# Indicators related to BMP performances: operational monitoring propositions

## Suivi opérationnel des performances des techniques alternatives, quelles mesures ?

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## RÉSUMÉ

Depuis de nombreuses années, les techniques alternatives se sont multipliées en France comme dans de nombreux pays. Ces techniques offrent des performances très intéressantes du point de vue du traitement des pollutions et sur le plan hydrologique. Cependant, ces techniques permettent également de rendre de nombreux services tout aussi importants : préservation de l'environnement, amélioration du microclimat local, valorisation de l'eau pour la vie urbaine (activités sociales et récréatives), etc. Cette communication cible plus particulièrement les praticiens en proposant une synthèse des performances à évaluer et des indicateurs utilisables pour ces évaluations. L'évaluation des performances doit permettre de suivre dans le temps chaque technique alternative. La communication propose également des protocoles de suivi en fonction des performances à suivre.

## ABSTRACT

This communication proposes a review on performance indicators related to the assessment of Sustainable Urban Drainage Systems (SUDS). The proposed indicators aims practitioners who want to monitor the performance of their technologies. A broad range of indicators related to hydraulic performance, hydrologic performance, economical aspects, others environmental and sanitary, social aspects, lifespan and long-term effectiveness are proposed. Indeed, the performance of sustainable drainage systems should not be limited to pollution and hydrology. Such systems play a broader role within integrated urban water management, providing benefits such as landscape amenity and amelioration of the biodiversity. This communication also proposes the construction of survey terms and data acquisition methods whose goal will be to assess the delivered service. The survey may be used to obtain feedback to assist in improving the design or the management of SUDS.

## KEY WORDS

BMP, Environmental, Economic, Investigation protocol, Performance indicator, Social

# 1 INTRODUCTION

In recent decades, the management of stormwater has evolved substantially, meaning that it now incorporates a wide range of concepts which fit within the broader concept of integrated urban water management. As this evolution tends to occur within a regional context, terminology tends to differ significantly between countries (and even between the regions within each country). It is well beyond the scope of this communication to attempt to define all terminology. We will thus use the terms “SUDS devices” and “Stormwater Control Measures” to describe these technologies, but the reader should consider “SUDS devices”, “BMPs”, “Stormwater Control Measures”, “Stormwater Control Devices” and “WSUD technologies” as essentially equivalent.

Designers of SUDS can evaluate the likely sources and characteristics of the target pollutants and then identify the appropriate treatment processes to address the target pollutants. Having identified the appropriate processes (Table 1), the designer can then select the appropriate treatment device *or combination of* treatment devices. These processes are described briefly below and Table 2 identifies the relative importance of each process within each of the broad categories of SUDS technology. Treatment processes and scales of application are major elements of technology choice. However, **designers must also take into account that elements of choice should also include environmental and social benefits which are presented in the communication.**

Table 1. Treatment processes in SUDS technologies – definitions.

| Process | Description |
|---|---|
| Detention | Provides a temporary for inflows, allowing release at a controlled rate. Detention will thus reduce the peak flow rate, but have little impact on the total runoff volume. Sedimentation is likely to occur to a greater or less extent, depending on the detention period (e.g. Urbonas & Stahre, 1990). |
| Retention | Provides storage of water, prior to the water being used or infiltrated. Retention essentially involves not only the retention of water, but of the associated pollutants, provided that they are not transferred into groundwater through infiltration. |
| Infiltration | Process by which stormwater on the ground surface enters the soil, where it percolates down to groundwater or remains within the upper soil layers, before being transpired by vegetation. Infiltration can be used to reduce peak flows and overall runoff volume, as well as removing pollutants, through filtration and adsorption |
| Sedimentation | Reduced flow velocity, resulting from detention or retention of stormwater within storage, results in sediment particles falling out of suspension. |
| Filtration | Pollutants present in water are physically trapped within a medium. Vegetation may also act as an effective filter. |
| Adsorption | Adhesion of pollutants to a surface (suspended particle, filter or vegetation). Materials adsorbed may be permanently bound or may be later released under certain environmental conditions. |
| Biological treatment | Degradation of specific pollutant by the means of microbial communities or vegetation. |

Table 2. Treatment processes and scales of operation in SUDS technologies. The hydrological outcomes (shown with an asterisk * of each stormwater control measure can be defined in terms of the attenuation of peak flows, the reduction of overall flow volume and the restoration of lost baseflows (i.e. replacement of lost subsurface flows).

