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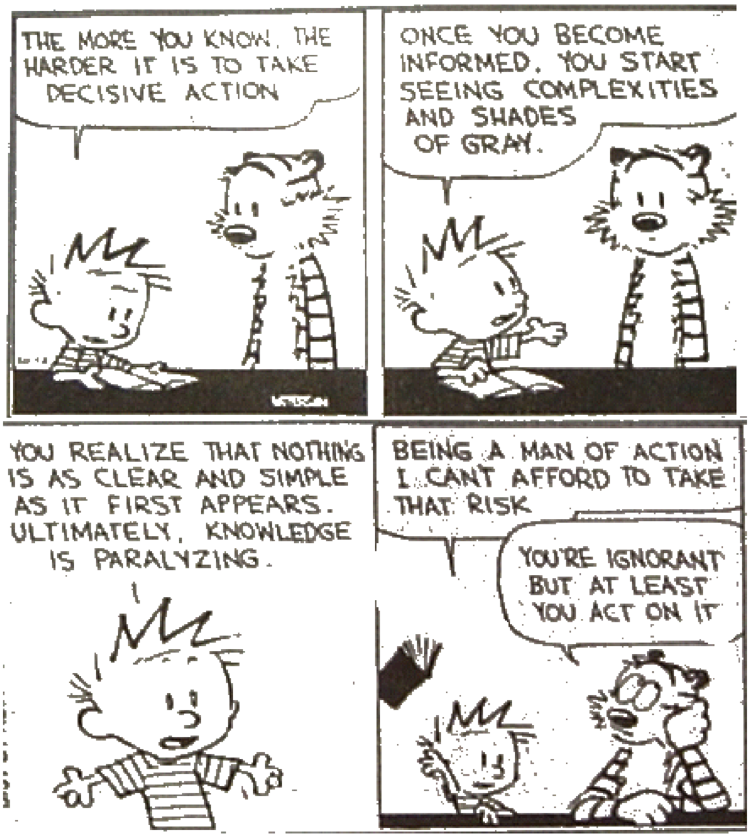

Whitepaper on incorporation of uncertainty in modelling and planning in the project

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Source Control Options for Reducing Emissions of Priority Pollutants (ScorePP)

Sixth Framework Programme, Sub-Priority 1.1.6.3, Global Change and Ecosystems

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Abstract (max. 200 words)

Recent international developments in systemising uncertainty and how it relates to model predictions, generation of scenarios and evaluation of strategies are consolidated into a methodology used in the project. Situations are distinguished where uncertainty is connected to the goal of a strategy, as often seen when several actors have conflicting interests, and to situations where uncertainty is connected with the means to achieve a clearly formulated goal, as often the case when aiming at predicting the future, i.e. applying models. Different levels of uncertainty are also distinguished (e.g. statistical uncertainty, scenario uncertainty, and ignorance) as well as the nature of uncertainty (epistemic or variability uncertainty). A common language is provided to the consortium partners when facing large uncertainties in knowledge, information or future policies. It is the aim that this whitepaper will not only introduce uncertainty to the project and project partners, but that it will also be of help when handling the various uncertainties throughout the project in order to provide more accurate and realistic source control options to reduce the emissions or priority pollutants in urban water systems.

Acknowledgement

The presented results have been obtained within the framework of the project ScorePP - “Source Control Options for Reducing Emissions of Priority Pollutants”, contract no. 037036, a project coordinated by Department of Environmental Engineering, Technical University of Denmark within the Energy, Environment and Sustainable Development section of the European Community’s Sixth Framework Programme for Research, Technological Development and Demonstration.

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Executive summary

The availability of a common ground to describe uncertainty-related issues is necessary to be able to systematically tackle them. The basic terminology consists of the definition of uncertainty: **location** (where can uncertainty hide? in model structure? parameters?), **level** (how bad is the knowledge we have? can we define probability distributions of quantities? do we know that we don't know about something?) and **nature** (is the phenomenon inherently variable? or can we reduce the uncertainty with more research?).

By making predictions of pollutant concentrations in the environment using a mathematical **model**, one should be aware of the limitations of the model's parameters, structure and inputs, which are always laden by a certain degree of uncertainty. Some instruments to cope with these uncertainties are Monte Carlo simulations, model structure comparisons and generation of input scenarios.

