives	• ELECTRE • QUALIFLEX • ORESTE • PROMETHEE • REGIME
Local or iterative aggregation	The situation is translated into local judgments, with a small number of analyzed alternatives and without an explicit rule for an answer.	• STEM • PREFCALC

Some of the most commonly used MCDA methods in water management and environmental engineering are briefly explored in this section (though the selected method(s) could vary with applications of the methodology). AHP could be an interesting choice, as it could be useful to obtain criteria weights from other methods. ELECTRE III is of the most popular partial aggregation methods, having numerous applications in environmental management [14]. There is also the Preference Ranking Organization Method for Enrichment of Evaluation (PROMETHEE) II, which is often considered a simpler alternative to ELECTRE [15]. On the other hand, the Modified Technique for Order Preference by Similarity to Ideal Solutions (MTOPSIS) could be included for its simple yet different approach to AHP, analyzing for each criterion how each alternative compares to the best ideal solution and the worst one and then adding up a total score [16].

2.1.1. AHP

The Analytic Hierarchy Process developed by Saaty was first introduced in 1980. The method is based on breaking down the problem of decision-making into different hierarchical levels. The different steps in the method are presented below as shown by Saaty and Vargas [17]. The AHP method uses pairwise comparisons for all alternatives to establish both the priorities (or weights) of all criteria, sub-criteria, and of the performance of each alternative.

The problem is first broken down into hierarchical levels. For example, if a problem consists of 4 main criteria where 5 alternatives are being compared, the bottom hierarchical level would compare each alternative within the individual criteria. The next level would compare the criteria priorities in relation to the overall problem. More levels could be introduced if sub-criteria were included. The binary comparisons of all elements in a given hierarchical level are expressed using a fundamental scale ranging from 1 to 9 (and their reciprocals), where a value of 1 indicates equal contribution of both elements being compared, and 9 establishes total dominance of one element over the other. The weight, or priority vector w for the n elements in the kth hierarchy level is calculated as shown in Equation (1).

$$Aw = \lambda w \tag{1}$$

In Equation (1), A is the square matrix of binary comparisons of n dimensions, and λ is the maximum eigenvalue. Different simplified methods for estimating vector w and λ include the "mean normalized values" and the "geometric mean" methods. Once all priority vectors have been calculated, the next part of the AHP process is the synthesis of priorities from all levels, starting at the bottom, until all hierarchic levels have been covered. To do so, the matrix M_k is constructed by grouping the different w vectors for the kth level of hierarchy.

$$M_k = \begin{pmatrix} w_1 \; w_2 \; \cdots w_p \end{pmatrix} \tag{2}$$

In Equation (2), p is the number of elements inside the kth hierarchy level being analyzed. In the example previously mentioned, M_k would then contain 4 w vectors with 5 elements each, specifiying the priority (or weight) that each alternative has within each of the 4 criteria. When moving up to the next hierarchic level to synthesize the priorities, vector P is calculated simply by multiplying M_k and the priority vector w of the k-1 hierarchic level. The alternative with the highest value in the final P vector is considered the best one.

$$P = \begin{pmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{pmatrix} = M_k w_{k-1} \tag{3}$$

Following the same example previously stated, if M_k consists of 4 w vectors, vector w_{k-1} would correspond to the priority vector of the next hierarchical level, specifying the priorities of each criterion. Vector P would then contain the priorities given to each of the 5 alternatives, but now in relation to the overall problem.

Finally, the numerical verification of the consistency of the data introduced to the A matrices is carried out. To do so, the consistency index CI is calculated for each matrix, where a higher index indicates a greater level of inconsistency. Next, the consistency ratio CR is calculated by comparing the consistency index previously calculated with the indexes resulted from experimental analysis of randomly generated reciprocal matrices RI. In practice, if the value of the consistency ratio is greater than 0.10, it is advised to go back and review the judgments used and perform adjustments if necessary [12].

$$CI = \frac{\lambda - n}{n - 1} \; CR = \frac{CI}{RI} \tag{4}$$

2.1.2. ELECTRE III

The first ELECTRE method was developed by Roy in 1968, and is based on outranking relationships. The following section details the basis of this method as described by Maystre *et al.* [4]. For ELECTRE III, the outranking relationships are based on the notions of "concordance" (used to establish to what extent alternative a_i is at least as good as alternative a_k) and "discordance" (used to express how strongly one can reject the outranking relationship), which are then used to assess the "credibility" of the relationship.