| | Hydrological processes *& outcomes (*)* | | | | | Treatment process | | | | Scales | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technologies | Detention (&/or Retention | Infiltration | *Flow attenuation** | *Volume reduction** | *Baseflow restoration** | Sedimentation | Filtration | Adsorption | Biological treatment | Household | Streetscape | Precinct/ Suburb |
| Soakaway | ++ | +++ | + | ++ | | + | +++ | ++ | ++ | X | X | |
| Green roof / detention roof | ++ | | ++ | + | | | ++ | ++ | +[2] | X | | |
| Swale | ++ | (++) | + | (+) | (+) | ++ | (+++) | ++ | ++ | | X | |
| Filter strips | . | +++ | + | (+) | (+) | + | +++ | +++ | ++ | | X | |
| Detention / infiltration trench | ++ | (++) | ++ | (+++) | (++) | + | (+++)[3] | (++)[3] | (++)[3] | X | X | |
| Rain garden / Biofiltration systems | +++ | +++ | +(+) | (++) | (++) | ++ | +++ | +++ | +++ | X | X | X |
| Porous Roads | ++ | (+++) | ++ | (++) | (++) | + | (+++)[4] | (+++)[4] | (++)[4] | X | X | X |
| Wet pond | +++ | | +++ | | | ++ | | + | + | | | X |
| Wetland | +++ | | ++ | | | ++ | ++ | + | +++ | | | X |
| Dry pond | +++ | (+++) | +++ | (++) | (+) | ++ | (+++) | +++ | + (+++) | | | X |
| Rainwater tank | +++ | | ++ | +++ | +[1] | ++ | | | | X | X | |

+ low ability; ++ medium ability; +++ high ability; () only if infiltration is possible; * These are not strictly hydrological *processes*, but rather *outcomes* in terms of changes to the flow regime. [1] Only if connected to irrigation or provided with a ‘trickle outlet’ specifically designed to enhance baseflows. [2] if green roof. [3] if covered by topsoil. [4] if infiltration porous structure or permeable surface

# 2 PERFORMANCE INDICATORS PROPOSITION

## 2.1 Hydraulic performance (flood mitigation)

The flood mitigation capability can be defined either from a local point of view (performance of a given stormwater control measure or a small group interconnected) or from a larger point of view (larger area including the global catchment in which several other measures can be implemented). Faulkner (1999) gives example of a local structure improving flood situation at a local scale (at the outlet of the basin discharging at a small creek) but deteriorate the flood situation downstream in a more vulnerable area. Especially when a strategy of systematic flow control is applied at a large catchment scale, **it is very important to be aware that controlling flows may have a significant hydraulic effect potentially beneficial at a small scale but counter-effective at a larger one** (Petrucci *et al.*, 2011). It should be particularly important to study carefully this aspect before stating municipal or regional policies, when defining the local urban development plan for example. At the site scale, hydraulic performance can be assessed using a range of simple indicators, relating either to the peak flow rate or to the flow volume or simply to conformity with design considerations. At the catchment scale, hydraulic performance can be assessed using the same indicators. As the scale is much wider and data unavailable at this scale, assessing the indicators requires (i) modelling with some measurements to calibrate models, (ii) the definition of specific points where the indicators should be evaluated. These hydraulic indicators can be measured on site during a rain event or several rain events or followed over the time. These performances may also be predicted using software, see Table 5 for further information.

Indicators to considered are (Burns *et al.*, 2012; Burns, unpublished data; Dechesne *et al.*, 2004; Quigley *et al.*, 2009):
- Flow attenuation at the outlet: the capability to reduce the flows (and more especially the peak flow);
- Volume reduction at the outlet. This performance is assessed by the ratio of volume measured at the outlet to the volume measured at the inlet. Technologies with infiltration (or evaporation) capability can reduce the volume of water at the outlet;
- Lag-time: in addition to the two primary indicators of peak flow rates and flow volumes, another important hydraulic indicator is related to lag-time – the ability of a system to delay the arrival of the peak flow from a given sub-catchment, thus allowing peak flows from other parts of the catchment to have passed. Use of this indicator may provide a surrogate measure of hydraulic performance where full modeling of the propagation of sub-catchment hydrographs through to the catchment outlet is not feasible or warranted. The lag-time of peak flow can be predicted easily using several tools such as MUSIC or SWMM.

