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Conceptualising uncertainty in environmental decision-making: the example of the EU Water Framework Directive

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Abstract

The question of how to deal with uncertainty in environmental decision-making is currently attracting considerable attention on the part of scientists as well as of politicians and those involved in government administration. The existence of uncertainty becomes particularly apparent in the field of environmental policy because environmental problems are regarded as highly complex and long-term and because far-reaching changes have to be taken into account; moreover, the knowledge available to practitioners and policy makers alike is often fragmentary and not systemised. One key issue arising from this is the challenge to develop scientific decision support methods that are capable of dealing with uncertainty in a systematic and differentiated way, integrating scientific and practical knowledge. This paper introduces a conceptual framework for perceiving and describing uncertainty in environmental decision-making. It is argued that perceiving and describing uncertainty is an important prerequisite for deciding and acting under uncertainty. The conceptual framework consists of a general definition of uncertainty along with five complementary perspectives on the phenomenon, each highlighting one specific aspect of it. By using the conceptual framework, decision-makers are able to reflect on their knowledge base with regard to its completeness and reliability and to gain a broad picture of uncertainty from various standpoints. The theoretical ideas presented here are based on two empirical studies looking at how uncertainty is dealt with in the implementation process of the EU Water Framework Directive (WFD). The rather abstract differentiations are illustrated by a number of examples in the form of interview statements and excerpts from the WFD and the WFD guidance documents Impress, Wateco und Proclan.

Key Words: uncertainty, probability, lack of knowledge, pure ignorance, environmental decision-making, EU Water Framework Directive (WFD).

1 Introduction

Every day each one of us is forced to act and to make decisions under conditions of uncertainty – this is true of our private lives as well as our involvement in public affairs. We are unsure as to which goals to pursue or what actions we should consider taking to achieve them, and neither can we predict all the consequences of these various actions. Uncertainty is a problem because it makes it difficult to decide what is best. Furthermore, decision-making is always affected by uncertainty because, by definition, a decision is a situation in which the decision-maker does not know *a priori* what to do.

In the context of environmental decision-making the problem of uncertainty is particularly apparent for several reasons:

- Environmental problems are often regarded as particularly intractable because of the overwhelming diversity of nature, the countless dynamic natural processes involved – often non-linear and chaotic – as well as the many complex interactions that take place between nature and human beings. Complexity and novelty makes it difficult to describe environmental problems precisely and to forecast the impacts of potential solutions. Typically the solution of environmental problems is not routine.
- In general, good solutions for environmental problems require a large amount of knowledge as a solid foundation for decision-making, but the knowledge available is fragmentary and not systemised (cf. Faber & Manstetten 2003). Moreover, it is typical of environmental problems that the relevant scientific knowledge is spread over different disciplines, from the natural sciences to the social sciences, and cannot be easily merged. Furthermore, the integration of scientific knowledge and practical knowledge (know-how), as well as communication between scientists and practitioners, often poses problems.
- It is not only the knowledge base for decision-making that is frequently patchy with regard to facts – the normative foundation is also often unclear. In public environmental decision-making, the private preferences and interests of those responsible for making decisions should not play a decisive role. Normative objectives for public decision-making such as sustainable development, efficiency,

welfare, justice and so on may provide a point of orientation but need to be rendered in practical terms in relation to each given situation.

The problem of uncertainty in environmental decision-making has recently received a great deal of attention on the part of scientists as well as of politicians and administrators (e.g. Faber *et al.* 1992; Handmer *et al.* 2001; Harremoes 2003; Morgan & Henrion 1990; Pahl-Wostl 2002, 2007). This paper explores the question of how to deal adequately with the inevitable uncertainty involved in environmental decision-making. In doing so we identify two separate elements, or stages:

1. perceiving and describing uncertainty and
2. deciding and acting under uncertainty.

Most of the relevant literature appears to concentrate on the second stage. However, the focus in this article is on the first stage, where the knowledge base is the main object of reflection with regard to its completeness and reliability. We are convinced that giving sufficient emphasis to the first stage is a prerequisite for making good decisions, particularly in complex situations where politicians or members of competent authorities have a public mandate to act and are therefore obliged to act in a responsible, considered and effective manner for the welfare of all.[1]

Our paper represents a contribution to the debate on uncertainty by presenting a conceptual framework for perceiving and describing uncertainty in environmental decision-making. This framework is intended to enable decision-makers to gain a comprehensive picture of their uncertainty in practical decision-making situations.

In order to illustrate and substantiate the conceptual framework we use the empirical example of the European Water Framework Directive (WFD) (EU 2000). The WFD came into force in December 2000 and sets the legal framework for the protection and management of water resources in the European Union. The Directive establishes ambitious and challenging environmental objectives. It is an interesting case for studying uncertainty in public environmental decision-making because its implementation is a complex matter that is taken very seriously by the EU Member States. Our empirical work is based on

[1] Note that both stages are interlinked: on the one hand, dealing consciously and responsibly with uncertainty (stage 2) requires a high level of awareness and cognition of uncertainties (stage 1). On the other hand, in most cases the perception and description of uncertainties takes place in a context of deciding and acting.

