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Feasibility of treatment options: Comparison of the approaches evaluated to maximise removal of Priority Pollutants

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Abstract

This deliverable firstly describes and assesses various water related decision-making approaches and tools reported in published literature. Secondly, a multi-criteria assessment (MCA) approach is presented for assessing the feasibility of treatment options for the removal of 12 selected priority pollutants (benzene, benzo(a)pyrene, cadmium, chlorpyrifos, di-(2-ethylhexyl)-phthalate, diuron, 1,2-dichloroethane, hexachlorobenzene, lead, mercury, nonylphenol, and polybromodiphenylether) listed in the Water Framework Directive. The treatment options assessed include municipal wastewater treatment, industrial treatment and structural stormwater Best Management Practices (BMPs).

The treatment options are assessed against technical feasibility, technical efficiency, financial considerations, and environmental impact. A scoring system was designed for each of the four indicators, with threshold values assigned to distinguish between the performances of each of the treatment options. Data gaps and inconsistencies are the main constraints to the successful application of the approach. This is shown for municipal wastewater treatment plants (WWTPs) where insufficient data prohibit the allocation of scores and therefore the comparison of municipal WWTPs with other technologies. The importance of available and complete datasets and comparable units is highlighted. However, comparing certain industrial treatment options and stormwater BMPs across the range of established criteria was possible, thus demonstrating the feasibility of a MCA approach providing data are available .

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1 Introduction

The aim of this deliverable is to conclude the research completed in Work Package (*WP*) 5 on "Treatment Options" within the ScorePP project ("Source Control Options for Reducing Emissions of Priority Pollutants"). This is to be achieved through an assessment of the technological options considered in deliverables *(D)5.1-5.5* with respect to their feasibility and appropriateness to remove priority pollutants (PPs) at the individual compound level. A similar task (*D4.5*) has been undertaken to conclude the research completed within WP4 (Limiting Release of Priority Pollutants), and efforts have been made to ensure that a compatible approach is taken to completing both deliverables with a view to facilitating work to be undertaken within *D9.7* (Multi-criteria analysis of emission control strategies).

To some extent *D5.6* is seen as a 'pilot' for the work to be undertaken in *D9.7* as completion of this deliverable has utilised, as far as possible, the criteria, indicators and approach initially identified by the ScorePP taskforce (London, March 2008). The outcomes have subsequently been reported on in *D9.4* (Methodology for comparative screening of emission control measures) as discussed at the 2nd Advisory Board meeting (Brussels, September 2008).

1.1 Assessing Feasibility

In a multi-objective scenario such as the selection of the most appropriate wastewater treatment option for a given situation, intuitive reasoning and expert judgement alone are usually not sufficient to achieve a decision resolution that satisfies all stakeholders (Brunner and Starkl, 2004). There is a need for transparency and accountability in order that stakeholders can see how a decision has been reached.

Assessing the feasibility of treatment options requires an analysis of the treatment options in terms of a number of qualities and characteristics that combine to define the overall performance of the treatment options. Given the complexity of the subject and the wide variability between the various treatment options, there is a strong likelihood that they will conflict in terms of their performance in different areas and it will therefore be necessary for the decision-maker to make trade-offs between their various qualities and characteristics. It is therefore suggested that feasibility is not a single unitary concept and it will therefore require a complex and multi-faceted assessment process.

In order to manage a complex decision-making process, criteria can be established that provide a measure against which the potential performance of an option can be assessed. Indicators can then be established to provide a measure of the extent to which the criteria are met by the selected options (Makropoulos *et al.*, 2008). In this way, the performance of each option can be assessed against a wide range of criteria, enabling the decision-maker to compare options in a robust, transparent and accountable way.

This is an approach used in multi-criteria analysis (MCA), which is widely reported to offer several benefits to decision-makers including the ability to incorporate both monetary and non-monetary values in the compared criteria, and supporting the use of data in a variety of formats (DCLG, 2009). It increases the transparency and auditability of the decision-making process as it allows stakeholders to influence the scores and weightings used, and it also supports the consideration of how alternative values would affect the generated results (Butler *et al.,* 2003; Ellis *et al.,* 2009a; and Scholes and Revitt, 2008).

Enabling stakeholder criticism and the testing of alternative values is valuable within the context of the ScorePP project as the project aims to support a diverse range of stakeholders in their need to identify and develop emission reduction strategies. This is particularly important as the number of objectives to be met within a particular context increase as the number of stakeholders increases. Whilst some of these objectives may be complimentary, others will conflict and with increasing frequency as stakeholder numbers increase (Brunner and Starkl, 2004).

In spite of concern over the conflict of interest that can arise from the involvement of multiple stakeholders, diverse stakeholder engagement is recognised as lending credibility to and enhancing the defensibility and acceptability of adopted solutions. This is illustrated by the EU Water Framework Directive (WFD) (2000/60/EEC) as it includes a compulsory requirement for stakeholder consultation. Legislatory requirements such as this have led to the development of a number of systems and analytical tools for addressing the issue. Regardless of any potential conflict of interest however, transparency in the decision-support tool choice and a full explanation and justification of any criteria, indicators and scores used are of paramount importance to any form of decision-making process where stakeholder confidence is required.

Some of the decision-support tools relevant to ScorePP that are described in the associated literature are outlined below.

1.1.1 Decision-making systems relevant to ScorePP

The European Environment Agency (EEA) approach to environmental indicators uses the Driving forces, Pressure, State, Impact, Response (DPSIR) framework (EEA, 1999). The Pressure-State-Response (PSR) system developed by the Organisation for Economic Co-operation and Development (OECD), expanded into DPSIR and was later adopted by EEA. The EEA uses descriptive indicators (development of a variable in relation to an environmental issue), performance indicators (a measure of the direction and speed of resource consumption for example; or a measure of performance towards quantified targets), and efficiency indicators.

The European DayWater project developed an Adaptive Decision Support System (ADSS) designed to support decision-making in relation to urban stormwater pollution source control. This approach assesses the scenario-specific suitability of options using a computerised Multi-Criteria Comparator (MCC) that develops a matrix of scores for the source control options (DayWater, 2009). The criteria used include technical, environmental and operational performance. The Sustainable Water Industry Asset Resource Decisions (SWARD) project by comparison, produced a guidebook that presents criteria and associated indicators that should be addressed by the water industry in order to successfully include sustainability principles in their decision-making processes (Butler *et al.*, 2003). This was achieved using a variety of tools that address economic, social and environmental concerns. Examples include cost-benefit analysis, life-cycle assessment, risk assessment, numerical modelling, and simulations of alternatives.

The building and civil engineering industries have tackled their own decision-making issues through the development of the Building Research Establishment Environmental Assessment Method (BREEAM) and the Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL) respectively (Venables *et al.,* 2005). These tools were developed in order to assess the environmental performance of new and existing developments. CEEQUAL is an awards system that assesses the extent to which a project exceeds the statutory and regulatory minima whereby basic compliance would produce an award score of zero. BREEAM by comparison focuses on the overall environmental performance of a development with the main objective being to mitigate environmental impacts throughout its lifecycle.

The development of numerous tools for projects with different objectives such as these, has led to concern that the use of an alternative tool on the same data set may lead to a different decision outcome (Brunner and Starkl, 2004). Due consideration must therefore be given to defining the objective of the study and the terminology used. For example, if performance is discussed then a precise measure of what equates to good or poor performance must be defined. Furthermore, should concepts like sustainability be included in the objectives of the study then it must be made very clear whether they address economic sustainability alone, or if they also include social and/or environmental sustainability.

1.2 Identifying Criteria and Indicators

Criteria used as decision-support tools can be defined as "major established factors on which the final judgement, evaluation or decision is made; these comprise the principal areas of concern in the decision-making process" (Ellis *et al.*, 2009b). Indicators however, refer to "diagnostic states or conditions that describe relevant and appropriate properties of the given criteria" (Ellis *et al.*, 2009b). The OECD considers indicators to be an evaluation tool, for revealing trends or change that may require action (EEA, 1999).

Ares and Serra (2008) describe the development stages of a typical multi-criteria decision making process as follows;

- Develop the range of alternative options to be assessed;
- Identify criteria and indicators to distinguish between the various options;
- Develop performance scores to rate the options against each indicator;
- Design tests to evaluate the decision process in terms of uncertainty, consistency, redundancy, sensitivity and robustness in the analysis (terminology explained below).

The UK Department of Communities and Local Government (DCLG) has published a manual on how to undertake and make best use of MCA, designed for use in environmental decision-making and other situations (DCLG, 2009). This guidance document explains that the selection of criteria should reflect the desired performance of each treatment option in relation to the study objectives. The performance of each option should be assessable or measurable in relation to each of the criteria, either quantitatively or in a qualitative manner prescribed with benchmarks that allow comparability between the various options.

Criteria and indicators should demonstrate the characteristics described below;

- *Operationality* – the criteria and indicators are precisely defined and the assessment is based on available and complete data in order that each treatment option can be assessed against each criterion;

- *Non-redundancy* – all criteria and indicators used should be necessary, important, and not duplicated. Any criteria against which all treatment options would score identically should be discounted from the analysis as the scoring will not affect the ranking of options;
- *Completeness* – the indicators should cover all important aspects of the primary criteria and the intrinsic value of each criterion and indicator should be detailed;
- *Mutual independence of preferences* – the scoring of each indicator should be independent from the scoring of all others.

Attention should also be given to the comprehensiveness, applicability, tractability, transparency and practicability of the criteria (Butler et al., 2003). The choice of criteria and the method by which they are compared have the potential to significantly affect the decision outcome so it is imperative that criteria are selected with due care and attention to these variables. It is important to note that although previous studies can be used for ideas and guidance, it is essential that the criteria and indicators used for an assessment are developed according to the objectives of the project, and are not simply duplicated from another study.

The consistency of the indicators and the weightings that are applied to them should be assessed in order to validate the process. Ares and Serra (2008) achieved this mathematically using normalised eigenvectors. Further analysis of these methods and of the available data is required in order to establish whether this type of approach is feasible in achieving the objectives of *D5.6*.

The OECD has developed guiding principles for the use of indicators in relation to international environmental policy that bear relevance to the understanding of the current analysis (OECD, 2004). Emphasis is placed on the need for background information, data, analysis and interpretation to surround and compliment any indicators used, and that some issues simply cannot be assessed using quantitative analysis or indicators. Further analytical tools are recommended in order to fully understand the implications of an applied indicator.

According to the OECD, the three fundamental requirements of successful indicators are feasibility due to data availability, scientific soundness, and policy relevance (EEA, 1999).

1.2.1 Feasibility

Indicators may be proposed for which data are incomplete or cannot be fully compiled. This may be due to time constraints or simply due to a lack of data because it has never been collected or because it is withheld by industry. This can cause an indicator to be unfeasible in achieving its objectives and it should therefore be discounted. An example relevant to *D5.6* is the unfeasibility of an amenity benefit indicator due to a lack of contextual data. An objective of *D5.6* was to understand the possible implications of the treatment options for the social issue of amenity benefits of having cleaner waterways. This is a highly context-specific indicator (see *Section 1.4*) as the level and type of amenity use will vary between water courses and therefore the extent of any improvement or deterioration of its amenity value will also vary by locality. The MCA proposed for *D9.7* is designed for general applicability and it therefore lacks any site-specific context. It is therefore unfeasible for this indicator to be used within the context of *D5.6* as it will be incapable of differentiating between treatment options.

The OECD recommends the classification of data in terms of short-term, medium-term and long-term availability in an attempt to refine the indicator list. The use of this approach enables indicator feasibility to be identified, and therefore also any need for the development of better additional indicators or for data gaps to be filled (OECD, 2009).

1.2.2 Scientific soundness

Data quality is an important consideration in ensuring that the interpretation is scientifically sound. The OECD refer to the timeliness of the datasets used, indicating that data should be as recent as possible and that time series data should be coherent in the longer term. If indicators are to be used in an international context as is the case of this work, they should be designed such that there is an appropriate level of comparability between countries. This may be achieved by specifying a common denominator such as Gross Domestic Product (GDP) or population density, or by ensuring that factors such as the measurement methods and definitions used are comparable from country to country. This challenge has been experienced in the analysis of economic data whereby the data has been collated from countries with different currencies and at different times and so subject to varying exchange rates. This data has been converted into Euros (€) for the purposes of this study, which renders it inaccurate in economic terms but does at least provide a comparable point of reference in terms of the scale of costs for the removal of the various PPs.

1.2.3 Policy relevance

There are certain issues that are important to the investigation but that may need to be excluded from the MCA if they cannot be operationalised into criteria and indicators (Smeets *et al.,* 2008). A relevant example is the issue of community awareness of PP issues that was suggested by the Advisory Board workshop during discussion of “identification of appropriate criteria to support the comparative screening of alternative emission control options”. Although it is important that the local community should be made aware of the potential for PPs to exist in their environment and of the measures being taken to reduce them, it is not possible to discriminate between treatment options depending on the extent to which awareness is achieved. The management of this issue depends on the policies and actions of the developer rather than on the choice of treatment option. It would therefore be best addressed through public consultation and information dissemination where the public are given the opportunity to offer an opinion and question the process rather than as part of the process that identifies potentially suitable solutions. It may be possible to offer feedback into a decision-making process if the various treatment options receive different degrees of public opinion, confidence, or acceptance. However, it is often the case that initial community concerns can be appeased by correct information dissemination.

In practice, total feasibility, scientific soundness, and policy relevance may not be entirely achievable. The quality of the available data may be poor or incomplete, high quality detailed scientific data may not be of operational use, and the available data may not provide the answers required to meet the policy objectives. A major challenge of this process is to avoid an endless quest for perfect new data and to instead use existing databases as much as possible and be creative in the approach to data handling.

1.3 Assessing Uncertainty and Awareness of Limitations

The use of poor quality or incomplete data in a decision-making process has the potential to mislead the user into making misjudged decisions. OECD (2009) refers to the importance of data measurability, timeliness, and coherence over time and location. These characteristics can be used to differentiate between datasets of high and low quality and an understanding of datasets in these terms can provide the user with an understanding of the level of uncertainty that they may face in their final decision outcome.

Uncertainty must be considered in all types of scientific analysis because our ability to control every variable is limited. Uncertainty may relate to any of the previously described characteristics that are desirable in developing perfect criteria and indicators. The assessment of the feasibility of the treatment options cannot successfully demonstrate all of the described characteristics that are necessary for ensuring a robust decision outcome. The limitations of the analysis and an explanation regarding the choices made are described below.

1.3.1 Operationality

The datasets available for *D5.6* are known to be incomplete. This will have consequences for the operationality of the decision-making process as the results will become skewed where an option cannot be compared against a particular indicator. It may be possible to deconstruct the criteria in question into more explicit sub-levels if this would allow the component parts of the treatment option to be compared against the problematic criteria. The work to be completed under *D9.7* intends to compile a complete dataset for each of the hypothetical city archetypes. This will ensure that the analysis for *D9.7* is operational in terms of its data coverage.

1.3.2 Redundancy

Within the scope of *D5.6*, it is not possible to determine which criteria may be redundant because there is no context for the analysis. Without a site-specific context for the application of each treatment option, the relative importance or weighting of each indicator cannot be allocated either. See *Section 1.4* for discussion regarding the importance of local context. Consideration of local context and redundancy will be considered within the context of *D9.7.*

1.3.3 Completeness

It is possible that some important criteria could be missed in the absence of a contextual background forming the basis of the indicator selection process. In order to cover every possible aspect of the chosen criteria applicable to every treatment option, particularly in the absence of context, the list of indicators has the potential to become excessive. This could lead to less meaningful results as the scores from each step of the analysis counterbalance each other. Therefore, it is essential that the criteria and indicators chosen are broad enough to be applicable to all treatment options, whilst remaining specific enough to be measurable. Expert opinion is pivotal in providing objectivity to the evaluation, contributing important insight and knowledge to the design and procedure of the decision-making process. Accordingly, the discursive nature of the criteria selection process intends to reduce bias and to ensure a balanced and fair assessment of the treatment options by complete consideration of the selected and rejected criteria and indicators. Following the work by Ares and Serra (2008), it is suggested that the selection of 10-20 indicators should be sufficient as an acceptable compromise between time and accuracy.

1.3.4 Mutual independence of preferences

Butler et al., (2003) explains that one of the main difficulties decision-makers face in devising sustainability criteria is that they must address social, environmental and economic systems in equal balance and that the consequences for each must be meaningfully compared. This typically involves an attempt to compare data presented in contrasting units of measurement and with varying levels of certainty (Ashley et al., 1999). Uncertainty arises in a decision-making process when the available data is incomplete or cannot be compared to any other dataset. In response to this, a study by Ares and Serra (2008) placed emphasis on measurable indicators even though the data available to them only supported a semi-quantitative evaluation. The chosen indicators were then defined in terms of their positive impact in order that the final scores could be meaningfully compared. This approach has potential for use within the context of *D9.7*.