The measurement of flow to assess performance of these indicators requires appropriate expertise and the choice of the best-adapted methods will depend on the site context. Several resources are available: worksheets established by the GRAIE (http://www.graie.org/graie/touslesdocs.htm#5) , and the BMPdatabase website (http://www.bmpdatabase.org/) proposes a manual dedicated to Urban Stormwater BMP Performance Monitoring (Quigley *et al.*, 2009).

**It is recommended that peak flow rates and storm event flow volumes be considered as essential indicators for most stormwater control devices.** The time-lag indicator could be optionally collected. All of these indicators require measurement over relatively long time-periods and so long-term monitoring programs should be considered for such indicators. It is interesting to mention that the performance can be defined as ratios (ratios of peak flows, ratios of volumes, etc.) or estimated as absolute values (peak flow at the outlet or more satisfactorily the statistical distribution of outlet peak flows, etc.) in order to compare the situation (and eventually its evolution over time) to targets or objectives defined.

## 2.2 Hydrologic performance

Unlike hydraulic performance indicators, assessment of hydrologic performance is typically dependent on the local catchment context. In broad terms, the aim is to assess the degree to which the natural water balance has been altered (before and after the implementation of the stormwater control measures). Such an assessment involves the measurement (or estimation) of: inflows, infiltration, (groundwater recharge), evapotranspiration, and overflows to stormwater system (frequency, rate, volume, etc.).

At the site scale, Fletcher *et al.* (2011) proposed an index which assesses the ability of a stormwater control measure to approach the pre-development flow regime that could be applied more generally to approach the expected flow regime. Their index included annual runoff volume, as well as the amount and timing of baseflows, in an attempt to ensure that all aspects of the flow regime are restored or evolve as expected (rather than a sole focus on peak flows).

At the catchment scale, a number of hydrologic indicators have been proposed, based on a number of reviews of the links between hydrologic characteristics and ecological indicators (Clausen & Biggs, 1997; Konrad, 2000; Olden & Poff, 2003). The indicators most commonly identified tend to be focused on the frequency and duration of high flow 'pulses', as well as the timing and duration of low flows. It is recommended that for a given catchment, appropriate indicators be chosen based on consultation with hydrologists and ecologists, who can ascertain the organisms considered important ecological indicators for that catchment, and the flow regimes necessary to sustain healthy populations of those organisms. Another (complementary) approach is the direct measurement of fluxes such as infiltration (groundwater recharge) and potentially (although less commonly) evapotranspiration. Infiltration can be measured relatively simply using piezometers to measure the change in water level over time. Generally, the evapotranspiration flux will be ignored, or estimated from meteorological data (Voyde *et al.*, 2010). Such an approach ignores the potential impacts of increased evapotranspiration in areas surrounding the particular stormwater device, as a result of increased soil moisture, although such impacts have not to date been shown to be large (Hamel *et al.*, in press). Groundwater recharge may also be measured using chemical approaches; for example, indicators such as electrical conductivity and dissolved oxygen in groundwater will be modified as a result of rainwater inflows, allowing (with the aid of an appropriate groundwater diffusion model) the volume of rainwater injected to be estimated.

It is recommended that the following indicators could be considered for application to measure hydrological performance of stormwater control measures: site-scale water fluxes (volume of inflow, outflow (runoff volume discharged from site), volume infiltrated and volume evapotranspired or extracted through harvesting), site-scale hydrologic indicators (frequency of runoff, flow duration curve), and optionally (where available), information on the catchment-scale outcomes in terms of relevant flow indicators. It is not envisaged that such information will be available for the majority of sites. The final choice will consider on the hydrological objectives for the given stormwater control device. All of these indicators require measurement over relatively long time-periods and so long-term monitoring programs should be considered for such indicators.