- a textual analysis[2] of the WFD as well as three guidance documents (Impress 2003; Proclan 2003; Wateco 2003) which are part of the common implementation strategy (CIS) of the European Commission (cf. Sigel 2007),
- expert interviews with representatives from German water management authorities who are responsible for implementing the WFD[3] (cf. Sigel 2007) and
- the consulting activities of the authors for several German federal states and competent authorities (Ammermüller *et al.* in press; Klauer *et al.* 2007a; Klauer *et al.* 2007b; Klauer *et al.* 2008).

The paper is organised as follows: first, we outline the main objectives and some basic principles of the WFD, with a special emphasis on the problems of uncertainty associated with its implementation. This is necessary for an understanding of the practical examples contained in the subsequent sections. In section 3, we introduce the conceptual framework used to describe uncertainty. The framework consists of (i) a general definition of uncertainty and (ii) five complementary perspectives on uncertainty which are explained in section 4 and section 5 respectively. The paper concludes in section 6 with some critical reflections on the opportunities and limits of the conceptual framework, the necessary prerequisites for its application, and further research needs.

2 The EU Water Framework Directive

The WFD has had a major influence on water resource management in the European Union since it came into force in 2000. The Directive is widely recognised as innovative in many respects (Klauer *et al.* in press; Moss 2003; Rumm *et al.* 2006). Some of its more significant innovative elements are:

- The environmental objective of ‘good status’. In Article 4.1 the WFD – for the first time in EU legislation – sets comprehensive and legally binding environmental objectives for the protection of all waters. These it sums up under the term good status. For surface waters, for instance, good status is comprised of

[2] The methodological procedure used is known in qualitative social scientific research as ‘structuring content analysis’ (Mayring 2003).

[3] Six qualitative interviews of about 90 min each were recorded, transcribed and analysed based on the expert interview methodology described by Lamnek (1995) and Meuser and Nagel (1991). The interview was structured by an interview guide consisting of a short introductory phase and five topics connected with the implementation of the WFD and uncertainty.

several components of ecological as well as chemical quality (WFD, Annex V). A river or a lake enjoys good ecological status if it "shows low levels of distortion resulting from human activity". For artificial and heavily modified water bodies, such as canals or drinking water reservoirs (Art. 4.3, WFD), the objective is not good ecological status but good ecological potential. In exceptional cases the Directive allows for deadlines to be extended (Art. 4.4, WFD) and for environmental objectives to be softened (Art. 4.5, WFD) – this issue is discussed under the umbrella term exemptions.

- Long-term perspective. The implementation of the WFD is spread over a period of more than 25 years. Some important milestones in water management are (i) the adoption of river basin management plans in 2009, including a programme of measures stipulating how the relevant environmental objectives are to be achieved (Art. 13 and 11, WFD) and (ii) the achievement of good status (or good potential) by 2015. After 2015 new management plans are to be devised and exemptions revised every six years.
- Integrated Water Resources Management (IWRM). The concept of IWRM emphasises the importance of spatial planning and sectoral integration in water resources management and places it in the context of sustainable development (OECD 1989, GWP 2000). The WFD can be seen as an attempt to realise IWRM (Klauer et al. in press), mainly because it requires the coordination of administrative arrangements among different river basin districts (Art. 3, WFD) as well as management measures in different economic sectors (particularly the water sector and agriculture) in order for its environmental objectives to be achieved.

The implementation of the WFD implies a considerable challenge for the competent authorities. In nearly all cases the authorities do not have a comprehensive knowledge base for making the necessary decisions, and hence they are forced to act and decide under uncertainty (Mysiak & Sigel 2005). The Wateco guidance document calls uncertainty one of the "key issues" that "remain to be explored". According to the document, the pressing methodological questions are: "How to deal with uncertainty: which approaches can be proposed to water managers for integrating uncertainty into decision-making and for developing adequate communication on uncertainty towards the public and stakeholders?" (Wateco 2003: 48).

Obviously, uncertainty may have a negative impact on the achievement of the WFD goals. Uncertainty is also relevant in relation to the fact that the decisions to be made by the competent authorities are public decisions. In order to be transparent and open to public scrutiny and possible criticism, uncertainties need to be clearly spelt out and reported during the decision-making process.

3 A conceptual framework for perceiving and describing uncertainty in environmental decision-making

The standard scientific approach for conceptualising perceptions and descriptions of uncertainty is to quantify uncertainty in terms of probabilities. Classical economic theory regarding decision-making, which investigates how uncertainty should be dealt with rationally, is also rooted in probability theory (von Neumann & Morgenstern 1944). However, it has been widely acknowledged in more recent environmental literature that probabilities are only one of many possibilities for conceptualising uncertainty. Several taxonomies of uncertainty that have been put forward attempt to systemise and conceptualise the many varied aspects of uncertainty and ignorance (e.g. Brown *et al.* 2005; Faber *et al.* 1992; Funtowicz & Ravetz 1990; Klauer & Brown 2004; Smithson 1989; van Asselt 2000; Walker *et al.* 2003; Wynne 1992). These taxonomies use several sorting criteria, or questions, to classify uncertainty such as “Is uncertainty reducible?” or ”Are all possible outcomes of a random experiment known?”. The latter question indicates that they also make some use of the concept of the theory of probability.