1.3.5 Presenting uncertainty

Awareness of uncertainty in an analysis of this type is essential to the correct interpretation of the results. Once the areas of uncertainty are identified and understood, it is then necessary to develop a method of presenting this information in order that the decision-maker can make fully informed choices. The statistical office of the EU, Eurostat, compiles data and uses indicators to demonstrate the performance of the EU with regard to numerous aspects of European development. Eurostat has devised a method of determining and presenting the quality and certainty of the data it uses. Each indicator has a quality profile page that provides an overall technical assessment via a three point grading system that relates to data accuracy and comparability between countries and over time. It is designed as a “warning system” to allow the user to quickly assess the certainty of the data and therefore the need for further research (Eurostat, 2009). This approach could be adapted for the purposes of ScorePP to demonstrate an awareness of the associated data uncertainty and to improve the transparency of the project. *D9.1* (Methodology for incorporating uncertainty in evaluations) describes the sources of uncertainty in the ScorePP project and proposes a method for evaluating them.

1.3.6 Subjectivity

Progress towards sustainable management of wastewater necessitates complex multi-criteria and multi-objective trade-offs within a subjective decision framework. This subjectivity is intrinsic in the varying objectives of the decision-maker and other stakeholders, and it cannot be avoided in this type of assessment because the scoring and weighting procedure is determined from a subjective standpoint. Decisions must sometimes be made regarding the relative importance of the chosen criteria and this will vary according to the subjectivity of the stakeholder. This is an unavoidable aspect of every decision-making process and must be carefully managed via thorough explanations of every decision made. If a scoring system is used, it is essential to describe exactly what is meant by each score to ensure clarity for the decision maker and for any end-point users, and also to prevent any potential duplication within the indicators that could lead to a multiplication of emphasis and eventually a skewed decision outcome.

Each assessment must therefore be carefully designed according to the specific objectives and standpoints of the decision makers. The most effective analysis will be developed accordingly whilst using lessons learnt from other projects and studies.

1.4 Local Context in Decision-Making: Implications for ScorePP

The factors that determine the suitability of a particular treatment option for any given effluent show a large degree of site-specific or contextual variability. Ares and Serra (2008) emphasise the need to clearly define the objectives to which a decision-making tool is being applied as the generation of appropriate alternative solutions can be strongly influenced by the context in which a particular problem is viewed.

The characteristics that provide the context for a decision-maker include functional or technical, economic, social, and environmental concerns (Balkema *et al*. 2000). Foxon *et al.* (2002) identified a non-exhaustive sub-set of secondary criteria under each of these four contextual headings as shown in *Table 1*. Each of the criteria can be measured by quantitatively or qualitatively defined indicators, forming the basis for the SWARD decision support process as reported by Butler *et al.* (2003).

The SWARD approach generates a number of conceptualised options that always included a 'do nothing' option. This use of a control is an important consideration that will be included in the MCA of *D9.7*.

Table 1 Generic criteria as used in SWARD

Technical Criteria	Economic Criteria	Social Criteria	Environmental Criteria
System performance	Life cycle costs	Impact on risks to human health	Resource use
Reliability	Willingness to pay	Acceptability to stakeholders	Service provision
Durability	Affordability	Participation and responsibility	Environmental impact
Flexibility and adaptability	Financial risk exposure	Public awareness and understanding	
		Social inclusion	

Source: Foxon *et al.* (2002)

Technical and economic criteria can generally be quantified due to their underlying numerical characteristics. The system performance of each treatment option for example, can be assessed in terms of its PP percentage removal efficiency whilst financial figures can be calculated for each stage of the treatment option life cycle cost. Many economic criteria change over time however, such as willingness to pay and affordability. Technical and economic variations are less site-specific on a national scale than social criteria, and the available data can be assessed hypothetically and without a local site-specific context

Social criteria however, are far more context-specific. The social context is determined by factors such as the local demographics, the local water demand and uses (domestic/agricultural/recreational), and the attitudes of the local society to water management through the community perception of benefits and risks to health and the local environment. This will vary according to the local culture and the level of information dissemination to the public and so a context-free analysis becomes practically meaningless.

The environmental context can be characterised by the nature of the receiving water in terms of its water quality, form, and ecology for example, which show significant spatial variation. The physical and chemical characteristics of the effluent and the temporal variability of its pollutant loading and discharge volume are also central to the environmental context. This is particularly true for surface water run-off and stormwater flows as the discharge is sporadic and can be affected by seasonal variability. Westerlund (2007) describes a higher pollutant load in snowmelt water compared to rainfall for example, resulting from the accumulation of pollutants in fallen snow during the winter months. It was also found that the effects of snowmelt on receiving water quality varied geographically within Sweden as northern areas have a longer snow-covered period than southern areas. A greater quantity of pollutants is able to accumulate in the northern areas as a result, which is then released during the thaw period causing elevated levels in the receiving waters compared to the more southerly areas following the thaw. Water quality patterns and therefore the potential performance of a given treatment option may therefore vary in different countries or at different locations within the same country due to climatic factors. Consideration of geographical differences will be given within the context of *D9.7* (MCA).

Some environmental indicators may be assessed in the absence of site-specific context such as the dilution of a PP required to reduce its concentration to within the regulatory limits, nutrient levels accepted for the mitigation of eutrophication, or the carbon footprint of constructing each treatment option. Other indicators such as the potential for a new installation to provide wildlife habitat will depend on the local ecology and its ability to adapt to environmental change. In the same way that the provision of discharge permits is assessed on a case-by-case basis to allow for site-specific variations, decisions regarding the selection of the most suitable treatment option for any given effluent also require an individual assessment.

In selecting sustainable projects for floodplain restoration, Ares and Serra (2008) identified concepts of sustainability in a local context and then applied weightings to their criteria that also incorporated contextual elements of the analysed situation. Throughout the process, expert opinion was applied in order to tailor the study to the context in question. The objectivity of the evaluation therefore depended on the technical background, experience and objectivity of the expert team. There will inevitably be an element of this in any study of this type, so it is therefore imperative that this type of feasibility study should be conducted by experts with innate contextual knowledge. A manual published by the International Water Association (IWA) (Ashley *et al.* 2004) provides a generic baseline for criteria selection but it warns that it is difficult to compare water service providers (WSPs) without additional complimentary knowledge regarding the context in which the individual suppliers operate. This is of particular importance to *D9.7* as the hypothetical cities may be based in different countries that operate and finance their WSPs in different ways.

The performance matrix idea developed as part of *D5.6* is currently in a generic form in that it does not relate to a specific city, site or scenario. Without the contextual or institutional constraints that a real scenario would impose, the range of criteria and indicators that can be used to discriminate between treatment options is limited to those that are ubiquitous in all wastewater treatment scenarios. Butler *et al.* (2003) identified short-term costs and regulatory constraints as the major drivers behind decisions on stormwater and wastewater management in the UK but criticised the use of these two indicators alone as they were found to encourage the adoption of unsustainable technologies and solutions. The implication illustrated here is that the risk of poor decision-making can increase where decisions are based on a limited range of indicators.

The lack of context in *D5.6* is a significant limitation of the current work in terms of allowing the feasibility of treatment options to be fully assessed. The process is rather intended to highlight the principles and techniques that should be used in *D9.7*, ways in which data can be presented, and to illustrate the potential for uncertainty to enter the MCA.

The use of indicators will be further developed and customised in relation to the semi-hypothetical case city archetypes within the context of *D9.6* (developing these archetypes) and *D9.7.* This will provide for a more comprehensive application of the indicators and will result in a more tailored and robust assessment of the available options in *D9.7.* For example, a list of characteristics or attributes to be defined in *D9.6* for the semi-hypothetical case cites is currently being developed in order to ensure that a complete and context-specific dataset is compiled for each case city before the final MCA of *D9.7* is attempted.

1.5 Application and Scoring of Criteria and Indicators

It is clear from the literature that sound definitions of the aims and objectives of a decision-maker are required, and of any related concepts such as sustainability (Brunner & Starkl, 2004). There are different types of decision-makers involved in PP source control such as local or national level planners and urban developers. These decision-makers have different interests and priorities so they place a varying emphasis on economic, environmental and social concerns. Transparency of approach is therefore of paramount importance in ensuring that the outcomes of a decision-making process are correctly understood. This approach is also necessary in defining criteria and the indicators used to assess them.

Butler *et al.* (2003) list examples of social, technical, economic and environmental criteria that were defined quantitatively or qualitatively in an attempt to establish whether the system is moving towards or away from greater sustainability. The performance of the treatment options should be assessed across all criteria, which will inevitably lead to conflict or trade-offs between them. In order to assess the treatment options in line with the WFD requirement for sustainability, each of the four main screening criteria (economic, environmental and social performance, and technical feasibility) should be allocated equal weighting. Within each of these however, it should be possible to rank the performance indicators in order of importance or preference, thereby allowing conflict and trade-offs to be more easily resolved.

A review of related literature has revealed a wide range of approaches that enable decision-makers to determine between the performances of different options. Some methods rely heavily on subjectivity in assessing the suitability of a given option, whilst others tend towards numerical thresholds in an attempt to reduce the potential for skew caused by subjectivity. It is not possible to address all the criteria relative to ScorePP in a purely objective manner, so it is therefore important to recognise and justify subjectivity where it occurs.

The ultimate main objective of the decision-making process here is to assess the overall performance of treatment options with regard to the various PPs. In the case of *D9.7*, this will be related to specific scenarios. The options should therefore not simply be compared against each other; they must be compared against robust criteria that will determine the total performance capabilities of the options. It may indeed be the case that none of the proposed options are entirely suitable for a given scenario, which would force the decision-maker into a total re-evaluation.

The assessment method used by CEEQUAL (Venables *et al*., 2005) involves a scoring framework resulting from 180 questions regarding 12 areas of environmental and social concern (eg ecology and biodiversity, energy and carbon, and relations with the local community). The responses to each question receive prescribed scores and each area of concern then receives a percentage score via the percentage weightings allocated to each area of concern. Following completion of the questionnaire, the resulting scores are ratified by CEEQUAL Ltd., which appears from the literature to depend on expert judgement. The CEEQUAL process is designed for application to individual projects so the line of questioning is inappropriate for use in *D5.6*. The approach may be useful however, if a new line of questions could be developed in line with the objectives of ScorePP and if the results could be ratified by a balanced panel of experts.

ARUP's SPeAR tool is based on the performance of each indicator against a scale of best and worst cases (Venables *et al.*, 2005). It scores the performance of the site/process being evaluated on a scale of +3 to -3, which are also colour coded. This approach may not be ideal for use in *D5.6* as the aim of ScorePP is to enable the identification of the best treatment option for a given scenario. The scale of best and worst cases is therefore currently an unknown variable so the data is unlikely to be assessable in this way. The SPeAR tool uses a visual spider web diagram method of data presentation that shows the averaged scores as four segments or quadrants on a chart. This method provides a unique profile of strengths and weaknesses for each project assessed. A visual method of presentation may be worth considering for *D9.7* if a numerical method proves to contain too much uncertainty.

A limitation of using numerical scoring is that a misinterpretation of results is possible whereby a score of 2 could be taken to be twice as important as a score of 1. Makropoulos *et al.* (2008) uses a scale of 1 to 5 to assess sustainability but notes that the assessment is has no units and is qualitative within a framework of context specific values. Indicator values are standardised through use of fuzzy inference systems against those of a user defined 'benchmark scenario'. The benchmark could be a 'business as usual scenario' enabling the use of both qualitative and quantitative criteria with different units, values and meanings in the same assessment process. Thus alternative scenarios are then compared to a user-defined point of reference making the assessment 'context aware'. This approach exploits case specific information or stakeholder input and assessment is thus a comparison between a standard solution and an alternative approach rather than involving allocation of scores.

The EU SOCOPSE project (Source Control of Priority Substances in Europe) has similar objectives to ScorePP but with its focus on the Priority Hazardous Pollutants (PHSs) identified in the WFD on a river basin scale (SOCOPSE, 2009). Focusing on industrial and municipal wastewater treatments, the PHSs are assessed in terms of technical feasibility, performance data, costs, and state of the art (distinguishing between Best Available Techniques (BAT), existing technologies, and emerging technologies). Scores are allocated on 5-point scale from good (++) to very bad (--), thereby avoiding the problem of numerical misinterpretation.

Other examples of approaches to scoring data include the DayWater Multi-Criteria Comparator (MCC) (DayWater, 2009). This is a MCA tool that allows criteria to be weighted according to the preferences or objectives of the user. An assessment of this tool may be of use to the MCA of *D9.7.*

Within any process that requires a ranking procedure or another way of assessing risk, it is imperative that any favourable attributes or elements to be avoided are identified specifically and unambiguously. A series of values or a short statement can be sufficient in justifying the allocation of the various ranks and ensuring clarity and transparency. The EU-funded SWITCH project developed a stormwater risk rating matrix whereby the level of consequence of an identified threat or uncertainty is described on five levels (Scholes *et al.*, 2007b). The descriptions of the consequence levels provided in the matrices were not intended to be definitive definitions, but they are able to provide a standardised means for a user to assess risk in a way that is comparable between scenarios. Similar matrices are often used in the Environmental Impact Assessments (EIA) required under EU law for new developments in order that the impact scores allocated to a project are clear and justified to the planners and other stakeholders (PB Power, 2008).

In line with this approach, the screening criteria and indicators for the assessment of the feasibility of industrial wastewater treatment options for the removal of PPs are described and justified in a matrix format. This includes the specification of threshold values where possible that distinguish between the performances associated with the allocable scores.

The main screening criteria selected for this analysis are described in *D9.4*, and are summarised in *Table 2* below. Social implications have been scoped out of this listing for the purposes of *D5.6* because they are too context-specific to be able to be meaningfully analysed in this way. All aspects including the social implications will be considered within the scope of *D9.7* however.

Data can be collected or generated for comparison against criteria in many ways, including direct measurement, stakeholder views, modelling, economic analysis tools (e.g. cost benefit analysis), or environmental analysis tools (e.g. life-cycle analysis). Some datasets may not be in a readily understood or comparable format and will need to be processed before they can be used in an MCA.

Within the scope of *D9.7*, it may be possible to include other indicators such as the level of impact on other environmental receptors, the predicted carbon footprint of each treatment option, or a cost-benefit analysis for wastewater treatment plants (WWTPs). The rationale behind any rejection of the currently proposed indicators or introduction of new indicators will be fully justified in *D9.7*.

Table 2 Agreed screening criteria for industrial treatment according to *D9.4*

Screening Criteria	Indicators	Benchmarks
Technical feasibility	Extent to which appropriate technology exists for removing PP	Level of establishment or development.
Efficiency of proposed procedure	Effectiveness of treatment technology	Potential or actual ability of treatment technology to remove target PP
Financial considerations	Cost associated with the treatment option	Initial investment costs (including adaptation)
		Operating and maintenance costs
Environmental impact	Level of impact on water quality of receiving water	Level of annual average dilution required for the receiving water to achieve the WFD EQS targets.

The threshold values that allow scores to be allocated to treatment options with regard to each of the screening criteria are discussed in *Section 3.*

Whilst the aim of this deliverable is to draw on the information provided within *D5.1-5.5* to support a comparison of the assessed treatment technologies, those evaluated within *D5.2* (PP behaviour in treatment and reuse systems for household wastewater) have not been included within the feasibility matrices developed as part of *D5.6*. This is because *D5.2* concluded that, whilst offering benefits in relation to the saving of potable water supplies, household treatment and reuse technologies would not significantly reduce PP loads because of their affinity for the sediment phase and the periodic discharge of the generated sludges to wastewater treatment plants. The findings of *D5.5* (PP behaviour in sludge) are not fully incorporated as the final version of the report is still in preparation.

2 Data Presentation and ScorePP Matrices

The indicators used must be clearly defined in order to ensure transparency. Work undertaken in relation to the integration of sustainable development into EU policy by the SPRU (Science and Technology Research at the University of Sussex) (SPRU, 2001) describes a number of indicators for use in integrating sustainability objectives with enterprise policy. SPRU uses Indicator Sheets to present information on the indicators such as their titles, units of measurement, relevance to policy, and the data sources used. This approach may be useful for clarifying the coverage of each indicator and the ways in which the associated criteria are able to assess performance.

