RIVM/MNP Guidance for Uncertainty Assessment and Communication

Detailed Guidance

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This report contains the *Detailed Guidance* of the *RIVM/MNP Guidance for Uncertainty Assessment and Communication*. The Guidance has been developed under the direction of Peter Janssen (RIVM/MNP) and Jeroen van der Sluijs (Utrecht University) as part of the strategic research project 'Uncertainty Analysis' (S/550002) at RIVM.

The *RIVM/MNP Guidance for Uncertainty Assessment and Communication Series* contains the following volumes:

1. *Mini-Checklist & Quickscan Questionnaire*, A. C. Petersen, P. H. M. Janssen, J. P. van der Sluijs et al., RIVM/MNP, 2003
2. *Quickscan Hints & Actions List*, P. H. M. Janssen, A. C. Petersen, J. P. van der Sluijs et al., RIVM/MNP, 2003
3. *Detailed Guidance*, J. P. van der Sluijs, J. S. Risbey et al., Utrecht University, 2003
4. *Tool Catalogue for Uncertainty Assessment*, J. P. van der Sluijs, J. S. Risbey et al., Utrecht University, 2003

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I Introduction to the Detailed Guidance

The present document provides a detailed guidance for dealing with uncertainty in terms of assessing and communicating uncertainties. It has been developed for the Netherlands Environmental Assessment Agency (MNP), a part of the National Institute for Public Health and the Environment (RIVM), and it provides assistance to RIVM/MNP in assessing and communicating uncertainties in its environmental assessment activities. In doing so it moreover promotes self-education and good practice in dealing with uncertainties; in its use it should not hinder the job of the analyst or be used so rigidly that it begins to mislead or provide a false sense of security. Further, some comprehensiveness must be sacrificed in any tool of this sort, and there will inevitably be important issues that fall outside its scope.

This detailed guidance is a component of the *RIVM/MNP Guidance for Uncertainty Assessment and Communication*. In parallel with the present detailed guidance, other components have been developed. These are provided in two separate documents, consisting of a mini-checklist together with a quickscan questionnaire (Petersen et al., 2003), which is linked up to a hints & actions list (Janssen et al., 2003), giving suggestions for dealing with uncertainty. The quickscan component renders a shorthand device for allowing different groups or individuals to set their own context for a problem. This in turn can facilitate comparison of quickscan results to reveal divergences of opinion or approach among team members early in the assessment process. The quickscan component can be used on its own, or as a portal to the present detailed guidance tool, since the associated quickscan hints & actions list provides explicit cross-reference to the current document.

This document is organized as follows. The rest of the introduction provides a description of the background and goals of the detailed guidance tool, a brief outline of its components, and briefly introduces an uncertainty typology to be used in this document. The detailed guidance tool then follows, and has been organized into a series of steps corresponding to each section. At the end of each section there is a brief outline in shaded boxes of the outputs that can be expected from that part of the tool. In some parts of the text there are plain boxes that indicate the reasoning underlying responses to the questions.

1.1 Goals

The goals for development of the *RIVM/MNP Guidance for Uncertainty Assessment and Communication* were as follows:

- Structure an approach to environmental assessment that facilitates an awareness, identification, and incorporation of uncertainty.

- Specifically address and relate the role of uncertainties in the context of policy advice.
- Not necessarily *reduce* uncertainties, but provide means to assess their potential consequences and avoid pitfalls associated with ignoring or ignorance of uncertainties.
- Provide guidelines for use and help against misuse of uncertainty assessment tools.
- Provide useful uncertainty assessments.
- Fit RIVM/MNP's specific role in the decision analytic cycle.
- Promote the adoption of uncertainty awareness methods in common practice at RIVM/MNP.
- Facilitate the design of effective strategies for communicating uncertainty.

Note that the guidance tool addresses 'uncertainty assessment' as an aid to, and part of, 'environmental assessment'. The former term refers to the set of methods and processes used to cope with uncertainty. This is one element of a larger process to assess a problem concerning the environment or nature, which goes by the term 'environmental assessment' here. The provided guidance tool is not a guide to environmental assessment methods in general (which encompass more than just uncertainty assessment), but focuses on the intersection between uncertainty assessment and environmental assessment. The form of assessment intended in each case will be made clear throughout this document.

1.2 Intended Users

The guidance tool is primarily intended for use in the environmental assessment process at RIVM/MNP. As such, it is pitched at project leaders and team members, but account managers and policy advisers can also benefit from parts of it. Users may place emphasis on different components depending on their own roles and tasks, but the guidance tool should be broadly accessible to all, and each part should be comprehensible to the project leaders. A short guidance component is provided elsewhere, and is denoted by the term 'quickscan' (Petersen et al., 2003, Janssen et al., 2003). Furthermore, at the lowest level of detail, the guidance includes a 'mini-checklist' (also provided elsewhere, Petersen et al., 2003), which can serve as a reminder list, as a log or as a portal to the quickscan. For more information on the use and the structure of the guidance the reader is referred to Petersen et al. (2003), where also advise is given on which components to use, given the importance of uncertainties and the resources available.

1.3 Existing Elements

Each environmental assessment project carried out by RIVM/MNP does not start with a blank slate. Furthermore, many analyses are iterative, building on earlier work, rather than wholly novel. In every case, there is some set of existing resources and experience that can be brought to bear. In addition, the guidance tool does not build from scratch either. There is by now a large body of uncertainty typologies, methodologies, and uncertainty assessment processes. A suitable selection has been made for use in the guidance. A summary of some of these existing elements follows.

Tasks. In the process of carrying out environmental assessments at RIVM/MNP a common set of tasks tends to be encountered. These tasks include monitoring studies (emissions, concentrations), model-based and data-based assessments, indicator choices, scenario development and analysis, policy analysis and evaluation. A body of experience has already been developed in carrying out these various tasks. Further, each task tends to have characteristic methods that are used in fulfilling the task. In turn, these methods have their own characteristic uncertainties associated with them.

Uncertainty types. The uncertainties characteristic of particular problems or methods should be organized in a form suitable for analysis. The organization of uncertainty types that is used in the guidance is described in the typology in section 1.4 and in appendix A.Different uncertainties have different properties, and a suite of uncertainty assessment methods have been developed to address them (see van der Sluijs et al., 2003).

Uncertainty tools. A range of methods exist to address both quantitative and qualitative aspects of uncertainty. Examples of such methods are sensitivity analyses, NUSAP, PRIMA, and checklist approaches. Many of these methods have been drawn together in an uncertainty assessment tool catalogue (see van der Sluijs et al., 2003).

Processes. A focus on uncertainty tools alone is inadequate for capturing many of the qualitative dimensions of uncertainty. For this purpose a number of process-based approaches have also been developed. This set includes extension of peer communities, incorporation of stakeholders into the assessment process, problem framing from multiple perspectives, education, and communication.

1.4 Uncertainty Typology

A variety of different types of uncertainty has been defined and used in the literature and practice. For the purpose of this guidance, it is important to agree upon a standard nomenclature and classification of uncertainties. There is no one particular uncertainty classification or typology that is universally agreed to be 'best' for all purposes. Thus, we had to be pragmatic and sought to compile a synthesis typology that makes reasonable sense for the kinds of tasks carried out by RIVM/MNP without claiming to be the only useful classification system. Use was made of an uncertainty typology recently proposed by Walker et al. 2003. Walker et al.'s typology classifies uncertainties according to three dimensions: their *'location'* (where they occur), their *'level'* (where uncertainty manifests itself on the gradual spectrum between deterministic knowledge and total ignorance) and their *'nature'* (whether uncertainty primarily stems from knowledge imperfection or is a direct consequence from inherent variability). Based on this typology, Walker et al. 2003, propose an uncertainty matrix as a heuristic for classifying and reporting the various dimensions of uncertainty, and to improve communication among analysts as well as between them and policymakers and stakeholders.

We have tuned the uncertainty matrix specifically for this guidance, and have explicitly extended it with two extra columns (dimensions) referring to *'qualification of knowledge base'* and *'value-ladenness of choices'*, see appendix A. The former refers to the level of underpinning and backing of the information (e.g. data, theories, models, methods, argumentation etc.) involved in the assessment of the problem; it points at the methodological acceptability and the rigour and strength of the employed methods, knowledge and information, and thus it characterizes to a certain extent their (un)reliability. The latter category (value-ladenness of choices) refers to the presence of values and biases in the various choices involved e.g. choices concerning the way the scientific questions are framed, data are selected, interpreted and rejected, methodologies and models are devised and used, explanations and conclusions are formulated etc. These aspects have also been briefly mentioned in Walker et al. 2003 in relation to uncertainty.

The proposed uncertainty typology and uncertainty matrix provide a common language for viewing uncertainty in this guidance tool. They play an important role in e.g. the problem-framing section, and in the identification, prioritization and assessment of uncertainties, as well in their reporting. In turn, the uncertainty typology and the uncertainty matrix render useful information concerning which kinds of methods and tools can be appropriate to deal with the various kinds of uncertainties (see the *Tool Catalogue for Uncertainty Assessment*, van der Sluijs et al., 2003).

1.5 Uncertainty Glossary

An extensive glossary of terms has been developed for the guidance tool. The glossary is available in appendix B and online at http://www.nusap.net. The aim of the glossary is to provide clear definitions of the various terms used throughout the guidance tool, or encountered in uncertainty assessment more generally. The glossary should also serve to minimize uncertainties due to linguistic imprecision or confusion about what particular terms are intended to convey.

1.6 Guidance Steps

The steps in the guidance tool are not necessarily made in a fixed sequence. While the quickscan and problem-frame steps need to be taken first to initiate an assessment, the other steps may follow and recur in any order and/or simultaneously, and the whole sequence can be iterated (see Fig. 1).

Mini-checklist and Quickscan. The mini-checklist is a short broad checklist to provide a first indication of possible key issues and uncertainties. If elaboration is needed it points to a 'quickscan questionnaire' and a 'quickscan hints & actions list' to further orient analysis and to provide *some* information prior to a full assessment. These mini-checklist and quickscan tools are provided elsewhere as separate documents (Petersen et al., 2003, Janssen et al., 2003). These 'instruments' can be used on their own for rapid scanning of problems. They provide explicit pointers to the detailed guidance tool described here, in case a further deepening of the quickscan analysis is deemed necessary.

Problem Framing and Context Analysis. Identify the problem, context and history. For whom is it a problem and how is it framed? Provide an initial outline of the main issues and characteristics, interests, disputes, and possible solutions. Classify the problem type and structure, together with implications of these characteristics for uncertainty assessment. Provide an initial ranking of the salience of sociopolitical and institutional uncertainties.

Communication. Produce a map of the information flow at RIVM/MNP between analysts, project leaders, the media, ministry, and other outside institutions. Identify relevant communication pathways and points in the assessment process at which they need to be active. The role of stakeholders is also key for communication and is addressed in the next step.

Process Assessment. Given the characteristics of the problem (problem framing), what are the implications for process? Identify the different stakeholder groups and their characteristic views, values and interests in regard to the problem. What are appropriate roles for each of these groups in the intended assessment study? Where and when in the problem formulation and solution phases should they be involved and via what processes? Identify appropriate processes.

Environmental Assessment Methods. The environmental assessment process will entail use of various methods or tools to carry out the analysis. Such methods may include monitoring, modelling, scenario generation, policy exercises, focus groups, questionaires, and backcasting exercises for instance. Identify the methods used and characterize the uncertainties associated with these methods using the uncertainty typology.

Uncertainty Identification and Prioritization. For each step above (problem framing, process assessment, and environmental assessment methods), identify key uncertainties using the nomenclature in the uncertainty typology. Identify the best available method to approach each uncertainty, along with an indication of the strengths and limitations of the method. Identify any gaps between uncertainty methods required and those used or proposed. Describe potential consequences of gaps or weaknesses in uncertainty assessment. Make an initial prioritization of the potentially most important uncertainties.

Uncertainty Analysis. Carry out the prescribed set of uncertainty analyses for this problem. Checklists and other uncertainty methods will be used in the analysis as appropriate to the task and methods in question (see e.g. the *Tool Catalogue for Uncertainty Assessment*, van der Sluijs et al., 2003).