One of the most useful tools to investigate the properties of a model (e.g. of a physical system like a river basin, or of a decision-making process) is a **sensitivity analysis**. It allows the identification of the parameters which deserve more attention (i.e. having more information on them would considerably reduce the prediction uncertainty ➔ list of research priorities) and situations in which prediction outcomes change substantially by changing some parameter values (e.g. the ranking of preferences in a multi-criteria decision analysis). Specific uncertainty assessment methods are available for substance flow analysis in order to compare the estimated substance fluxes in the studied system.

Other categories of uncertainty which may be encountered are **scenario uncertainty** and **goal uncertainty**. These types of uncertainty reveal, respectively, the possibility to indicate a trend consequent to system modification while not quantifying it (e.g. will voluntary reduction decrease PPs in the environment? The answer is probably 'yes', but we can not say how much), and the difficulty in setting well-defined objectives for an activity since they can vary without the control of who has to set them (e.g. we want to reduce PP concentrations in the environment, but down to what limit? we don't know which will be the local regulation to apply).

All the previously mentioned types of uncertainty may be found in the ScorePP project, and the locations which can be pointed out a priori are listed in this document. Other areas of uncertainty will most likely arise throughout the project as work in the different work packages is conducted and results are obtained. Some areas of uncertainty are specifically addressed and indicated in this document, while other areas will require additional attention, particularly those that are less obvious.

1. Introduction

Scientists and engineers are often taught that uncertainty lies merely within the realm of statistical uncertainty, whereby several statistical tests and parameters are employed to capture much of this uncertainty and variability quantitatively. However, it is increasingly more evident that we need to go beyond statistical descriptions of uncertainty in order to accurately and realistically describe current models, regardless if they are simple systems or extremely complex systems, as in the case of urban water systems and receiving environments pertaining to the ScorePP project. Quantitative and qualitative descriptions of uncertainty have become increasingly more prevalent within describing and predicting model systems, and in fact, uncertainty involved in global climate change, for example, has played a major role in scientific and debate, policy and decision-making. The ScorePP project attempts to describe some of the uncertainty involved in some areas of the project, such as the project's dimensions and formulation, interpretation of results, assumptions, uncertainties on chemical properties and the receiving environments. As will be described in this whitepaper, there are areas within the "total ignorance" uncertainty category in which we, as uncertainty analysers and project participants, may be completely unaware that these uncertain areas exist (i.e. we are ignorant of what we do not know). Nonetheless we attempt to describe areas of uncertainty within this project.

Therefore, this whitepaper attempts to describe and document in a systematic manner the identified areas of uncertainty within the ScorePP project, and is set-up in the following manner. First, the terminology used to describe uncertainty is presented; introducing concepts and terminology of uncertainty, such as location, level and nature, and scenario uncertainty, recognized and total ignorance will also be presented and addressed. Then, uncertainty in model prediction is introduced, with its contributors being parameters, structure and inputs. Next, the uncertainty matrix and sensitivity analysis are described. Uncertainty in scenario formulations is also described, which occurs when the relationships between factors influencing the model are not well-understood. Finally, the locations where uncertainties arise within the ScorePP project are documented and are listed according to the defined project tasks.

The present deliverable report contains only the summary description suitable for an external audience, i.e. Appendix B is not included.

2. Terminology

In order to adequately begin describing concepts of uncertainty within this project, as well as to compare these uncertain areas to other projects and studies, it is important to use a consistent terminology in this analysis. Similar to other areas of science, only when scientists can agree on the terminology to be used can there be a starting point to begin describing and elaborating on a model's property, such as uncertainty parameters. Terminology presented by Walker et al. (2003) is used throughout this project, and is described in more detail in the following sections.

2.1. Location of uncertainty

This dimension attempts to identify the various sources of uncertainty within a model, or in our case, within the SCOREPP project. The locations of uncertainties may be further identified by:

- *Context*, which identifies the boundaries of the system according to the various stakeholders;
- *Model*, where uncertainty in the model's structure reveals gaps in the relationships between variables, etc. (*model structure uncertainty*) as well as technical uncertainties such as soft- or hardware errors, etc. within the model (*model technical uncertainty*);
- *Inputs*, which involve primary data in the model and include uncertainty about *external driving forces*, which can produce changes within the system from external sources, and the *system data*, where uncertainties arise from a lack of knowledge on the properties of the system;
- *Parameters* used in the model; and
- *Model outcome uncertainty*, which results from the summation of all other uncertainties within the model.