In the following we introduce a conceptual framework of uncertainty that aims to describe uncertainty in environmental decision-making in a broad and differentiated way. For this, several important aspects of uncertainty (some of which have been specified within existing approaches and taxonomies) have been selected, explored in greater detail, expanded in scope and integrated into the framework. The framework consists of a general definition of uncertainty and five complementary perspectives on uncertainty (see Table 1).

Table 1: Structure of the conceptual framework of uncertainty

- General definition of uncertainty
- Complementary perspectives on uncertainty:
  1. Description of uncertainty on the basis of the theory of probability
  2. Sources of uncertainty
  3. Fact-related and norm-related uncertainty
  4. Causes of uncertainty
  5. Reducibility of uncertainty

The general definition serves as a broad characterisation of uncertainty and provides the basis for an advanced description of uncertainty using different 'perspectives on uncertainty'. Each perspective highlights one specific aspect of uncertainty. As these perspectives are complementary, they combine to produce a broad and differentiated description of uncertainty. This can be imagined in terms of different spotlights illuminating a single object from different points of view. Thus the relationship between the five perspectives is not as systematic as is usually the case in taxonomies[4]. However, complementary perspectives enrich our understanding of the multifaceted nature of uncertainty. The general definition as well as the perspectives on uncertainty are supplemented and reinforced by further definitions of uncertainty-related notions such as 'certainty', 'lack of knowledge', 'fact-related uncertainty' and 'norm-related uncertainty'.

The focus of the concept lies on uncertainty from the viewpoint of a single decision-maker. In the case of the WFD, decisions are taken by the competent authorities. These authorities exist in the form of complicated networks and hierarchies consisting of several individuals with different competencies and responsibilities and of the social interactions that take place between them. The assumption of a single decision-maker constitutes a considerable simplification which means that uncertainties relevant to the deci-

[4] In contrast to our conceptual framework, taxonomy is a classification. That is, it divides all possible cases into several categories so that every case belongs to exactly one category. In other words, the categories do not overlap.

sion-making process remain neglected.[5] However, we are confident that in a first approach it is sensible to separate these aspects.

The two parts of the concept of uncertainty – 'General definition of uncertainty' and 'Complementary perspectives on uncertainty' – are described in detail in the two sections that follow.

4 A general definition of uncertainty

In order to express more precisely what we are talking about, we shall now provide a formal definition of the terms 'uncertainty', 'certainty' and 'lack of knowledge', and offer some explanatory comments on 'pure ignorance'. All these definitions refer to the context of public decision-making situations in the field of environmental politics, even if this is not stated explicitly.

> ***Definition of uncertainty:*** *A person is uncertain if he[6] lacks confidence about his knowledge relating to a specific question.*

Anyone who wants to describe their uncertainty relating to a specific question has to reflect on their state of knowledge. These reflections refer to two different levels: (i) their knowledge about the situation and (ii) their degree of confidence about this knowledge. Being confident or not is a subjective perception. Hence, uncertainty as understood here is a subjective phenomenon.[7] This implies that an adequate assessment of uncertainty always requires an attitude of openness and a person's ability to assess the reliability of their knowledge.

For the purpose of better understanding, the theoretical ideas presented here will be illustrated in the following using empirical examples from the WFD (based on Sigel 2007). These examples are separated from the main text by boxes.

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[5] In the literature this kind of uncertainty is often described as 'ambiguity', 'interaction uncertainty' or 'political uncertainty' (Handmer *et al.* 2001: XV; Morgan & Henrion 1990: 24; Walker & Marchau 2003).

[6] Although the male personal pronoun is used at times in this text to make for easier reading, the reference is always to both women and men.

[7] Nevertheless, uncertainty in general has also objective aspects. For example, the fact that rolling a common dice has six different potential outcomes is independent from the person throwing the dice.

The understanding of uncertainty in the WFD

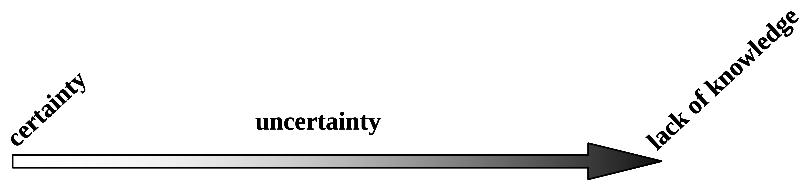
The WFD does not refer to ‘uncertainty’ as such. Instead the converse expression adequate level of confidence and precision is used. Regarding frequency in relation to monitoring the status of water bodies it is said, for example:

> “Frequencies shall be chosen so as to achieve an acceptable level of confidence and precision. Estimates of the confidence and precision attained by the monitoring system used shall be stated in the river basin management plan” (Annex V 1.3.4, WFD).

Instead of the term ‘adequate’ (as applied to the level of confidence and precision), the WFD also uses the expressions ‘sufficient’ and ‘acceptable’. The term ‘confidence’ refers to the subjective nature of uncertainty, as in our definition. By using the term ‘precision’ the WFD also refers to the objective nature of uncertainty.