The data compiled for this analysis are complex and varied. Clear and methodical data presentation is therefore required in order that the performance of each treatment option can be compared. An aspect common to three *WP5* deliverables (*D5.1* - PP behaviour in stormwater BMPs; *D5.3* - PP behaviour in on-site treatment systems for industrial wastewater; and *D5.4* - PP behaviour in end-of-pipe wastewater treatment plants) is the acknowledgement of limited, or in some cases absence, of data on the behaviour of many of the PPs within respective treatment systems. Furthermore, data that is available is reported in a wide range of formats and units. These two aspects in particular (the lack of data and use of multiple reporting units) have serious implications for the robust comparison of alternative technologies.

In order to present the data that have been gathered, a series of matrices have been compiled. PP-specific matrices have been developed in two formats; as the raw data providing an easily accessible overview of the relevant information contained in various ScorePP reports, and in a ‘scored’ format in which the authors have tried to comparatively assess the performance of various treatment technologies identified to remove a particular PP. The rationale and method for this are described in *Section 2.1* and an example matrix containing raw data for benzene is shown in *Table 3.* The scored matrices are presented in *Section 3.2.*

It should be noted that the source of the data contained in the matrices comes from a number of sources as referenced, including the following ScorePP deliverables;

- *D4.1* – List of possible substitutes for each defined use of PP, in particular for diffuse uses;
- *D5.1* - PP behaviour in stormwater BMPs;
- *D5.3* - PP behaviour in on-site treatment systems for industrial wastewater; and
- *D5.4* - PP behaviour in end-of-pipe wastewater treatment plants

Table 3 Matrix containing raw data for benzene (CAS No. 71-43-2)

Type of source and example uses	Type of measure	Available technology	Efficiency	Economic aspects (all costs are treatment as opposed to pollutant specific)			Environmental impact
		Extent to which treatment technology targets removal of PP[a]	Effectiveness of treatment technology		Investment costs	Operational costs	Role in achieving EQS (AA-EQS 10µg/l for inland and 8µg/l other surface waters; MAC-EQS 50µg/l for inland and other surface waters) (EU, 2008) Annual average dilution factor for Inland Surface Waters
Pre-Environmental Release Treatment Production of petrol, styrene, polystyrene, phenol, adipic acid, aniline dyes, polyurethane foams, explosives and drugs, surfactants, polyester resins, plant protection products, lubricating oil additives and disinfectants (Lecloux, 2008)	Industrial wastewater treatment - applicable processes [b]						
	A6 + C3	TS	<0.001 - 1mg/l in effluent [c]	A6	No data		99 times dilution
				C3	0.025-0.267€/m^3[d]	0.04-0.2€/m^3[d]	
	B3 + C3	TS	>99.9%	B3	0.001-0.007€/m^3[e]	0.063-1.62€/m^3[e]	Data not calculable as a dilution ratio
				C3	0.025-0.267€/m^3[d]	0.04-0.2€/m^3[d]	
	B4	TS	No data		8.932-32.191€/m^3[f]	37.545-98.595€/m^3[f]	No data
	B5	TS	80%		No data		Data not calculable as a dilution ratio
	B9	TS	95% removal from feed containing 1mg/l		0.002-0.278€/m^3[g]	0.005-0.685€/m^3[g]	4 times dilution
	B14	TS	99% removal from		0.007-1.292€/m^3[g]	No data	1 times dilution

			concentration of 2mg/l				
	B14 + B9	TS	50mg/l reduced to 500µg/l	B9	0.002-0.278€/m^{3}[f]	0.005-0.685€/m^{3}[f]	49 times dilution
				B14	0.007-1.292€/m^{3}[g]	No data	
	Municipal wastewater treatment						
	WWTP	TNS	83 - >99%[h]; 68.9 – 98.9%[i]; 93±7%[j]; 92-98%[k]	29.0M € [l] 9.7 M € [l]		1.6 € / m^{3} [l] 1.2€ / m^{3} [l] 0.5€ / m^{3} [l]	0.5 times dilution
	Secondary treatment	TNS	~97% ± 3%[j], 94%[j]	No data		No data	No data
	MBNDC [v]	TNS	90%[k]	No data		No data	No data
Post-Environmental Release Treatment Unavoidable by-product of gasoline mobilised by mobilised by e.g. urban runoff	Stormwater BMPs						
	IB; CW SSF; CW SF; PP; EDB; RP; Sw [n, o]	TNS	L/M[m]	See below		See below	Predicted discharge levels of benzene from stormwater BMPs are consistently below the AA-EQS value for benzene and therefore no dilution is required
	Retention pond[n]	TNS	70%[x]	30€/m^{3}[p] ; 119€/m^{3}[q]		1.5€ /m^{3} [p]	
	Infiltration trench[n]	TNS	50%[x]	167€ / m^{3} [p]		11€/ m^{3} [p]	
	Infiltration basin[n]	TNS	90%[x]	31€/m^{3} [p]		0.8€/m^{3} [p]	
	Porous paving[n]	TNS	70% [x]	117€/m^{2} [p]; 100€ / m^{2} [q]		643€ [p, r]	
	Filter strip[n]	TNS	30% [x]	21,503€ [p, s]		694€ [p, s]	
	Swale[n]	TNS	50% [x]	32,961€ [p, t]; 24€ / m^{2} [q]		932€ [p, t]	
	Porous asphalt[n]	TNS	10% [x]	492 €/m^{2} [p]		35€/m^{2} [p]	

	Settlement tank[n]	TNS	10% [x]	120€/m^3 [p]	2€/m^3 [p]	
	Soakaway[n]	TNS	50% [x]	6,445€ [p, u]	271€ [p, u]	
	Detention basin[n]	TNS	30% [x]	60€/m^3 [q]	No data	
	Filter drain[n]	TNS	30% [x]	179€/m [q]	No data	
	Extended detention basin	TNS	70% [x]	No data	No data	
	Lagoon	TNS	10% [x]	No data	No data	
	Surface flow constructed wetland	TNS	90% [x]	No data	No data	
	Sub-surface flow constructed wetland	TNS	90% [x]	No data	No data	

Key

[a] TS Technology available and targets specific PP; TNS technology available but does not target specific PP removal; TUD technology under development; TN technology does not exist

[b] A6 oil-water separation; B3 Chemical Oxidation (ozone); B4 Wet Air Oxidation; B5 super-critical water oxidation; B9 Adsorption to powdered activated carbon; B14 Stripping; C3 Aerobic Treatment (for further information see Revitt et al., 2009)

[c] for full information see Revitt *et al*., (2009)

[d] BREF (2003); ElDefrawy and Shaalan (2007); Van Haandel *et al.* (2007).

[e] Shaalan *et al.* (2007); ElDefrawy and Shaalan H.F. (2007); Canizares *et al.* (2009).

[f] Gamble *et al.* (2008); US ARMY Chemical Materials Agency (2003); Aymonier (2000).

[g] BREF (2003); Shaalan *et al.* (2007); Wang *et al*. (2005).

[h] relates to conventional activated sludge treatment plants; for full information see Seriki *et al.,* (2008)

[i] range of values reflecting predictions made using Byrns, STPWIN and fate models; for full information see Seriki *et al*., (2008)

[j] combined data from the literature; for full information see Seriki *et al.,* (2008)

[k] data from Danish wastewater treatment plants; for full information see Seriki *et al.,* (2008)

[l] data relates to 3 French biological wastewater treatment plants (working document supplied by ESTUDIS)

[m] L/M = low/medium allocated according to an assessment of the relative potential for removal based on a comparison of the removal potential of 52 PPs by the 7 most highly ranking BMPs; for further details see Scholes *et al.,* (2007)

[n] RP retention pond; IT infiltration trench; IB infiltration basin; PP porous paving; FS filter strip; Sw swale; PA porous asphalt; ST settlement tank; So soakaway; DB detention basin; FD filter drain; IB infiltration basin; CW SSF subsurface flow constructed wetland; CW SF surface flow constructed wetland; EDB extended detention basin

[o] 7 mostly highly ranked BMPs; for further details see Scholes *et al*., (2007)

[p] Costs calculated over 50 year lifespan using a 6% discount rate;

[q] whole life cost (including operating costs etc) calculated over 50 year design life using a discount rate of 3.5%; WERF (2005)

[r] cost /ha/yr; Ellis (2005)

[s] relates to a filter strip 7.5m wide; Ellis (2005)

[t] relates to a swale 0.5m deep by 3m wide (double check difference with JBE); Ellis (2005)

[u] relates to a soakaway 1m deep by 1.2m wide; Ellis (2005)

[v] RBC Rotating Biological Contactor; MBR Membrane BioReactor; CW Constructed Wetland; CS Community Scale; MBNDC mechanical, biological, nitrifying/denitrifying, chemical treatment.

[w] Eriksson *et al.* (2009).

[x] Predicted average removal efficiencies for BMPs as calculated using the method described in *Section 2.5.3*.

2.1 Matrix Data Focus

A consequence of the limited availability of data is that the matrices developed to date cover a short-list of 12 PPs. The purpose of *D5.6* is to demonstrate the applicability and usefulness of the MCA approach in preparation for analysis of the semi-hypothetical case-city archetypes in *D9.7*. Hence, it was not deemed necessary at this stage to develop a matrix for every PP, particularly in the absence of essential data for certain PPs. The PPs selected include both Priority Substances (PS) and Priority Hazardous Substances (PHS) as presented in *Table 4*.

Table 4 Short-list of Priority Pollutants assessed in this report

Priority Pollutant	**CAS Number**	**WFD Class**
Benzene	71-43-2	PS
Benzo(a)pyrene	50-32-8	PHS
Cadmium	7440-43-9	PHS
Chlorpyrifos	2921-88-2	PS
Di-(2-ethylhexyl)-phthalate (DEHP)	117-81-7	PS
Diuron	330-54-1	PS
1,2-dichloroethane (EDC)	107-06-2	PHS
Hexachlorobenzene (HCB)	118-74-1	PS
Lead (Pb)	7439-92-1	PHS
Mercury (Hg)	7439-97-6	PHS
Nonylphenols	104-40-5	PHS
Polybromodiphenolether (PBDE)	32534-81-9	PS

The same PPs have, as far as practicable, been short-listed for consideration in *D4.5*. For an overview of how this shortlist corresponds with the PPs selected for work in other WPs, please refer to *Table 3.2* in *D3.2* (Identification of potential PP sources).

2.2 Data Sources

The data used in this deliverable comes from a number of sources. Much of the financial data relating to industrial wastewater treatment comes from the Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques (BAT) in Common Wastewater and Waste Gas Treatment / Management Systems in the Chemical Sector (EEC, 2003a). Data regarding the effectiveness of the industrial wastewater treatment technology was sourced from work conducted in D5.3 (Revitt & Scholes, 2009). Other sources that were used include published scientific literature and a number of websites, all of which are fully referenced where appropriate.

2.3 Data Gaps

In compiling the data necessary to complete the analysis of the 12 selected PPs, it became apparent that certain data could not be obtained from the sources available. Some datasets were incomplete at source, whilst other data could not be obtained due to industrial or commercial confidentiality. It will be necessary to demonstrate which data sets are absent or incomplete for *D9.7* because data gaps can cause uncertainty and a lack of confidence in the final output. An uncertainty analysis is a risk management tool that can be in the form of a discussion of data gaps and the qualitative impact this can have on the results, or it can be in the form of a mathematical appraisal relating to statistical probabilities and resulting in confidence intervals for quantitative datasets. The purpose of this is to identify the critical data gaps that could significantly impact the outcome of the assessment and to promote further data collection if possible, or to discount data gaps as insignificant if they are unlikely to be detrimental to the analysis performance. The importance of this, particularly to *D9.7*, is described in *Section 4.3.*

In order to highlight the gap between the extent of the currently available data and the extent of the data that is required for the more thorough assessment intended for *D9.7*, *Table 5* shows a "wish-list" of information that is desirable for the completion for *D9.7* and a comparison with the available data.

Table 5 "Wish-list" of data to support *D9.7* and comparison with available data

Attribute	**Reason for inclusion**	**Availability**
Treatment efficiency of option	To inform on the desirability of selecting a specific treatment and to support assessment of EQS achievement	Data is currently available for most treatment options but the units are inconsistent – some are provided as a final effluent concentration whilst others show percentage removal efficiency.
Treatment option development status and availability	To advise on treatment feasibility and ability to provide investment costs versus operational costs	Available for most treatment option but in a variety of currencies.
Treated effluent dilution factors such that EQS is achieved	Support assessment of EQS achievement	Calculable from discharged effluent concentrations
River with defined background concentrations of PPs and flow rate	Support assessment of EQS achievement	To be compiled on a site-specific basis for *D9.7*
Number and location of wastewater treatment plants and discharge rate	For investment costs versus operational costs; type of pollutants and indication of importance of source; removal potential; impact on receiving water quality etc.	To be compiled on a site-specific basis for *D9.7*
Location and types of industry	Types of pollutants and indication of importance of source	To be compiled on a site-specific basis for *D9.7*
Types of technology utilised by identified industries and their discharge rates	For investment costs versus operational costs; removal potential etc.	To be compiled on a site-specific basis for *D9.7*
Economic turn-over of industry	Feasibility of implementing additional cost measures	To be compiled on a site-specific basis for *D9.7*
Population of city including proportion employed in various sectors	Indication of impact on employment market; loads entering and leaving WWTP etc.	To be compiled on a site-specific basis for *D9.7*
Indication of local concerns/attitudes	Consideration of public acceptability/uptake of alternative approaches	To be compiled on a site-specific basis for *D9.7*
Land use	Indication of relative importance of sources such as application of pesticides, traffic etc.	To be compiled on a site-specific basis for *D9.7*
Traffic density	Relative importance of sources	To be compiled on a site-specific basis for *D9.7*
Local climate	Indication of seasonal effects on receiving water quality and WWTP loading	To be compiled on a site-specific basis for *D9.7*

2.4 Matrix Format

The criteria and associated indicators used in this assessment were agreed through discussions between the ScorePP partners, and through feedback received from the Advisory Board.

2.4.1 Source control and treatment option categories

The source control and treatment options have been placed in three categories in order to provide a means of distinguishing between the most appropriate solutions for different situations within the matrices. The categories used are described as follows;

- **Pre-Application Control** - This covers all measures put in place before any PP has been produced, used, consumed, or released into the natural environment. This includes voluntary and regulatory initiatives, legislation, emission limit values (ELVs) that may be associated to an industrial discharge consent, preventative measures, phasing out, substitutions etc.

- **Pre-Environmental Release Treatment** - This covers all treatment options that are put in place to remove PPs once they have been produced, used or consumed, but before they have been released into the natural environment. This includes municipal and industrial WWTPs and greywater treatment because the influent is received through pipes from the source and is therefore not released into the natural environment or receiving water until after it has passed through the treatment plant.

- **Post-Environmental Release Treatment** - This covers all treatment options that are put in place to remove PPs after they have been produced, used or consumed, and after they have been released into the natural environment by any means described in the EC Regulation 166/2006/EEC definition. The treatment options included in this category are the stormwater BMPs.

Within the scope of these three categories, each industrial wastewater treatment option has been compared to the selected criteria in the matrices. The criteria have been developed specifically for the industrial wastewater treatment options and may therefore require modification when used in relation to other types of wastewater. They appear as main columns in the scoring matrices and are described and justified in *Sections 2.5*, *2.6*, *2.7,* and *2.8.*

2.4.2 Wastewater treatment options

The wastewater treatment options assessed in this deliverable can be divided into industrial treatment options, municipal WWTPs, and stormwater BMPs (see below). As described in *D5.3*, the industrial treatment options have been coded in order to facilitate the research analyses. The allocated codes are also used in this deliverable and are listed here for reference.

Industrial wastewater treatment processes appropriate for the removal of suspended solids and insoluble liquids

A1. Grit Separation
A2. Settling/sedimentation/clarification
A3. Air Flotation
A4. Filtration
A5. Microfiltration and ultrafiltration
A6. Oil-water separation

Industrial wastewater treatment processes appropriate for the removal of inorganic/non-biodegradable/poorly biodegradable soluble pollutants

B1. Precipitation
B2. Crystallisation
B3. Chemical Oxidation
B4. Wet Air Oxidation
B5. Supercritical water oxidation
B6. Chemical reduction
B7. Chemical hydrolysis
B8. Nanofiltration and Reverse Osmosis
B9. Adsorption
B10. Ion Exchange
B11. Solvent Extraction
B12. Distillation/Rectification
B13. Evaporation
B14. Stripping
B15. Sludge Incineration

Industrial wastewater treatment processes appropriate for the removal of biodegradable soluble pollutants

C1. Anaerobic Treatment
C2. Biological removal of sulphur and heavy metals
C3. Aerobic Treatment
C4. Biological nitrogen elimination

Stormwater BMPs appropriate for the removal of PPs from wastewater

- Retention pond
- Infiltration trench
- Infiltration basin
- Porous paving
- Filter strip
- Swale
- Porous asphalt
- Settlement tank
- Soakaway
- Detention basin
- Filter drain
- Lagoon
- Surface flow constructed wetland
- Subsurface flow constructed wetland

The municipal WWTPs assessed in this deliverable are conventional activated sludge systems.