2.2. Level of uncertainty

Different levels of uncertainty refer to the range of available knowledge or rather, lack of. Walker et al. (2003) identified a range of uncertainty levels extending from determinism, an unrealistic, ideal situation in which no uncertainty exists, to total ignorance (see Figure 1). The levels in between determinism and total ignorance include:

- *Statistical uncertainty*, usually described in statistical terminology and attributed to uncertainties surrounding measurement and sampling errors, probabilities, etc.;
- *Scenario uncertainty*, which describes possible outcomes or scenarios in the future without well-understood mechanisms and probabilities of the likelihood of different scenarios are not developed; and
- *Recognized ignorance*, the state where fundamental uncertainty exists and the scientific basis is insufficient to develop functional relationships, statistics, or scenarios.
- Finally, *total ignorance* is the deepest level of uncertainty, which is the state when one does not know what is unknown.

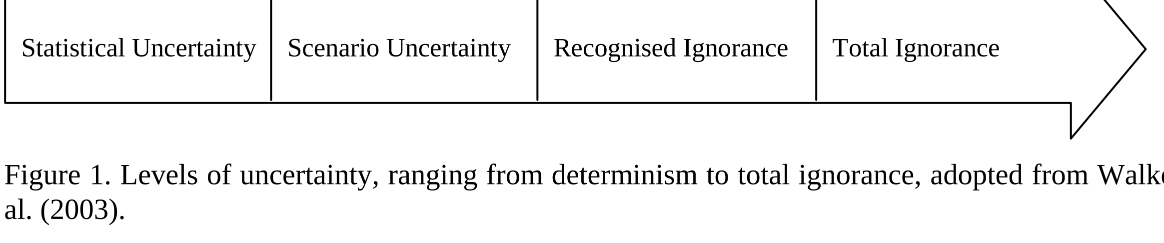

Figure 1. Levels of uncertainty, ranging from determinism to total ignorance, adopted from Walker et al. (2003).

2.3. Nature of uncertainty

This dimension describes uncertainty according to whether it can be reduced if more research or empirical efforts were conducted, termed *epistemic uncertainty*, or if the uncertainty is due to inherent variability and further research/efforts will not reduce it, termed *variability uncertainty*. Because natural and human systems as well as social, economic, cultural and technological dynamics occur in often unpredictable manners, increased research may not succeed in reducing uncertainties laying within these fields.

2.4. Scenario uncertainty

A scenario is a possible scheme or situation that may develop in the future, using realistic assumptions about relationships and/or driving forces within the model. Scenarios are similar to realistic "brain-storming" activities formulated, and because the scenarios are based upon assumptions that can not be verified, *scenario uncertainty* incorporates uncertainty that is beyond mere statistical uncertainty. Scenario uncertainty involves a range of different scenarios that may happen, and because the relationships between the relationships/driving forces are not well understood it is not possible to derive the probabilities of the scenarios taking place.

2.5. Recognized and total ignorance

When it is acknowledged that there is a sufficient lack of information or certainty in deriving the relationships/driving forces of a model, *recognized ignorance* occurs. As stated previously, *total ignorance* is the state where a deep level of uncertainty exists and also extends to the situation where one is unaware of own ignorance of the system studied, such as when it is unknown what is unknown.

4. Uncertainty in model predictions

The outputs of model simulations are uncertain due to three main sources on uncertainty: parameters, structure and inputs. The impact with regards to model-assisted decision-making is of extreme importance, and uncertainty analyses should always be performed in any modelling study. A comprehensive guidance on uncertainty analysis has been produced by Refsgaard *et al.* (2006), and the reader is directed to that document for more detailed information. A brief description of the three uncertainty sources is given below together with suggestions on how to evaluate uncertainties within ScorePP.

4.1 Parameters uncertainty

Model parameters – quantities which stay constant throughout a model simulation – are seldom known with certainty. Parameters like gravity acceleration can be assumed to be actually known, while quantities like the maximum growth rate of bacteria in an activated sludge tank are much more uncertain due to the difficulties in measuring them and because they may even vary according to different process conditions. In these cases, instead of assuming crisp values for the parameters, probability density functions (PDFs) should be used to describe them, built from available information sources like literature values, conducted experiments, expert knowledge, etc.