Review and Evaluation. Provide a review and summary of the analyses undertaken. Redo earlier steps or add steps if appropriate. Evaluate the robustness of results from the environmental assessment.

Reporting. Engage the identified audiences in a process of understanding results and their implications. Include dissenting or minority viewpoints. This may take the form of advice, a dialogue, or other, as appropriate to the context and processes identified (process assessment step). Note that though listed at the end here, the process assessment step may have identified communication and reporting efforts to occur throughout the assessment period.

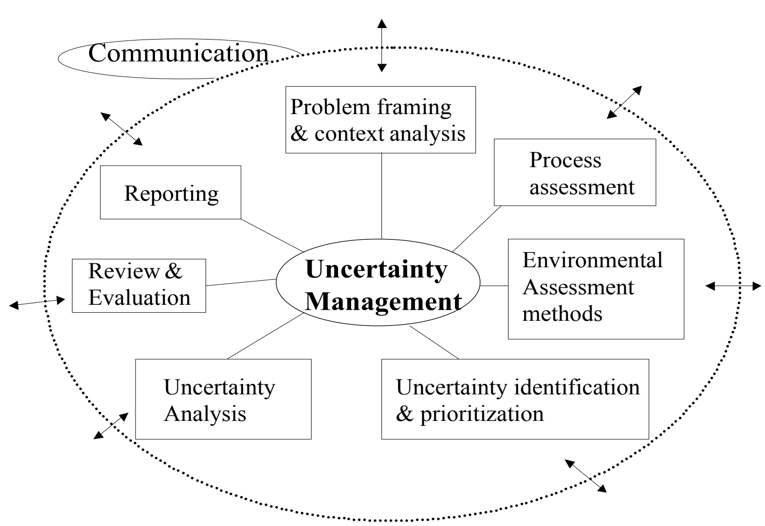

Figure 1: Uncertainty management

II Detailed Guidance for Uncertainty Assessment and Communication in Environmental Assessments

In this chapter a detailed elaboration is given of the various steps from problem framing to reporting. This elaboration serves as a guidance for dealing with uncertainty in environmental assessments, as highlighted in section 1.6.

1 Problem Framing and Context

First, the broad context of the problem is set by identifying major issues, past work, the level of contention, and the role of assessment. The identification and role of stakeholders will be elaborated in section 2.

1.1 Problem Frames

A problem frame is literally a way of seeing or framing a problem. The following questions provide a problem frame scan to analyse a problem frame from any given perspective — that of the analyst or different stakeholder groups. The frame may be one that you use or that is used by someone with whom you have to communicate.

Since the problem frame section comes before the section on identification of stakeholders, the idea is that you will complete the problem frame section primarily from your own perspective the first time. After you have identified relevant stakeholders in section 2.1, you may wish to return to this section and redo it from the different stakeholder perspectives.

1. Describe the problem from your point of view.

   ⇁

2. Describe the history of this problem in broader socio-political context.

   ⇁

3. To what extent is the problem interwoven with other problems? Discuss the implications of studying the problem separately from other problems.

   ⇁

4. What boundary do we/they draw around the problem? In other words, what aspects of the problem situation do we/they leave out of scope?

   ⇁

5. What criteria and benchmarks do we/they use to measure success in managing the problem?

→

6. How is the burden of proof set?

   Choose one of the following:

   - ☐ this is a problem requiring action until proven otherwise
   - ☐ this is not a problem until proven otherwise
   - ☐ other (describe)

7. What metaphors or analogies do we/they use to think about this problem?

→

8. What is being under- or over exposed in the problem frame we/they use?

→

9. Can we summarize our/their problem frame in a single slogan?

→

1.2 Problem Assessment

1. What is the role of analysis/assessment for this problem?

   Check all that apply:

   - ♢ ad hoc policy advice
   - ♢ to evaluate existing policy
   - ♢ to evaluate proposed policy
   - ♢ to foster recognition of new problems
   - ♢ to identify and/or evaluate possible solutions
   - ♢ to provide counter-expertise
   - ♢ other (describe)

2. How urgent is the problem? What is the time frame for analysis?

days	months	years
☐	☐	☐

3. Describe the results of any previous studies on this problem.

→

4. For whom is this a problem: Who loses? Who gains?

5. Identify key public interests at stake.

6. Identify key private interests at stake.

7. Describe any solutions that have been put forward for this problem. Comment on the feasibility, acceptability, and effectiveness of each proposed solution.

8. Describe any key disputed facts

9. Describe key value issues.

10. What are the key inputs to assessment?

11. What are the key outputs or indicators from the assessment process?

12. How well do the key outputs or indicators address the problem?

scarcely	moderately	adequately
☐	☐	☐

13. For some environmental assessments there may be specific indicators that have been declared in advance that must be monitored. Are there (legal) norms or policy targets to which any of the key outputs from the assessment must comply?

no targets	general policy targets	legally binding targets
☐	☐	☐

If so, specify them.

14. When estimates for a particular indicator are close to a legal norm or target, then estimates of uncertainty are particularly critical. How close are current estimates of any indicators to these norms or targets?

well below	just around	well above
▭	▭	▭

15. What roles do models play in the assessment?

    Check all that apply:

    ◇ to provide a structured knowledge archive

    ◇ for communication of knowledge and educating

    ◇ for building community and shared understanding

    ◇ for exploration and discovery

    ◇ to provide predictive information to policy

    ◇ other (describe)

16. How is the problem reflected in the 'model'?

scarcely	moderately	adequately
▭	▭	▭

17. List any key aspects of the problem that are not reflected (or poorly reflected) in the 'model'.

18. What methods will be used in assessment?

    Check all that apply:

    ◇ modelling

    ◇ scenario generation or use

    ◇ focus groups

    ◇ stakeholder participation

    ◇ expert elicitation

    ◇ sensitivity analysis

    ◇ qualitative uncertainty methods

    ◇ other (describe)

1.3 Problem Structure

This section is intended to help draw out the broad structure of the problem to place it on a spectrum from more structured technical problems to more unstructured post-normal science problems (see the glossary in appendix B). The degree of structure of the problem will have implications for the kinds of uncertainties and approaches to use as well as for the involvement of stakeholder groups. Note that different stakeholders may have different views of the problem structure from one another and from the analysts. In that event it may be useful to redo this section from the point of view of each of the relevant stakeholders. In the plain boxes below use is made of the uncertainty typology presented in appendix A. See also the glossary in appendix B.for information on other concepts such as reflexive science and partisan mutual adjustment.

Implications from structure diagram

1. Score the problem according to the level of agreement about what kind of knowledge is needed to solve the problem

low	high
☐	☐

2. Score the problem according to the level of consent on norms and values

low	high
☐	☐

> If agreement on what kind of knowledge is needed is low and consent on norms and values is low, then the problem is unstructured. Highlight uncertainties of type (recognized) ignorance and value-ladenness. Typically requires public debate, conflict management, and reflexive science.

> If agreement on what kind of knowledge is needed is high and consent on norms and values is high, then the problem is well structured. Typically requires normal scientific procedures.

> If agreement on what kind of knowledge is needed is low and consent on norms and values is high, then the problem is moderately structured. Highlight uncertainties involving unreliability (i.e. the backing/underpinning is weak) and (recognized) ignorance. Typically requires partisan mutual adjustment, stakeholder involvement, and extended peer acceptance.

If agreement on what kind of knowledge is needed is high and consent on norms and values is low, then the problem is moderately structured. Highlight uncertainties involving value ladenness, particularly related to knowledge utilization. Typically requires accomodation on the policy side and reflexive science.

Implications from Post-normal science

3. Score the problem according to the level of decision stakes

low	high
☐	☐

4. Score the problem according to the level of systems uncertainty

low	high
☐	☐

If the decision stakes are low and system uncertainty is low, then the problem is mostly in the technical domain. Highlight only uncertainties involving inexactness (e.g. expressed as a range of possible values, in terms of statistical uncertainty and scenario uncertainty) and unreliability (i.e. the backing/underpinning is weak). Stakeholder involvement is not so key.

If the decision stakes are high and system uncertainty is high, then the problem is one of post-normal science. Highlight uncertainties involving value ladenness and (recognized) ignorance. Typically require extended peer communities in working the problem and close stakeholder involvement.

If the decision stakes are high and system uncertainty is low, then the problem is still post-normal, but with less emphasis on scientific uncertainty. Explore instead legal, moral, societal, institutional, proprietary, and situational uncertainties. Typically requires efforts to bring stakeholders together in the solution phase.

If the decision stakes are low and system uncertainty is high, then the problem may be subject to changes in its structure. Highlight uncertainties involving unreliability (i.e. the backing/underpinning is weak) and (recognized) ignorance. While the low decision stakes may imply a diminished role for stakeholders, they should be involved as a precaution since the system uncertainty is high.

1.4 Problem Lifecycle

The life-cycles of environmental problems do not readily conform to idealized models. Nonetheless, it is useful to speak of problems as being in certain phases, such as recognition, active debate, implementation, monitoring, and so on. In practice a problem may move back and forth between various stages as new information comes to light. In this section we try to determine the current phase of the problem, if such exists. This can be useful to gauge the level and stage of involvement of different groups on this issue.

1. Is the issue recognized as a problem among the following groups[1]:

	hardly	partially	mostly
Cabinet and ministries (national)	☐	☐	☐
Parliament (national)	☐	☐	☐
Governmental advisory boards and councils	☐	☐	☐
Other governmental actors (local/regional/international)	☐	☐	☐
Other governmental 'planning offices' (CPB, SCP, RPB)	☐	☐	☐
Research institutes/consultancies	☐	☐	☐
Scientists/universities	☐	☐	☐
Sector-specific actors (from, e.g., agriculture, transport, industry)	☐	☐	☐
Umbrella organizations (e.g. VNO)	☐	☐	☐
Environmental and consumer organizations	☐	☐	☐
Unorganized stakeholders; citizens	☐	☐	☐
Media	☐	☐	☐
Other (specify)	☐	☐	☐

2. Have solutions been actively discussed and debated?

hardly	moderately	intensively
☐	☐	☐

3. Have efforts at implementation of solutions begun?

hardly	moderately	intensively
☐	☐	☐

[1] The listed groups are considered to be characteristic for the environmental assessment field RIVM/MNP is working on; other working areas for other institutes will possibly require a somewhat different categorization of stakeholder-groups.

4. To what extent will current efforts (if any) at implementing solutions likely solve the problem?

hardly	moderately	mostly
☐	☐	☐

5. Has monitoring of policies been put into effect?

none	partial	intensive
☐	☐	☐

6. Are there any indications that this problem has been under or overestimated so far? By whom?

	under estimated	well estimated	over estimated
Cabinet and ministries (national)	☐	☐	☐
Parliament (national)	☐	☐	☐
Governmental advisory boards and councils	☐	☐	☐
Other governmental actors (local/regional/international)	☐	☐	☐
Other governmental 'planning offices' (CPB, SCP, RPB)	☐	☐	☐
Research institutes/consultancies	☐	☐	☐
Scientists/universities	☐	☐	☐
Sector-specific actors (from, e.g., agriculture, transport, industry)	☐	☐	☐
Umbrella organizations (e.g. VNO)	☐	☐	☐
Environmental and consumer organizations	☐	☐	☐
Unorganized stakeholders; citizens	☐	☐	☐
Media	☐	☐	☐
Other (specify)	☐	☐	☐

7. Based on your answers to the previous questions, how would you rate this problem overall?

immature	active	mature
☐	☐	☐

Implications for methods and uncertainty types

if problem phase immature — important to identify stakeholders
if problem structure indicates that values are important or decision stakes high — involve stakeholders early in the project
if problem phase active — work with existing stakeholders
if problem phase mature — less critical to engage stakeholders

1.5 Uncertainty in Socio-Political Context

The uncertainty typology illustrated in appendix A provides most detail on scientific uncertainty and less detail on sociopolitical and institutional uncertainties. This section provides more detail on the latter uncertainties to address their implications for the environmental assessment process. De Marchi et al. (1994) have outlined seven distinct types of uncertainty, which are defined in the glossary (appendix B). In the left hand column of the table below, rank the uncertainties in terms of their relative salience to the problem, from '1' (most salient uncertainty type) to '3' (third most salient uncertainty type). Independent of the relative salience of each uncertainty, you should also provide a judgment on the severity of each type of uncertainty by selecting one of the boxes to the right. Some examples may illustrate the point. It is possible that scientific uncertainty could by severe (high), but the scientific uncertainties may not be important to the policy process — in which case the salience of scientific uncertainty would be ranked low relative to the other uncertainties. Conversely, scientific uncertainties could be relatively mild, but still dominate a problem that was relatively technical and devoid of salience in the other uncertainty dimensions.