Confidence about knowledge may range from ‘being certain’ to ‘admitting to know nothing’ (of use). In other words, the spectrum of uncertainty ranges between two extremes: certainty and lack of knowledge (see Figure 1).

Figure 1: The spectrum of uncertainty



In practice, it is barely possible to distinguish clearly between certainty, uncertainty and lack of knowledge because a continuous transition exists between certainty and lack of knowledge. Pure certainty and pure lack of knowledge rarely occur in practice. Nevertheless, for the purpose of understanding uncertainty it is helpful to define even these extreme forms:

Definition of certainty: *A person is certain if he is confident about his knowledge relating to a specific question.*[8]

Definition of lack of knowledge: *Lack of knowledge is a state in which a person has no knowledge relating to a specific question but is nonetheless able to specify precisely what knowledge he lacks.*

In the case of 'lack of knowledge' there is no knowledge to evaluate regarding its reliability. However, the person has an idea what he could or should know about the problem at issue. This means he is already aware of the problem that he lacks specific knowledge.

Examples of certainty in the implementation of the WFD

An example of 'certainty' can be found in the WFD guidance document Impress, in a short paragraph about modelling approaches as tool for the analysis of pressures and impacts:

> "Such models, if applied appropriately, are generally good at representing the water quality along a river in which the inflows from tributaries and point sources are well known or can be estimated reliably" (Impress 2003: 35).

In the following example taken from one of the expert interviews, a water manager expresses his certainty about point discharges:

> "What we know quite well are point discharges, in other words sewage plants" (interview statement).

Examples of lack of knowledge in the implementation of the WFD

The expression 'gaps in information and knowledge' used by the guidance document Wateco comes very close to the expression 'lack of knowledge' as defined here. In the context of economic analysis, Wateco points out

[8] Note that certainty does not automatically imply that the person knows everything that is relevant for making the decision.

that the 'information and knowledge base' has to be improved by 'filling key information and knowledge gaps' (Wateco 2003). Similar expressions used by Wateco are 'gaps in technical expertise', 'gaps in available data', 'information and knowledge needs' or 'research needs'. According to Wateco these gaps have to be filled over time. Thus, what Wateco is referring to here is a form of reducible uncertainty.

In the following example, a water manager expresses his lack of knowledge relating to the effectiveness of fish passes:

> "It starts with the fish passes, that you can't predict whether it will be accepted by the fish or not. There are experiments where the fish eventually come up but don't come down because they can't find it. There are so many possibilities, it's nearly impossible to make any predictions" (interview statement).

To sum up, one can say that uncertainty (including certainty and lack of knowledge) is a state characterised by a person's reflection on and confidence in his knowledge. The person is able to reflect on his knowledge, or rather to specify in which he lacks knowledge. Consequently, uncertainty is situated within a person's knowledge horizon.

We now turn to address a domain that is located outside the range of uncertainty: *pure ignorance*. Pure ignorance cannot be described or defined; it can only be known in an abstract sense. According to Faber et al. (1992) pure ignorance is of an indefinite nature, like the future itself. It cannot be limited or constrained to any particular area of knowledge, as it encompasses all areas of life and development. We can identify pure ignorance only *ex post* as, for example, when things happen that make us aware of a problem to which we had previously paid no attention – this phenomenon is also described as surprise. Dealing in a conscious way with pure ignorance is only possible to the extent that we have a desire continuously to broaden our knowledge horizons. This means adopting an attitude of openness towards and awareness of novelty and unexpected events. With regard to the development of strategies for dealing with uncertainty it is important to realise that pure ignorance exists and that there is a continuous transition between uncertainty and pure ignorance.

5 Complementary perspectives on uncertainty

The concept of uncertainty introduced in this paper comprises five perspectives on uncertainty (see Table 1). In the following we will describe each of the different perspectives in turn in greater detail.

5.1 Description of uncertainty on the basis of the theory of probability

Probabilities are the standard scientific approach to conceptualising uncertainty. The aim of probability theory is to quantify uncertainty in order to (i) predict the outcome of possible future events or to (ii) assess past events in terms of whether they can be seen as common or unusual. (Both are usually done with a view to assessing and calculating opportunities and risks.)

Within the theory of probability, uncertainty is represented by (i) several potential ‘outcomes’ of events (processes, actions, random experiments) and (ii) ‘probabilities’ (likelihood, chance) expressing the degree of confidence (belief) that the specific outcome will occur. The basic idea is that probabilities can be interpreted as frequencies (e.g. “it happens in one of six cases”).[9] When applying probability theory to a specific situation, it is necessary to make sure (i) that all possible outcomes are deemed to be known and (ii) that probabilities can be determined reliably (Brown 2004). Only in this case – also known as ‘risk’ (Faber et al. 1992) – can the powerful tools of probability theory, statistics and classical economic theories of decision-making be applied.