When PDFs are available for uncertain and relevant parameters, information can be obtained by performing a sensitivity analysis of the model. The uncertainty parameter can be propagated to the model output uncertainty by means of Monte Carlo (MC) simulations. A MC simulation consists of performing multiple simulations with the same model, but each time randomly sampling different parameters from the PDFs, then doing a statistical analysis of all simulation outputs (Benedetti et al., 2006).

When necessary, MC simulations can be performed within ScorePP, since the modelling and simulation software which is used in the project (WEST) is capable of running them. With this perspective, **all information useful to create the PDFs for the parameters should be collected when encountered during the investigations carried out in all work packages**.

4.2 Structure uncertainty

Concerning this type of uncertainty, not many attempts can be found in the literature, due to inherent complexity. The major obstacle is that it is difficult to test many different model structures, which in principle should also be tested relative to their parameter uncertainty, making the number of necessary simulations difficult to handle. Furthermore, it is not straightforward to decide with which criteria the model structure should be modified from the original one. However, what is usually done is to test two or more different acceptable (or proposed) models and evaluate the differences between the outputs. Conclusions can be drawn by assessing the sensitivity of results to the model structure.

Within ScorePP, structure uncertainty will not be explicitly considered for the integrated model, because of the complexity of the task. However, in the model development phase for the unit process models, several alternatives should be compared to evaluate sensitivity to model structure.

As for the model structure technical uncertainty, which refers to the model coding errors, two independent implementations of some of the models are foreseen to be performed by UGent and model*EAU* so that potential differences can help finding errors.

4.3 Input uncertainty

The uncertainty due to model inputs, at least in the water domain, is usually a mixture of both variability and epistemic uncertainty. Some phenomena are inherently chaotic (e.g. instantaneous precipitation), while for some others we lack sufficient knowledge or predicting power, especially in the long-term (e.g. local yearly rainfall, air temperature, chemicals consumption and release). To deal with this, several different input scenarios are usually fed to the model, and the range of model responses is analysed. This will be the approach adopted for the ScorePP project.

4.4 Uncertainty matrix

As presented by Walker et al. (2003), an uncertainty matrix provides a graphical overview of the uncertainties within a model (Table 1). This matrix representation of uncertainty will be applied during the development of the models throughout the project.

Table 1. Uncertainty matrix, adopted from Walker et al. (2003).

<table>
<tr><th colspan="2" rowspan="2">Location</th><th colspan="3">Level</th><th colspan="2">Nature</th></tr>
<tr><td>Statistical uncertainty</td><td>Scenario uncertainty</td><td>Recognized ignorance</td><td>Epistemic uncertainty</td><td>Variability uncertainty</td></tr>
<tr><td>Context</td><td>Natural, technological, economic, social and political, representation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Model</td><td>Model structure</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Technical model</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Inputs</td><td>Driving forces</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>System data</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Parameters</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

4.5 Sensitivity analysis

Sensitivity analysis (SA) is the study of how the variation in the output of a model (numerical or otherwise) can be qualitatively or quantitatively apportioned to different sources of variation, and of how the outputs of a given model depend upon the information fed into it (Saltelli et al., 2000, 2004). SA is the one of the main instruments to address uncertainty when quantification is possible (e.g. models, multi-criteria assessment). Its application locates the most important contributions to the output uncertainty, either to find out whether inputs are more important than parameters, or e.g. to rank the most sensitive parameters. SA is therefore fundamental to direct the limited resources to reduce uncertainty by trying to gather more information on the most sensitive model parts.

SA should be used in any activity which requires it in ScorePP. In particular, for model predictions global SA techniques are suggested due to the complexity and non-linearity of the models used in this project (Saltelli et al., 2000, 2004). For multi-criteria decision analysis, several techniques are also available (Triantaphyllou and Sánchez, 1997; Hyde et al., 2005) and the choice will be made during the dedicated task.

4.6 Uncertainty in Substance Flow Analysis

A specific case of relevance for the project is the assessment of uncertainties in the context of Substance Flow Analysis (SFA). For SFA, dedicated methods have been developed to estimate the confidence in the predicted flows, based on the quality of the data used (Danius and Burström, 2001).

5. Uncertainty in scenario formulations

As defined previously, scenario uncertainty involves a range of feasible outcomes, which are elaborated in the “What if” scenario below. Scenario uncertainty is not able to predict the probabilities of the range of outcomes since the relationships between factors influencing the model are not well understood. There is also uncertainty surrounding the goals or the outcome of the project, in this case, which is termed goal uncertainty.