2.5 Technical feasibility of wastewater treatment options

The technical feasibility of each wastewater treatment option (including industrial treatments, stormwater BMPs, and municipal WWTPs) refers to the practical availability of the option to the decision-makers. This was determined by an extensive review of published scientific literature and other reliable sources such as the IPPC Reference Document on BAT in Common Wastewater Treatment/Management Systems (EEC, 2003a). For example, some of the considered industrial wastewater treatment options are technical methods that have been developed and used for some time. This includes treatment methods that are known to remove certain PPs such as nanofiltration and reverse osmosis. These options therefore have a high technical feasibility for immediate use as they are known to be available on the market and their treatment capabilities are known.

The feasibility for other treatment options to be successfully implemented cannot be so easily defined. This is particularly true of conceptual or non-technical wastewater treatment options such as the use of information campaigns to encourage the public to dispose of banned substances in a correct and safe manner, or the complete implementation of all existing legislatory instruments. These options are less easily defined in terms of feasibility because the extent to which they can be achieved remains unclear. It may be necessary to develop further criteria that are more appropriate to these treatment options within the scope of *D9.7*.

The WWTPs and the stormwater BMPs investigated are unable to specifically target any of the PPs assessed in this deliverable via the pollutant removal mechanisms they employ. Some of the industrial treatment options are able to target specific PPs however. The technical feasibility of the industrial treatment options that apply to the 12 PPs investigated is shown in *Table 6* and the scoring protocol for technical feasibility is shown in *Section 3.1.1*.

Table 6 Technical feasibility of industrial treatment options

PP	Available treatment options		Technical feasibility*
Benzene	A6 + C3 B3 + C3 B4 B5	B9 B14 B14+B9	All target specific
Benzo(a)pyrene)	A2+A4+C3 A3+A4+C3 B3 B4	B5 B9 B14+C3	All TS
Cadmium	A2 A2+A4 A4+B8 B1 B1+A2+A5 and/or B8	B1 with A2, A3, or A4 B8 B9 B10 C2	All TS
Chlorpyrifos	B4+B15+C3 B7 B8	B9 B11 B14+B3+C3	All TS
DEHP	B5 C3		TS TNS
Diuron	B4 B5 B9		TNS TNS TS
EDC	B3 B4 B5 B8 B9+A2	B11 B12 B14 B14+C3	All TS
HCB	A2 B14+C3		All TS
Lead	B1+A2+A4 B1+A2 A4 A4+B8	A2 B1+A2+A4 A4+B1+A2+B10	All TS
Mercury	A2 A2+B10 B1 B1+A2 B1+A3 B1+A4	B1+A5 B1+A2+A4+B9 B3+B10 B8 B9 B10	All TS
Nonylphenol	No applicable industrial treatment processes listed in the BREF documents (BREF, 2003)		
PBDE			

* TS = treatment option targets PP specifically and
TNS = treatment option is non-specific in its PP target

2.6 Technical efficiency of wastewater treatment options

The technical efficiency of a treatment option refers to its effectiveness in removing PPs from the water cycle. In the case of industrial and municipal wastewater treatment options, this may be the actual removal efficiency of a treatment technique that can be calculated from the difference between the influent and effluent concentrations to an industrial or municipal WWTP for example. In relation to other types of treatment option, efficiency may refer to the extent to which an information campaign can change stakeholder behaviour and may lead to reduced releases of PPs. This is a more subtle and complex type of efficiency that is harder to measure and may therefore also require an adaptation of the current criteria for industrial wastewater treatment options within the scope of *D9.7*.

PP removal efficiency data has been gathered from a number of sources as described by *D5.4* for the municipal wastewater treatment options. There is very little data available regarding the technical efficiency of stormwater BMPs for priority pollutants. An effective method for assessing their performance in relation to technical efficiency will be developed within the scope of *D9.7*. The scoring protocol for technical efficiency of industrial wastewater treatment options is shown in *Section 3.1.2*.

2.7 Financial considerations of wastewater treatment options

There are a variety of financial considerations that a decision maker must take into account when assessing the feasibility of treatment options for their specific circumstance. *WP8* addresses the socio-economic analysis of source control options in depth, but of concern here are the financial implications of each treatment option.

The financial considerations associated with the implementation of industrial wastewater treatment options of prime concern to a decision maker can generally be divided into two categories; initial investment costs, and operational and maintenance costs. The initial investment costs refer to the amount that it will cost to introduce a new measure such as for the construction costs associated with a new addition to a WWTP. Operational and maintenance costs are associated with the running costs of a given option, which may include the energy costs associated with a new treatment system or employing operational staff, or the cost estimations for necessary future repair and maintenance work.

This principle can also be applied to other types of treatment option such as the Pre-Application Control options where the initial investment costs might be the funding required for setting up an effective information dissemination campaign. The operational costs in this case, would relate to the cost of disseminating the information and to the cost of any follow-up work required for ensuring campaign success.

Other financial indicators that can be considered are the balance between investment cost and turnover. Although this may be useful in commercial decision-making, this is not suitable for the generic approach adopted at this stage as some stakeholders such as municipalities and protection agencies do not create turnover. It may however be possible to introduce more complex indicators such as this within the scope of *D9.6/7* following input from *WP8*.
Before starting the decision-making process, the decision-maker should identify the amount of capital available for investment in any treatment options that may form part of a wider emission control strategy. This information can then be used to form the basis for the identification of a scale of high/medium/low cost thresholds relating to the budget available and against which the treatment options performance can be assessed. The grading of these thresholds will be developed in detail within the scope of *D9.7* as the values are likely to be subject to a wide degree of variability in different scenarios.

D8.1 (Cost implications of different source control treatment options – Industrial treatment and stormwater BMPs) presents a database of costs for each of the treatment options considered. This database has been used as a reference document in the compilation of the costs of the various treatment options. The scoring protocol for the financial considerations is shown in *Section 3.1.3* and a summary of the financial data referred to in this deliverable is presented in *Table 7* and *Table 8*.

Table 7 Summary of investment and operational costs for industrial treatment options

Industrial treatment options		Investment costs	Operational costs	References
A2	Settling	0.004-0.027€/m^3	0.036-0.074€/m^3	BREF (2003) Shaalan *et al.* (2007)
A4	Filtration	0.001-0.007€/m^3	0.008-0.05€/m^3	BREF (2003) Shaalan *et al.* (2007) ElDefrawy and Shaalan H.F. (2007)
B3	Chemical oxidation	0.001-0.462€/m^3 Not cost effective [*]	0.063-1.620€/m^3	Shaalan *et al.* (2007) ElDefrawy and Shaalan (2007) Canizares *et al*. (2009) [*] Not cost effective when high contaminant levels expected (EC, 2003)
B4	Wet air oxidation	8.932-32.191€/m^3	37.545-98.595€/m^3	Gamble *et al*. (2008) US ARMY Chemical Materials Agency (2003) Aymonier (2000)
B8	Nanofiltration-Reverse osmosis	0.043-0.191€/m^3 [†]	0.013-0.403€/m^3 [‡]	[†] Madwar and Tarazi (2002) Shalaan *et al.* (2001) Ciardalli *et al.* (2000) ElDefrawy and Shaalan (2007) [‡] Ali *et al.* (2005) Van der Bruggen *et al.* (2001) Lastra *et al.* 2004) Madwar & Tarazi (2002) Shaalan *et al.* (2001) Ciardelli *et al.* (2000) ElDefrawy & Shaalan (2007).
B9	GAC	0.002-0.278€/m^3	0.005-0.685€/m^3	BREF (2003) Shaalan *et al.* (2007) Wang *et al*. (2005)
B14	Stripping	0.007-1.292€/m^3	5.22685€/m^3	BREF (2003)
C3	Aerobic treatment	0.025-0.267€/m^3	0.04-0.2€/m^3	BREF (2003) ElDefrawy and Shaalan (2007) Van Haandel *et al*. (2007)
Industrial treatment options discussed in this deliverable that are not listed in this table are omitted due to insufficient data availability.				

Table 8 Summary of financial data for Stormwater BMPs

Stormwater BMPs	Investment costs	Operational costs	Notes
Retention pond	30€/m^{3}[a] ; 119€/m^{3}[b]	1.5€ /m^{3} [a]	[a] Costs calculated over 50 year lifespan using a 6% discount rate [b] whole life cost (including operating costs etc) calculated over 50 year design life using a discount rate of 3.5%; WERF (2005) [c] cost /ha/yr; Ellis (2005) [d] relates to a filter strip 7.5m wide; Ellis (2005) [e] relates to a swale 0.5m deep by 3m wide (double check difference with JBE); Ellis (2005) [f] relates to a soakaway 1m deep by 1.2m wide; Ellis (2005)
Infiltration trench	167€ / m^{3} [a]	11€/ m^{3} [a]	
Infiltration basin	31€/m^{3} [a]	0.8€/m^{3} [a]	
Porous paving	117€/m^{2} [a]; 100€ / m^{2} [b]	643€ [a, c]	
Filter strip	21,503€ [a, d]	694€ [a, d]	
Swale	32,961€ [a, e]; 24€ / m^{2} [b]	932€ [a, e]	
Porous asphalt	492 €/m^{2} [a]	35€/m^{2} [a]	
Settlement tank	120€/m^{3} [a]	2€/m^{3} [a]	
Soakaway	6,445€ [a, f]	271€ [a, f]	
Detention basin	60€/m^{3} [b]	No data available	
Filter drain	179€/m [b]	No data available	
Extended detention basin	No data available	No data available	
Lagoon	No data available	No data available	
Surface flow constructed wetland	No data available	No data available	
Sub-surface flow constructed wetland	No data available	No data available	

Some economic data was collected for three WWTPs in France. However, this data is not presented here because the data availability was considered to be too sparse to be representative of the wide variability that exists across Europe.

2.8 Environmental impact of wastewater treatment options

There is a clear focus on the performance of treatment options with respect to PP removal in *WP5*. However, in order to address the sustainability requirements specified in the WFD, it is necessary to consider the environmental impacts of the assessed technologies. As a contribution to addressing this need, additional sources of data were reviewed including:

- The EU FP5 DayWater Adaptive Decision Support System (Ellis, 2005);
- The WERF (2005) Report on the Post-Project Monitoring of Sustainable Urban Drainage Systems (SUDS);
- Integrated Pollution Prevention and Control Reference Document on Best Available Techniques in Common Wastewater and Waste Gas Treatment / Management Systems in the Chemical Sector (EEC, 2003a);
- Capital and operating costs for three wastewater treatment plants (working document provided by ESTUDIS); and

- Published scientific literature dated from 1999 to 2009. Older publications were referred to on occasion but the emphasis was on literature published within the past 10 years.

The environmental impact of a given treatment option will depend to some degree on the baseline environmental conditions of the receiving water into which the treatment facility discharges. A wide range of receptors can be impacted by the development of new wastewater treatment options, all of which are of relevance to the decision-making process.

The sources of impact and possible receptors are not limited to the receiving water however, and the impacts can be both positive and negative on the receptors. *Table 9* indicates some of the possible generic positive and negative environmental impacts that may result from the implementation of the treatment options. This list is not exhaustive and the actual impacts perceived will vary according to site-specific variations and also according to the chosen treatment option.

Table 9 List of possible environmental impact receptors relating to treatment options

Impact description	**Common impact type**	**Receptor**	**Cause of impact**
Potential for improved water quality and EQS achievement	Positive	Water quality of receiving water body	Removal of PPs from water body
Potential for improved aquatic ecosystem health and EQS achievement	Positive	Ecology of receiving water body	Removal of PPs from water body
Potential for improved amenity value due to improved water quality	Positive	Amenity value of receiving water body	Removal of PPs from water body
Waste streams are inevitable during construction and operation (and also during decommissioning)	Negative	Waste streams	Construction of new development
Increased local noise particularly during the construction phase	Negative	Local population – noise	Installation activities
Increased traffic flows lead to an increase in local accident risk and a deterioration of local air quality	Negative	Local population and air quality	Construction traffic
Potential for a decreased risk to human health, particularly for water users	Positive	Local population – human health	Removal of PPs from water body
The new treatment option may be visible to residents who perceive the development to be attractive/unattractive	Positive/ Negative	Local population – aesthetics	Installation

Environmental performance in industry is strongly driven by regulation. The assessment of environmental impacts resulting from the selection of a given treatment option should therefore be in reference to the standards and indicators included in national and international legislation wherever possible such as the EU Waste Directive (2006/12/EEC) (EEC, 2006b).

The extent of some of the potential environmental impacts listed above will not be determinable until a proposal for development is submitted and a formal Environmental Impact Assessment (EIA) is conducted. For example, the increase due to traffic flow can only be accurately determined once a construction plan is developed. It is therefore not feasible to assess treatment options in this way at this stage. Consideration of these types of variables may be possible within the scope of *D9.7* if there is a sufficient availability of site-specific data. These types of impacts should certainly be considered by future decision-makers that are assessing treatment options for specific real-life scenarios.

D5.3 emphasises the use of Best Available Techniques (BATs), which have been selected by the IPPC as a partial result of their optimum environmental performance. The various BATs will differ in their environmental performance however, during both their construction and operational phases. The identification of a BAT takes into account technical characteristics of installation, geographical location, and local conditions. These factors will play an important role in the development of *D9.7.*

A possible option for assessing the environmental impact of each treatment alternative is the use of the dilution factors that are necessary for an effluent to comply with the Environmental Quality Standards (EQS) stated in the WFD. Using PP removal efficiency data and the PP concentrations permissible for EQS compliance, indices of dilution ratio can be used to compare the treatment method performance with regard to its environmental impact on the water quality of the receiving water body. As water quality has implications for other environmental receptors such as aquatic ecology and amenity value, it is a particularly valuable indicator for treatment option performance. This approach also links the decision-making process with the requirements of the WFD and the IPPC, which is essential to if this study is to meet its objectives.

The method by which dilution factors are calculated is described in *Section 2.8.1*, with *Table 10* to *Table 15* showing the results of the analysis for benzene, benzo(a)pyrene, cadmium, HCB, lead and mercury, respectively.

2.8.1 Wastewater treatment removal efficiencies and dilution ratios

Data relating to the discharge concentrations and pollutant removal efficiency of industrial and municipal treatment options, and stormwater BMPs are compiled in the pollutant matrices presented in this deliverable. The discharge concentration values have been compared with the relevant EQS values for each of the 12 selected PPs and have been used to calculate the dilution ratios required to conform to the legislation for different types of receiving water. This as achieved by applying a mass balance equation (*Equation 1*) at the point of mixing, whilst working under the assumptions that instantaneous mixing occurs and that the upstream PP concentration is zero.

$$\mathbf{Q_uC_u + Q_eC_e = Q_dC_d} \qquad \textbf{Equation 1}$$

where;

Q_u = upstream discharge
C_u = upstream concentration
Q_e = effluent discharge
C_e = effluent concentration
Q_d = downstream discharge
C_d = downstream concentration

To calculate a dilution ratio from this equation, the following substitutions are made;

$C_u = 0$ (i.e. the considered PP is not present in the receiving water upstream of the discharge)
C_d = EQS
n = dilution ratio
$Q_u = n$
$Q_e = 1$, and
$Q_d = n + 1$

The substituted equation can then be rearranged to find the dilution ratio as follows;

$$\mathbf{Q_uC_u + Q_eC_e = Q_dC_d}$$
$$\mathbf{(n \times C_u) + (1 \times C_e) = nC_d + C_d}$$

$$\mathbf{Ce = (n + 1)C_d = nC_d + C_d}$$
$$\mathbf{nC_d = C_e - C_d}$$
$$\mathbf{n = (C_e/C_d) - 1 = (C_e/EQS) - 1}$$

Therefore;

$$\mathbf{Dilution\ ratio = (C_e/EQS) - 1} \qquad \textbf{Equation 2}$$

As there are other factors that are likely to play a role in the downstream concentration of a PP such as infiltration and biodegradation, it is acknowledged that the dilution ratios produced by this calculation are approximate values and that their main purpose is to provide a scale of the likely dilution required. The data produced by this method should not be taken as absolute, but should be used as an indication of the degree of dilution required compared with other treatment options.