1. Rank the salience and severity of the different types of uncertainty for this problem:

			severity	
salience rank		low	medium	high
☐	scientific	☐	☐	☐
☐	legal	☐	☐	☐
☐	moral	☐	☐	☐
☐	societal	☐	☐	☐
☐	institutional	☐	☐	☐
☐	proprietary	☐	☐	☐
	situational	☐	☐	☐

Implications for methods and uncertainty types

if scientific uncertainty salient and severe, highlight inexactness (e.g. expressed as a range of possible values, in terms of statistical uncertainty and scenario uncertainty), unreliability (i.e. the backing/underpinning is weak) and (recognized) ignorance as appropriate manifestations of uncertainty
if legal uncertainty salient and severe, the assessment process should involve legal analysts
if moral uncertainty salient and severe, highlight value loadingladenness issues of uncertainties and involve stakeholders with different views of problem frame
if societal uncertainty salient and severe, involve stakeholders representative of different social views of the problem and decision process
if institutional uncertainty salient and severe, highlight communication between RIVM/MNP and other institutions that may reduce this
if proprietary uncertainty salient and severe, identify inequity in access to knowledge and highlight communication steps or empowerment issues to address this
if situational uncertainty salient and severe, describe the decision process and highlight communication steps within RIVM/MNP or with outside people that may reduce this

Outputs from section 1

→A description of the problem.
→A gauge of how well assessment tools address the problem.
→A list of which uncertainties are salient on the basis of problem structure.
→An indication of the relevance of uncertainty for the policy problem at hand.
→An indication of whether to involve stakeholders or not.
→A scoring of the maturity of the problem in the policy process.
→A relative ranking of scientific and socio-political uncertainties.

2 Process Assessment

The assessment of problem frames, structure, life-cycle, history, conflict, and values has implications for the set of stakeholders who ought reasonably to be involved, how they should be involved, and when they might be involved in the assessment process. This step of the guidance aims to help identify appropriate sets of stakeholders, together with some information about their positions, their values, and their possible roles in the environmental assessment process. It renders only a partial picture; we don't strive for a complete actor analysis, involving e.g. a mapping of belief systems and perceptions, stakes, influence and power relations, action strategies etc.

2.1 Stakeholder Identification

The identification of stakeholders on any given problem is an art in itself, and there is no single way to do this that avoids all forms of selection bias. Thus, the best approach is to use several different methods. As an example we provide two different methods, though they need not both be used in all cases.

In identifying stakeholders from different segments of society it is useful to classify them in some form. The classification scheme can then provide a form of checklist to go back and see if relevant members from each group have been identified or not. Of course, not all groups are actively involved in all issues, and so they may not all provide stakeholders. The following classification scheme is offered as a loose checklist in identifying stakeholders:

Cabinet and ministries (national)
Parliament (national)
Governmental advisory boards and councils (national)
Other governmental actors (local /regional /international)
Other governmental 'planning offices' (CPB, SCP, RPB)
Research institutes/consultancies
Scientists and universities
Sector-specific stakeholders/actors (from, e.g., agriculture, transport, industry)
Umbrella organizations (e.g. VNO)
Environmental and consumer organizations
Unorganized stakeholders; citizens
Media
Other (specify) ....

Stakeholder and client groups

2.1.1 Knipselkrant Method

We assume that in the RIVM/MNP a dossier of newspaper clippings ('knipselkrant') has been compiled on the problem. The identification of stakeholders proceeds by scanning the 'knipselkrant' and identifying stakeholder groups and the frequency with which they are mentioned. The frequency with which members of each stakeholder type are mentioned in the 'knipselkrant' can be catalogued as in table 1.

name of stakeholder group	frequency

Table 1: Stakeholder frequency in the 'knipselkrant'.

The main stakeholder groups can be identified from the 'knipselkrant' analysis. This method falls however short when an issue has not been well covered in the media or in the compiled 'knipselkrant', or when some stakeholders have been excluded from debate or media coverage. Since this is often the case, we recommend supplementing this method with scans of the issue in historical and legal records, on the web, and via consultation with experts.

2.1.2 Snowball Method

Another method to find out who are the actors involved in a problem is the snow ball method which can be done by telephone interview. The snowball method asks persons involved in the problem at hand to name others who are involved in or have a stake in the problem at hand. To increase the probability that one covers the full spectrum of value orientations and dissent one can specifically ask stakeholders to mention names of others with whom they disagree. The groups named by the respondent are then contacted and asked the same question. The procedure is repeated and a graph is made with on the X-axis the number of actors asked to mention names and on the Y-axis the cumulative number of unique names mentioned. One can stop the snowball if the curve flattens out (no new names being mentioned). One can also make a frequency count indicating how often each actor was mentioned. Frequently mentioned names are assumed to be formal or informal leading actors in the problem. Note that the snowball method is also biased, as it is not likely to capture unorganised interests.

2.2 Value mapping and Argumentative Analysis

This section provides a means to map out key value positions held by the respective stakeholder groups. In societal debates on policy problems, different levels of argumentation can be distinguished (Fischer, 1995). These are:

Ideological view. This is the deepest level of disagreement and can lead to very different views of whether there is a problem or what it is. One can hold the view that a radically different ideological starting point is required. Ideological argumentation focuses typically on ideology and alternative societal orders.

Problem setting and goal searching. Groups may agree on the existence of a problem, but not on identifying precisely what the problem is, how to formulate it, and what the end goal or solution point should be.

Problem solving. Groups may agree on the existence of a problem and further agree on policy goals but disagree on the strategies and instruments required to reach the goal. Problem solving argumentation typically focus on effectiveness, side effects, and efficiency of methods.

Outcomes and fairness. Groups often care about the fairness of solutions to problems, but can hold different views on what constitutes fair outcomes. For example, one can hold the view that the policy at hand does not serve the public interest or public wellbeing. Fairness argumentation focuses typically on public interest, unexpected societal side effects, and distributive justice.

As part of the context analysis, it is useful to map 'what level of arguments' are put forward by 'what actors'. Ideological argumentation reflects deeper value conflicts amongst actors than problem solving argumentation for instance. A simple way to do the mapping is to extend the 'knipselkrant' actor analysis by classifying arguments put forward by each of the actors identified according to the classification given above. Write down all arguments found in table 2 on page 20. When finished, scan each row and flag areas of agreement and disagreement. For reasons of space table 2 provides only three different stakeholder groups, but this can easily be extended to the number of groups which is considered appropriate for the problem at hand.

Level of argumentation	Stakeholder 1	Stakeholder 2	Stakeholder 3	Agreement	Disagreement
Ideological view					
Problem setting and goal searching					
Problem solving					
Outcomes and fairness					

Table 2: Stakeholder argumentation table.

2.3 Communication and Engagement

Communication concerning the assessment process and the role of uncertainty in it occurs at several levels. In this section the role of communication within RIVM/MNP as it relates to project management, and externally with clients and stakeholders is addressed.

2.3.1 Client/Customer Level

It is important to obtain general agreement on the main issues to be addressed in the assessment; moreover the potential role and influence of uncertainty should be explicitly addressed.

1. What are the clients minimal requirements with respect to uncertainty management?

   Check all that apply:

   ◇ Uncertainty is not an issue

   ◇ The robustness of the conclusions w.r.t. uncertainty should be assessed

   ◇ Uncertainty in the major outcomes should be indicated

   ◇ The major causes of the uncertainty should be determined

   ◇ The effects of uncertainty on policy-level should be indicated

   ◇ Other (specify) ....

2. What level of detail is requested by the client in this uncertainty assessment?

qualitative indication	quantitative indication
☐	☐

3. Explain why this is the (minimal) requirement w.r.t. uncertainty management.

   ↵

4. Describe any further requirements by the client about the form in which uncertainty should be presented?

   ↵

2.3.2 Stakeholder Level

One should gauge here how important it will be to engage stakeholders actively in the assessment process (why, who, when, and how). If stakeholders will be involved, mutual agreement on roles, tasks, form of interaction etc. is important.

1. At what stage should primary stakeholders first be engaged in the assessment for this problem?

before the assessment	during the assessment	after the assessment
☐	☐	☐

2. Stakeholders can contribute to the process in three different ways: (1) by helping to improve the formulation and framing of the problem, (2) by contributing their knowledge and imagination on the problem at hand, and (3) by assisting in quality control through extended peer review.

   What contribution and role of each of the stakeholders is envisaged?

	problem definition and choice of indicators	source of knowledge	extended peer review
Cabinet and ministries (national)	☐	☐	☐
Parliament (national)	☐	☐	☐
Governmental advisory boards and councils	☐	☐	☐
Other governmental actors (local/regional/international)	☐	☐	☐
Other governmental 'planning offices' (CPB, SCP, RPB)	☐	☐	☐
Research institutes/consultancies	☐	☐	☐
Scientists/universities	☐	☐	☐
Sector-specific actors (from, e.g., agriculture, transport, industry)	☐	☐	☐
Umbrella organizations (e.g. VNO)	☐	☐	☐
Environmental and consumer organizations	☐	☐	☐
Unorganized stakeholders; citizens	☐	☐	☐
Media	☐	☐	☐
Other (specify)	☐	☐	☐

3. Describe the forms this engagement should take for each of the identified stakeholder groups (using table 3). The forms of engagement could include written or verbal communication, presentations, site visits, focus groups, meetings, requests for feedback or participation, research partnerships, and so on.

name of stakeholder group	forms of engagement

Table 3: Stakeholder engagement forms.

2.3.3 Project Management Level

For project management purposes, various groupings within RIVM/MNP can be identified:

- Advisory and Steering group (klankbordgroep).
- Other project teams.
- Suppliers/producers of information (data, model results, expertise) and facilities (software, hardware) in the assessment process. This applies to internal as well as external groups (sub-contractors).
- Members of the project team.

Bear these groups in mind in answering the following:

1. Identify in an early stage on the basis of consultation of experts and subcontractors involved (information/knowledge suppliers) what is achievable for this project given the available resources (information-base, expertise, time, budget). Briefly summarize your view in this regard.

$\neg$

2. Identify any critical pathways, bottle-necks and break-down risks in performing the assessment. List them.

→

3. Assess and describe their potential consequences for the results. These issues should be communicated to the persons involved (on the various levels given above), discussing potential lines of actions to be taken, decisions to be made.

→

4. Identify any requirements or boundary conditions with which one has to account in performing the assessment process (e.g. the use of a quality system), and describe what this means for internal and external communication with respect to line-, project and team-management, and external contacts.

→

Outputs from section 2

→A list of relevant stakeholders.
→An identification of areas of agreement and disagreement among stakeholders on value dimensions of the problem.
→Recommendations on when and how to involve different stakeholders in the assessment process.
→Guidance on internal management of the assessment process

3 Environmental Assessment Methods

The environmental assessment process will entail use of various methods or tools to carry out the analysis. Such methods may include monitoring, modelling, and scenario generation for instance. The methods used for this assessment were identified in section 1.2.

1. Write down the methods used in table 4 and characterize the uncertainties associated with these methods using the uncertainty typology.

List of methods to be used	List of associated uncertainties

Table 4: Assessment methods used and associated uncertainties

Outputs from section 3

→A list of uncertainties associated with the environment assessment tools.