Theoretically, situations involving uncertainty can always be described in such a way that all possible outcomes are known (by adjusting representations of the real world situation in a certain way) and that all probabilities are known (by using subjective probabilities) (Eisenführ & Weber 1999: 152). However, in the context of environmental decision-making it can be argued that such a conceptualisation of uncertainty may not do justice to the problems involved. There are several reasons for this. First, there are situations in which it is inappropriate to assume that all (relevant) possible outcomes are known. Consider, for example, a situation where the possible long-term

[9] It is often argued that frequentistic probabilities assume a large number of similar events while subjective probabilities can also be applied to special, one-off events (Eisenführ & Weber 1999: 152-153). This argument can be countered by the fact that subjective probabilities also need a kind of repetition because they can be substantiated only if the person has experience with similar situations (Sigel 2007: 55-56).

impacts of a new chemical substance on aquatic ecosystems are relevant. Due to the complex behaviour of chemical substances in the environment it is possible – and even likely – that new, unexpected reactions and effects will occur. Second, probabilities trace uncertainty back to frequencies and repetitions. In situations characterised by their uniqueness, it is doubtful whether recourse to the frequency of phenomena in similar situations offers much insight into the uncertainties involved.[10]

The quantification of uncertainty in terms of probabilities requires extensive knowledge of the situation under consideration and simultaneously narrows down the uncertainty perception on a few aspects. Nevertheless, the theory of probability remains an important approach because statistics is a powerful tool for describing uncertainty and for developing recommendations for action. However, our empirical studies on the implementation process of the WFD have shown that the authors of the guidance documents and the practitioners working at the competent authorities rarely use probabilities for dealing with uncertainties.

5.2 Sources of uncertainty

In the relevant literature, the expression 'sources of uncertainty' is often used but rarely explained. Whereas several authors use the term 'sources' to refer to causes (e.g. van Asselt 2000) we will use this term in the following sense:

> ***Definition of source of uncertainty****: The source of uncertainty refers to the point of reference of uncertainty, i.e. it indicates to what knowledge or what specific question the uncertainty of a person is related.*

Sources of uncertainty are manifestations of uncertainty in a specific context. They emphasize the relational and context-specific nature of uncertainty in decision-making. The key question is: with regard to what does uncertainty occur? Causes of uncertainty – as will be explained in more detail below – refer to either the epistemological origin of or practical reasons for uncertainty.

Knowing where the sources of uncertainty lie is helpful for making an initial de scription of the uncertainty and 'localising' it within a decision-making process. Local-

[10] For an extensive discussion of probability theory in the light of environmental decisions, see Sigel (2007).

isation is easier if the decision-making process follows a given structure. One example of such a structure in the context of the implementation of the WFD can be found in Klauer et al. (2007a), where the process of selecting measures to be included in the overall programme of measures is divided into nine consecutive steps. The most important steps are: (i) assessing the water status, (ii) identifying causes and setting development targets, (iii) pre-selecting measures and estimating their costs and impacts, (iv) creating combinations of measures and selecting the most appropriate combination, (v) checking for exemptions and prioritising measures where necessary. Each step represents one potential source of uncertainty. As these steps aim to describe the entire selection process, a description of sources of uncertainty based on this structure can claim to be complete. However, one should be aware that a different structure may lead to other sources of uncertainty.

Examples of sources of uncertainty in the implementation of the WFD and in scientific literature on hydrological modelling

In the following example, the WFD expert being interviewed refers to uncertainty in the context of selecting measures, and more specifically of assessing the effectiveness of measures:

> "Regarding the programme of measures, I think that the most difficult part will be to identify those measures with the greatest effectiveness" (interview statement).

The guidance document Impress mentions two main sources of uncertainty in the analysis of pressures and impacts: uncertainties relating to environmental conditions and uncertainties relating to estimated impacts:

> "Member States will need to complete the first analyses using appropriate estimates for pressures and impacts but they should be aware, and take account of the uncertainties in the environmental conditions required to meet the Directives' objectives and the uncertainties in the estimated impacts" (Impress 2003: 19).

In terms of reflecting on the reliability of hydrological models, the identification of possible sources of uncertainty plays an important role. Brown and Heuvelink (2003), for instance, distinguish between data and models in relation to uncertainty, pointing out that there are "unique sources of uncertainty in each case":

> "In practice, the main sources of uncertainty in *data* include (…): lack of measurements; measurement error; errors in the calibration of measurement instruments; imprecise or otherwise ambiguous language; use of inadequate or inappropriate scales (sampling); data transformation errors; errors in measurement units; conceptual errors in formulating sampling strategies; logical errors in formulating sampling strategies and recording errors" (Brown & Heuvelink 2003: 3).
>
> "In practice, errors and uncertainties in *models* arise from three main sources, namely: 1) model structure (fixed), 2) model variables and 3) model solution (mainly numerical models)" (Brown & Heuvelink 2003: 3-4).