5.1 What if?

The “What if” category under scenario uncertainty deals with brainstorming about possible scenarios that could plausibly happen in the future and which present further sources of uncertainty. The main scenarios considered are situations where defined Emissions Control Strategies are implemented.

5.2 Goal uncertainty

The main goal of the SCOREPP project is to reduce the emissions of priority pollutants (PPs) in urban water systems. However, there may be some uncertainty related to the extent to which a reduction in the PPs is considered satisfactory. On one hand, the extent of reducing PPs is, nonetheless, aimed at complying with the Water Framework Directive and supporting the EU strategy for Sustainable Development. However, on the other hand, because ScorePP involves several different countries across Europe, where each country may have different situations (economic, cultural values, etc), uncertainty may be added to the extent in which the reduction of PPs is achieved.

6. Uncertainty within ScorePP

6.1 Overview of uncertainty, categorized in three subsystems

In order to begin identifying where uncertainty lies within the ScorePP project, an identification of the location, level, and nature of uncertainty is needed. Similar to previous work by Hauger et al. (2003, Draft version), three main subsystems are identified where uncertainties may lie within the scope of the project and which are based on the urban water system (Figure 2):

- technical system
- social system
- environmental system

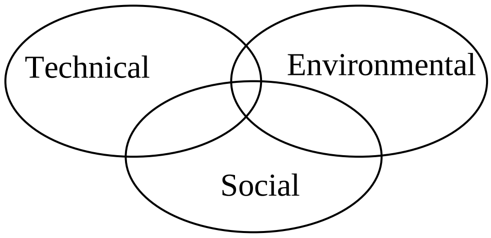

Figure 2. The three subsystems identified within the ScorePP project which contain uncertainties, adopted from and Hauger et al. (2003, Draft version).

6.2 Questionnaire developed for work package leaders

In order to systematically describe uncertainty within the ScorePP project, a questionnaire was developed and disseminated to the work package leaders at the beginning of Task 9.1. Since the work package leaders would naturally be more familiar with their respective work package(s), it was advantageous to ask them to identify and characterize the known uncertainties on the work package level. The work package leaders were asked to read the Walker et al. (2003) paper, which explains the terminology on uncertainty, and the following questions were posed:

- Where is uncertainty located in the work to be carried out in the WP? Which are the aspects within the WP that have uncertainty? (posed both before/after reading the Walker et al. (2003) paper).
- Then, for each of the mentioned locations of uncertainty,
    - Identify the level of uncertainty (statistical uncertainty < scenario uncertainty < recognised ignorance < total ignorance).
    - Identify the nature of uncertainty (reducible, non-reducible).
    - How are these uncertainties usually dealt with in your experience?
- What do you expect as potential benefits from an uncertainty assessment in the WP?

A copy of the questionnaire is provided in Appendix A. The locations of uncertainty within each work package were compiled after receiving completed questionnaires from the work package leaders. However, only a total of 2 out of 10 questionnaires were completed and returned, and therefore the missing questionnaires were supplemented by input from DTU and UGent (Task 9.1 partners). The locations of uncertainties on a task basis are shown in Appendix B (not part of this publicly available deliverable report).