4 Uncertainty Identification and Prioritization

Central in this step is highlighting areas in the uncertainty matrix (appendix A) that need attention in the problem at hand. The matrix is spanned by a table which distinguishes five dimensions for characterizing uncertainties: on the one hand 'location' of uncertainty is put forward as a central dimension for indicating 'where' uncertainty will occur, while four additional dimensions or features are used to characterize how the uncertainties at these specific locations can be further characterised:

- The *'location'* scale distinguishes between context (ecological, technological, economic, social and political representation and embedding), expert judgment and considerations (storylines, narratives, advices), models (including model inputs (input data, driving forces, input scenarios), model structure and model parametrization, model implementation (hardware and software) issues), data (measurements, monitoring and survey data) and outputs (outcomes of interest such as indicators; statements etc.).
- The four additional dimensions which are used to characterize the specific uncertainties at their various locations are: (a) *'level of uncertainty'* as a means to express how uncertainty can be classified on the gradual scale from 'knowing for certain' to 'complete ignorance', (b) *'nature of uncertainty'* to express whether uncertainty primarily stems from inherent system variability or from deficiencies in our knowledge and information, (c) *'qualification of knowledge base'* referring to the level of underpinning and backing of involved results/statements, and finally (d) the *'value-ladenness of choices'* involved in the study at hand e.g. choices concerning the way the scientific questions are framed, data are selected, interpreted and rejected, methodologies and models are devised and used, explanations and conclusions are formulated etc.

In a separate document (*Tool Catalogue for Uncertainty Assessment*, van der Sluijs et al., 2003) we have compiled a description of available tools for addressing uncertainty, providing information on:

- The types of uncertainty that the tool addresses
- The resources required to use the tool
- Strengths and limitations of each tool
- Some guidance on the application of the tools and on their complementarity with other tools
- Pitfalls of each tool
- References to handbooks, user-guides, case studies, web-sites, and experts

Once uncertainties have been identified, the uncertainty tool(s) which are suitable to cope with them can be selected on basis of the information in the uncertainty tool catalogue.

1. Work through the uncertainty matrix (appendix A) to identify uncertainties. List the uncertainties indicated from the uncertainty matrix and from table 4 in the left column of table 5. Next, identify the tools best suited for addressing each uncertainty in the right column in table 5.

Type of uncertainty	Method/tool for addressing

Table 5: Uncertainties and tools to address them

Outputs from section 4

→A prioritized list of uncertainties.
→For each uncertainty, a recommendation for what tool to use to address it.

5 Uncertainty Analysis

Carry out analyses for this problem, including both uncertainty analyses and the environmental assessment. The *Tool Catalogue for Uncertainty Assessment* (van der Sluijs et al., 2003) provides further guidance on the application of the uncertainty assessment tools selected. Take particular care to avoid the pitfalls listed for each tool in the tool catalogue.

Outputs from section 5

→The set of outputs from this section depend on the methods used from the uncertainty assessment tool catalogue, and will correspond to the outputs from each method described there. Examples of such outputs are diagnostic diagrams, error bars from sensitivity runs, multiple perspective views, and so on.

6 Review and Evaluation

This step of the detailed guidance provides an opportunity to review results of the environmental assessment and check on the robustness of results obtained.

6.1 Revisit the Problem and Assessment Steps

At various points in the assessment process it may be useful to review the progress to date and to reassess the appropriateness of earlier steps. Some reanalysis or new analysis may be warranted to keep abreast of any new information, new directives, or changes in the problem being considered. Such a review and reanalysis should be undertaken if it has not already been done so.

6.2 Robustness of Results

Before proceeding to the reporting of results, some checks on the robustness of the environmental assessment may be in order. The following questions are designed to aid that process.

1. Describe the main results of the environmental assessment.

2. What is new from the last time an assessment on this problem took place?

3. If some results have changed, what explains the difference?

4. Given your assessment of the most critical assumptions underlying the results, your assessment process has encompassed and tested:

few of the major assumptions	some of the major assumptions	most of the major assumptions
☐	☐	☐

5. Can you imagine a scenario by which it turned out that the main results were substantially incorrect or not valid?

not imaginable	conceivable	quite possible
☐	☐	☐

If so, describe such a scenario.

6. Would results come out differently if the burden of proof was reversed?

no	yes
☐	☐

7. How certain are you about the main results? How would you rate your confidence in them?

low	medium	high
☐	☐	☐

8. Who might/would disagree with the main results and why?

9. Could any disagreement be reconciled by (check all that apply):

Strategy	**Priority**		
	low	medium	high
Further Research	☐	☐	☐
New Information	☐	☐	☐
Better measurements	☐	☐	☐
Better models	☐	☐	☐
Scientific consensus building	☐	☐	☐
Convergence on value/societal consensus building	☐	☐	☐
Other (specify)	☐	☐	☐
☐ Impossible			

10. From the perspective of the policy process, do the results matter?

hardly	somewhat	critical
☐	☐	☐

11. If so (critical), why? And if not (hardly), why not?

12. Is RIVM/MNP devoting the right amount of attention to this problem?

not enough	about right	too much
☐	☐	☐

13. If too little or too much, why is that?

Outputs from section 6

→An assessment of the robustness of results (low, medium, high)
→An indication of what it might take to make results more robust.
→An assessment of the relevance of results to the problem.

7 Reporting

The purpose of this section is to help engage the identified audiences in a process of understanding results and their implications (including dissenting or minority viewpoints). This may take the form of advice, a dialogue, or other as appropriate to the context and processes identified (process assessment step). Note that though listed at the end here, the process assessment step may have identified communication and reporting efforts to occur throughout the assessment period/process.

Communicating and reporting uncertainty entails a number of issues that should be taken into consideration. These issues are outlined in the following subsections.

7.1 Context of Communication of Uncertainty

1. Why is uncertainty being reported?

   Check all that apply:

   ♢ To serve a political purpose

   ♢ To conform to good scientific practice (for scientific purposes)

   ♢ Practice of the institution that carries out the environmental assessment

   ♢ Required by legislation

   ♢ Requested by stakeholders involved in the process

2. At which stage is uncertainty being reported? Check all that apply:

   ♢ During the environmental assessment process

   ♢ Delivered with final report/delivery of the environmental assessment process

   ♢ Some time after the final report

3. What is the context of reporting/communicating uncertainty? Check all that apply:

   ♢ Active involvement of audiences requiring setting up of participatory processes (e.g. debate, deliberative process, policy making, extended peer review)

   ♢ Unilateral information supply

   ♢ Other?

4. What is the setting in which communication/reporting takes place? Check all that apply:

   ◇ report

   ◇ meeting

   ◇ focus group

   ◇ press articles

   ◇ public session

   ◇ scientific journal

   ◇ internet

   ◇ other

7.2 Who are the Target Audiences?

The target audience may correspond to the stakeholders identified for the problematique of concern. It might not correspond to the whole set of stakeholders but it is surely a subset of those. The type of audience will determine amongst other things the 'language' of the communication/report and its content. Note that because the reporting of uncertainty within the scientific community has a reasonably well established protocol, the remainder of this section addresses mainly non-scientific audiences. It should also be pointed out that non-scientific audiences possess resources and knowledge that can enrich debates about uncertainty. In fact, the engagement of non-scientific audiences is often critical for the overall success of the assessment.

1. Who are your target audiences ? (list according to your stakeholder list)

7.3 Language

The language used in the communication and reporting of uncertainty is one of the most important issues. Careful design of communication and reporting should be done in order to avoid information divide, misunderstandings, and misinterpretations.

1. Is the communication of uncertainty (scientific) jargon free?

jargon free	some jargon	jargon loaded
☐	☐	☐

2. If there is some jargon in the reporting document, are there guidelines to facilitate clear and consistent use of terms provided?

no guidelines	some guidelines	clear guidelines
☐	☐	☐

3. Are values made explicit in the reporting process?

value explicit	mixed	values implicit
☐	☐	☐

4. What is the potential for ambiguity in the wording of the report or in the use of metaphors?

low	medium	high
☐	☐	☐

7.4 Method

The method used to manage uncertainty and hence, the types of information generated, is a crucial aspect of communicating and reporting uncertainty.

1. What methods were used to address uncertainty management?

   Check all that apply (see van der Sluijs et al., 2003):

   ◇ Uncertainty analysis (e.g. statistical analysis)

   ◇ Quality assurance (e.g. NUSAP, Pedigree)

   ◇ Explanatory frameworks (e.g. cultural theory)

   ◇ Other - specify

2. Uncertainty methods can operate in the *foreground* when applied explicitly to produce information on uncertainty (e.g. written material, graphs), or in the *background* as when run behind a model and results are embedded in the output (e.g. model outputs, scenarios).

   Are the methods used primarily:

background	mixed	foreground
☐	☐	☐

7.5 Style

A variety of different reporting formats and media can be used (numbers, words, narratives, graphs, pictures, multimedia). No one format is more valid than others. The choice of format depends on communication settings, type of audience, and uncertainty management methods.

1. What is the format and style of reporting/ communicating uncertainty?

   Check all that apply:

   Written material:

   - ◇ A section of the environmental assessment report
   - ◇ Press articles
   - ◇ Scientific journal papers
   - ◇ Internet publication
   - ◇ Supporting resources for internet material

   Models:

   - ◇ Model results in the form of graphs, tables, ...
   - ◇ Model runs (by the audience)

   Scenarios:

   - ◇ Narratives
   - ◇ Graphs, tables
   - ◇ Pictures, collages
   - ◇ Animations
   - ◇ Other

   Multi-media material:

   - ◇ Internet based, CD-ROM

   Audiences of reporting documents will have varying amounts of resources and time to digest any information that is presented. The following tips may be useful:

   Policymakers typically have time to read an A4 sheet of paper

   Focus groups require at least two and a half hours and are good settings to make oral presentations

   Information on the internet allows access to those with internet resources (not always all groups) whenever the audience has time

2. Was the availability of each of the audiences considered in packaging uncertainty information?

barely	somewhat	extensively
☐	☐	☐

3. Can the target audiences with fewest resources likely access reported information on uncertainty?

not readily accessible	with some effort	readily accessible
☐	☐	☐

4. Rehearsing communication is important to achieve effective dialogue on uncertainty with audiences. Have efforts at rehearsing communication been made?

no	yes
☐	☐

7.6 Content

1. Have implications for policy and for social context been stated?

not stated	some attention	explicitly stated
☐	☐	☐

2. Were uncertainty relations with risk (namely consequences for different risk management strategies; risky uncertainties; uncertain risks) stated?

not stated	some attention	explicitly stated
☐	☐	☐

3. Have areas of ignorance (what we don't know) been acknowledged where they are relevant to results?

not acknowledged	partially acknowledged	fully acknowledged
☐	☐	☐

4. To what extent does the report reflect engagement or dialogue with the intended audiences?

barely	partially	extensively
☐	☐	☐

5. Are there many examples of scientific arbitrariness ('abracadabra') in the report? That is, steps where the underlying reasoning is not supplied?

none	some	many
☐	☐	☐

6. Is citation of other similar studies done?

no	yes
☐	☐

7. Does the report offer pedigree of results?

   Check all that apply:

   ♢ references

   ♢ background documents

   ♢ other

Outputs from section 7

→A set of guidelines and tips for reporting results.

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Appendix A Uncertainty Matrix

The uncertainty matrix is an aid in making an inventory of *where* ('locations') the most (policy) relevant uncertainties are expected, and how they can be *characterized* in terms of a number of uncertainty features. It can serve as a first step of a more elaborate uncertainty assessment, where the size of uncertainties and their impact on the policy-relevant conclusions are explicitly assessed. The matrix[2] is structured in five principal dimensions, *'location', 'uncertainty level', 'nature of uncertainty', 'qualification of knowledge base', 'value-ladenness of choices'*, which are further explained below:

A.1 Uncertainty location

This dimension indicates *where* uncertainty can manifest itself in the problem configuration at hand. Five categories are distinguished along this dimension:

- The ***'context'*** concerns the framing of the problem, including the choices determining what is considered inside and outside the system boundaries ('delineation of the system and its environment'), as well as the completeness of this representation in view of the problem issues at hand. Part of these context-related choices is also reflected in the other location categories, such as 'data' which are considered to play a role, 'models' which are chosen to be used, and 'outcomes' which are taken to be of interest.