## 2.3 Treatment performance

### *2.3.1 Treatment performance of retention-based techniques*

Treatment performance concerns the ability of a stormwater control measure to reduce the concentration and/or loads of pollutants. Two main indicators are used: pollutant concentration reduction and mass of pollutant removed. Strecker and Quigley (1999) propose a review of a variety of pollutant removal methods utilised in BMP monitoring to evaluate efficiency (of pollutants removal). Five methods are described with examples. Moreover Quigley *et al.*, (2009) discuss the sampling strategies which vary for each technology. A technology with a short hydraulic detention time will require fewer samples than a technology with a large detention time. In a technology that contains water for extended periods (e. g. wetland or wet pond), the dilatation of effluent will mainly depend on initial water volume; a "flushing ratio" may be useful to calculate for these technologies. It may also be interesting information to assess pollutant removal over a longer period (e.g. annual base) including current and diverse situations all together and which can estimate the potential for cumulative impact on receiving water. However to be relevant, continuous measurements on existing systems or modelling on both existing and planned systems have to be carried out. This approach is most often used with global parameter such as TSS on which the major part of the pollutant is supposed to be bound and for which continuous series can be estimated by means of indirect and simple measurements (e.g. Turbidity). However it remains very difficult to estimate this type of ratio on longer periods for other substances because of the specificity of each site and the extreme variability of concentrations from one event to another. Some modelling approaches were tried (e.g. Dechesne, 2002) based on Monte Carlo generation of mean concentrations over the time, but the results were very poor and often non consistent.

### *2.3.2 Treatment performance of infiltration-based techniques*

The performance of infiltration systems can be measured by measuring the ratio of inflow (volume and pollutant load) to outflow. This is the first, basic performance measure of an infiltration system. Where there are concerns about pollution of ground water, monitoring wells can be used to measure the change in quality and amount of groundwater. Soil-related measurements may include: pollution retention performance [%], pollution retention [m], and contamination indicator [mg/L] (mean concentration in the first 30 cm of soil). Important concentration may lead to risk for staff or public (if basin is open to the public). The choice of pollutants to monitor will depend on the site specificities (permit requirements, land uses in the catchment area and associated pollutants, existing monitoring data for the catchment area, beneficial uses of the receiving water and anticipated pollutant removal mechanisms and targeted pollutants for BMP being monitored). The reader should refer to the report "Urban Storm Water Performance Monitoring" (Quigley *et al.*, 2009) for more detailed information.

## 2.4 Economic aspects

Data on the costs of a given stormwater control measure provide very useful information to inform future investments. The following indicators should be considered as part of the assessment of economic performance:

- Preliminary costs: total costs associated with defining the need for the BMP (e.g. running site selection processes, feasibility studies, grant application costs) and total conceptual, preliminary and detailed design costs;
- Construction costs: costs of construction (broken down into design costs, construction costs, acquisition of land, and other capital costs) related to information about factors affecting construction cost (e.g. size and design details, site difficulties, labour costs, heritage protection requirements, etc.);
- Operational costs: operational costs (broken down into: regular maintenance costs and reactive maintenance costs) related to factors influencing operational costs (as above);
- Savings/return on investment: income generated (e.g. for supply of water), other direct financial benefit and other calculated indirect financial benefits (i.e. externalities).

It is recommended that where such information is collected by survey, the method given by Taylor (2003) be used as a basis.

## 2.5 Other environmental & sanitary aspects

Whilst it is commonly claimed that carefully designed stormwater control measures can provide other benefits like (i) creating habitat and thus enhancing biodiversity, (ii) fighting against the urban heat island or (iii) providing resources for other urban activities, there are few studies which attempt to provide a framework for assessing such secondary benefits. Moore and Hunt (2012) have recently proposed such a framework – applied initially to wetlands and ponds. Their framework assesses three aspects: carbon sequestration, biodiversity and cultural services. They assess carbon sequestration through a measure of carbon (organic matter) accumulation in the system; whilst biodiversity was measured using the Shannon diversity index (applied to both vegetation and the aquatic macroinvertebrate communities). Cultural services were qualitatively assessed based on the potential for recreational and educational opportunities at each site. However, qualifying these aspects with these indicators is a first step and will need further research, the problem being very complex and multi-objective. **Many stormwater control devices will not have an objective of contributing to habitat or to biodiversity, but in some cases (e.g. wetlands, buffer strips), this may be an important objective, and thus important to measure.** It is thus recommended that indicators be chosen, based on locally defined biodiversity objectives for the project, using indicators selected by ecologists and related specialists, such that the indicators are (i) readily measurable, (ii) relate to the ecological values which are of concern and (iii) capable of detecting trends or impacts. The chosen indicators may need to include nuisance species (plant or animal).