2.8.2 Environmental impact of industrial treatment options

To illustrate the method described in *Section 2.8*, *Table 10* shows the results obtained by applying the mass balance and dilution ratio equations to the effluent concentrations for benzene following various types of industrial wastewater treatments. The data shows the dilution ratios required for a discharge containing benzene to comply with the EQS for Inland Surface Waters (ISW) and Other Surface Waters (OSW) in terms of the Annual Average (AA) and the Maximum Allowable Concentration (MAC). If the industrial effluent was subjected to the treatment option of “B9” (adsorption to powdered activated carbon) it would require a dilution of 4 times in order to achieve the Inland Surface Water Annual Average EQS (ISW AA) of <10µg/l. By comparison, the combined treatment option of “A6” (oil-water separation) and “C3” (aerobic treatment) requires a dilution of 99 times before the concentration will be low enough to achieve the ISW AA. The implication here is that combined treatment options of “A6” and “C3” can be considered as having a potentially greater environmental impact than “B9” with regard to the removal of benzene from wastewater because a significantly higher level of dilution is required before the receiving water complies with the EQS.

Suitable industrial effluent data was available for benzene, benzo(a)pyrene, cadmium, HCB, lead, and mercury and the calculated dilution ratios are shown in *Table 10* to *Table 15* respectively. The only available data for chlorpyrifos, DEHP, diuron, and EDC were based on percentage removal efficiencies and in the absence of achievable industrial effluent concentrations for these PPs, it has not been possible to calculate the dilution ratios required for them to meet the EQS. No removal efficiency or effluent concentration data were available at all for PBDE.

The mass balance approach will be used within the scope of *D9.7* for the site-specific scenarios where it may be possible to expand the level of detail applied given that more data will be available at that stage.

Table 10 Dilution factors required for waters receiving wastewater containing benzene to reach EQS

Industrial treatment option	Treatment efficiency & achievable emission level	Dilution factor required to meet benzene EQS (Relevant EQS shown in brackets)			
		AA ISW (10µg/l)	AA OSW (8 µg/l)	MAC ISW (50 µg/l)	MAC OSW (50 µg/l)
A6	10 mg/l	999	1249	199	199
A6+C3	1 mg/l	99	124	19	19
B3+C3	>99.9% removal efficiency	Insufficient data to calculate dilution ratio			
B5	80% removal efficiency	Insufficient data to calculate dilution ratio			
B9	0.05 mg/l	4	5	0	0
B14	0.02 mg/l	1	2	-0.6	-0.6
B14+B9	99% removal efficiency	Insufficient data to calculate dilution ratio			

Table 11 Dilution factors required for waters receiving wastewater containing benzo(a)pyrene to reach EQS

Industrial treatment option	Treatment efficiency & achievable emission level	Dilution factor required to meet benzo(a)pyrene EQS (Relevant EQS shown in brackets)			
		AA ISW (<0.05 µg/l)	AA OSW (<0.05 µg/l)	MAC ISW (<0.1 µg/l)	MAC OSW (<0.1 µg/l)
A2+A4+C3	0.05 mg/l	999	999	499	499
A3+A4+C3					
B14+C3					

Table 12 Dilution factors required for waters receiving wastewater containing cadmium to reach EQS

Industrial treatment option	**Treatment efficiency & achievable emission level**	**Dilution factor required to meet cadmium EQS at maximum & minimum hardness[1]** **(Relevant EQS shown in brackets)**							
		AA ISW		AA OSW		MAC ISW		MAC OSW	
		Class 1[2] (<0.08µg/l)	Class 5[3] (0.25 µg/l)	Class 1 (0.2 µg/l)	Class 5 (0.2 µg/l)	Class 1 <0.45 µg/l)	Class 5 (<0.45 µg/l)	Class 1 <0.45 µg/l)	Class 5 (<0.45 µg/l)
A2 (electrical insulator)	0.005 mg/l	61.5	19	24	24	10	2	10	2
B1 with A2, A3 or A4	<0.01 mg/l	1249	399	499	499	221	66	221	66
C2									
A2 (desulphurisation)	<0.05 mg/l	624	199	249	249	110	32	110	32
A4 + B8 (reverse osmosis)									
A2 + A4	<0.1 mg/l	1249	399	499	499	221	66	221	66
B1									
B1 + A4									
B8	>90% removal efficiency	Insufficient data to calculate dilution ratio							

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[1] Different EQS are set for cadmium in waters of varying hardness (calcium carbonate content) as the solubility of cadmium decreases with increasing hardness.

[2] Hardness Class 1 (softest) is determined as surface water containing <40mg $CaCO_3$/l

[3] Hardness Class 5(hardest) is determined as surface water containing >200mg $CaCO_3$/l

Table 13 Dilution factors required for waters receiving wastewater containing HCB to reach EQS

Industrial treatment option	Treatment efficiency & achievable emission level	Dilution factor required to meet HCB EQS (Relevant EQS shown in brackets)	
		AA ISW & AA OSW (0.01µg/l)	MAC ISW & MAC OSW (0.05µg/l)
A2	59%	Insufficient data to calculate dilution ratio	
B14 + C3 (1st reduction)	1 mg/l	99999	19999
B14 + C3 (2nd reduction)	1 mg/l	99	19

Table 14 Dilution factors required for waters receiving wastewater containing lead to reach EQS

Industrial treatment option	Treatment efficiency & achievable emission level	Dilution factor required to meet lead EQS (Relevant EQS shown in brackets)
		AA ISW & AA OSW (7.2µg/l)
B1+A2+A4	<0.5 mg/l	68
B1(calcium carbonate)+A2		
B1 (lime or iron sulphate)+A2	0.2 mg/l	27
A2	<0.05 mg/l	6
B1 (sodium hydrogen sulphide)+A2+A4 (sand)	>99.9% mg/l	5
A4 (sand)+B8 (reverse osmosis)	0.06 mg/l	0.4
A4+B1+A2+B10	<0.1 mg/l	13
B1 (combined hydrogen sulphide)+A2		

Table 15 Dilution factors required for waters receiving wastewater containing mercury to reach EQS

Industrial treatment option	Treatment efficiency & achievable emission level	Dilution factor required to meet mercury EQS (Relevant EQS shown in brackets)	
		AA ISW & AA OSW (0.05µg/l)	MAC ISW & MAC OSW (0.07µg/l)
A2	70%	Not calculable	Not calculable
A2+B10	0.05 mg/l	999	713
B1(NaHS)+A2	0.004 mg/l	None	None
B1+A4	50 mg/l	999	713
B1+A2+A4+B9	99.8% from flow of 7m^3/h	Not calculable	Not calculable
B3(Cl_2)+B10	0.005 mg/l	99	70
B8	>90%	Not calculable	Not calculable
B9	>90%	Not calculable	Not calculable
B10	<0.5 mg/l	9999	7142

The data presented here have been used to allow the environmental impact of the industrial treatment options to be compared. The scoring protocol for this comparison is described in *Section 3.1.3*

2.8.3 Environmental impact of municipal wastewater treatment plants

In order to assess the environmental impact of municipal wastewater treatment plants (WWTPs), a review of WWTP influent and effluent concentrations from existing literature was conducted. The extent of relevant data available in the literature varied and only a few data sources were found from countries throughout Europe and the USA regarding the composition of effluents from WWTPs. Using this data, the amount of dilution required by receiving waters for the discharge of pollutants through these treatment options to conform to the latest EQS values has been conducted. Data marked with an asterisk (*) represents an influent concentration and the assumption is made that the concentration of the given PP in the effluent following treatment will be less than this figure. Many of the effluent concentrations were found to be below the EQS AA so these effluents are unlikely to cause a receiving water to exceed the relevant water quality standards.

Table 16 Reported PP concentration ranges in WWTP effluent

PP	Effluent concentration range (single figures represent a mean)	Literature source	EQS AA ISW (µg/l)	Dilution required
Benzene	14.94 µg/l	Stangroom *et al.* (1995)	10	0.5
Benzo(a)pyrene	<0.002-0.104 µg/l*	Stangroom *et al.* (1995)	0.05	None-1.1
Cadmium	<LoD[a]-2.3 (following primary sedimentation) µg/l	Lester *et al.* (1979) Karvelas (2003)	0.1	None- 28
Chorpyrifos	<LoD (0.005 µg/l)	Rule *et al.* (2006b)	0.03	None
DEHP	0.5-8	Kobuke *et al.* (2002) quoted in Press-Kristensen (2007) and Marttinen *et al.* (2003)	1.3	None-5
Diuron	<LoD (0.005 µg/l)	Rule *et al.* (2006b)	0.2	None
EDC	2000-2900 µg/l*	Shokrollahzadeh *et al.* (2008)	10	199-289
HCB	0.0017-0.0091 µg/l[b]	Katsoyiannis (2004)	0.01	None
Lead	27-31 µg/l	Karvelas (2003)	7.2	3
Mercury	0.0035 µg/l	Balogh & Nollet (2007)	0.05	None
Nonylphenol	<LoD-37 µg/l	Ying *et al.* (2002)	0.3	None-122
PBDE	0.0063-0.0093 µg/l*	Vogelsang (2006)	0.0005	12-18

* WWTP influent concentration data

[a] LoD = Limit of Detection

[b] primary and secondary treated effluent respectively

2.8.4 Environmental impact of stormwater BMPs

In order to assess the environmental impact of stormwater BMPs, an assessment of the amount of dilution required by receiving waters for the discharge of pollutants through these treatment options to conform to the latest EQS values has also been conducted. This requires knowledge of the typical discharge concentrations from stormwater BMPs and there are very little data available on this in the literature. Alternatively, the discharge levels can be estimated from the influent levels following the application of an appropriate treatment efficiency percentage. This is the adopted approach and the following sections describe how this has been achieved.

Table 17 contains details of the concentration ranges that are reported together with the sources of the data. In some cases, where extreme values have been reported, these have been excluded from the identified concentration ranges.

Table 17 Reported concentration ranges of PPs in untreated stormwater

PP	Concentration range	Literature source
Benzene	0.03 – 0.15 µg/l	Borden *et al.*, 2002 Lopes *et al.*, 2000
Benzo(a)pyrene	322 – 542 ng/l	Hwang and Foster, 2006 Diblasi *et al.*, 2009
Cadmium	0.25 – 1.4 µg/l	Rule *et al.*, 2006a Prestes *et al.*, 2006 Revitt *et al.*, 2004
Chorpyrifos	0.16 – 1.67 µg/l	Dabrowski *et al.*, 2002 Sherrard *et al.*, 2004 Gill *et al.*, 2008 Hunt *et al.*, 2008
EDC	1.7 – 4.2 µg/l	Sheffield *et al.*, 1995
DEHP	0.70 – 2.60 µg/l	Zeng *et al.*, 2008 Rule *et al.*, 2006b Karlsson, 2006. Fromme *et al.*, 2002
Diuron	3.2 – 34.8 µg/l	Huang *et al.*, 2005 Blanchoud *et al.*, 2004 Powell *et al.*, 1996 Revitt *et al.*, 2002
HCB	0.5 – 1.0 µg/l	Lönnermark *et al.*, 2008 Palm Beach County, 2004
Lead	2.0 – 35.0 µg/l	Davis *et al.*, 2003 Lancaster *et al.*, 2009 Prestes *et al.*, 2006 ISBMPD (2009)
Nonylphenol	1.9 – 5.8 µg/l	Kueh and Lam, 2008 Eriksson *et al.*, 2007 Rule *et al.*, 2006b Herrera, 2007 King County, 2007
Mercury	0.1 – 0.82 µg/l	Rule *et al.*, 2006a Nelson *et al.*, 2003
PBDE	NO DATA	-

Data in the literature on the BMP removal efficiencies of Priority Substances (PS) and Priority Hazardous Substances (PHS) is also quite limited, and what does exist mainly refers to constructed wetlands. Therefore, in order to be able to compare across a range of different BMPs it has been decided to use the hierarchy of removal performances for PS and PHS that was developed in *D5.1* for 15 different BMPs. In this study the potential removal mechanisms were assessed both in terms of the specific pollutant and the processes involved in the different BMPs in order to derive removal order of preferences. It is important to note that this order does not have a clear quantitative basis and therefore it has been necessary to make some assumptions in order to convert the order of preference position into a predicted removal efficiency percentage. Where possible this has been done by taking into account the comparability with the limited number of monitored removal efficiencies. The proposed conversion of orders of preference to percentage removal efficiencies is shown in *Table 18*.

Table 18 Relationships between order of removal preference and percentage removal efficiency

Order of preference in removal hierarchy from Deliverable 5.1	Corresponding range of removal efficiencies	Average removal efficiency
1-3	80-100%	90%
4-6	60-80%	70%
7-9	40-60%	50%
10-12	20-40%	30%
13-15	0-20%	10%

It should be noted that the percentages listed here do not correspond to the percentages listed for the industrial treatment options or to those listed in relation to the scoring system described in *Section 3.1*. They are predictions taken from a method described in *D5.1* and are used to create an approximate average removal efficiency for BMPs where a complete dataset was not otherwise available in the literature. Some data does exist in the literature however, that supports the choice of these percentages as being appropriate to the various BMPs. The predicted 90% removal efficiency for benzene in a sub-surface flow constructed wetland for example, compares well with the reported 85% removal of this pollutant in a vertical flow treatment system (Eke and Schulz, 2007). In a study of a stormwater bioretention cell, which has similar removal processes to surface and sub-surface flow constructed wetlands, Diblasi *et.al.* (2008) observed an event mean concentration reduction of 90% for total hydrocarbons. This is consistent with the 90% removal predicted for benzo(a)pyrene for the different types of constructed wetland. A 52% removal of chlopyrifos by vegetated filter strips has been reported by Hunt et.al. (2008), which is slightly higher than the 30% removal predicted for this pollutant. Davis *et al.* (2003) reported close to 100% removal of lead from bioretention facilities receiving synthetic stormwater runoff. Constructed wetlands are predicted to remove lead form sub-surface flow and surface flow systems at levels of 90% and 70% respectively. The mercury predictions in *Table 19* are based on methylmercury and therefore may not be directly comparable with the results reported in the literature. However, the overall reported ranges for constructed wetlands of 70 – 99% (Nelson *et.al.*, 2003; Daukas *et. al.*, 1989; Dorman *et.al.*, 2009) are in good agreement with the predicted removal efficiency of 90%.

The predicted effluent concentration ranges shown in *Table 19* have been used to calculate the dilution capacities required to achieve the annual average EQS for each of the pollutants following discharge into receiving waters. These calculations are based on the assumption that the upstream receiving water system is completely free of each pollutant. *Table 20* to *Table 30* show the calculations for the 12 chosen PPs.

The extent of the dilutions required to meet the AA-EQS for each PP range vary considerably between the different treatment options. The predicted effluent concentrations for benzene from the different BMPs for example, are such that the AA-EQS value for inland surface waters of 1000 ng/l is never exceeded and no dilutions are required for this PP (*Table 20*). In the case of chlorpyrifos, the range of required dilutions is variable both across the different BMPs and also within specific BMPs as a consequence of the varied effluent concentrations that have been predicted for this pollutant. This variability is taken into account within the allocation of the scoring system described in *Section 3.1.4*.

Typical stormwater concentration data was not available for PBDE so it has not been possible to predict a BMP effluent concentration and assess the removal efficiency potential of BMPs with regard to this pollutant.