5.3 Fact-related and norm-related uncertainty

According to the general definition, uncertainty is always related to knowledge. In this perspective on uncertainty we distinguish between two forms of knowledge that are very important for decision-making: knowledge about facts and knowledge about norms and values. Accordingly, we differentiate between fact-related and norm-related uncertainty. The literature contains very varied definitions of fact-related and norm-related uncertainty (Arentsen *et al.* 2000; Gottschalk-Mazouz 2003; Newig *et al.* 2005). The definitions we propose are derived from the general definition of uncertainty given in the previous section:

> ***Definition of fact-related uncertainty:*** *Fact-related uncertainty exists when a person lacks confidence about his knowledge regarding facts.*
>
> ***Definition of norm-related uncertainty:*** *Norm-related uncertainty exists when a person lacks confidence about his knowledge regarding norms and values.*

Fact-related knowledge is necessary for describing reality. It claims to be true, comprehensible to others and, thus, objective. Furthermore, fact-related knowledge often claims to be value-free. There are many different ways to acquire fact-related knowledge – from gaining practical experience to conducting scientific studies.

Examples of fact-related uncertainty in the implementation of the WFD

In implementing the WFD the competent authorities need a large amount of fact-related knowledge; this knowledge is often affected by uncertainty. In the following example, the guidance document Wateco calls attention to uncertainty in relation to the programme of measures designed to be the main WFD instrument for achieving good status (at least) for all waters:

> "Uncertainty on costs, effectiveness and time-lagged effects of measures needs to be dealt with throughout the economic analysis process, and more generally throughout the process of identifying measures and developing the river basin management plan" (Wateco 2003: 26).

The following statement by an expert refers to the pressures and impacts analysis prescribed by the WFD. Here, the water manager expresses uncertainty relating to hydromorphological pressures and their biological impacts:

> "When speaking about hydromorphological pressures there are some basic uncertainties concerning the impacts for the aquatic ecosystem. For instance, it can't be argued simply that a dam always affects the aquatic organisms – presumably rather not" (interview statement).

The European legislator can not and does not want to prescribe every detail of implementation of the WFD. In many cases the Directive needs to be interpreted and substantiated individually by the member states and their competent authorities. Uncertainty occurring in this context is norm-related uncertainty.

Norm-related uncertainty can be interpreted in a positive sense, as it gives room for freedom of action and for processes of social learning and adaptation. However, norm-related uncertainty also entails the risk of arbitrariness in decision-making and of neglecting one's responsibilities.

Examples of norm-related uncertainty in the implementation of the WFD

Of the analysed guidance documents Impress, Wateco und Proclan, only Impress refers to norm-related uncertainty. Under the heading 'taking account of uncertainty' it is said:

> "The first pressures and impacts analyses must be complete by the end of 2004. However, the environmental conditions required to meet most of the Directive's objectives will not have been firmly defined by this date. For example, the values for the boundaries between the ecological status classes for surface waters are not expected to be finally determined until after the end of the intercalibration exercise (Annex V 1.4 WFD*)* and the start of the monitoring programmes in 2006 (Article 8)" (Impress 2003: 17).

For most of the water managers interviewed, normative uncertainty is a major challenge. In the following citation, the interviewee refers to the problem that the expression 'good ecological status' used by the WFD has to be interpreted and rendered concrete:

> "Certainly we will have to define again what we mean exactly by 'good ecological status' or what we want to achieve at best, because this is also a socio-political question" (interview statement).

In the context of environmental decision-making, both forms of knowledge – fact-related and norm-related – are important in most cases. In practice it is often difficult to distinguish clearly between fact-related and norm-related uncertainty. One reason for this is that both kinds are partially interdependent (Morgan & Henrion 1990). If, for example, a decision-maker implementing the WFD has to evaluate whether the costs of the programme of measures selected for a certain water body are proportionate or not, he has to know what these costs are (fact-related knowledge). If he is uncertain about these costs, the evaluation of (dis-)proportionality will also be affected by uncertainty. Thus norm-related uncertainty may be rooted in fact-related uncertainty.

At the same time, fact-related knowledge is determined to a great extent by norm-related knowledge. Within the process of pre-selection of measures, a decision-maker will presumably prefer those measures that correspond best to his interpretation of the WFD's objectives and that accord with his interests. Accordingly, he will try to gain as much fact-related knowledge about these measures as possible and will not pay as much attention to the others. In general, fact-related knowledge is inevitably associated with more or less implicit value judgements. Pure fact-related knowledge and pure fact-related uncertainty rarely exist. Whether a decision-maker concentrates more on fact-related or more on norm-related knowledge and uncertainty depends on the problem at hand and on his cognitive interest.

5.4 Causes of uncertainty

Some taxonomies are built at least partially on a distinction between different causes of uncertainty (Brown 2004; Faber *et al.* 1992; Jaeger 2002; van Asselt 2000). In our conceptual framework of uncertainty, a basic distinction is made between 'fundamental' causes of uncertainty and 'practical' causes of uncertainty. We shall discuss each of these in turn, paying greater attention to the latter because it is more relevant with regard to the implementation of the WFD.

There are two forms of fundamental causes of uncertainty: phenomenological uncertainty and epistemological uncertainty. The first relates to phenomena and the second to the cognition of these phenomena by a person. If the question is, for example, why weather forecasts are affected by uncertainty, there are two basic options for a response: either the processes in the atmosphere are not predictable (because of their chaotic behaviour, say) or our weather models are not good enough to provide a precise description of the relevant processes. In practice, it is not possible to make a clear distinction between these two fundamental causes of uncertainty. Uncertainty is always rooted in both, in the phenomena and in the cognitive faculties of the observer. This implies that uncertainty is of both an objective and a subjective nature.