Czemiel Berndtsson (2010) has discussed the thermal benefits of green roofs, reducing air conditioning needs and urban island effect. Rowe (2011) has recently also discussed on how green roofs influence air pollution, carbon dioxide emissions and carbon sequestration. Bianchini and Hewage (2012) evaluate the environmental benefits of green roofs using life cycle analysis. Other indices may be appropriate – depending on local context. The expansion of green techniques in the city should be an important issue in the future. At last, the problem of re-use has to be tackled (re-use of water but also the possibility to re-use materials extracted during maintenance phases). Some approaches has already been tested (e.g. attrition to separate fine particles known to be polluted from grosser ones which seem to be cleaner) in order to re-use the coarse elements for the construction of road basements (e.g. Petavy, 2007). A deep reflexion has to be carried out to find new channels for treatment and re-use. For the sanitary aspects, once again, very few studies are carried out showing their potential risks or benefits. The risks can be due to presence of polluted sediment potentially much more in contact with users and workers in charge of maintenance. The OMEGA project (http://www.omega-anrvillesdurables.org/) may provide explanation of how to undertake such an assessment and reinforces the need for local expertise in making the selection of indicators (Granger *et al.*, 2008).

## 2.6 Social aspects

Social aspects related to BMPs may be divided into several categories: public perception for the public (if the technology is open to the public) or for the neighbourhood; potential uses or social benefits; and safety issues. Table 3 below details the categories and proposes means of measurement.

Table 3. Proposition of indicators related to social aspects.

| Aspect | Detail | Assessment |
|---|---|---|
| Public perception | Odours | - Number of complaints [number]<br>- Kind of odours smelled [checklist]<br>- Survey [% of satisfaction] |
| | Nuisance species (plant or animal), mosquitoes, litter and debris | - Number of complaints [number] |
| Potential uses / social benefits | Walking track, viewing platform, aesthetics (such as ornamental ponds), element of nature in town, sport platform, other | - [yes / no]<br>- scoring system (Moore and Hunt, in review) |
| Water storage | landscape irrigation, fire fighting, external cleaning, snow making, amelioration of the microclimate, other | See (Martinez M., 2010) for further information |
| Misuse | potential to invite unsocial behaviour or potentially even crime, through the creation of isolated places with poor visibility | - Number of complaints [number]<br>- Field observation |
| Safety | For the staff | - Number and gravity of personnel accidents |
| | For the public | - Level of security for the staff or the public (accessibility, information…) |

The list is not exhaustive because social aspects may differ a lot between technology and indirect social aspects are difficult to identify. For example, Green roofs “enhance aesthetical values followed by increased property prices” (Czemiel Berndtsson, 2010). It is thus important that definition of appropriate social indicators involve local consultation.

## 2.7 Lifespan and long-term effectiveness

Long term functionality depends on several factors: whether maintenance is done or not, whether the maintenance is efficient or not, the potential evolution of the uses or functions over time, the misuse of the systems, the evolution of the catchment drained, etc. So it may useful to check whether an ongoing technique or project evolves normally or not at different stage of its lifespan. Based on (Moura, 2008) work dedicated to infiltration systems, a list of indicators can be defined and completed concerning long term functionalities: flooding frequency indicator, global hydraulic performance measuring the potential for clogging, low degradation of groundwater quality, low degradation of receiving water, low soil pollution but high efficiency in pollution retention, aptitude to be well and easily maintained / efficiency of the maintenance, protection of users and workers health and safety, waste production and management, normal maintenance costs, good social acceptance.

Understanding maintenance programmes undertaken for a particular stormwater control device is a prerequisite to interpreting its performance. Survey participants should be asked to provide the following information: a check-list of maintenance actions (routine or reactive), maintenance period, frequency of maintenance, monitoring and maintenance costs, responsibility for maintenance, and the defects that have been observed and the actions necessary to address them.

# 3 RECOMMANDATION FOR IMPLEMENTATION OF THE SURVEY

In this section, we provide a synthesis of indicators or data that can be used to assess the performance of stormwater control measures and resources needed to assess them. Initially, these data could be used in the development of the proposed survey of owners/operators of stormwater devices. We firstly summarise the data relating to the design of a stormwater device, background information that may be necessary to establish a link between the expected performance and the design of the system (Urbonas, 1995). We then summarise investigation protocols required for each type of performance.