The concordance index calculation uses the indifference threshold q and the preference threshold p for each criterion. Thus, the concordance index c for criterion j, measuring to what extent the performance g of alternative a_i is at least as good as that of alternative a_k, is calculated as follows:

$$
\begin{aligned}
c_j(a_i, a_k) &= 0 \leftrightarrow p_j < g_j(a_k) - g_j(a_i) \\
c_j(a_i, a_k) &= 1 \leftrightarrow g_j(a_k) - g_j(a_i) \leqslant q_j \\
c_j(a_i, a_k) &= \frac{g_j(a_i) + p_j - g_j(a_k)}{p_j - q_j} \leftrightarrow q_j < g_j(a_k) - g_j(a_i) \leqslant p_j
\end{aligned} \tag{5}
$$

For each pairing of alternatives, the general concordance C is a result of the weighted average of the concordance indexes of each criterion, as shown in Equation (6), where m is the total number of criteria being analyzed and P_j is the weight associated with criterion j.

$$
C_{i,k} = \frac{\sum_{j=1}^{m} P_j * c_j(a_i, a_k)}{\sum_{j=1}^{m} P_j} \tag{6}
$$

The discordance indexes are then calculated using the preference and the veto thresholds. The veto threshold v refers to a limit, deemed reasonable, that if crossed will automatically reject all credibility of alternative a_i outranking alternative a_k, regardless of the performance it may present in other criteria. Thus, the discordance index d is calculated as shown in Equation (7):

$$
\begin{aligned}
d_j(a_i, a_k) &= 1 \leftrightarrow v_j < g_j(a_k) - g_j(a_i) \\
d_j(a_i, a_k) &= 0 \leftrightarrow g_j(a_k) - g_j(a_i) \leqslant p_j \\
d_j(a_i, a_k) &= \frac{g_j(a_k) - p_j - g_j(a_i)}{v_j - p_j} \leftrightarrow p_j < g_j(a_k) - g_j(a_i) \leqslant v_j
\end{aligned} \tag{7}
$$

Next, the credibility index $\delta_{i,k}$ is calculated, which is the general concordance index reduced or weakened by the discordance indexes of the ensemble of criteria for which $d_j(a_i, a_k) > C_{i,k}$ (called ensemble $\overline{F}$).

$$
\delta_{i,k} = C_{i,k} * \prod_{j \in \overline{F}} \frac{1 - d_j(a_i, a_k)}{1 - C_{i,k}} \tag{8}
$$

For pairings in which there are no such criteria, the credibility index is equal to the global concordance index. If there is at least one criterion where the veto threshold is crossed ($d_j(a_i, a_k) = 1$), the credibility index $\delta_{i,k}$ is automatically 0.

For the outranking relationships, alternative a_i outranks alternative a_k if two conditions are met. The first is that $\delta_{i,k}$ should be greater than a credibility index cut-off value λ_1 (calculated from the credibility matrix of the available alternatives). The second condition is that $\delta_{i,k}$ should be greater than $\delta_{k,i} + s(\delta_{i,k})$, where s is a function defined as the discrimination function and also used to calculate the λ_1 value. A commonly accepted form of this function is:

$$
s(\lambda) = 0,30 - 0,15\lambda \tag{9}
$$

If λ_0 is considered as the maximum credibility index from the available alternatives, then the value λ_1 is the maximum credibility index in the matrix whose value is lower than $\lambda_0 - s(\lambda)$.

$$
\lambda_1 = \left\{ \max(\delta_{i,k}), \delta_{i,k} < \lambda_0 - s(\lambda) \right\} \tag{10}
$$

For constructing the rankings themselves, the distillation (either ascending or descending) is carried out, ranking one alternative at a time. Each time one alternative has been ranked, the process of constructing all outranking relationships, including the calculation of the cut-off values, and alternative qualification is repeated with the remaining alternatives. The descending distillation ranks the alternative with the highest qualification, while the ascending distillation ranks the one with the smallest.

If more than one alternatives share the maximum qualification value (or minimum, depending on the distillation used), then the process described above is carried out separately for that subgroup. In such a case, λ_0 assumes the value of λ_1 previously calculated, and is used to obtain a new cut-off level that is lower than the one used before. This continues until one of the alternatives has a different qualification than the others or if the cut-off level eventually reaches 0, in which case the alternatives sharing the qualification value are granted the same rank, and removed altogether from the remaining alternatives.