- ***'Data'*** refers to e.g. measurements, monitoring data, survey data etc. used in the study, that is the category of information which is directly based on empirical research and data gathering. Also the data which are used for calibration of the models involved are included in this category.

[2]For this appendix we have made extensive use of the material presented in the recent paper of Walker et al. 2003. In that paper a typology and an associated uncertainty matrix was presented which classify uncertainty according to three dimensions: its 'location' (where it occurs), its 'level' (where uncertainty manifests itself on the gradual spectrum between deterministic knowledge and total ignorance) and its 'nature' (whether uncertainty primarily stems from knowledge imperfection or is a direct consequence of inherent variability). We have extended this typology - and the associated uncertainty matrix - by explicitly adding two additional dimensions (represented by columns) denoted 'qualification of knowledge base' and 'value-ladenness of choices'. These additional characteristics have also been briefly mentioned by Walker et al. 2003, as being specific features of knowledge-related uncertainty. Due to their importance for assessing and communicating uncertainties, we have decided to explicitly incorporate these dimensions in the uncertainty matrix as two additional columns. Moreover we have also slightly modified the location-axis of Walker et al. 2003, which was specifically designed for model-based decision support studies. Two novel location categories have been added, viz. 'expert judgment' and 'data', since these can often be clearly distinguished as separate identities apart from the other categories. Finally, the 'model-category' has been extended by classifying the original separate separate categories 'inputs' and 'parameters' of Walker et al. 2003 as subcategories of the 'models'.

- ***'Model'***[3] concerns the 'model instruments' which are employed for the study. This category can encompass a broad spectrum of models, ranging from mental and conceptual models to more mathematical models (statistical models, causal process models etc.) which are often implemented as computer models. Especially for the latter class of models subcategories have been introduced, distinguishing between model structure (relations), model parameters (process parameters, initial and boundary conditions), model inputs (input data, external driving forces), as well as the technical model, which refers to the implementation in hard and software.

- ***'Expert judgment'*** refers to those specific contributions to the assessment that are not fully covered by context, models and data, and that typically have a more qualitative, reflective, and interpretative character. As such this input could also be alternatively viewed as part of the 'mental model'.

- The category ***'Outputs'*** from a study refers to the outcomes, indicators, propositions or statements which are of interest in the context of the problem at hand.

Remark Notice that 'scenarios' in a broad sense have not been included as a separate category on the location axis. In fact they show up at different locations, e.g. as part of the context, model structure, model input scenario, expert judgment etc.

The various aforementioned uncertainties on the location axis can be further characterized in terms of four other uncertainty features/dimensions, which are described in the subsequent sections.

A.2 Uncertainty level

This dimension expresses how a specific uncertainty source can be classified on a gradual scale running from 'knowing for certain' to 'no know'. Use is made of three distinct classes:

- ***Statistical uncertainty:*** this concerns the uncertainties which can adequately be expressed in statistical terms, e.g. as a range with associated probability (examples are statistical expressions for measurement inaccuracies; uncertainties due to sampling effects, uncertainties in model-parameter estimates, etc.). In the natural sciences, scientists generally refers to this category if they speak of uncertainty, thereby often implicitly assuming that the involved model-relations offer adequate descriptions of the real system under study, and that

[3] We define 'models'in a broad sense: a model is a (material) representation of an idea, object, process or mental construct. A model can exist solely in the human mind (mental, conceptual model), or be a physical representation of a larger object (physical scale model), or be a more quantitative description, using mathematical concepts and computers (mathematical and computer model).

the(calibration)-data employed are representative for the situation under study. However, when this is not the case, 'deeper' forms of uncertainty are at play, which can surpass the statistical uncertainty in size and seriousness and which require adequate attention.

- ***Scenario uncertainty:*** this concerns uncertainties which can not be depicted adequately in terms of chances, probabilities, but which can only be specified in terms of (a range of) possible outcomes. For these uncertainties it is impossible to specify a degree of probability or belief, since the mechanisms which lead to the outcome are not sufficiently known. Scenario uncertainties are often construed in terms of 'what-if' statements.

- ***Recognized ignorance:*** this concerns those uncertainties of which we realize - some way or another - that they are present, but of which we cannot establish any useful estimate, e.g. due to limits of predictability and knowledgeability ('chaos'), or due to unknown processes.

Continuing on the scale beyond recognized ignorance, we arrive in the area of complete ignorance ('unknown unknowns') of which we cannot yet speak and where we inevitably grope in the dark.

We should notice that the uncertainties which manifest themselves at a specific location (e.g. uncertainties on model relations) can appear in each of the abovementioned guises: while some aspects can be adequately expressed in 'statistical terms', other aspects can only be expressed in terms of 'what-if' statements; moreover there are typically aspects judged relevant but about which we know that we are (still) largely 'ignorant'. Judging which aspects manifests themselves in what forms is often a subjective (and uncertain) matter.

A.3 Nature of uncertainty

This dimension expresses whether uncertainty is primarily a consequence of the incompleteness and fallibility of knowledge (***'knowledge-related'*** or ***'epistemic' uncertainty***)or that it is primarily due to the intrinsic indeterminate and/or variable character of the system under study (***'variability-related'*** or ***'ontic' uncertainty***). The first form of uncertainty can possibly, though not necessarily[4], be reduced by more measurements, better models and/or more knowledge; the second form of uncertainty is typically not reducible by more knowledge (e.g. inherent indeterminacy and or unpredictability; randomness, chaotic behavior[5]).

[4]However, it is also possible that this knowledge-related uncertainty is increased by doing more research and by the progress of insight

[5]Although it is possible to know the characteristics of a system on a certain level of aggregation, e.g., knowing the probability distribution or the 'strange attractor', it is not always possible to

We notice that in many situations uncertainty manifests itself as a mix of both forms; not in all cases the delineation between 'epistemic' and 'ontic' can be made unequivocally. Moreover a combination of taste, tradition, specific problem features of interest and the current level of knowledge and ignorance with respect to the specific subject determines to a large part where the dividing line is drawn. In practice it is therefore the active choice of the researcher which often determines the distinction between epistemic and ontic, rather than that it is an innate and fundamental property of reality itself. Notice that this choice can be decisive for the outcomes and interpretations of the uncertainty assessment. Moreover using the distinction between 'epistemic' and 'ontic' uncertainty can render important information on the (im)possibility of reducing the uncertainties by, e.g., more research, better measurements, better models, or whether this is not possible. That is, although not being completely equivalent, this distinction reflects to a large extent the distinction between uncertainties which are 'reducible' and those which are 'not reducible' by means of further research.

A.4 Qualification of the knowledge base

The fourth dimension which is relevant in characterizing the uncertainties concerns the ***'qualification of the knowledge base'***. This refers to the degree of underpinning of the established results and statements. The term 'established results and statements' can be interpreted in a broad sense here: it can refer to the policy-advice statement as such (e.g. 'the norm will still be exceeded when the proposed policy measures become effective', 'the total annual emission of substance A is X kiloton') as well as to statements on the uncertainty in this statement (e.g. 'the uncertainty in the total annual emission of substance A is ... (95 % confidence interval)'). The degree of underpinning is divided into three classes: weak/fair/strong. If underpinning is weak, this indicates that the statement of concern is surrounded by much (knowledge-related) uncertainty, and deserves further attention. This classification moreover offers suggestions about the extent to which uncertainty is reducible by providing a better underpinning.

Notice that this dimension in fact characterizes the *reliability* of the information (data, knowledge, methods, argumentations etc.) which is used in the assessment. Criteria such as 'empirical', 'theoretical' or 'methodological' underpinning and 'acceptance/support within and outside the peer community' can be employed for assessing and expressing the level of reliability. If required, a so-called 'pedigree analysis' can be done, which results in a semi-quantitative scoring of the underpinning on the basis of a number of qualitative criteria such as the aforementioned ones (see the tool-catalogue, (van der Sluijs et al., 2003)).

predict the behavior or properties of individuals/elements which form part of the system on a lower level

A.5 Value-ladenness of choices

The final dimension for characterizing uncertainties denotes whether a substantial amount of ***'value-ladenness'*** and subjectiveness is involved in making the various - implicit and explicit - choices during the environmental assessment. This concerns, among other things, the way in which (i) the problem is framed *vis à vis* the various views and perspectives on the problem, (ii) the knowledge and information (data, models) is selected and applied, (iii) the explanations and conclusions are expressed and formulated. If the value-ladenness is high for relevant parts of the assessment, then it is imperative to analyze whether or not the results of the study are highly influenced by the choices involved, and whether this could lead to a certain arbitrariness, ambiguity or uncertainty of the policy relevant conclusions. This could then be a reason to explicitly deal with different views and perspectives in the assessment and to discuss the scope and robustness of the conclusions in an explicit manner. In order to identify this value-ladenness one could e.g. use the methods proposed in section 2.2.

A.6 Instructions for filling out the uncertainty matrix

As explained in the foregoing sections, the uncertainty matrix (cf. table 6) employs 5 main dimensions for characterizing the sources of uncertainty: *'location', 'uncertainty level', 'nature of uncertainty', 'qualification of knowledge base'* and *'value-ladenness of choices'*. These main characteristics have been projected into a two-dimensional matrix:

- by means of the rows one can denote on which specific 'location' the respective uncertainty sources will manifest itself (e.g. a specific uncertain model input, driving force, model parameter etc.).
- by means of the columns one can subsequently indicate how the specific (location-dependent) uncertainty source can be further characterized in terms of the four other qualification-dimensions. Notice that for these dimensions a number of subcategories have been distinguished which enable a differentiated characterization. For the features 'uncertainty level' and 'nature of uncertainty' these sub-characteristics need not be mutually exclusive/disjunct: part of a specific uncertainty source (e.g. a model-input) can be adequately expressed as statistical uncertainty, while another part can e.g. be only expressed in terms of a 'what-if' characterization etc. The last two main columns 'qualification of knowledge base' and 'value-ladenness of choices' provide a reflection on the underpinning and biasedness of the employed knowledge and the choices made, and can usually be characterized in a unique fashion in terms of the corresponding sub-categories (e.g. 'weak/ fair/ strong', resp. 'small/ medium/ large')

It is recommended to use an ***ABC-coding*** to indicate the relevance of the item of concern (don't fill in anything if the item is (nearly) not important):

- **A**= of crucial importance;
- **B**= important;
- **C**= of medium importance.

By attaching an index to this coding, e.g. A_1,B_1,C_1, A_2,B_2,C_2 etc., one can indicate to which uncertainty source the respective coding refers: index 1 refers to uncertainty source 1, index 2 to source 2, etc. Notice that a specific source can appear at different points in the matrix with different coding-scores, dependent on how it manifests itself and how it can be characterized.

For reasons of transparency and accountability it is recommended to use the associated table 7 to briefly specify the relevant information on each separate source of uncertainty, and to explain/motivate its uncertainty characterization (location, level, nature etc.) and (A,B,C)-scoring given in the uncertainty matrix. Appropriate literature references or concise background information on these choices can be included.

UNCERTAINTY MATRIX			**Level of uncertainty** *from determinism, through probability and possibility, to ignorance*			**Nature of uncertainty**		**Qualification of knowledge base (backing)**			**Value-ladenness of choices**		
Location ⇓			**Statistical uncertainty (range+ chance)**	**Scenario uncertainty (range as 'what-if' option)**	**Recognized ignorance**	**Knowledge-related uncertainty**	**Variability-related uncertainty**	**Weak** -	**Fair** 0	**Strong** +	**Small** -	**Medium** 0	**Large** +
Context		Ecological, technological, economic, social and political representation											
Expert judgment		Narratives; story-lines; advices											
Model	**Model structure**	Relations											
	Technical model	Software & hardware implementation											
	Model parameters												
	Model inputs	Input data; driving forces; input scenarios											
Data (in general sense)		Measurements; monitoring data; survey data											
Outputs		Indicators; statements											

Table 6: Uncertainty Matrix for localizing and characterizing the various uncertainties involved.