## 3.1 Design and circumstance data

As described above, design indicators provide the basic information necessary to understand how a particular system works. Equally importantly, such information is necessary to predict how a particular treatment device works (Duncan, 1998). For example, Urbonas (1995) provides recommendations for standard parameters that should always be measured, to allow comparison between sites and potentially to develop regression relationships between design parameters and observed performance. We take a similar approach here to Urbonas, but, because we cover a wider range of treatment devices, we attempt to provide more general guidance, which can then be customised as required for specific device types (e.g. wetlands, biofilters, infiltration systems). In doing so, we acknowledge the important role of local context in defining objectives and thus performance objectives.

Table 4. Basic information on design and circumstance

| | | |
|---|---|---|
| Available resources & context | Site specifications | Contacts (owner, contractors, etc.), location, active surfaces [m²] and active surface types (activities), type of water and quality (concentration of pollutants), climate, site constraints, other information (density of population, contaminant sources, etc.) |
| | Design | Regulatory framework (regulations taken into account), guidelines & practices used, design parameters (design flow, hypothesis, etc.), treatment objectives, vulnerability of flooded zones in case of flooding |
| Technology itself | General information | Construction year, expected life span, final inspection at the end of construction (detail points of verification), guarantee: guarantee period and elements guarantied, available documentation and studies |
| | Dimensions and structure of the system | Geometry (slope [%], surface [m²], thickness [m], etc.), retention volume [m³], infiltration surface [m²], space requirement [m²], detention depth, pit crest, vadoze zone [m], detailed plan |
| | Components | Inlet(s) and energy dissipation features, filter media (soil or other media), media composition (porosity, hydraulic conductivity, pH, organic content, type of vegetation observed, etc.), drainage pipe(s) if present (dimension, shape, material, type of slots, rigidity), outlet(s) and their type, etc. |

## 3.2 Investigation protocol

As discussed, performance indicators to assess are strongly dependant on the technology and on the site context. Program objectives should be considered in light of available resources to determine the best mix of monitoring frequency, locations, and parameters. Performance to monitor should be chosen according to: objectives of the survey, expected main functions of the studied technology or project, site specificities, and resources available regarding performance to monitor. Table 5 focuses on the objectives and exigencies of the survey. Four kinds of survey are proposed:

- Questionnaire and document consultation consist of a series of questions for the purpose of gathering documents and information from the owner, the manager and if possible the contractor for maintenance;
- Single site inspection / monitoring consists of a field investigation in order to gather information (measures, samples, photos, questionnaire to stakeholders, etc.) regarding the technology and its environment. It may also involve the use of tools (modelling, drafting, analysing, etc.);
- Short-term monitoring campaign consists of semi-continuous or continuous monitoring. Short-term means less than a year. The monitoring programme may include the overall objectives. However the key feature is the listing of what is being monitored and how that monitoring is done (where and how long). A monitoring programme also provides a table of locations, dates and sampling methods that are proposed.
- Long-term monitoring involves documenting measurements and observations for several years. Several years may be necessary in order to assess performance such as hydrologic performance. Measurements will be made at regular, well-spaced time intervals in order to determine the long-term trend in a particular parameter.

For more detailed information on types of monitoring, the reader may refer for example to the useful guidance provided by the California Rangelands Research and Information Center (1995). In the table, text underlined corresponds to the recommended method.

Table 5. Performance indicators and investigation required for practitioners.