2.1.3. PROMETHEE II

The PROMETHEE method was first developed in 1982, and it includes two variations, one for partial ranking (PROMETHEE I), and one for complete ranking (PROMETHEE II). PROMETHEE is also based on outranking relationships. Through pairwise comparisons, the method evaluates "total" preference or dominance achieved by one alternative over others. The method is explained below as presented by Brans and Mareschal [15].

The preference index π of alternative a over alternative b is calculated with Equation (11), where w is the criterion weight, and P is level of preference of alternative a over alternative b for criterion j. The level of preference is a function of the difference d in the performance of both alternatives. Each criterion is treated as any of 6 crtieria types, shown in Table 2, which determine the function used to calculate the level of preference. For the different criteria types, q is the indifference threshold, p is the preference threshold, s is the distance to the inflection point, and x is an intermediate level of preference (between 0 and 1). The values of these variables are fixed by the decision makers.

$$\pi\left(a,b\right) = \sum_{j=1}^{k} P_j\left(a,b\right) w_j \tag{11}$$

Table 2. PROMETHEE Criteria types [13].

Type	Description	Function
I	Usual criterion	$P\left(d\right) = \begin{cases} 0 & d \leqslant 0 \\ 1 & d > 0 \end{cases}$
II	Quasi criterion	$P\left(d\right) = \begin{cases} 0 & d \leqslant q \\ 1 & d > q \end{cases}$
III	Linear criterion	$P\left(d\right) = \begin{cases} 0 & d \leqslant 0 \\ \frac{d}{p} & 0 \leqslant d \leqslant p \\ 1 & d > p \end{cases}$
IV	Level criterion	$P\left(d\right) = \begin{cases} 0 & d \leqslant q \\ x & q < d \leqslant p \\ 1 & d > p \end{cases}$
V	Linear with indifference	$P\left(d\right) = \begin{cases} 0 & d \leqslant q \\ \frac{d-q}{p-q} & q \leqslant d \leqslant p \\ 1 & d > p \end{cases}$
VI	Gaussian criterion	$P\left(d\right) = \begin{cases} 0 & d \leqslant 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d > 0 \end{cases}$

The next step is obtaining the outranking flows. The positive flow $\phi^{+}\left(a\right)$ measures the average global preference that alternative a has over the other alternatives in the set A. The negative flow $\phi^{-}\left(a\right)$, in the opposite way, measures the average global preferences that other alternatives in the set A have over alternative a. The PROMETHEE II method presents a complete ranking, introducing the concept of the net flow $\phi\left(a\right)$, which is basically the difference between the positive flow and the negative flow for a given alternative, as shown in Equation (12). The higher the value of the net flow, the more that the alternative is dominant over the others.

$$\begin{gathered} \phi^{+}\left(a\right) = \frac{1}{n-1} \sum_{x \in A} \pi\left(a,x\right) \ \phi^{-}\left(a\right) = \frac{1}{n-1} \sum_{x \in A} \pi\left(x,a\right) \\ \phi\left(a\right) = \phi^{+}\left(a\right) - \phi^{-}\left(a\right) \end{gathered} \tag{12}$$

2.1.4. MTOPSIS

The original TOPSIS method, presented by Hwang and Yoon in 1981, was developed mainly as an alternative to ELECTRE. Alternatives are ranked based on how "far" they are from the ideal solutions. The following section explains the basis for the method as presented by San Cristobal [16].

The weighted normalized performance value v_{ij} is first calculated using the criteria weight w and the performance values f of alternative j in criterion i, as shown in Equation (13), where m is the total number of alternatives analyzed.

$$v_{ij} = w_i \frac{f_{ij}}{\sqrt{\sum_{j=1}^{m} f_{ij}^2}} \tag{13}$$

Next, the ideal solution A^* and negative-ideal solution A^- need to be obtained. The ideal solution is comprised of the maximum normalized value found for the benefit criteria I' (criteria where higher performance values are desired, like pollutant removal rates) and the minimum normalized values for the cost criteria I'' (criteria where lower performance values are desired, like economic capital required). On the other hand, the negative-ideal solution includes the minimum normalized values for I' and the maximum values for I'', as shown in Equation (14).