Brief description of the selected sources of uncertainty	Explanation and justification of the specifications in the uncertainty matrix
Source 1:	...
Source 2:	...
Source 3	...
...	...
...	...

Table 7: Background information on the uncertainty sources depicted in the uncertainty matrix (table 6)

Appendix B Glossary

The latest version of this glossary can be found at www.nusap.net

Aggregation Aggregation is the joining of more or less equivalent elements. Aggregation can take place across different scale dimensions, leading to different resolutions on these scales. The most relevant scale dimensions in environmental assessment are: temporal scale (e.g. diurnal; seasonal; annual; century), spatial scale (e.g. local; regional; continental; global), and systemic scales (e.g. individual plants; ecosystems; terrestrial biosphere).

Aggregation error Aggregation error arises from the scaling up or scaling down of variables to meet a required aggregation level. The scaling-up or scaling-down relations are, especially for non-additive variables, to a certain degree arbitrary.

Assessment Assessment is a process that connects knowledge and action (in both directions) regarding a problem. Assessment comprises the analysis and review of knowledge for the purpose of helping someone in a position of responsibility to evaluate possible actions or think about a problem. Assessment usually does not mean doing new research. Assessment means assembling, summarizing, organizing, interpreting, and possibly reconciling pieces of existing knowledge, and communicating them so that they are relevant and helpful to an intelligent but inexpert policy-maker or other actor(s) involved in the problem at hand.

Behavioural variability One of the sources of variability distinguished in the PRIMA typology (Van Asselt, 2000). It refers to 'non-rational' behaviour, discrepancies between what people say and what they actually do (e.g. cognitive dissonance), or to deviations from 'standard' behavioural patterns (micro-level behaviour).

Bias A constant or systematic deviation as opposed to a random error. It appears as a persistent over- or under-estimation of the quantity measured, calculated or estimated. See also related concepts as cognitive bias, disciplinary bias, motivational bias and value ladenness.

Cognitive bias Experts and lay people alike are subject to a variety of potential mental errors or shortcomings caused by man's simplified and partly subconscious information processing strategies. It is important to distinguish these so-called cognitive biases from other sources of bias, such as cultural bias, organizational bias, or bias resulting from one's own self-interest (from Psychology of Intelligence Analysis, R.J. Heuer, 1999; http://www.cia.gov/csi/books/19104/index.html). Some of the sources of cognitive bias are as follows: overconfidence, anchoring, availability, representativeness, satisficing, unstated assumptions, coherence. A fuller description of sources of cognitive bias in expert and lay elicitation processes is available in Dawes (1988).

Cognitive bias: Anchoring and adjustment Assessments are often unduly weighted toward the conventional value, or first value given, or to the findings of previous assessments in making an assessment. Thus, they are said to be 'anchored' and 'adjusted' to this value.

Cognitive bias: Availability This bias refers to the tendency to give too much weight to readily available data or recent experience (which may not be representative of the required data) in making assessments.

Cognitive bias: Coherence Events are considered more likely when many options/scenarios can be envisaged that lead to the event, or if some options/scenarios are particularly coherent. Conversely, events are considered unlikely when options/scenarios can not be imagined. Thus, probabilities tend to be assigned more on the basis of one's ability to tell coherent stories than on the basis of intrinsic probability of occurrence.

Cognitive bias: Overconfidence Experts tend to over-estimate their ability to make quantitative judgements. This is often manifest with an estimate of a quantity and its uncertainty range that does not even encompass the true value of the quantity. This is difficult for an individual to guard against; but a general awareness of the tendency can be important.

Cognitive bias: Representativeness This relates to the tendency to place more confidence in a single piece of information that is considered representative of a process than in a larger body of more generalized information.

Cognitive bias: Satisficing This refers to the tendency to search through a limited number of solution options and to pick from among them. Comprehensiveness is sacrificed for expediency in this case.

Cognitive bias: Unstated assumptions A subject's responses are typically conditional on various unstated assumptions. The effect of these assumptions is often to constrain the degree of uncertainty reflected in the resulting estimate of a quantity. Stating assumptions explicitly can help reflect more of a subject's total uncertainty.

Conflicting evidence One of the categories on the spectre of uncertainty due to 'lack of knowledge' as distinguished in the PRIMA typology (Van Asselt, 2000). Conflicting evidence occurs if different data sets/observations are available, but allow room for competing interpretations. 'We don't know what we know'.

Context validation Context validity refers to the probability that an estimate has approximated the true but unknown range of (causally) relevant aspects and rival hypotheses present in a particular policy context. Context validation thus is minimizing the probability that one overlooks something of relevance. It can be performed by a participatory bottom-up process eliciting from stakeholders those aspects considered relevant as well as rival hypotheses on underlying causal relations, and rival problem definitions and problem framings. See Dunn,1998, 2000.

Cultural theory , also known as 'grid-group cultural theory' or theory of socio-cultural viability has been developed over the past thirty years by the British anthropologists Mary Douglas, Michael Thompson, and Steve Rayner, the American political scientists Aaron Wildavsky and Richard Ellis, and many others. The theoretical framework was originally designed to deal with cultural diversity in remote places by an author interested in rituals, symbols, witchcraft, food and drinking habits, Mary Douglas. Her aim was to show the relevance of anthropology for 'modern' societies. And indeed her neo-Durkheimian approach emerged as a useful tool in so many fields of social science. Until present, the theory has been used most extensively in anthropology and political science, especially in policy analysis and in the interdisciplinary field of risk analysis (taken from the Grid-Group Cultural Theory web-site; see http://gp.fmg.uva.nl/ggct/agate/home.html for more information). Cultural theory employs two axes (dimensions) for describing social formations and cultural diversity, 'group' and 'grid'; when these are at 'high' and 'low', they yield types described as 'hierarchist', 'egalitarian', 'fatalist' and 'individualist'. Michael Thompson has added a fifth type, residing in the middle, called 'hermit'. In recent applications the 'fatalist' has been eliminated from the scheme. Recently Ravetz (2001) proposed a modification of the scheme using as dimensions of social variation: Style of action (isolated / collective) and location (insider / outsider), yielding the types: 'Administrator', 'Business man', 'Campaigner', and 'Survivor' (ABCS).

Disciplinary bias Science tends to be organized into different disciplines. Disciplines develop somewhat distinctive traditions over time, tending to develop their own characteristic manner of viewing problems, drawing problem boundaries and of selecting the objects of inquiry etc. These differences in perspective will translate into forms of bias in viewing problems.

Epistemology The theory of knowledge.

Extended facts Knowledge from other sources than science, including local knowledge, citizens' surveys, anecdotal information, and the results of investigative journalism. Inclusion of extended facts in environmental assessment is one of the key principles of Post-Normal Science. (Funtowicz and Ravetz, 1993)

Extended peer communities Participants in the quality assurance processes of knowledge production and assessment in Post-Normal Science, including all stakeholders engaged in the management of the problem at hand. (Funtowicz and Ravetz, 1993)

Extrapolation The inference of unknown data from known data, for instance future data from past data, by analyzing trends and making assumptions.

Facilitator A person who has the role to facilitate a structured group process (for instance participatory integrated assessment, i.e. integrated assessment where public participation (stakeholders) is an explicit and crucial part of the whole assessment process) in such a way that the aim of that group process will be met.

Focus group Well-established research technique applied since the 1940's in the social sciences, marketing fields, evaluation and decision making research. Generally, a group of 5 to 12 people are interviewed by a moderator on a specific focused subject. With the focus group technique the researcher can obtain at the same time information from various individuals together with the interactions amongst them. To a certain extent such artificial settings simulate real situations where people communicate with each other.

Functional error Functional error arises from uncertainty about the form and nature of the process represented by the model. Uncertainty about model structure frequently reflects disagreement between experts about the underlying causal mechanisms.

GIGO Literally, Garbage In, Garbage Out, typically referring to the fact that outputs from models are, at their best, only as good as the inputs. See e.g. Stirling, 2000. A variant formulation is 'Garbage In, Gospel Out' referring to a tendency to put faith in computer outputs regardless of the quality of the inputs.

Global sensitivity analysis Global sensitivity analysis is a combination of sensitivity and uncertainty analysis in which "a neighborhood of alternative assumptions is selected and the corresponding interval of inferences is identified. Conclusions are judged to be sturdy only if the neighborhood of assumptions is wide enough to be credible and the corresponding interval of inferences is narrow enough to be useful". Leamer (1990) quoted in Saltelli (2002).

Hardware error Hardware errors in model outcomes arise from bugs in hardware. An obvious example is the bug in the early version of the Pentium processor for personal computers, which gave rise to numerical error in a broad range of floating-point calculations performed on that processor. The processor had already been widely used worldwide for quite some time, when the bug was discovered. It cannot be ruled out that hardware used for environmental models contains undiscovered bugs that might affect the outcomes, although it is unlikely that they will have a significant influence on the models' performance.

To secure against hardware error, one can test critical model output for reproducibility on a computer with a different processor before the critical output enters the policy debate.

Hedging Hedging is a quantitative technique for the iterative handling of uncertainties in decision making. It is used, for instance, to deal with risks in finance and in corporate R&D decisions. For example, a given future scenario may be considered so probable that all decisions which are made assume that the forecast is correct. However, if these assumptions are wrong, there may be no flexibility to meet other outcomes. Thus, rather than solely developing a course of action for one particular future scenario, business strategic planners prefer to tailor a hedging strategy that will allow adaptation to a number of possible outcomes. Applied to climate change, it could for example be used by stakeholders from industry to reduce the risks of investing in energy technology, pending governmental measures on ecotax. Anticipating a range of measures from government to reduce greenhouse gases emissions, a branch of industry or a company could estimate the cost-effectiveness of investing or delaying investments in more advanced energy technology.

Ignorance The deepest of the three sorts of uncertainty distinguished by Funtowicz and Ravetz (1990): Inexactness, unreliability and border with ignorance, which refer to technical, methodological and epistemic aspects of uncertainty. In terms of the NUSAP notational system for describing uncertainty in information (data, model-outcomes etc.) the technical uncertainty (inexactness) in our knowledge of the behavior of the 'data' is expressed by the spread (S), while the methodological uncertainty (unreliability) refers to our knowledge of the data-production process. This latter aspect is expressed by the assessment-qualifier (A) in the NUSAP notation. Besides the technical and methodological uncertainty dimensions, there is still something more. No process in the field or laboratory is completely known. Even physical constants may vary unpredictably. This is the realm of our ignorance: it includes all the different sorts of gaps in our knowledge not encompassed in the previous sorts of uncertainty. This ignorance may merely be of what is considered insignificant, such as when anomalies in experiments are discounted or neglected, or it may be deeper, as is appreciated retrospectively when revolutionary new advances are made. Thus, space-time and matter-energy were both beyond the bounds of physical imagination, and hence of scientific knowledge, before they were discovered. Can we say anything useful about that of which we are ignorant? It would seem by the very definition of ignorance that we cannot, but the boundless sea of ignorance has shores, which we can stand on and map. The Pedigree qualifier (P) in the NUSAP system maps this border with ignorance in knowledge production. In this way it goes beyond what statistics has provided in its mathematical approach to the management of uncertainty.

In the PRIMA typology (Van Asselt, 2000) 'ignorance' is one of the categories on the continuum scale of uncertainty due to lack of knowledge. The PRIMA typology distinguishes between: reducible ignorance and irreducible ignorance. Reducible ignorance refers to processes that we do not observe, or theoretically imagine, at this point in time, but probably in the future: 'We don't know what we do not know'. Irreducible ignorance refers to processes and interactions between processes that cannot, or not unambiguously, be determined by human capacities and capabilities: 'We cannot know'.

Indeterminacy Indeterminacy is a category of uncertainty which refers to the open-endedness (both social and natural) in the coupled natural-social processes. It applies to processes where the outcome cannot (or only partly) be determined from the input. Indeterminacy introduces the idea that contingent social behavior also has to be included in the analytical and prescriptive framework. It acknowledges the fact that many knowledge claims are not fully determined by empirical observations but are based on a mixture of observation and interpretation. The latter implies that scientific knowledge depends not only on its degree of fit with nature (the observation part), but also on its correspondence with the social world (the interpretation part) and on its success in building and negotiating trust and credibility for the way science deals with the 'interpretive space'.