6.3 Identified uncertainties

Technical system

Description	**WP**
Priority Pollutant list a. metabolites inclusion b. summary parameters c. information available on properties, etc. d. Case city baseline information- variability between cities/nations, etc	3 2
Emission statistics and release factors produced a. uncertainty across spatial/temporal scales b. uncertainty on monitoring of emissions and releases – depending on funding schemes, which PPs monitored, etc.	3
Feasibility of strategies to reduce the use of PPs a. Substitution options: uncertainty lies within the determination of choosing which product is "better"- depending on information available, values of person(s) judging, which end-points are monitored (cancer, endocrine disruption, etc.) b. The definition of "feasibility": different people/cultures may think of something as "feasible" in different ways.	4
Technologies available for eliminating the discharge of PPs to receiving waters a. Identification of most feasible and appropriate PP reducing technologies (see above description of uncertainty in feasibility) b. The effectiveness of the technologies under unpredictable circumstances- flooding, droughts, cost-effectiveness, etc. c. For stormwater BMPs, household re-ruse and treatment systems, wastewater technologies and treatment processes there are a choice of options available (i.e. context uncertainty). Also, options which have yet to be devised or widely publicised may be omitted from the ScorePP project.	5
BMP ranking method a. Input of the data for applying the developed method of ranking BMPs for PP emission control (system data uncertainty). b. Uncertainty in the PP information available from T3.1 for input into WP5. There is a need to choose which values to use for input parameters in some cases (due to a lack of data and/or variation in the experimentally determined parameters reported). c. Some level of uncertainty is inherent in our BMP ranking method as this is in fact a key point leading to the development of the method (i.e. practitioners need to make decisions even in the face of incomplete knowledge which is why we have developed this ranking system). d. The ranking system is quite simple in its structure (model structure uncertainty). e. There is uncertainty involved in choosing the cut-offs for classifying the importance of particular removal mechanisms as high, medium, and low. This involves personal opinions and hence a degree of subjectivity. f. Uncertainty in relation to the application of weightings for individual processes (e.g. volatilisation) considered in the ranking method.	5
GIS tool for showing sources and loads of PPs a. Within software programme b. Accuracy of sources and loads, taking into account spatial/temporal variability. c. Accuracy of "exactness"- depending on which scale will be shown (across Europe,	6

across a nation, etc.)	
Statistical and conceptual models to evaluate several scenarios a. Uncertainty within the models themselves- model assumptions? b. How realistic are the chosen scenarios? c. What about under unexpected circumstances or even under pressure from climate change?	6
Decision support tool/system (DSS) to allow optimal allocation of emission control measures a. Determination of "optimal"- taking into effectiveness? Costs? Long-term solutions? b. "Optimal" for each specific nation or city? Or how to generalize these optimal allocation of control measures?	6
Modelling and monitoring the effects of source control options a. Within models and monitoring schemes themselves- depending on model assumptions, personnel entering data, frequency and extent of monitoring. b. Interpreting the model and monitoring results-what is a "good" vs. "bad" situation?	7
Source-and-flux models a. Within models themselves- assumptions? (i.e., West program) b. Spatial/temporal variability c. Behaviour under unpredicted circumstances?	7

Environmental system

Description	**WP**
Release of PPs in environmental systems Loads, locations, different environmental types (wetland vs. stream, etc.)	3
Effects of PPs into environmental systems a. short/long term effects b. effects of flora and fauna c. interaction of compounds, interaction with other compounds in environment d. effect of different environmental systems (wetland vs. aquatic vs. roadside, etc.)	3, 5, 6, 7
Environmental response under less-predictable situations a. building development b. upcoming legislation/governments c. climate change	2, 3, 5, 6, 7, 8

Social system

Description	**WP**
Representatives from end-users of project (on AB board) a. chemical/water industry, etc. may bias project outcomes- uncertainties introduced with the inclusion of perhaps special interest groups	1
Baseline situation of case study cities a. Differences stemming from social settings between cities- in evaluation of different emission control strategies, uncertainties lie within differences in economic situations,	2

political climates, etc.	
<u>Feasibility of strategies to reduce the use of PPs</u> a. substitution: uncertainty lies within which product is "better" (different people may have different values) b. Legislative or regulative measures to reduce activities leading to release of PPs and voluntary options: lead to the question of "will these legislations/voluntary measures really work"?	4
<u>DSS to allow optimal allocation of emission control measures</u> a. Definition of "optimal" b. Different nations may have different optimal plans c. Different economic states may affect optimal plans	6
<u>Modeling and monitoring the effects of source control options</u> a. Monitoring: social systems will introduce uncertainty on which is the best way to monitor the effects of the source control options, depending on values, economic states, etc. b. Determining a "good" monitoring scheme	7
<u>Identify criteria and develop a methodology which enables the socio-economic impacts of different PP reduction strategies to be transparently evaluated</u> a. Involves subjective analysis (and therefore uncertainty, depending on who is performing the analysis)	8
<u>Uncertainty within the uncertainty analysis</u> a. We may not identify all the sources of uncertainty (and may be totally ignorant) b. Uncertainty in how to actually incorporate uncertainty within project	9
<u>Project management</u> a. uncertainty within international collaboration project, where different countries have different languages, values, ways of working, ways of communicating, etc.	10

6.4 Suggested approach

In order to foster the individuation and understanding of uncertainty related aspects throughout the project, each deliverable could incorporate a synthetic description of the uncertainties involved in the developed subject. It should be not more than half-page text well in evidence, e.g. a text box at the end of each deliverable document. This is designed to use the task leaders and participants' knowledge of their task or work package in order to most accurately describe the areas of uncertainty in their work, as opposed to an analysis performed by 'outside' persons who may not be as familiar with the topic, etc.