$$\begin{aligned} A^* &= \{v_1^*, \ldots, v_n^*\} = \left\{\left(\max_j v_{ij} \,|i \in I'\right), \left(\min_j v_{ij} \,|i \in I''\right)\right\} \\ A^- &= \{v_1^-, \ldots, v_n^-\} = \left\{\left(\min_j v_{ij} \,|i \in I'\right), \left(\max_j v_{ij} \,|i \in I''\right)\right\} \end{aligned} \tag{14}$$

Afterwards, each alternative is compared to A^* and A^-, calculating the separation between them through Euclidean distances. The distances D of alternative j from the ideal solution and negative ideal solutions are calculated using Equation (15).

$$D_j^* = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^*\right)^2} \; D_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)^2} \tag{15}$$

In the final step, the relative closeness to the ideal solution is determined for each alternative. In the modified version of the method, presented by Ren *et al.* [18], the "optimized ideal reference point" ($\min(D_j^*)$ and $\max(D_j^-)$) is introduced. The modified relative closeness C^M for alternative j is shown in Equation (16), where the best alternative presents the smallest value.

$$C_j^M = \sqrt{\left(D_j^* - min\left(D_j^*\right)\right)^2 + \left(D_j^- - max\left(D_j^-\right)\right)^2} \tag{16}$$

Once the MCDA methods have been chosen, criteria selection should proceed in a similar way, based on available data and the relevance for the site. For example, the pollutants of greatest concern vary between different watersheds, depending on land-use cover [19]. However, if BMP selection is to be made under a sustainable land-use management framework, the criteria selected should at least address, in one way or another, the different dimensions or spheres considered in sustainable development. This would mean including some form of social performance, investment costs, and impacts on the environment (both in quantity and quality of the water) [20]. Ideally, when available, local government manuals for BMP sizing and conception should be used to guide the rest of the process.

2.2. Preliminary Site Analysis

Once the problem definition has been finished, the first main step calls for a preliminary analysis of the site. The main objective of this step is to obtain the most relevant BMPs adapted to the case. As much information as possible should be gathered on the physical, topographical, and hydrological conditions of the site as the different BMPs could require specific terrain slopes, soil infiltration capacities or water table depths [2]. Additionally, the land-use cover and construction constraints could play an important role as some BMPs are only suited for some specific urban context. For example, large open spaces might be suited for detention ponds, while the presence of smaller green areas could favor rain garden implementation. The location of possible BMPs along the watershed needs to be considered as well. For instance, detention ponds could be more effective downstream, while BMPs with smaller capacity, like permeable pavement, might be better suited higher up the watershed [2]. Existing infrastructure could also play a role in this step, as it is important to have an idea of how to connect the BMPs and where might the outflow be sent to. The information gathered should be compared with the technical constraints specified in the chosen guidelines to filter out the BMPs inappropriate for the selected site, forming a reduced list of those best adapted for the case, specifying possible locations for them

2.3. Analysis of Alternatives

The next step consists of developing the alternatives for consideration. The different BMPs could be analyzed individually or in combination, though it would be highly relevant to explore alternatives of BMPs interacting together in as many combinations as possible. The watershed modeling should be done at this stage to provide means for calculating the performance of each alternative in terms of water quantity and quality control.

The choice of hydrological model could vary from place to place. The United States Environmental Protection Agency (USEPA) developed a tool called System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) for evaluating the implementation of BMPs at a watershed level. This tool can integrate hydraulic, hydrological and water quality components for comparison of different BMP scenarios. However, the different parameters needed for the watershed modeling require the use of geographic information systems (GIS) running on specific software platforms. For this reason, the use of this tool has been relatively limited [21].

One of the more popular models developed in Europe is MIKE-URBAN, developed by the Danish Hydraulics Institute (DHI). Some of its advantages include the integration of all urban water networks under a single model manager. It is also capable of real-time control, modeling of BMPs, and is based on a GIS interface [22].

However, in North America, where the present work has been developed, the most commonly used hydrological model is the Storm Water Management Model (SWMM) [2]. Under SWMM, which follows a deterministic method, each sub-basin is simulated as a non-linear reservoir. The resulting flow can be either treated as inflow as for another sub-basin, or it can enter a pipe system where it is conveyed and transported across the network. For the hydraulic routing, kinematic wave, dynamic wave, and uniform steady flow are possible [2].