In addition to these fundamental causes, a decision-maker will normally try to identify the practical causes of his uncertainty in a specific case, not least because this may be helpful for reducing uncertainty. The key question here is: why is it not possible in practice to generate 'certain' knowledge? By way of an example, let us answer this question in relation to the implementation of the WFD. The analysis of the WFD expert interviews and the selected guidance documents makes it possible to establish a list of possible causes of uncertainty in the implementation of the WFD, as shown in Table 2 (cf. Sigel 2007).

Table 2: Possible causes of uncertainty in the implementation of the WFD

- Difficulties in describing water-related problems.
- Difficulties in interpreting the normative demands of the WFD and relating them to practical circumstances.
- Developments and factors which cannot be influenced or controlled.
- Difficulties in predicting human behaviour, particularly in social interactions and negotiation processes.
- Restricted capacities for analysis due to finite financial resources.

Five 'causes of uncertainty' are listed here. Each bullet point refers to a specific issue and also represents in part a specific approach to uncertainty. Hence, there may be some degree of overlap. Furthermore, the list may be refined and each of the causes split into different 'sub-causes'.

Unlike a taxonomy, the list is not the result of a systematic top-down sorting process but rather a bottom-up clustering process. *Prima facie* this could be seen as a disadvantage. However, its advantage is that the clustering facilitates the identification of typical causes in practical decision-making situations and can easily be expanded and adapted to new situations. Bullet points 1 and 2 correspond to 'fact-related uncertainty' and 'norm-related uncertainty'. The following examples from the implementation of the WFD will therefore focus on causes 3, 4 and 5. Bullet point 3 corresponds to the understanding of uncertainty as expressed in classical economic theory on decision-making: a decision is considered to be uncertain if there are developments and factors which cannot be influenced or controlled by the decision-maker. Against the background of our conceptual framework of uncertainty and, in particular, the other possible causes, the limited nature of the perception of uncertainty in classical economic decision-making theory becomes apparent.

Examples of causes of uncertainty in the implementation of the WFD

- Developments and factors which cannot be influenced or controlled:

> "There are some states of dependence which are fairly blatant, like with agriculture. We can only influence agricultural developments indirectly, mainly via subsidies, incentive schemes or land purchase" (interview statement).

- Difficulties in predicting human behaviour, particularly in social interactions and negotiation processes:

> "There are some difficulties concerning non-point sources …. Here we have a conflict situation characterised by relatively strong economic interests …. It is possible that twenty percent of the stakeholders just don't believe in the facts, even if they are proven, that's just the way it is" (interview statement).

- Restricted capacities for analysis due to finite financial resources:

> "In the end we are faced with a financial problem. If I think about the financial situation, the total amount of money needed to implement the WFD, then I am really concerned" (interview statement).

Thinking about the causes of uncertainty is of particular interest if one wants to reduce uncertainty. The causes may provide pointers towards whether it is possible to reduce uncertainty and, if so, how this could be done.

5.5 *Reducibility of uncertainty*

Reducibility is a key characteristic of uncertainty and is closely related to the second stage of how to deal appropriately with inevitable uncertainty: deciding and acting under uncertainty (cf. section 1). In practice, a decision-maker is often confronted with the question of whether he should make a decision on the basis of his actual (uncertain) knowledge or whether he should first try to reduce his uncertainty. According to our general definition of uncertainty there are two different levels that can serve as starting points for reducing uncertainty: (i) the level of knowledge and (ii) the level of confidence about knowledge.

In relation to (i), uncertainty can be reduced by generating knowledge. If the knowledge required is already available in society but not available for a specific individual, this can be denoted as *learning*. *Scientific research* refers to knowledge that has not yet become available in society (Faber et al. 1992). Another way of reducing uncertainty is (ii) to increase confidence about a given aspect of knowledge, for example by clarifying whether or not this knowledge stems from reliable sources.

When thinking about the reducibility of uncertainty, it is possible to distinguish between 'fundamental' reducibility and 'practical' reducibility – much as we did in relation to 'causes of uncertainty'. The reducibility of uncertainty is restricted *fundamentally*. This means that uncertainty never can be eliminated entirely. The reasons for this are, amongst others, the emergence of unpredictable events (novelty), the chaotic behaviour of certain dynamic systems, and freedom of action on the part of human beings.[11]

However, from a *practical* point of view as well the question of whether or not uncertainty is reducible is of considerable importance. The following examples show what the experts and authors think about the reducibility of uncertainty in relation to the implementation of the WFD. One can see that the answer strongly depends on the causes to which they attribute their uncertainty.

[11] A detailed description of reasons for the restricted reducibility of uncertainty can be found in Faber et al. (1992). Here, the authors distinguish between 'irreducible phenomenological ignorance' and 'irreducible epistemological ignorance'.