Table 19 Predicted removal efficiencies for PPs within different BMPs and the resulting discharge effluent concentrations

	Benzene (ng/l)	Benzo(a)-pyrene (ng/l)	Cadmium (ng/l)	Chlorpyrifos (ng/l)	DEHP (ng/l)	Diuron (ng/l)	EDC (ng/l)	HCB (ng/l)	Lead (ng/l)	Mercury (as polymercury) (ng/l)	Nonylphenol (ng/l)	PBDE
Retention pond	9-45 (70%)	160-270 (50%)	175-980 (30%)	80-835 (50%)	350-1300 (50%)	160-17400 (50%)	850-2100 (50%)	250-500 (50%)	1400-24500 (30%)	30-246 (70%)	850-2900 (50%)	No data
Infiltration trench	15-75 (50%)	160-270 (50%)	125-700 (50%)	80-835 (50%)	350-1300 (50%)	160-17400 (50%)	1190-2940 (30%)	250-500 (50%)	600-10500 (70%)	70-574 (30%)	850-2900 (50%)	No data
Infiltration basin	3-15 (90%)	32-54 (90%)	25-140 (90%)	16-167 (90%)	70-260 (90%)	320-3480 (90%)	170-420 (90%)	50-100 (90%)	200-3500 (90%)	10-82 (90%)	190-580 (90%)	No data
Porous paving	9-45 (70%)	96-162 (70%)	25-140 (90%)	48-501 (70%)	210-780 (70%)	960-10440 (70%)	850-2100 (50%)	150-300 (70%)	200-3500 (90%)	50-410 (50%)	570-1740 (70%)	No data
Filter strip	21-105 (30%)	224-378 (30%)	175-980 (30%)	112-1169 (30%)	490-1820 (30%)	2240-24360 (30%)	1190-2940 (30%)	350-700 (30%)	1.4-24.5 (30%)	70-574 (30%)	1330-4060 (30%)	No data
Swale	15-75 (50%)	96-162 (70%)	125-700 (50%)	80-835 (50%)	210-780 (70%)	960-10440 (70%)	500-1260 (70%)	150-300 (70%)	1000-17500 (50%)	30-246 (70%)	570-1740 (70%)	No data
Porous asphalt	27-135 (10%)	288-486 (10%)	225-1260 (10%)	144-1503 (10%)	630-2340 (10%)	2880-31320 (10%)	1530-2780 (10%)	450-900 (10%)	1.4-31.5 (10%)	90-738 (10%)	1710-5220 (10%)	No data
Settlement tank	27-135 (10%)	288-486 (10%)	225-1260 (10%)	144-1503 (10%)	630-2340 (10%)	2880-31320 (10%)	1530-2780 (10%)	450-900 (10%)	1.4-31.5 (10%)	90-738 (10%)	1710-5220 (10%)	No data
Soakaway	15-75 (50%)	160-270 (50%)	125-700 (50%)	80-835 (50%)	350-1300 (50%)	160-17400 (50%)	1190-2940 (30%)	250-500 (50%)	600-10500 (70%)	70-574 (30%)	850-2900 (50%)	No data
Detention basin	21-105 (30%)	224-378 (30%)	175-980 (30%)	112-1169 (30%)	490-1820 (30%)	2240-24360 (30%)	850-2100 (50%)	350-700 (30%)	1.8-31.5 (10%)	50-410 (50%)	1330-4060 (30%)	No data

Filter drain	21-105 (30%)	224-378 (30%)	125-700 (50%)	112-1169 (30%)	490-1820 (30%)	2240-24360 (30%)	1190-2940 (30%)	350-700 (30%)	1.0-17.5 (50%)	70-574 (30%)	1330-4060 (30%)	No data
Extended detention basin	9-45 (70%)	96-162 (70%)	125-700 (50%)	48-501 (70%)	210-780 (70%)	960-10440 (70%)	500-1260 (70%)	150-300 (70%)	1000-17500 (50%)	30-246 (70%)	570-1740 (70%)	No data
Lagoon	27-135 (10%)	288-486 (10%)	225-1260 (10%)	144-1503 (10%)	630-2340 (10%)	2880-31320 (10%)	1530-2780 (10%)	450-900 (10%)	1.8-31.5 (10%)	90-738 (10%)	1710-5220 (10%)	No data
Constructed wetlands (SF)	3-15 (90%)	32-54 (90%)	75-420 (70%)	16-167 (90%)	210-780 (70%)	960-10440 (70%)	170-420 (90%)	150-300 (70%)	600-10500 (70%)	10-82 (90%)	570-1740 (70%)	No data
Constructed wetlands (SSF)	3-15 (90%)	32-54 (90%)	25-140 (90%)	16-167 (90%)	70-260 (90%)	320-3480 (90%)	170-420 (90%)	50-100 (90%)	200-3500 (90%)	10-82 (90%)	190-580 (90%)	No data

Table 20 Calculated dilution ratios required for predicted benzene discharge levels after treatment in different stormwater BMPs

Stormwater BMP	Benzene (ng/l)	Dilutions required to achieve the AA-EQS for inland surface waters of 1000 ng/l
Infiltration basin	3-15	PREDICTED DISCHARGE LEVELS OF BENZENE ARE CONSISTENTLY BELOW THE AA-EQS VALUE AND THEREFORE NO DILUTION IS REQUIRED
Constructed wetlands (SSF)	3-15	
Constructed wetlands (SF)	3-15	
Porous paving	9-45	
Extended detention basin	9-45	
Retention pond	9-45	
Swale	15-75	
Infiltration trench	15-75	
Soakaway	15-75	
Detention basin	21-105	
Filter drain	21-105	
Filter strip	21-105	
Lagoon	27-135	
Porous asphalt	27-135	
Settlement tank	27-135	

Table 21 Calculated dilution ratios required for predicted benzo(a)pyrene discharge levels after treatment in different stormwater BMPs.

Stormwater BMP	Benzo(a)pyrene (ng/l)	Dilutions required to achieve the AA-EQS for inland surface waters of 50 ng/l
Infiltration basin	32-54	None – 0.1
Constructed wetlands (SSF)	32-54	None – 0.1
Constructed wetlands (SF)	32-54	None – 0.1
Porous paving	96-162	0.9-2.2
Extended detention basin	96-162	0.9-2.2
Retention pond	160-270	2.2-4.4
Swale	96-162	0.9-2.2
Infiltration trench	160-270	2.2-4.4
Soakaway	160-270	2.2-4.4
Detention basin	224-378	3.5-6.6
Filter drain	224-378	3.5-6.6
Filter strip	224-378	3.5-6.6
Lagoon	288-486	4.8-8.7
Porous asphalt	288-486	4.8-8.7
Settlement tank	288-486	4.8-8.7

Table 22 Calculated dilution ratios required for predicted cadmium discharge levels after treatment in different stormwater BMPs.

Stormwater BMP	Cadmium (ng/l)	Dilutions required to achieve the AA-EQS for inland surface waters of ≤ 80 ng/l (for water hardness Class 1) and 250 ng/l (for water hardness Class 5)
Infiltration basin	25-140	Class 1: none – 0.8 Class 5: none
Constructed wetlands (SSF)	25-140	Class 1: none – 0.8 Class 5: none
Constructed wetlands (SF)	75-420	Class 1: none – 4.3 Class 5: none – 0.7
Porous paving	25-140	Class 1: none – 0.8 Class 5: none
Extended detention basin	125-700	Class 1: 0.6 – 7.8 Class 5: none – 1.8
Retention pond	175-980	Class 1: 1.2 – 11.3 Class 5: none – 2.9
Swale	125-700	Class 1: 0.6 – 7.8 Class 5: none – 1.8
Infiltration trench	125-700	Class 1: 0.6 – 7.8 Class 5: none – 1.8
Soakaway	125-700	Class 1: 0.6-7.8 Class 5: none – 1.8
Detention basin	175-980	Class 1: 1.2 – 11.3 Class 5: none – 2.9
Filter drain	125-700	Class 1: 0.6 – 7.8 Class 5: none – 1.8
Filter strip	175-980	Class 1: 1.2-11.3 Class 5: none – 2.9
Lagoon	225-1260	Class 1: 2.1-14.8 Class 5: none – 4
Porous asphalt	225-1260	Class 1: 2.1 – 14.8 Class 5: none – 4
Settlement tank	225-1260	Class 1: 2 – 14.8 Class 5: none – 4

Table 23 Calculated dilution ratios required for predicted chlorpyrifos discharge levels after treatment in different stormwater BMPs.

Stormwater BMP	Chlorpyrifos (ng/l)	Dilutions required to achieve the AA-EQS for inland surface waters of 30 ng/l
Infiltration basin	16-167	None – 5
Constructed wetlands (SSF)	16-167	None – 5
Constructed wetlands (SF)	16-167	None – 5
Porous paving	48-501	0.6 – 15.7
Extended detention basin	48-501	0.6 – 15.7
Retention pond	80-835	1.7 – 26.8
Swale	80-835	1.7 – 26.8
Infiltration trench	80-835	1.7 – 26.8
Soakaway	80-835	1.7 – 26.8
Detention basin	112-1169	2.7 – 40.1
Filter drain	112-1169	2.7 – 40.1
Filter strip	112-1169	2.7 – 40.1
Lagoon	144-1503	3.8 – 49.1
Porous asphalt	144-1503	3.8 – 49.1
Settlement tank	144-1503	3.8– 49.1

Table 24 Calculated dilution ratios required for predicted DEHP discharge levels after treatment in different stormwater BMPs.

Stormwater BMP	**DEHP (µg/l)**	**Dilutions required to achieve the AA-EQS for inland surface waters of 1.3 µg/l**
Infiltration basin	0.07-0.26	PREDICTED DISCHARGE LEVELS OF DEHP FOR THESE TREATMENT SYSTEMS ARE CONSISTENTLY BELOW OR EQUAL TO THE AA-EQS VALUE AND THEREFORE NO DILUTION IS REQUIRED
Constructed wetlands (SSF)	0.07-0.26	
Constructed wetlands (SF)	0.21-0.78	
Porous paving	0.21-0.78	
Extended detention basin	0.21-0.78	
Retention pond	0.35-1.30	
Swale	0.21-0.78	
Infiltration trench	0.35-1.30	
Soakaway	0.35-1.30	
Detention basin	0.49-1.82	None – 0.4
Filter drain	0.49-1.82	None – 0.4
Filter strip	0.49-1.82	None – 0.4
Lagoon	0.63-2.34	None – 0.8
Porous asphalt	0.63-2.34	None – 0.8
Settlement tank	0.63-2.34	None – 0.8

Table 25 Calculated dilution ratios required for predicted diuron discharge levels after treatment in different stormwater BMPs.

Stormwater BMP	**Diuron (µg/l)**	**Dilutions required to achieve the AA-EQS for inland surface waters of 0.2 µg/l**
Infiltration basin	0.32-3.48	0.6 – 16.4
Constructed wetlands (SSF)	0.32-3.48	0.6 – 16.4
Constructed wetlands (SF)	0.96-10.44	3.8 – 51.2
Porous paving	0.96-10.44	3.8 – 51.2
Extended detention basin	0.96-10.44	3.8 – 51.2
Retention pond	1.60-17.4	7 – 86
Swale	0.96-10.44	4 – 51
Infiltration trench	1.60-17.4	7 – 86
Soakaway	1.60-17.4	7 – 86
Detention basin	2.24-24.36	10.2 – 121.7
Filter drain	2.24-24.36	10.2 – 121.7
Filter strip	2.24-24.36	10.2 – 121.7
Lagoon	2.88-31.32	13.4 – 155.6
Porous asphalt	2.88-31.32	13.4 – 155.6
Settlement tank	2.88-31.32	13.4 – 155.6

Table 26 Calculated dilution ratios required for predicted EDC discharge levels after treatment in different stormwater BMPs.

Stormwater BMP	EDC **(µg/l)**	**Dilutions required to achieve the AA-EQS for inland surface waters of 10 µg/l**
Infiltration basin	0.17- 0.42	PREDICTED DISCHARGE LEVELS OF EDC ARE CONSISTENTLY BELOW THE AA-EQS VALUE AND THEREFORE NO DILUTION IS REQUIRED
Constructed wetlands (SSF)	0.17- 0.42	
Constructed wetlands (SF)	0.17- 0.42	
Porous paving	0.85-2.10	
Extended detention basin	0.5–1.26	
Retention pond	0.85-2.10	
Swale	0.5–1.26	
Infiltration trench	1.19-2.94	
Soakaway	1.19-2.94	
Detention basin	0.85-2.10	
Filter drain	1.19-2.94	
Filter strip	1.19-2.94	
Lagoon	1.53-2.78	
Porous asphalt	1.53-2.78	
Settlement tank	1.53-2.78	

Table 27 Calculated dilution ratios required for predicted HCB discharge levels after treatment in different stormwater BMPs.

Stormwater BMP	HCB (ng/l)	Dilutions required to achieve the AA-EQS for inland surface waters of 10 ng/l
Infiltration basin	50-100	4-9
Constructed wetlands (SSF)	50-100	4-9
Constructed wetlands (SF)	150-300	14 – 29
Porous paving	150-300	14 – 29
Extended detention basin	150-300	14 – 29
Retention pond	250-500	24 – 49
Swale	150-300	14 – 29
Infiltration trench	250-500	24 – 49
Soakaway	250-500	24 – 49
Detention basin	350-700	34 – 69
Filter drain	350-700	34 – 69
Filter strip	350-700	34 – 69
Lagoon	450-900	44 – 89
Porous asphalt	450-900	44 – 89
Settlement tank	450-900	44 – 89

Table 28 Calculated dilution ratios required for predicted lead discharge levels after treatment in different stormwater BMPs.

Stormwater BMP	**Lead (µg/l)**	**Dilutions required to achieve the AA-EQS for inland surface waters of 7.2 µg/l.**
Infiltration basin	0.2-3.5	PREDICTED DISCHARGE LEVELS OF LEAD FOR THESE TREATMENT SYSTEMS (AND POROUS PAVING) ARE CONSISTENTLY BELOW THE AA-EQS VALUE AND THEREFORE NO DILUTION IS REQUIRED
Constructed wetlands (SSF)	0.2-3.5	
Constructed wetlands (SF)	0.6-10.5	None - 0.5
Porous paving	0.2-3.5	None
Extended detention basin	1.0-17.5	None – 1.4
Retention pond	1.4-24.5	None - 2.4
Swale	1.0-17.5	None – 1.4
Infiltration trench	0.6-10.5	None - 0.5
Soakaway	0.6-10.5	None – 0.5
Detention basin	1.8-31.5	None – 3.4
Filter drain	1.0-17.5	None – 1.4
Filter strip	1.4-24.5	None – 2.4
Lagoon	1.8-31.5	None – 3.4
Porous asphalt	1.8-31.5	None – 3.4
Settlement tank	1.8-31.5	None – 3.4

Table 29 Calculated dilution ratios required for predicted mercury discharge levels after treatment in different stormwater BMPs.

Stormwater BMP	Mercury (as Polymercury) (ng/l)	Dilutions required to achieve the AA-EQS for inland surface waters of 50 ng/l.
Infiltration basin	10-82	None – 0.6
Constructed wetlands (SSF)	10-82	None – 0.6
Constructed wetlands (SF)	10-82	None – 0.6
Porous paving	50-410	None – 7.2
Extended detention basin	30-246	None – 3.9
Retention pond	30-246	None – 3.9
Swale	30-246	None – 3.9
Infiltration trench	70-574	0.4 – 10.5
Soakaway	70-574	0.4 – 10.5
Detention basin	50-410	None – 7.2
Filter drain	70-574	0.4 – 10.5
Filter strip	70-574	0.4 – 10.5
Lagoon	90-738	0.8 – 13.8
Porous asphalt	90-738	0.8 – 13.8
Settlement tank	90-738	0.8 – 13.8

Table 30 Calculated dilution ratios required for predicted nonylphenol discharge levels after treatment in different stormwater BMPs.

Stormwater BMP	**Nonylphenol (µg/l)**	**Dilutions required to achieve the AA-EQS for inland surface waters of 0.3 µg/l.**
Infiltration basin	0.19-0.58	None – 0.9
Constructed wetlands (SSF)	0.19-0.58	None – 0.9
Constructed wetlands (SF)	0.57-1.74	1.6 – 4.8
Porous paving	0.57-1.74	1.6 – 4.8
Extended detention basin	0.57-1.74	1.6 – 4.8
Retention pond	0.85-2.90	1.8 – 8.7
Swale	0.57-1.74	1.6 – 4.8
Infiltration trench	0.85-2.90	1.8 – 8.7
Soakaway	0.85-2.90	1.8 – 8.7
Detention basin	1.33-4.06	3.4 – 12.5
Filter drain	1.33-4.06	3.4 – 12.5
Filter strip	1.33-4.06	3.4 – 12.5
Lagoon	1.71-5.22	4.7 – 16.4
Porous asphalt	1.71-5.22	4.7 – 16.4
Settlement tank	1.71-5.22	4.7 – 16.4

3 Scored ScorePP Matrices

Data have been collected regarding the performance of municipal wastewater treatment plants, industrial treatment options and stormwater BMPs. The data are to be analysed and compared in order to allow an assessment of the feasibility of these treatment options in relation to the previously described indicators (*Section 2.4*). *Section 3.1* describes the scoring protocols for the four indicators, and justifies the rationale behind theses scores. The treatment options are then assigned scores (*Section 3.2*) within a matrix for each of the assessed PPs.

3.1 Scoring Protocol

Suggested criteria for scoring the raw data are described in *Sections 3.1.1, 3.1.2, 3.1.3,* and *3.1.4*. Each criterion is assigned a hierarchy of three values with the score of 1 representing the best performance with regard to the given criterion with scores 2 and 3 representing the poorer performances. This approach is considered to be the most suitable given the available data. It will be possible to amend the criteria and associated scoring system as required for future work within the context of the MCA in *D9.7*.

3.1.1 Technical feasibility

The technical feasibility of each treatment option has been defined in terms of its availability to practitioners. Initially, four categories were identified to express the availability of the technology. The first two categories denote technologies that are already developed and currently available for a given PP, with a distinction made between those technologies that target a specific PP and those that are more general in their level of water treatment. The third category represents technologies that are not yet available or are currently under development, and the fourth represents technologies that do not yet exist for the removal of the PP in question.