At this step in the methodology, the economic performance should also be calculated. Detailed cost descriptions can be found in the literature. However, measuring the economic benefits derived from the usage of BMPs is more difficult for various reasons. Some of these benefits are simply not monetary (like aesthetics and recreational opportunities), while others are derived indirectly and cannot easily be traced back to the BMPs themselves (like environmental impacts avoided through their use) [23,24]. Additionally, some BMPs present benefits in many branches outside of water management. Green roofs, for instance, also present advantages because of savings in heating and cooling of the buildings, apart from other environmental services [25]. As such, balancing the cost of implementation of BMPs against all of the benefits provided is a significant challenge for which no conclusive answers are yet available. Despite this, any inclusion of economic benefits in the analysis could help obtain a more realistic representation of the overall performance of the BMPs.

The Toronto and Region Conservation Authority, under the Sustainable Technologies Evaluation Program (STEP), developed a particularly relevant tool used for determining life cycle costs of BMPs in the regional context of this work. It can estimate all incurred costs (which include construction, maintenance, and end-of-life rehabilitation) in present values [26]. The present value PV for costs incurred at year n is calculated with Equation (17).

$$PV_n = \frac{FC_n}{(1+r)^n}\ FC_n = C\,(1+e)^n \quad (17)$$

where:

- FC_n: Future cost analyzed at year n ($)
- r: Discount rate (expressed as a decimal)
- n: Year associated with the future cost.
- C: Current base value of the cost analyzed ($)
- e: Inflation rate (expressed as a decimal)

The present value costs have to be calculated each year during the k number of years in the time period analyzed (25 or 50 in the STEP tool) and then added up to get the Net Present Value (NPV).

$$NPV = \sum_{n=1}^{k} PV_n \quad (18)$$

2.4. Stakeholder Analysis

Afterwards, the stakeholder analysis is needed. The relevant stakeholders could vary from place to place, but ideally would include ordinary citizens, some group of technical experts, and individuals involved in the local land-use planning bodies. The resources and time available would dictate the sampling process and way of approaching stakeholders, but including their different views and opinions is important. A way of doing this could be through survey application. However, participatory workshops, public opinion forums or other methods are also possible, depending on resources available, as well as the level of detail desired for the collected information. In any case, the stakeholder analysis should provide information on the group's interests or priorities concerning the criteria analyzed, while the citizen's analysis should additionally provide data for calculating the social performance of the different BMPs.

If possible, background information on the different stakeholders should be gathered as well. This could be helpful to determine if there are any factors influencing people's interests and priorities. Such information could prove useful if stakeholders need to be brought together for negotiations to find common ground.

The proposed methodology treats every stakeholder separately and does not consider grouping or averaging priorities across stakeholders in order to carry out a single evaluation of the BMP alternatives. Doing so could result in final selections that do not really reflect the priorities of any of the different groups. As such, the stakeholders should be comprised of relatively homogenous groups. Further subdivision of the 3 main ones suggested could be done, if necessary.

The importance of using real data on stakeholder priorities should not be understated, and it should not be left to the decision maker to simply assume them according to his or her understanding on the situation. Including this information will not only increase the quality of solutions found, but also contributes to the improvement of stakeholder engagement, which is a key issue under a sustainable development paradigm [20].

2.5. Application of the MCDA Methods

The next step consists of the application of the MCDA methods themselves, providing a final ranking of the different BMP alternatives. The application of the methods should be as transparent as possible, clearly stating any considerations for treating the input data and the required parameters. As mentioned in the survey analysis, each stakeholder group should be treated separately. This means that the methods should be applied to each one to obtain separate BMP rankings.

2.6. Analysis and Comparison

The final step consists of an analysis of these results. Ideally, the most appropriate MCDA would be one providing similar ranking results across stakeholders and other methods, while showing little sensitivity to modification in the input parameters. Nevertheless, there is no exact threshold or direct indication on how to choose and there is need for the decision maker's own critical judgment. Suggested approaches include calculation of rank correlations, comparison of top ranked choices, as done by Athawale and Chakraborty [27], and testing of each method's robustness (though each one might require different sensitivity analyses). If there is no clear alternative preferred by all stakeholders, it is up to the decision maker's knowledge of the situation to determine how to deal with the differences when stating his or her final recommendations (for example, creating collaborative workshops between stakeholders, information campaigns, *etc.*). Additionally, the rankings themselves could provide incomplete information on the overall performance of BMP alternatives. For instance, the final synthesized priorities from AHP, the net flows from PROMETHEE II, and the relative closeness from MTOPSIS are all forms of final scores used to grade the overall performance. Looking at how far off the scores are between alternatives could also help the decision makers determine if one BMP was largely preferred over another, or if it was a close call. Methods like ELECTRE III do not give a final score, but the inclusion of incomparabilities also helps determine if alternatives are relatively similar or not.