In the PRIMA typology (Van Asselt, 2000) indeterminacy is one of the categories on the continuum scale of uncertainty due to lack of knowledge. Indeterminacy occurs in case of processes of which we understand the principles and laws, but which can never be fully predicted or determined: 'We will never know'.

Inexactness One of the three sorts of uncertainty distinguished by Funtowicz and Ravetz (1990): Inexactness, unreliability and border with ignorance. Quantitative (numerical) inexactness is the simplest sort of uncertainty; it is usually expressed by significant digits and error bars. Every set of data has a spread, which may be considered in some contexts as a tolerance or a random error in a (calculated) measurement. It is the kind of uncertainty that relates most directly to the stated quantity, and is most familiar to student of physics and even the general public. Next to quantitative inexactness one can also distinguish qualitative inexactness which occurs if qualitative knowledge is not exact but comprises a range.

In the PRIMA typology (Van Asselt, 2000) inexactness is one of the categories on the continuum scale of uncertainty due to lack of knowledge. Inexactness is also referred to as lack of precision, inaccuracy, metrical uncertainty, measurement errors, or precise uncertainties: 'We roughly know'.

Institutional uncertainty One of the seven types of uncertainty distinguished by De Marchi (1995) in their checklist for characterizing uncertainty in environmental emergencies: institutional, legal, moral, proprietary, scientific, situational, and societal uncertainty. Institutional uncertainty is in some sense a subset of societal uncertainty, and refers more specifically to the role and actions of institutions and their members. Institutional uncertainty stems from the "diverse cultures and traditions, divergent missions and values, different structures, and work styles among personnel of different agencies" (De Marchi, 1995). High institutional uncertainty can hinder collaboration or understanding among agencies, and can make the actions of institutions difficult to predict.

Lack of observations/measurements In the PRIMA typology (Van Asselt, 2000) 'lack of observations/measurements' is one of the categories on the continuum scale of uncertainty due to lack of knowledge. It refers to lacking data that could have been collected, but haven't been: 'We could have known'.

Legal uncertainty One of the seven types of uncertainty distinguished by De Marchi (1995) in their checklist for characterizing uncertainty in environmental emergencies: institutional, legal, moral, proprietary, scientific, situational, and societal uncertainty. Legal uncertainty is relevant "wherever agents must consider future contingencies of personal liability for their actions (or inactions)". High legal uncertainty can result in defensive responses in regard to both decision making and release of information. Legal uncertainty may also play a role where actions are conditioned on the transparance of a legal framework in allowing one to predict the consequences of particular actions.

Limited knowledge One of the sources of uncertainty distinguished in the PRIMA typology (Van Asselt, 2000). Limited knowledge is a property of the analysts performing the study and/or of our state of knowledge. Also referred to as 'subjective uncertainty', 'incompleteness of the information', 'informative uncertainty', 'secondary uncertainty', or 'internal uncertainty'. Limited knowledge results partly out of variability, but knowledge with regard to deterministic processes can also be incomplete and uncertain. A continuum can be described that ranges from unreliability to structural uncertainty.

Model-fix error Model-fix errors are those errors that arise from the introduction of non-existent phenomena in the model. These phenomena are introduced in the model for a variety of reasons. They can be included to make the model computable with today's computer technology, or to allow simplification, or to allow modelling at a higher aggregation level, or to bridge the mismatch between model behaviour and observation and or expectation. An example of the latter is the flux adjustment in many coupled Atmosphere Ocean General Circulation Models used for climate projection. The effect of such model fixes on the reliability of the model outcome will be bigger if the simulated state of the system is further removed from the (range of) state(s) to which the model was calibrated. It is useful to distinguish between (A) model fixes to account for well understood limitations of a model and (B) model fixes to account for a mismatch between model and observation that is not understood.

Monte Carlo Simulation Monte Carlo Simulation is a statistical technique for stochastic model calculations and analysis of error propagation in calculations. Its purpose is to trace out the structure of the distributions of model output. In its simplest form this distribution is mapped by calculating the deterministic results (realizations) for a large number of random draws from the individual distribution functions of input data and parameters of the model. To reduce the required number of model runs needed to get sufficient information about the distribution in the outcome (mainly to save computation time), advanced sampling methods have been designed such as Latin Hyper Cube sampling. The latter makes use of stratification in the sampling of individual parameters and of pre-existing information about correlations between input variables.

Moral uncertainty One of the seven types of uncertainty distinguished by De Marchi (1995) in their checklist for characterizing uncertainty in environmental emergencies: institutional, legal, moral, proprietary, scientific, situational, and societal uncertainty. Moral uncertainty stems from the underlying moral issues related to action and inaction in any given case. De Marchi notes that, though similar to legal responsibility, moral guilt may occur absent legal responsibility when negative consequences might have been limited by the dissemination of prior information or more effective management for example. "Moral uncertainty is linked to the ethical tradition of a given country be it or not enacted in legislation (juridical and societal norms, shared moral values, mores), as well as the psychological characteristics of persons in charge, their social status and professional roles" (De Marchi, 1995). Moral uncertainty would typically be high when moral and ethical dimensions of an issue are central and participants have a range of understandings of the moral imperatives at stake.

Motivational bias Motivational bias occurs when people have an incentive to reach a certain conclusion or see things a certain way. It is a pitfall in expert elicitation. Reasons for occurrence of motivational bias include: a) a person may want to influence a decision to go a certain way; b) the person may perceive that he will be evaluated based on the outcome and might tend to be conservative in his estimates; c) the person may want to suppress uncertainty that he actually believes is present in order to appear knowledgeable or authoritative; and d) the expert has taken a strong stand in the past and does not want to appear to contradict himself by producing an estimate that lends credence to alternative views.

Multi-criteria decision analysis A method of formalising issues for decision, using both 'hard' and 'soft' indicators, not intended to yield an optimum solution but rather to clarify positions and coalitions.

Natural randomness One of the sources of variability distinguished in the PRIMA typology (Van Asselt, 2000). It refers to the non-linear, chaotic and unpredictable nature of natural processes.

Normal science Normal science is a term which was originally coined by Thomas Kuhn (1962), and was later on further expanded, by Funtowicz and Ravetz (1990) who introduced the term 'post-normal science' to denote the kind of science which is needed to tackle the current complex, boundary-crossing problems which society faces, and where system uncertainties or decision stakes are high. In their words: "By 'normality' we mean two things. One is the picture of research science as 'normally' consisting of puzzle solving within an unquestioned and unquestionable 'paradigm', in the theory of T.S. Kuhn (Kuhn 1962). Another is the assumption that the policy environment is still 'normal', in that such routine puzzle solving by experts provides an adequate knowledge base for policy decisions. Of course researchers and experts must do routine work on small-scale problems; the question is how the framework is set, by whom, and with whose awareness of the process. In 'normality', either science or policy, the process is managed largely implicitly, and is accepted unwittingly by all who wish to join in."

Numerical error Numerical error arises from approximations in numerical solution, rounding of numbers and numerical precision (number of digits) of the represented numbers. Complex models include a large number of linkages and feedbacks which enhances the chance that unnoticed numerical artifacts co-shape the model behaviour to a significant extent. The systematic search for artifacts in model behaviour which are caused by numerical error, requires a mathematical 'tour de force' for which no standard recipe can be given. It will depend on the model at hand how one should set up the analysis. To secure against potential serious error due to rounding of numbers, one can test the sensitivity of the results to the number of digits accounted for in floating-point operations in model calculations.

NUSAP Acronym for Numeral Unit Spread Assessment Pedigree Notational system developed by Silvio Funtowicz and Jerry Ravetz to better manage and communicate uncertainty in science for policy. In NUSAP, the increasing severity of uncertainty is marked by the three categories of uncertainty, Spread for technical uncertainty (or error-bar), Assessment for methodological (or unreliability) and Pedigree for border with ignorance (or the essential limitations of a particular sort of scientific practice). (Funtowicz and Ravetz, 1990)

Parameter A quantity related to one or more variables in such a way that it remains constant for any specified set of values of the variable or variables.

Partisan Mutual Adjustment Charles Lindblom (1965) described governance in pluralist democracies as a 'Science of Muddling Through' that relies on Disjointed Incrementalism as its strategy of decision and whose intelligence is produced through what he calls Partisan Mutual Adjustment. Both of these practices are primarily justified ex negativo - by comparison, that is, to the counterfactual ideal of hierarchical governance based on 'synoptic' analyses of all pertinent issues and affected interests. While the synoptic ideal is said to overtax the bounded rationality of real-world decision makers, the incrementalist strategy will disaggregate large and complex issues into series of small steps that reduce the risks of misinformation and miscalculation, and that can use rapid feedback to correct any errors. Similarly, instead of relying on the benevolence and omniscience of central decision makers, Partisan Mutual Adjustment will directly involve representatives of affected groups and specialized office holders that are able to utilize local information, and to fend for their own interests in pluralist bargaining processes in which the opposing and different views need to be heard. In short, compared to an impossible ideal, muddling through is not only feasible but likely to produce policy choices that are, at the same time, better informed and more sensitive to the affected interests. (Scharpf and Mohr, 1994)

Pedigree Pedigree conveys an evaluative account of the production process of information (e.g. a number) on a quantity or phenomenon, and indicates different aspects of the underpinning of the numbers and scientific status of the knowledge used (Funtowicz and Ravetz, 1990). Pedigree is expressed by means of a set of pedigree criteria to assess these different aspects. Examples of such criteria are empirical basis or degree of validation. These criteria are in fact yardsticks for strength. Many of these criteria are hard to measure in an objective way. Assessment of pedigree involves qualitative expert judgement. To minimise arbitrariness and subjectivity in measuring strength a pedigree matrix is used to code qualitative expert judgements for each criterion into a discrete numeral scale from 0 (weak) to 4 (strong) with linguistic descriptions (modes) of each level on the scale. Note that these linguistic descriptions are mainly meant to provide guidance in attributing scores to each of the criteria. It is not possible to capture all aspects that an expert may consider in scoring a pedigree in a single phrase. Therefore a pedigree matrix should be applied with some flexibility and creativity. Examples of pedigree matrices can be found in the Pedigree matrices section of the NUSAP-net website (http://www.nusap.net).

Pitfall A pitfall is a characteristic error that commonly occurs in assessing a problem. Such errors are typically associated with a lack of knowledge or experience, and thus may be reduced by experience, by consultation of others, or by following procedures designed to highlight and avoid pitfalls. In complex problems we sometimes say that pitfalls are ‘dense’, meaning that there is an unusual variety and number of pitfalls.

Post-Normal Science Post-Normal Science is the methodology that is appropriate when “facts are uncertain, values in dispute, stakes high and decisions urgent”. It is appropriate when either ‘systems uncertainties’ or ‘decision stakes’ are high. See http://www.nusap.net for a tutorial.

Practically immeasurable In the PRIMA typology (Van Asselt, 2000) ‘practically immeasurable' is one of the categories on the continuum scale of uncertainty due to lack of knowledge. It refers to lacking data that in principle can be measured, but not in practice (too expensive, too lengthy, not feasible experiments): 'We know what we do not know'.

Precautionary principle The principle is roughly that "when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically" (Wingspread conference, Wisconsin, 1998). Note that this would apply to most environmental assessments since cause-effect statements can rarely be fully established on any issue. If the burden of proof were set such that one must demonstrate a completely unequivocal cause-effect relationship before taking action, then it would not be possible to take action on any meaningful environmental issue. The precautionary principle thus relates to the setting of burden of proof.

PRIMA approach Acronym for Pluralistic fRamework of Integrated uncertainty Management and risk Analysis (Van Asselt, 2000). The guiding principle is that uncertainty legitimates different perspectives and that as a consequence uncertainty management should consider different perspectives. Central to the PRIMA approach is the issue of disentangling controversies on complex issues in terms of salient uncertainties. The salient uncertainties are then 'coloured' according to various perspectives. Starting from these perspective-based interpretations, various legitimate and consistent narratives are developed to serve as a basis for integrated analysis of autonomous and policy-driven developments in terms of risk.