However, for the purposes of scoring the performance of each treatment option, it has been necessary to reduce the number to three categories. The available technologies that specifically or non-specifically target PPs have been combined into one category, which enables the resulting three categories to be matched directly with the adopted scoring system. The assumption underlying the scoring system is that greater feasibility amounts to a greater availability of technology. A score of 1 is therefore allocated to treatment options that are fully developed and are in use as opposed to options that remain under development. The scores allocated to the different categories are as follows;

- Score 1: Technology available – targeted removal of a specific PP (TS) or non-specific removal (TNS)
- Score 2: Technology under development for a given PP (TD)
- Score 3: Technology not known to exist for a given PP (TN)

The Score 3 category is included to account for PPs for which no technology has yet been developed for the removal of a given PP. In such a case, the feasibility is therefore low for treating effluents that contain that particular PP so other emission control strategies should be explored.

3.1.2 Technical efficiency

Where available, technical efficiency data are usually quoted either as a percentage removal efficiency within a treatment facility, or as an end-of-pipe effluent concentration. Where influent pollutant concentrations are known, it is possible to calculate the percentage removal efficiency. Based on the data compiled for municipal wastewater treatment plants and industrial treatment options, the following technical scores are proposed for comparing the technical efficiencies of all of the treatment options;

- Score 1: >90%
- Score 2: 70-90%
- Score 3: <70%

Data from stormwater BMPs were not used in the compilation of these percentages as data from WWTP and industrial treatment data were more readily available and were considered to be from a more controlled source and therefore to be more reliable.

Most treatment options investigated perform at a level of removal efficiency above 60%. The scored percentage removal efficiencies were chosen in the upper range of the available data in order to distinguish between the best performing treatment options. An assumption is made that any removal efficiency below 70% is inadequate in facilitating the effective removal of PPs from receiving waters. This is particularly relevant for those substances classed as priority hazardous substances (PHS) such as cadmium and HCB, because EU law (Directive on Priority Substances 2008/105/EEC) states that they must be completely eradicated or phased out within a 20 year timescale.

3.1.3 Financial considerations

The financial considerations of the treatment options relate to investment costs and the operational/maintenance costs. Considerations such as costs to downstream users, marketing costs, or any necessary compensation payments are not considered within the scope of this study as they cannot be calculated with sufficient accuracy given the known data gaps and the site-specific differences. Data are available for the costs of some options but not for all of those investigated. A detailed presentation of economic data is provided by *D8.1*.

An assumption is made that the least costly options will be preferable to decision-makers compared to other more expensive options so a score of 1 is allocated to the cheapest options. This assumption may not be true in all cases due to different types of budget management, but it is considered to be a reasonable assumption for this preliminary analysis. The cost ranges were selected to reflect the range of costs reported in existing literature, whilst also allowing an indication of the cheapest options. The data collected are presented in a number of different units that cannot always be directly compared. The data have been grouped according to the units used and cost range scores have been allocated to each group (*Table 31).*

Table 31 Data range scores for costs presented in different units

	Score	Industrial treatment costs (€/m³)	BMP costs (€/m³, €/m², or €/m)	BMP costs (€)
Investment costs	1	≤ 0.1	≤ 50	≤ 5000
	2	>0.1-1.0	>50-500	>5000-25000
	3	>1.0	>500	>25000
Operation and maintenance costs	1	≥ 0.2	≤ 2	≤ 100
	2	>0.2-2.0	>2-20	>100-500
	3	>2.0	>20	>500

It is accepted that there is an economy of scale for many of the treatment options. The basic principle of this is that money can be saved per cubic metre of treated water by installing large or combined treatment units in place of small units or those conducting fewer treatment techniques (Revelle and McGarity, 1997). The extent to which this effect occurs varies between the various technologies as a result of the economic timing of any technological developments, and the baseline conditions of the city such as its topography and rainfall patterns for example as they affect the peak flows from combined sewers (Hopkins, 2004).

Investment and maintenance cost data were available for only three French wastewater treatment plants. This amount of data was not considered sufficient to allow the development of a meaningful scoring system so it has not been possible to allocate scores for wastewater treatment plant costs.

3.1.4 Environmental impact

Environmental impact is considered here as the potential for a treatment option to contribute towards the achievement of the WFD EQS for each PP by 2015. The extent of the environmental impact for each PP is determined by the dilution ratio necessary for the receiving water to conform to the AA-EQS value for inland surface waters after full mixing with the receiving water. It is accepted that whilst the dilution ratios provide an indication of the potential impact, there is an unavoidable level of uncertainty inherent in the analysis due to processes such as biodegradation, adsorption, and uptake that have the potential to alter the distribution of a given PP in the environment. Furthermore, this method of analysis does not indicate an overall environmental impact as only one environmental receptor is assessed (ie receiving water quality). The applied approach provides an indication of the potential environmental impact that can be used in a comparative sense to allow an assessment of the various treatment options. It should be noted that this approach can only be applied to rivers and is not suitable for lakes or estuaries due to the different mixing processes involved.

The proposed scores for environmental impact for municipal wastewater treatment plants, industrial treatment options, and stormwater BMPs in relation to the annual average EQS (AA-EQS) for each PP are as follows;

- Score 1: ≤ 5 x dilution
- Score 2: 6-25 x dilution

- Score 3: ≥ 25 dilution

Technical Guidance Documents from the European Chemicals Bureau (EBC) recommend the use of dilution factors in assessing the impact of an effluent on the receiving water (EEC, 2003b). The appropriate dilution factor for any given scenario is dependent on the flow rate of the receiving water and the effluent, but the ECB recommends an average minimum dilution factor of 10 for sewage from municipal treatment plants with this figure also used as a default dilution value for other types of substances (EEC, 2003b).

It is accepted that the use of dilution ratios assumes that complete mixing occurs at the effluent's point of entry to the receiving water when in fact there will always be a mixing zone in which higher concentrations occur. Mixing zones are larger when the effluent pollutant concentration is high. As a result, the ECB recommends that a dilution ratio of 1000 should not be exceeded to rivers for site-specific assessments. It should be noted that the range of dilution ratios used here have been selected to include the average dilution factor of 10 stated in the guidance documents. This is to ensure that it is not possible to underestimate the potential environmental impact to water quality caused by the treatment option effluents assessed here.

3.1.5 Total scores

Section 3.2 assesses the 12 PPs addressed in this deliverable and allocates scores for each of the indicators. In some cases, data were not available for certain PPs or treatment options or the existing data could not be cited in a format comparable with other PPs or treatment options. Details are provided in the scored matrices whenever this occurs. Where data were unavailable for a given indicator, it has not been possible to allocate a score. The result of this is that a total score can only be calculated for a given indicator when it has been possible to assign a score for each of the contributing indicators. This represents a limitation of the current analysis and highlights the need for complete datasets when using this approach.

The total scores allocated to the different treatment options can be classified into categories that identify the appropriateness of the overall treatment performance as indicated below;

- **Good** overall treatment performance: Total score **4-6**
- **Satisfactory** treatment performance: Total score **7-9**
- **Poor** treatment performance: Total score **10-12**

3.2 PP Scores

Presented below are the scored matrices for the 12 PPs selected for the current analysis. The scores are allocated according to the ranges identified in *Section 3.1.1* to *Section 3.1.4*, and the scores for the investment costs and the operational and maintenance costs have been combined to show a single score for the financial considerations. Where the data collected for a given treatment option showed a distribution that crossed the ranges allocated for scoring, the score is also presented as a range. The use of ranges extends to the total score allocated for each treatment option with regard to each PP.

Unless otherwise stated, data used to score WWTPs was taken from conventional WWTPs that use biological treatment.

3.2.1 Benzene

Table 32 Scored matrix for benzene (PS)

Treatment Type	Treatment Option	Criteria				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Industrial treatments**					
	A6 + C3	1	**	1-2[a]	3	-
	B3 + C3	1	1	1-2	***	-
	B4	1	*	3	*	-
	B5	1	2	*	***	-
	B9	1	1	1-2	1	4-5
	B14	1	1	*	1	-
	B14 + B9	1	1	1-3	3	6-8
	Municipal wastewater treatment					
	WWTP	2	1-3	*	1	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	2	1	1	5
	Infiltration trench	1	3	2	1	7
	Infiltration basin	1	1	1	1	4
	Porous paving	1	2	2	1	6
	Filter strip	1	3	3	1	8
	Swale	1	3	1-3	1	6-8
	Porous asphalt	1	3	2-3	1	7-8
	Settlement tank	1	3	1-2	1	6-7
	Soakaway	1	3	3	1	8
	Detention basin	1	3	2	1	7
	Filter drain	1	3	2	1	7
	Extended detention basin	1	2	*	1	-
	Lagoon	1	3	*	1	-
	Surface flow constructed wetlands	1	1	*	1	-
	Sub-surface flow constructed wetlands	1	1	*	1	-

* Insufficient data available
** Data not calculable as percentage removal efficiency
*** Data not calculable as a dilution rate
[a] Data for C3 only. No data available for A6
[b] Data for B9 only. No O&M data available for B14
\- Incalculable total score due to data gaps

3.2.2 Benzo(a)pyrene

Table 33 Scored matrix for benzo(a)pyrene (PHS)

Treatment Type	**Treatment Option**	**Criteria**				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Industrial treatments**					
	A2 + A4 + C3	1	**	1-2	3	-
	A3 + A4 + C3	1	**	1-2^{a}	3	-
	B3	1	*	1-2	*	-
	B4	1	*	*	*	-
	B5	1	*	*	*	-
	B9	1	*	1-2	*	-
	B14 + C3	1	**	1-3	3	-
	C3	1	**	1-2	3	-
	Municipal wastewater treatment					
	WWTP	2	1-3	*	1	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	3	1	1	6
	Infiltration trench	1	3	2	1	7
	Infiltration basin	1	1	1	1	4
	Porous paving	1	2	2	1	6
	Filter strip	1	3	3	1-2	8-9
	Swale	1	2	1-3	1	5-7
	Porous asphalt	1	3	2-3	1-2	7-9
	Settlement tank	1	3	1-2	1-2	6-8
	Soakaway	1	3	3	1	8
	Detention basin	1	3	2	1	7
	Filter drain	1	3	2	1-2	7-8
	Extended detention basin	1	2	*	1	-
	Lagoon	1	3	*	1-2	-
	Surface flow constructed wetlands	1	1	*	1	-
	Sub-surface flow constructed wetlands	1	1	*	1	-

* Insufficient data available
** Data not calculable as percentage removal efficiency
*** Data not calculable as a dilution rate
[a] Data for A4 and C3 only. No data available for A3
[b] Data for C3 only. No O&M data available for B14
\- Incalculable total score due to data gaps

3.2.3 Cadmium

Table 34 Scored matrix for cadmium (PHS)

Treatment Type	Treatment Option	Criteria				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Industrial treatments**					
	A2	1	1	1	3	6
	A2+A4	1	**	1	3	-
	A4+B8	1	**	1-2	3	-
	B1	1	**	*	3	-
	B1+A2+A5 and/or B8	1	**	1-2[a]	*	-
	B1 + A2, A3 or A4	1	**	1[a]	3	-
	B8	1	1	1-2	***	-
	B9	1	*	1-2	*	-
	B10	1	**	*	*	-
	C2	1	1	*	3	-
	Municipal wastewater treatment					
	WWTP	2	1-3	*	1	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	3	1	1-2[b] (1[c])	6-7
	Infiltration trench	1	3	2	1-2[b] (1[c])	7-8
	Infiltration basin	1	1	1	1	4
	Porous paving	1	1	2	*	-
	Filter strip	1	3	3	1-2[b] (1[c])	8-9
	Swale	1	3	1-3	1-2[b] (1[c])	6-9
	Porous asphalt	1	3	2-3	*	-
	Settlement tank	1	3	1-2	1-2[b] (1[c])	6-8
	Soakaway	1	3	3	1-2[b] (1[c])	8-9
	Detention basin	1	3	2	1-2[b] (1[c])	7-8
	Filter drain	1	3	2	1-2[b] (1[c])	7-8
	Extended detention basin	1	3	*	1-2[b] (1[c])	-
	Lagoon	1	3	*	1-2[b] (1[c])	-
	Surface flow constructed wetlands	1	2	*	1-2[b] (1[c])	-
	Sub-surface flow constructed wetlands	1	1	*	*	-

* Insufficient data available
** Data not calculable as percentage removal efficiency
*** Data not calculable as a dilution rate
[a] Data for A2, A4 and B8 only. No data available for B1, A5 or A3.
[b] Environmental impact for Class 1 waters
[c] Environmental impact for Class 5 waters
\- Incalculable total score due to data gaps

3.2.4 Chlorpyrifos

Table 35 Scored matrix for chlorpyrifos (PS)

Treatment Type	Treatment Option	Criteria				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Industrial treatments**					
	B4 +B15 + C3	1	*	1-2[a]	*	-
	B7	1	*	*	*	-
	B8	1	1	1-2	***	-
	B9	1	1	1-2	***	-
	B11	1	*	*	*	-
	B14 + B4 + C3	1	*	1-3	*	-
	Municipal wastewater treatment					
	WWTP	2	1-2	*	*	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	3	1	1-3	6-8
	Infiltration trench	1	3	2	1-3	7-9
	Infiltration basin	1	1	1	1	4
	Porous paving	1	2	2	1-2	6-7
	Filter strip	1	3	3	1-3	8-10
	Swale	1	3	1-3	1-3	6-10
	Porous asphalt	1	3	2-3	1-3	7-10
	Settlement tank	1	3	1-2	1-3	6-9
	Soakaway	1	3	3	1-3	8-10
	Detention basin	1	3	2	1-3	7-9
	Filter drain	1	3	2	1-3	7-9
	Extended detention basin	1	2	*	1-2	-
	Lagoon	1	3	*	1-3	-
	Surface flow constructed wetlands	1	1	*	1	-
	Sub-surface flow constructed wetlands	1	1	*	1	-

* Insufficient data available
** Data not calculable as percentage removal efficiency
*** Data not calculable as a dilution rate
[a] Data for C3 only. No data available for B4 or B15
\- Incalculable total score due to data gaps

3.2.5 DEHP

Table 36 Scored matrix for DEHP (PS)

Treatment Type	Treatment Option	Criteria				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Industrial treatments**					
	B5	1	1	*	***	-
	C3	2	2-3	1-2	***	-
	Municipal wastewater treatment					
	WWTP	2	1-3	*	1	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	3	1	1	6
	Infiltration trench	1	3	2	1	7
	Infiltration basin	1	1	1	1	4
	Porous paving	1	2	2	1	6
	Filter strip	1	3	3	1	8
	Swale	1	2	1-3	1	5-7
	Porous asphalt	1	3	2-3	1	7-8
	Settlement tank	1	3	1-2	1	6-7
	Soakaway	1	3	3	1	8
	Detention basin	1	3	2	1	7
	Filter drain	1	3	2	1	7
	Extended detention basin	1	2	*	1	-
	Lagoon	1	3	*	1	-
	Surface flow constructed wetlands	1	1	*	1	-
	Sub-surface flow constructed wetlands	1	1	*	1	-

* Insufficient data available
** Data not calculable as percentage removal efficiency
*** Data not calculable as a dilution rate
\- Incalculable total score due to data gaps

3.2.6 Diuron

Table 37 Scored matrix for diuron (PS)

Treatment Type	Treatment Option	Criteria				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Industrial treatments**					
	B4	2	1	3	***	-
	B5	2	*	*	*	-
	B9	1	*	1-2	*	-
	Municipal wastewater treatment					
	WWTP	2	2-3	*	*	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	2	3	1	2-3	8-9
	Infiltration trench	1	3	2	2-3	8-9
	Infiltration basin	1	1	1	1-2	4-5
	Porous paving	1	2	2	1-3	6-8
	Filter strip	1	3	3	2-3	9-10
	Swale	1	2	1-3	1-3	5-9
	Porous asphalt	1	3	2-3	2-3	8-10
	Settlement tank	1	3	1-2	2-3	7-9
	Soakaway	1	3	3	2-3	9-10
	Detention basin	1	3	2	2-3	8-9
	Filter drain	1	3	2	2-3	8-9
	Extended detention basin	1	2	*	1-3	-
	Lagoon	1	3	*	2-3	-
	Surface flow constructed wetlands	1	2	*	1-3	-
	Sub-surface flow constructed wetlands	1	1	*	1-2	-

*	Insufficient data available
**	Data not calculable as percentage removal efficiency
***	Data not calculable as a dilution rate
-	Incalculable total score due to data gaps

3.2.7 EDC

Table 38 Scored matrix for EDC (PS)