2.7. Sequence in the Methodology

The different steps previously described, as well as their respective products and tasks are summarized in Table 3. The BMP selection methodology presented here establishes a suggested general order of steps, indicating the expected product to be obtained from each one, while also having certain flexibility to go back, adjust and include new information as it becomes available. This can be particularly important when selecting the MCDA methods, the criteria, and the modeling process, all of which are choices that could influence each other. This possible exchange of information is explored in Figure 1. In the figure, the 6 main steps are shown in blue, with their respective main products in green. Intermediary tasks of products are kept in black. Since not all of the information produced in a particular step is directly used in the next one, it is possible to carry out some tasks in parallel.

Table 3. Methodology step summary.

Step	Tasks	Product
1. Problem definition	• Analysis of initial information available on the case study	• Selection of relevant criteria, MCDA methods, and design guidelines
2. Preliminary site analysis	• Analysis of physical characteristics of case study site (existing lots and network) • Comparison of physical parameters against BMP technical constraints.	• List of relevant BMPs
3. Analysis of alternatives	• Watershed modeling • BMP sizing and placement • Rain event simulation and development of outflow hydrographs • Cost calculation	• Performance values for quantitative criteria for each alternative
4. Stakeholder Survey	• Selection of relevant stakeholders • Survey application	• Criteria priorities for all stakeholders • Social performance values for all BMPs
5. MCDA method applications	• Assignment of relevant thresholds and type of criteria (if necessary) • Calculation of criteria weights • Application of all MCDA methods	• Final BMP rankings for all stakeholders and methods
6. Analysis and comparison	• Comparison and correlation calculations between rankings • Sensitivity analysis	• Recommendations on MCDA methods and BMP selection