| Performance | Questionnaire | Single site inspection/monitoring/ document consultation | Short-term monitoring campaign (e.g. <1 year) | Long-term monitoring |
|---|---|---|---|---|
| Design and circumstance data | Required | Required | *Not appropriate* | *Not appropriate* |
| Hydraulic performance (flood mitigation)<br>At the site scale / At the catchment scale<br>Flow attenuation at the outlet<br>Volume reduction at the outlet<br>Lag-time<br>Overflow frequency indicator<br>Drainage duration indicator | Only if information is known | Using modelling tool such as MUSIC /STORM / SWMM / CANOE/ MOUSE/ Hydroworks | *Not appropriate* | At least 1 year for current events<br>Long series for flood mitigation |
| Hydrological performance<br>At the site-scale<br>*Depends highly on the site and the objectives*<br>-Reduction in mean annual runoff volume back to natural volume<br>-Runoff frequency<br>-Similarity between the pre-developed (or expected) volume of *baseflow* and the volume of stormwater released as filtered flows.<br>-Reduction of days in which filtered flow exceeds "pre-developed baseflow" or drops to zero back to natural (or expected). | Only if information is known | Using modelling tool | *Not appropriate* | At least 1 year<br>Long series preferable for evolution |
| At the catchment-scale<br>*Depends highly on the site and the objectives*<br>-Site-scale water fluxes (volume of inflow, outflow (runoff volume discharged from site), volume infiltrated and volume evapotranspired or extracted through harvesting)<br>-Site-scale hydrologic indicators (frequency of runoff, flow duration curve)<br>-Optionally information on the catchment-scale outcomes in terms of relevant flow indicators | Only if information is known | Using modelling tool<br>*But with measurements to calibrate the models* | *Not appropriate* | At least around 5 years |
| Treatment performance<br>-Pollutant concentration attenuation (Event Mean Concentration)<br>-Event –based pollutant removal (mass) | Only if information is known | Using modelling tool such as MUSIC or SWMM | Several events at least | Better on long-term |
| -Pollution retention performance | | | *Not appropriate* | At least 1 year |
| -Depth of polluted soil<br>-Contamination indicator (soil) | | *Not appropriate* | One or several "snapshots" at a single point time | Required to monitor the evolution |
| Economic aspects<br>-Preliminary costs<br>-Construction costs<br>-Operational costs<br>-Savings/return on investment | Required | Not appropriate | Not appropriate | Not appropriate<br>Required to monitor the evolution |
| Other environmental or sanitary aspects<br>*Depends highly on the site and the objectives* | Only if information is known | *Not appropriate or* Required (depending on the indicator) | Required : duration of observation depends on indicators chosen | Required : duration of observation depends on indicators chosen |
| Social acceptance<br>Social aspect | | Required for [yes / no] indicators | Required for survey at different time (e.g. season) of the year | Required to monitor the evolution |
| Lifespan and long-term effectiveness<br>Long term functionalities | Only if information is known | Required (depending on the indicator) | Required (depending on the indicator) | Required (depending on the indicator) |
| Monitoring and maintenance check-list | Required | Required | *Not appropriate* | Required to monitor the evolution |

# 4 CONCLUSION / DISCUSSION

This last section is an open discussion to broaden the reflexions provided within this communication. The authors do not pretend to give all the answers, and moreover it seems that many answers are very specific to the objectives of the investigation, the resources available and the site. Hence, this section should attempts to outline the type of questions that should be asked before commencing any monitoring or investigation.

## 4.1 Assessment of combination of technologies

Combinations of systems are often used, to match the objectives and context of a particular project. For example, a swale or buffer strip may be used as a pre-treatment before water enters into an infiltration trench. Similarly, a wetland may contain a sediment basin at its upstream end. Performance assessment of multiple technologies on the same site may become a challenging question. A combination can consist in a retention basin + an infiltration basin. In this case of “simple” combination (same scale, in series), the solution is to monitor the inlet and the outlet of each technology. However, some cases may become more difficult due to scale difference (e.g. many green roofs in a precinct + one infiltration basin), or difficulty to define the frontier of each technology (e.g. buffer strip + swale). In these cases, the investigation protocol must be site specific.

In every case, it is very interesting (if possible) to monitor the performance of the combination and each technology.

## 4.2 Influence of monitoring and maintenance on the performance of technology

During investigation, it is important to know that investigations interfere with the performance measurement. The protocol of investigation must be studied in order to assess the level of interference. Too many tests of permeability on a small infiltration surface for example can lead to modify the evolution of clogging, preference flow paths and why not pollution transfer.

Monitoring an existing technology (which has not been design for) will require a modification of the structure, and so the anterior performance cannot be known.

## 4.3 Business opportunities

There are a number of potential business opportunities that emerge from the need to monitor stormwater management systems. These may include (but not limited to):

- Monitoring of technology: there is no contractor specialized in monitoring these technologies on the long term, although monitoring is becoming indispensable in order to manage these technologies. Monitoring can include social aspects, as many technologies interact with the public;

- Managing technology: in the same way that there are contracts to manage specifically Waste Water Treatment Plant, there may be contract to manage all retention basin, all swale or all BMPs of a town or a urban community;

- Training for staff: because there are needs for monitoring and management of BMP, there is a need for training. The training can be internal (in the firm) or external (for a client).


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