Treatment Type	Treatment Option	Criteria				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Industrial treatments**					
	B3	1	*	1-2	*	-
	B4	1	*	3	*	-
	B5	1	*	*	*	-
	B8	1	2	1-2	***	-
	B9 + A2	1	*	1-2	*	-
	B11	1	*	*	*	-
	B12	1	*	*	*	-
	B14	1	3	*	3	-
	B14 + C3	1	3	1-3[a]	3	8-10
	Municipal wastewater treatment					
	WWTP	2	1-3	*	*	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	3	1	1	6
	Infiltration trench	1	3	2	1	7
	Infiltration basin	1	1	1	1	4
	Porous paving	1	3	2	1	7
	Filter strip	1	3	3	1	8
	Swale	1	2	1-3	1	5-7
	Porous asphalt	1	3	2-3	1	7-8
	Settlement tank	1	3	1-2	1	6-7
	Soakaway	1	3	3	1	8
	Detention basin	1	3	2	1	7
	Filter drain	1	3	2	1	7
	Extended detention basin	1	2	*	1	-
	Lagoon	1	3	*	1	-
	Surface flow constructed wetlands	1	1	*	1	-
	Sub-surface flow constructed wetlands	1	1	*	1	-

*	Insufficient data available
**	Data not calculable as percentage removal efficiency
***	Data not calculable as a dilution rate
[a]	Data for C3 only. No O&M data available for B14
-	Incalculable total score due to data gaps

3.2.8 HCB

Table 39 Scored matrix for HCB (PHS)

Treatment Type	**Treatment Option**	**Criteria**				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Industrial treatments**					
	A2	1	3	1	***	-
	B14 + C3	1	**	1-3	3	-
	Municipal wastewater treatment					
	WWTP[a]	2	1-3	*	1	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	3	1	2-3	7-8
	Infiltration trench	1	3	2	2-3	8-9
	Infiltration basin	1	1	1	1-2	4-5
	Porous paving	1	2	2	2-3	7-8
	Filter strip	1	3	3	3	10
	Swale	1	2	1-3	2-3	6-9
	Porous asphalt	1	3	2-3	3	9-10
	Settlement tank	1	3	1-2	3	8-9
	Soakaway	1	3	3	2-3	9-10
	Detention basin	1	3	2	3	9
	Filter drain	1	3	2	3	9
	Extended detention basin	1	2	*	2-3	-
	Lagoon	1	3	*	3	-
	Surface flow constructed wetlands	1	2	*	2-3	-
	Sub-surface flow constructed wetlands	1	1	*	1-2	-

* Insufficient data available
** Data not calculable as percentage removal efficiency
*** Data not calculable as a dilution rate
\- Incalculable total score due to data gaps
[a] Conventional WWTP with activated sludge

3.2.9 Lead

Table 40 Scored matrix for lead (PS)

Treatment Type	Treatment Option	Criteria				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Industrial treatments**					
	B1 + A2 + A4	1	**	1[a]	3	-
	B1 + A2	1	**	1[a]	3	-
	A4	1	*	1	*	-
	A4 + B8	1	1	1-2	***	-
	A2	1	**	1	2	-
	A4 + B1 + A2 + B10	1	**	1[a]	2	-
	Municipal wastewater treatment					
	WWTP	2	1-3[b]/ 2[c]	*	3	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	3	1	1	6
	Infiltration trench	1	2	2	1	6
	Infiltration basin	1	1	1	1	4
	Porous paving	1	1	2	1	5
	Filter strip	1	3	3	1	8
	Swale	1	3	1-3	1	6-8
	Porous asphalt	1	3	2-3	1	7-8
	Settlement tank	1	3	1-2	1	6-7
	Soakaway	1	2	3	1	7
	Detention basin	1	3	2	1	7
	Filter drain	1	3	2	1	7
	Extended detention basin	1	3	*	1	-
	Lagoon	1	3	*	1	-
	Surface flow constructed wetlands	1	2	*	1	-
	Sub-surface flow constructed wetlands	1	1	*	1	-

* Insufficient data available
** Data not calculable as percentage removal efficiency
*** Data not calculable as a dilution rate
[a] Data for A2 and A4 only. No data available for B1 or B10.
[b] Conventional WWTP with biological treatment
[c] Mechanical, Biological, Nitrifying/Denitrifying, Chemical Treatment (MBNDC)
\- Incalculable total score due to data gaps

3.2.10 Mercury

Table 41 Scored matrix for mercury (PHS)

Treatment Type	Treatment Option	Criteria				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Industrial treatments**					
	A2	1	2	1	***	-
	A2 + B10	1	**	1	3	-
	B1	1	*	*	*	-
	B1 + A2	1	**	1	3	-
	B1 + A3	1	*	*	*	-
	B1 + A4	1	*	1	3	-
	B1 + A5	1	**	*	*	-
	B1 + A2 + A4 + B9	1	1	1-2	***	-
	B3 + B10	1	**	1-2	3	6-7
	B8	1	1	1-2	***	-
	B9	1	1	1-2	***	-
	B10	1	**	*	3	-
	Municipal wastewater treatment					
	WWTP	2	2-3	*	*	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	2	1	1	5
	Infiltration trench	1	3	2	1-2	7-8
	Infiltration basin	1	1	1	1	4
	Porous paving	1	3	2	1-2	7-8
	Filter strip	1	3	3	1-2	8-9
	Swale	1	2	1-3	1	5-7
	Porous asphalt	1	3	2-3	1-2	7-9
	Settlement tank	1	3	1-2	1-2	6-8
	Soakaway	1	3	3	1-2	8-9
	Detention basin	1	3	2	1-2	7-8
	Filter drain	1	3	2	1-2	7-8
	Extended detention basin	1	2	*	1	-
	Lagoon	1	3	*	1-2	-
	Surface flow constructed wetlands	1	1	*	1	-
	Sub-surface flow constructed wetlands	1	1	*	1	-

* Insufficient data available

** Data not calculable as percentage removal efficiency

3.2.11 Nonylphenols

Table 42 Scored matrix for nonylphenols (PHS)

Treatment Type	**Treatment Option**	**Criteria**				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Municipal wastewater treatment**					
	WWTP	2	1-3	*	3	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	3	1	1-2	6-7
	Infiltration trench	1	3	2	1-2	7-8
	Infiltration basin	1	1	1	1	4
	Porous paving	1	2	2	1	7
	Filter strip	1	3	3	1-2	8-9
	Swale	1	2	1-3	1	5-7
	Porous asphalt	1	3	2-3	1-2	7-9
	Settlement tank	1	3	1-2	1-2	6-8
	Soakaway	1	3	3	1-2	8-9
	Detention basin	1	3	2	1-2	7-8
	Filter drain	1	3	2	1-2	7-8
	Extended detention basin	1	2	*	1	-
	Lagoon	1	3	*	1-2	-
	Surface flow constructed wetlands	1	2	*	1	-
	Sub-surface flow constructed wetlands	1	1	*	1	-

* Insufficient data available

\- Incalculable total score due to data gaps

3.2.12 PBDE

Table 43 Scored matrix for PBDE (PS)

Treatment Type	Treatment Option	Criteria				
		Technical feasibility	Technical efficiency	Financial considerations	Environmental Impact	Total Score
Pre-Environmental Release Treatment	**Municipal wastewater treatment**					
	WWTP	2	1	*	*	-
Post-Environmental Release Treatment	**Stormwater BMP treatments**					
	Retention pond	1	*	1	*	-
	Infiltration trench	1	*	2	*	-
	Infiltration basin	1	*	1	*	-
	Porous paving	1	*	2	*	-
	Filter strip	1	*	3	*	-
	Swale	1	*	1-3	*	-
	Porous asphalt	1	*	2-3	*	-
	Settlement tank	1	*	1-2	*	-
	Soakaway	1	*	3	*	-
	Detention basin	1	*	2	*	-
	Filter drain	1	*	2	*	-
	Extended detention basin	1	*	*	*	-
	Lagoon	1	*	*	*	-
	Surface flow constructed wetlands	1	*	*	*	-
	Sub-surface flow constructed wetlands	1	*	*	*	-

* Insufficient data available

\- Incalculable total score due to data gaps

4 Conclusions and recommendations for Tasks 9.6 and 9.7

The objective of the comparative feasibility assessment presented in this deliverable has been to pilot an approach, or a range of approaches that may be suitable for implementation in *D9.7*. It is therefore accepted that the chosen approaches described in this deliverable may require refinement or even replacement where necessary before being incorporated into *D9.7*. This section discusses the appropriateness of the proposed methods of analysis and offers recommendations for improvements to the adopted approach.

4.1 Comparative assessment approach

The approach adopted for this pilot study has been developed to reflect research progress in the field and has followed guidance provided by European and international organisations. The process of assessing treatment options through the identification and scoring of criteria and indicators is considered to be suitable for the current task. It may not be ideal for other projects however, and future projects should incorporate the lessons learnt from the process set out here in order that they can optimise the performance of their own analysis through tailored design.

As described in the introduction, Ares & Serra (2008) suggest the selection of 10-20 indicators as a suitable level of compromise between accuracy and effort. This report has only considered four indicators, which may be considered as insufficient in producing an accurate outcome. This small selection of indicators was chosen to save time at this stage because this deliverable has been designed to demonstrate the approach to MCA assessment rather than to conduct a full assessment of the data. A full MCA will be conducted on the treatment options that are appropriate to the case cites planned within the scope of *D9.7*. This full assessment will include a wider range of indicators in order to ensure a greater level of accuracy in the assessment of the data.

4.2 Data quality

A clear issue for this type of analysis is the necessity for the data set being considered to be as complete as possible in order to provide a robust and reliable outcome. The presence of significant data gaps can result in unfair comparisons of the treatment options, and this has the potential to lead to misguided decision-making by practitioners. It is recommended that tailored research be conducted prior to any feasibility study in order to establish a complete and up-to-date set of data.

The “wish-list” shown in *Table 5* presents a list of data to support *D9.7* that is desirable to allow for a more complete and robust analysis than has been possible here. Projects that adopt the comparative assessment approach presented here should develop a similar list in relation to their specific needs as this can highlight data gaps and areas for further study.

In particular, a study is recommended into the pollutant removal efficiency of the various treatment options because the data set used within the scope of this work has been compiled from a number of sites that are inevitably subject to different climatic conditions and that operate on varying scales. A database of reliable and comparable pollutant removal efficiencies would allow practitioners to quickly assess the potential performance of their wastewater treatment plans. A database of this nature would also be beneficial to urban planning where new wastewater treatment developments are to be in installed to promote the achievement of WFD objectives. This would enable planners to assess the current PP removal capability of a region’s wastewater treatment facilities and to select the most appropriate techniques for improving regional performance with regard to specific pollutants.

The use of pollutant removal efficiencies as an indicator of BMP performance has been criticised in a number of ways as it is claimed to be an over-simplification of the processes involved (Wright Water Engineers and Geosyntec Consultants, 2007). Some of these criticisms may also be relevant to the assessment of industrial treatment options and WWTPs and so it is recommended that the methods used for assessing technical performance are reviewed within the scope of *D9.7*. A memorandum prepared in cooperation with the US Environmental Protection Agency (Strecker and Quigley, 1999) recommends a number of points for consideration when assessing the efficiency and performance of treatment techniques and reviews efficiency calculation methods. This document may serve as a useful guide in the redesign of this element of the ScorePP project.

It is recommended that further study should focus on the selection of a reliable and accurate method of assessing the technical performance of treatment options for PP removal. All of the suggested methods necessitate the use of a comprehensive dataset and so the need is highlighted again for further work into pollutant loadings for the influents and effluents of all treatment options being assessed.

The assessment of economic criteria and associated data has again identified data gaps and issues of data quality and comparability. A detailed cost analysis is essential to any pre-implementation treatment option feasibility assessment in reflection of location-specific traits and variables. Up to date reviews are particularly important as costs change over time in response to changes in the economic climate and in light of the development of new or improved treatment options.

The data relating to financial considerations often showed a range of values for the costs of implementing each treatment option. The data came from a number of sources so the reliability of the data should be considered as variable as the reported costs are likely to vary geographically and temporally.

The use of dilution ratios to assess environmental impact has been developed as an approach that enables a straightforward comparison with the established EQS values for a specific priority pollutant. However, its does represent a considerable simplification of the true situation in that it is assumed that the pollutant is absent from the receiving water upstream of the discharged effluent and that there is immediately complete mixing of the contaminated effluent with the receiving water. There are many factors that influence the mixing process and a more sophisticated assessment of the potential impact of an effluent on its receiving water would take some of these into account.

4.3 Sensitivity and uncertainty

Uncertainty is a well-documented concept that should be considered in a model-based decision support tool such as the approach presented here (Walker *et al.*, 2003). Uncertainty arises within the scope of *D5.6* from a number of sources and at various different levels. The data inputs represent an important location of uncertainty, such as the treatment option data or the benchmarks allocated to the scores. For example, there is a recognised lack of data regarding some of the criteria being assessed for certain PPs or treatment options. This can be due to issues of data confidentiality whereby it is not made available to the public, or because it simply does not exist. Some data have been found to be incomparable with other datasets being used, and in other cases it is not known how reliable the existing data is or to what extent it may be applied to the scenarios described in the deliverable.

It is planned that a complete dataset will be formulated for each of the cities examined in *D9.7* in an attempt to allow a full MCA to be conducted and to reduce the level of uncertainty involved.

It will be necessary to perform a sensitivity analysis on the MCA developed in *D9.7* in order to understand the degree to which the outcome may change if the model is altered. A sensitivity analysis was not conducted in *D5.6* because its purpose was to demonstrate the approach to be used in *D.9.7.* The lack of data has resulted in an incomplete outcome so it would not be possible to complete a meaningful sensitivity analysis on this work.

4.4 Scoring protocols

The scoring protocols suggested in this report are somewhat arbitrary and subjective as they were chosen in the absence of a contextual scenario or location. The scores were allocated in line with the data that was available at the time of writing, which included some significant data gaps and uncertainties. The importance of the scenario to which a feasibility study is applied is made clear by the benchmarks for technical efficiency used within this report. The scores distinguish between the upper ranges of pollutant removal performances, offering no means of distinguishing between treatment options with a lower level of removal efficiency. Within the scope of this study it was not deemed necessary to distinguish between methods that were able to remove less than 70% of the influent pollutant concentration. The percentage removal that is achievable by any given treatment method is a function of the influent pollutant content so it is possible that a lower percentage removal may be capable of achieving an acceptable effluent concentration if the influent concentration is already low. The indicator ranges used for this approach to feasibility assessment must be adapted to fit the objectives of the study in question and should be developed in line with reliable data regarding effluent flows and concentrations.

4.5 Total scores

The purpose of the scoring system within this approach to feasibility assessment is to allow a total score relating to each treatment option to be compared as an aid to decision-making. The data used within the scope of this deliverable had many gaps and inconsistencies as it was sourced from a wide range of papers and other studies in different locations and on different scales of wastewater treatment. This has resulted in some of the indicators failing to receive a score for certain treatments with the consequence of preventing a total score from being reached. Without a total score, treatment options cannot be comprehensively compared with one another and the full objective of the analysis cannot be achieved. It is essential therefore, that the datasets used for this type of analysis are as complete as possible and that the indicators are selected according to the strength of the data that will be used to assess them.

As previously described, the grading system for total scores applied within this deliverable has resulted in a total score for only some of the treatment options. Municipal wastewater treatment plants were unable to achieve a total score for any of the pollutants, highlighting the insufficient nature of the data used for this treatment option. For benzene, cadmium, EDC, and mercury, a total score was achieved for at least some of the industrial treatment processes as well as for some of the BMPs. This allows a comparison between industrial treatments and BMPs for the treatment of wastewater containing the target pollutants (*Table 44*). For example, BMPs have a lower bottom-end to their total score range for the treatment of EDC. This may be used to indicate that the BMPs in question are more feasible for the treatment of wastewater containing EDC than the industrial treatments for which data were available. However, the upper-end of the same ranges overlap so it is clear that a decision-maker would need to investigate further before using these results definitively.

Table 44 Comparable total score ranges of industrial treatment options and BMPs for benzene, benzo(a)pyrene, EDC and mercury

PP	Total score ranges	
	Industrial treatment options	**BMPs**
Benzene	4-8	5-8
Benzo(a)pyrene	6	5-9
EDC	8-10	5-10
Mercury	6-7	5-9

For all the pollutants assessed, removal from stormwater has been predicted to be successful via the use of infiltration basins and retention ponds as they consistently contributed to good total scores. Those pollutants demonstrating evidence of poor removal by BMPs were chlorpyrifos and diuron (filter strips, swales, porous asphalt, and soakaways), EDC (swales and soakaways), and HCB (filter strips, porous asphalt, and soakaways). However, the majority of the BMP performances for the assessed pollutants can be seen to perform at least satisfactorily.

5 References

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