8. Conclusions

This whitepaper attempts to describe and document in a systematic manner the identified areas of uncertainty within the ScorePP project. Based on recent international literature within uncertainty assessment it provides a common language for the project participants and serves as a guide for when addressing uncertainty in the different tasks.

8. References

Benedetti, L., Bixio, D. and Vanrolleghem, P. A. (2006). Assessment of WWTP design and upgrade options: balancing costs and risks of standards' exceedance. Water Science and Technology 54(6-7), 371-378.

Danius, L. and Burström, F. (2001) Regional material flow analysis and data uncertainties: can the results be trusted?, In: Proceedings of 15th International Symposium on Informatics for Environmental Protection, Zurich (Switzerland), 10-12 October 2001.

Hauger, M.B., de Roo, C., Geldof, G.D., and Mikkelsen, P.S. (2003) Whitepaper on Risk perception, risk assessment and risk management in the DayWater Context. Final draft (for internal review), WP 4 / Task 4.1 / Deliverable No. 4.1: Dissemination Level: CO (will be PU after internal review).

Hyde, K.M., Maier, H.R., Colby, C.B. (2005) A distance-based uncertainty analysis approach to multi-criteria decision analysis for water resource decision making. Journal of Environmental Management 77, 278–290.

Refsgaard, J.C., van der Sluijs, J.P., Brown, J. & van der Keur, P. (2006) A framework for dealing with uncertainty due to model structure error. Advances in Water Resources 29(11): 1586-1597.

Saltelli A, Chan K and Scott M (2000) Sensitivity Analysis John Wiley & Sons publishers, Probability and Statistics Series.

Saltelli A, Tarantola S, Campolongo F and Ratto M (2004) Sensitivity Analysis in Practice: A Guide to Assessing Scientific Models, John Wiley & Sons Publishers.

Triantaphyllou, E. and Sánchez, A. (1997) A sensitivity analysis approach for some deterministic multi-criteria decision making methods. Decision Sciences 28(1), 151-194.

Walker, W.E., Harremöes, P., Rotmans, J., Van der Sluijs, J.P., Van Asselt, M.B.A., Janssen, P. Krayer Von Krauss, M.P. (2003) Defining uncertainty: a conceptual basis for uncertainty management in model-based decision support. Integrated Assessment 4(1), 5-17.

Appendix A – Questionnaire developed for work package leaders

A copy of the questionnaire posed to the work package leaders is shown below.

Questionnaire to WP Leaders

The following questionnaire is designed to form a basis for which an uncertainty assessment is conducted for the ScorePP project, according to Task 9.1. Please answer the following questions about uncertainty in your Work Package (WP), and respond no later than 19 February, 2007 to Lorenzo Benedetti at lorenzo.benedetti@biomath.ugent.be.

Before answering the following questions posed here, please read chapters 4, 5 and 6 of the attached article by Walker et al. (2003) if you are not familiar with terminology commonly used in uncertainty analyses. Please do not read the attached document entitled "Locations of Uncertainty within ScorePP, 2007-02-02" until after completing the following question.

1. Where is uncertainty located in the work to be carried out in the WP? Which are the aspects within the WP that have uncertainty?
2. Next, please read the attached document entitled "Locations of Uncertainty within ScorePP, 2007-02-02" and generate an updated list of locations of uncertainty within your WP. List as many locations of uncertainty as is feasible/appropriate.

Name of Location	Description
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

3. Then, for each of the mentioned locations of uncertainty (in question 2):
   a. Identify the level of uncertainty (statistical uncertainty < scenario uncertainty < recognised ignorance < total ignorance).
   b. Identify the nature of uncertainty (reducible, non-reducible).
   c. How are these uncertainties usually dealt with in your experience?

Location	Level	Nature	Usual practice of dealing with uncertainty
1.			
2.			

3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

e. Finally, what do you expect as potential benefits from an uncertainty assessment in the WP?

Appendix B – Locations of uncertainty within ScorePP on the task level

Empty in this public version.