Probabilistic Based on the notion of probabilities.

Probability density function (PDF) The probability density function of a continuous random variable represents the probability that a random variable will take its value in a infinitely small variable interval. The probability density function can be integrated to obtain the probability that the random variable takes a value in a given interval.

Problem structuring An approach to analysis and decision making which assumes that participants do not have clarity on their ends and means, and provides appropriate conceptual structures. It is a part of 'soft systems methodology'.

Process error Process error arises from the fact that a model is by definition a simplification of the real system represented by the model. Examples of such simplifications are the use of constant values for entities that are non-constant in reality, or focusing on key processes that affect the modelled variables significantly whilst omitting processes that are considered to be not significant.

Proprietary uncertainty One of the seven types of uncertainty distinguished by De Marchi (1995), in their checklist for characterizing uncertainty in environmental emergencies: institutional, legal, moral, proprietary, scientific, situational, and societal uncertainty. Proprietary uncertainty occurs due to the fact that information and knowledge about an issue are not uniformly shared among all those who could potentially use it. That is, some people or groups have information that others don't and may assert ownership or control over it. "Proprietary uncertainty becomes most salient when it is necessary to reconcile the general needs for safety, health, and environment protection with more sectorial needs pertaining, for instance, to industrial production and process, or to licensing and control procedure" (De Marchi, 1995). De Marchi notes that 'whistle blowing' is another source of proprietary uncertainty in that there is a need for protection of those who act in sharing information for the public good. Proprietary uncertainty would typically be high when knowledge plays a key role in assessment, but is not widely shared among participants. An example of such would be the case of external safety of military nuclear production facilities.

Proxy Sometimes it is not possible to represent directly the quantity or phenomenon we are interested in by a parameter so some form of proxy measure is used. A proxy can be better or worse depending on how closely it is related to the actual quantity we intend to represent. Think of first order approximations, over-simplifications, idealisations, gaps in aggregation levels, differences in definitions etc..

Pseudo-imprecision Pseudo-imprecision occurs when results have been expressed so vaguely that they are effectively immune from refutation and criticism.

Pseudo-precision Pseudo-precision is false precision that occurs when the precision associated with the representation of a number or finding grossly exceeds the precision that is warranted by closer inspection of the underlying uncertainties.

Reflexive Science Reflexive science is to be understood in the sense of reflex (self-confrontation with own unanticipated or unintended consequences of the science) and reflection (self criticism of value ladenness and assumptions in the science). Reflexive science does not simply report 'facts' or 'truths' but transparently constructs interpretations of his or her experiences in the field and then questions how those interpretations came about.

Resolution error Resolution error arises from the spatial and temporal resolution in measurement, datasets or models. The possible error introduced by the chosen spatial and temporal resolutions can be assessed by analyzing how sensitive results are to changes in the resolution. However, this is not as straightforward as it looks, since the change in spatial and temporal scales in a model might require significant changes in model structure or parameterizations. For instance, going from annual time steps to monthly time steps in a climate model requires the inclusion of the seasonal cycle of insolation. Another problem can be that data are not available at a higher resolution.

Robust finding A robust finding is "one that holds under a variety of approaches, methods, models, and assumptions and one that is expected to be relatively unaffected by uncertainties" (IPCC, 2001). Robust findings should be insensitive to most known uncertainties, but may break down in the presence of surprises.

Robust policy A robust policy should be relatively insensitive to over- or underestimates of risk. That is, should the problem turn out to be much better or much worse than expected, the policy would still provide a reasonable way to proceed.

Scenario A plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and driving forces (e.g., rate of technology changes, prices). Note that "scenarios are neither predictions nor forecasts, since they depend on assumed changes in key boundary conditions (e.g. emissions), and neither are they fully projections of what is likely to happen because they have considered only a limited set of possible future boundary conditions (e.g., emissions scenarios). For the decision maker, scenarios provide an indication of possibilities, but not definitive probabilities." (see MacCracken, 2001, http://sciencepolicy.colorado.edu/zine/archives/1-29/26/guest.html)

Scientific uncertainty One of the seven types of uncertainty distinguished by De Marchi (1995) in their checklist for characterizing uncertainty in environmental emergencies: institutional, legal, moral, proprietary, scientific, situational, and societal uncertainty. Scientific uncertainty refers to uncertainty which emanates from the scientific and technical dimensions of a problem as opposed to the legal, moral, societal, institutional, proprietary, and situational dimensions outlined by De Marchi (1995). Scientific uncertainty is intrinsic to the processes of risk assessment and forecasting.

Sensitivity analysis Sensitivity analysis is the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input. From Saltelli (2001).

Situational uncertainty One of the seven types of uncertainty distinguished by De Marchi (1995) in their checklist for characterizing uncertainty in environmental emergencies: institutional, legal, moral, proprietary, scientific, situational, and societal uncertainty. Situational uncertainty relates to "the predicament of the person responsible for a crisis, either in the phase of preparation and planning, or of actual emergency. It refers to individual behaviours or personal interventions in crisis situations" (De Marchi, 1995) and as such represents a form of integration over the other six types of uncertainty. That is, it tends to combine the uncertainties one has to face in a given situation or on a particular issue. High situational uncertainty would be characterized by situations where individual decisions play a substantial role and there is uncertainty about the nature of those decisions.

Societal randomness One of the sources of variability distinguished in the PRIMA typology (Van Asselt, 2000). It refers to social, economic and cultural dynamics, especially to the non-linear, chaotic and unpredictable nature of societal processes (macro-level behaviour).

Societal uncertainty One of the seven types of uncertainty distinguished by De Marchi (1995) in their checklist for characterizing uncertainty in environmental emergencies: institutional, legal, moral, proprietary, scientific, situational, and societal uncertainty. Communities within society may differ in their set of norms, values, and manner of relating. This in turn can result in differences in approach to decision making and assessment. Some salient characteristics of these differences will be different views about the role of consensus versus conflict, on locating responsibility between individuals and larger groups, on views about the legitimacy and role of social and private institutions, and on attitudes to authority and expertise. From De Marchi (1995). Societal uncertainty would typically be high when decisions involve substantial collaboration among groups characterized by divergent decision making styles.

Software error Software error arises from bugs in software, design errors in algorithms, type-errors in model source code, etc. Here we encounter the problem of code verification which is defined as: examination of the implementation of the numerical model in the computer code to ascertain that there are no inherent implementation problems in obtaining a solution. If one realizes that some environmental models have hundreds of thousands of lines of source code, errors in it cannot easily be excluded and code verification is difficult to carry out in a systematic manner.

Stakeholders Stakeholders are those actors who are directly or indirectly affected by an issue and who could affect the outcome of a decision making process regarding that issue or are affected by it.

Stochastic In stochastic models (as opposed to deterministic models), the parameters and variables are represented by probability distribution functions. Consequently, the model behavior, performance, or operation is probabilistic.

Structural uncertainty Uncertainty about what the appropriate equations are to correctly represent a given causal relationship.

In the PRIMA typology (Van Asselt, 2000) structural uncertainty refers to the lower half of the continuum scale of uncertainty due to lack of knowledge, and is also referred to as radical, or systematic uncertainty. It comprises conflicting evidence, reducible ignorance, indeterminacy, and irreducible ignorance.

Structured problems Hisschemöller and Hoppe (1995) have defined structured problems as those for which there is a high level of agreement on the relevant knowledge base and a high level of consent on the norms and values associated with the problem. Such problems are thus typically of a more purely technical nature and fall within the category of 'normal' science.

Surprise Surprise occurs when actual outcomes differ sharply from expected ones. However, surprise is a relative term. An event will be surprising or not depending on the expectations and hence point of view of the person considering the event. Surprise is also inevitable if we accept that the world is complex and partially unpredictable, and that individuals, society, and institutions are limited in their cognitive capacities, and possess limited tools and information.

Sustainable development "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs." (Brundtland Commission, 1987)

Technological surprise One of the sources of variability distinguished in the PRIMA typology (Van Asselt, 2000). It refers to unexpected developments or breakthroughs in technology or unexpected consequences of technologies.

Transparency The degree to which a model is transparent. A model is said to be transparent if its pedigree is well documented and all key assumptions that underlie the model are accessible and understandable for the users.

Type I error also: Error of the first kind. In hypothesis testing, this error is caused by incorrect rejection of the hypothesis when it is true. Any test is at risk of being too selective and too sensitive. The design of the test, especially confidence limits, aims at reducing the likelihood of one type of error at the price of increasing the other. Thus, all such statistical tests are value laden.

Type II error also: Error of the second kind. In hypothesis testing this error is caused by not rejecting the hypothesis when it is false.

Type III error also: Error of the third kind. Assessing or solving the wrong problem by incorrectly accepting the false meta-hypothesis that there is no difference between the boundaries of a problem, as defined by the analyst, and the actual boundaries of that problem (Raifa, 1968, redefined by Dunn, 1997, 2000).

Unreliability One of the three sorts of uncertainty distinguished by Funtowicz and Ravetz (1990): Inexactness, unreliability and border with ignorance. Unreliability relates to the level of confidence to be placed in a quantitative statement, usually represented by the confidence level (at say 95 % or 99 %). In practice, such judgements are quite diverse; thus estimates of safety and reliability may be given as "conservative by a factor of n". In risk analyses and futures scenarios estimates are qualified as 'optimistic' or 'pessimistic'. In laboratory practice, the systematic error in physical quantities, as distinct from the random error or spread, is estimated on an historic basis. Thus it provides a kind of assessment (the A in the NUSAP acronym) to act as a qualifier on the number (the NU in the NUSAP acronym) together with its spread (the S in the NUSAP acronym). In doing so it accounts for potential 'methodological limitations' and 'bias/value ladenness' in the process of providing the number and the spread.

In the PRIMA typology (Van Asselt, 2000) unreliability refers to the upper half of the continuum of uncertainty due to lack of knowledge and comprises uncertainty due to inexactness, lack of observations/measurements and practical immeasurability.

Unstructured problems Hoppe and Hisschemöller have defined unstructured problems as those for which there is a low level of agreement on the relevant knowledge base and a low level of consent on norms and values related to the problem. Compare with structured problems. Unstructured problems have similar characteristics as post-normal science problems.

Validation Validation is the process of comparing model output with observations of the 'real world'. Validation can not 'validate' a model as true or correct, but can help establish confidence in a model's utility in cases where the samples of model output and real world samples are at least not inconsistent. For a fuller discussion of issues in validation, see Oreskes et al., (1994).

Value diversity One of the sources of variability distinguished in the PRIMA typology (Van Asselt, 2000). It refers to the differences in people's belief systems, mental maps, world views and norms and values) due to which problem perceptions and definitions differ.

Value-ladenness Value-ladenness refers to the notion that value orientations and biases of an analyst, an institute, a discipline or a culture can co-shape the way scientific questions are framed, data are selected, interpreted, and rejected, methodologies are devised, explanations are formulated and conclusions are formulated. Since theories are always underdetermined by observation, the analysts' biases will fill the epistemic gap which makes any assessment to a certain degree value-laden.

Variability In one meaning of the word, variability refers to the observable variations (e.g. noise) in a quantity that result from randomness in nature (as in 'natural variability of climate') and society. In a slightly different meaning, variability refers to heterogeneity across space, time or members of a population. Variability can be expressed in terms of the extent to which the scores in a distribution of a quantity differ from each other. Statistical measures for variability include the range, mean deviation from the mean, variance, and standard deviation.

In the PRIMA typology (Van Asselt, 2000), variability is one of the sources of uncertainty, and refers to the fact that the system/process under consideration can behave in different ways or is valued differently. Variability is an attribute of reality. Also referred to as 'objective uncertainty', 'stochastic uncertainty', 'primary uncertainty', 'external uncertainty' or 'random uncertainty'. The PRIMA typology distinguishes as sources of variability: natural randomness, value diversity, behavioral variability, societal randomness, and technological surprise.