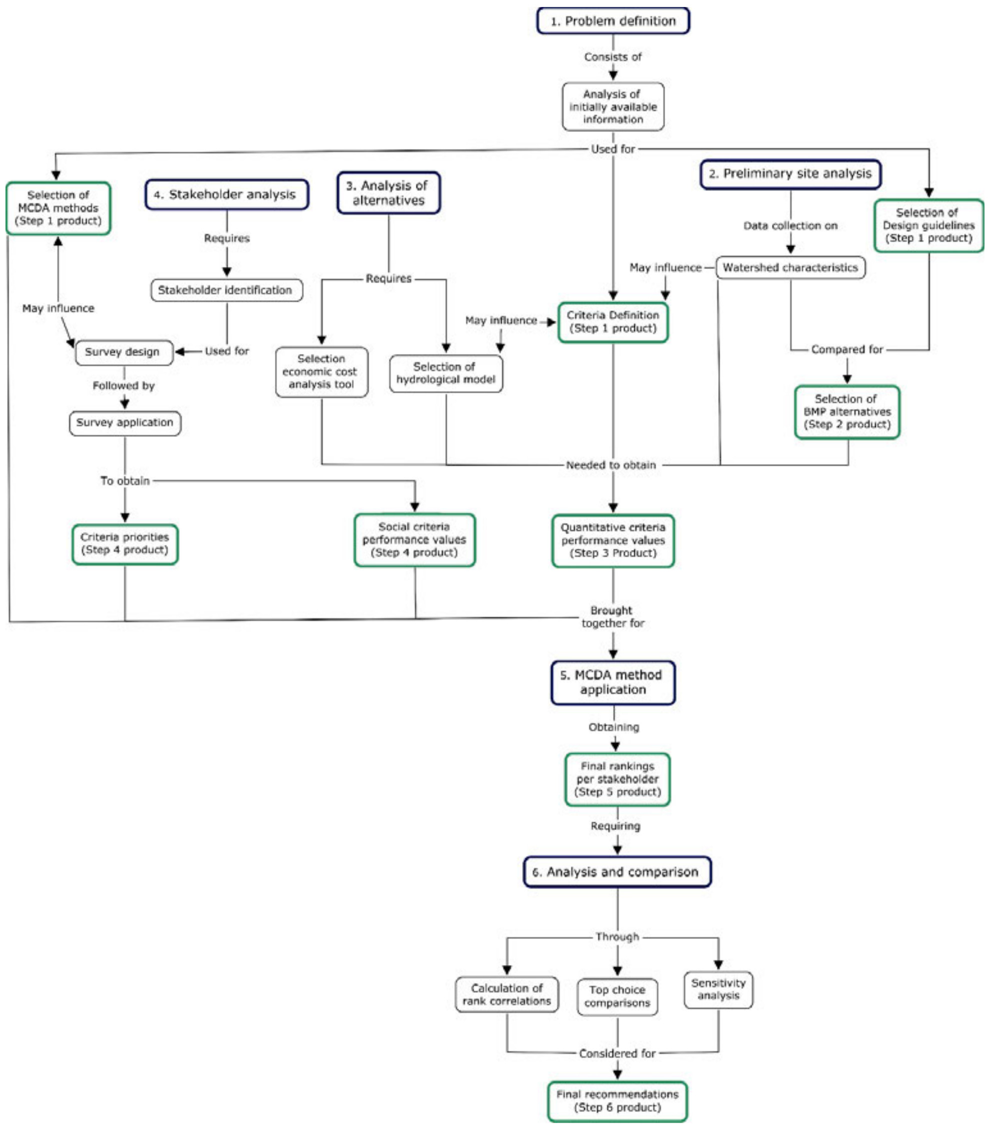

Figure 1. Exchange of information in the proposed methodology.

3. Discussion

The present work's main objective was to present a methodology for selecting BMPs based on MCDA methods while also incorporating different stakeholder views and priorities, aiming to obtain solutions under a sustainable land development framework. Though combinations of BMPs are considered and encouraged, sizing and placement in the methodology is kept relatively simple, with no optimization considered.

Future improvements to the methodology could explore the inclusion of multiple-objective constraints (if specified in the design guidelines) coupled with the MCDA analysis. This means that some of the criteria could be transformed into constraints (like the pollutant removal rates), seeking to minimize an objective function (like the economic cost), and then applying MCDA methods for the rest of the criteria. Additionally, due to the subjective nature of the social performance values, alternative approaches could be developed, other than survey applications.

As cases can vary considerably, it becomes important to present a methodology to approach the multi-criteria problem by showing a clear sequence of actions to be taken, while still allowing great flexibility for case specific considerations, and there lies the relevance of the work presented in this report. To show the suggested methodology's potential, Part 2 of this article explores a case study in the Montreal area where this methodology was applied.

4. Conclusions

Implementing BMPs in urbanized watersheds could help re-establish the natural hydrological cycle prior to land development. However, varying levels of performance across a wide range of criteria and conflicting stakeholder views could complicate the selection process of these practices. A methodology based on MCDA methods was proposed to help decision makers address the situation, seeking solutions under a sustainable development paradigm. The six main steps include the problem definition, preliminary site analysis, analysis of alternatives, stakeholder survey, MCDA method application and the final analysis and comparison.

The proposed sequence of steps presents the advantage of showing a clear path for analysis, while allowing feedback and corrections to be done along the process. Additionally, the steps' flexibility leaves room for case-specific considerations. The proposed methodology presents opportunities for future research, and its potential applications are explored in Part 2 of this article.

Acknowledgments: The authors would like to thank the Ecole Polytechnique de Montreal for covering the costs associated with the publication of this article.

Author Contributions: Mauricio Carvallo Aceves developed the methodology presented here and the case study as part of a Master's of Engineering project under the supervision and review of Musandji Fuamba. Mauricio Carvallo Aceves also prepared the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytical Hierarchy Process
BMPs	Best Management Practices
DHI	Danish Hydraulics Institute
ELECTRE	Elimination et Choix Traduisant la Réalité
GIS	Geographic information systems
MCDA	Multi-criteria decision aid
MTOPSIS	Modified Technique for Order Preference by Similarity to Ideal Solutions
NPV	Net Present Value
PROMETHEE	Preference Ranking Organization Method for Enrichment of Evaluation
STEP	Sustainable Technologies Program
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration
SWMM	Storm Water Management Model
USEPA	United States Environmental Protection Agency

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