Examples of the reducibility of uncertainty in the implementation of the WFD

The guidance document Proclan points out that uncertainty is an inevitable element in planning processes and hence cannot be reduced to zero:

> "Uncertainty is always an element in the planning process. It arises because of the complexity of the many factors involved. In fact, meteorological, demographic, social, technical, and political conditions which will determine the planning process have behaviour patterns not always known with sufficient accuracy" (Proclan 2003: 16).

According to several interview partners uncertainty is reducible, depending mainly on the financial resources available:

> "Either it is possible to gain information or it is impossible. And this depends mostly on the funds available" (interview statement).

However, some also reason that a kind of uncertainty exists which cannot be reduced easily:

> "When evaluating ecosystems, one has to recognise that within the assessment process statistics always plays some kind of role. (…) The status of an ecosystem is always defined by a statistical value. This cannot be compared with laboratory values in chemical engineering. And here I think that the potential improvements are limited" (interview statement).

Environmental decision-making is always affected by uncertainty. The question as to whether or not a decision-maker should try to reduce his uncertainty cannot be answered easily – this must be decided from case to case.

6 Concluding remarks

Our starting point for developing a conceptual framework to describe uncertainty in environmental decision-making was the conviction that the question "How to deal appropriately with uncertainty?" should be addressed in two stages: (1) perceiving and describing uncertainty and (2) deciding and acting under uncertainty. In this paper we have been concerned mainly with the first stage. Our new concept enables the decision-makers to perceive and describe uncertainty in a specific decision-making situation from several different perspectives within the context of an overarching, general definition of uncertainty. In doing so, the concept builds on elements of existing taxonomies and integrates different approaches to describing uncertainty. In future, the concept may be expanded by including additional perspectives on uncertainty where this is deemed necessary.

The analysis of the interviews with WFD experts and of the CIS guidance documents Impress, Wateco and Proclan reveals that all aspects of uncertainty addressed by our concept do indeed play a role in the practice of implementing the WFD. However, the empirical work shows that uncertainty is not handled systematically neither in the guidance documents nor in the daily work of the interviewed experts. Their approach towards describing as well as dealing with uncertainty can be characterised as 'muddling through': the experts act on the basis of their practical experience in dealing with similar situations, and so they make use of more or less ad-hoc solutions.

In contrast to this, the standard scientific approach for dealing with uncertainty, i.e. probability theory, describes uncertainties in decision-making situations consistently and systematically. Although probability theory is reductionistic and not able to grasp various aspects of uncertainty on the one hand, it is fairly demanding with respect to data and information needs on the other. Therefore, our opinion is that probability theory, in many situations, is not appropriate for describing uncertainty in environmental decision-making – at least without being supplemented by some other approach.

Our framework for conceptualising uncertainty is an attempt to bridge the gap between the 'muddling through' of the practitioners and the demanding but narrow probability-based standard approach of the scientists. The concept emphasizes the context-dependent nature of uncertainty, which corresponds to a more realistic description of real world decision-making situations. It may encompass qualitative as well as quantitative information about uncertainty and it can refer to uncertainty about scientific knowledge as well as practical knowledge.

The gap between scientific rigour and pragmatism

The challenge to find a balance between the systematic and consistent but reductionistic scientific approach and the muddling through of the practitioners is addressed in the following statement from one of the experts:

> "And certainly it will be worked out as scientifically as possible and afterwards, when it comes to concrete problems, one will definitely become more and more pragmatic"(interview statement).

Gathering information about uncertainty is costly and takes time. Even if it is not possible to make an exact calculus of the trade-off between the costs and benefits of additional information about uncertainty, it obviously makes sense to invest more effort the more serious and far-reaching the decision is, the more people are affected and the more long-run impacts are involved. The planning decisions involved in the implementation of the WFD are examples of decisions that justify considerable effort.

Other important prerequisites for dealing appropriately with uncertainty lie in the personal characteristics and personalities of the decision-makers, including

(i) their interest in making good decisions and

(ii) their ability to make good decisions.

Issue (i) embraces an attitude of openness and an awareness that there might be pure ignorance, as well as a willingness to take responsibility, to consider public interests and to be transparent. Issue (ii) comprises the decision-makers' communicative skills, their assertiveness as well as their respect for divergent opinions and, above all, their power of judgement.

In case of important public environmental decisions (where the prerequisites listed are fulfilled), we recommend the following prototypic mode of proceeding when describing uncertainty:

1. Detect any potential sources of uncertainty and, where applicable, prioritise these sources.
2. Characterise these sources with regard to the categories fact-related and norm-related uncertainty.
3. Trace the relevant causes of uncertainty.
4. Assess the reducibility of uncertainty.
5. Where appropriate, quantify some of these uncertainties using probabilities.

This mode of proceeding enables the decision-maker to obtain a differentiated and systematic description of his uncertainty and provides an information base that simultaneously provides information about what is known, what is not known, and what can be expected or assumed. In the process, the decision-maker's knowledge base – comprising both scientific knowledge and practical knowledge – will be enlarged by awareness of the degree of confidence he has in his knowledge.

Our concept has been developed in relation to environmental decisions. However, neither the general definition of uncertainty nor the five complementary perspectives on uncertainty refer to exclusively environmental issues, concepts or notions. So the question may be raised as to whether our framework for perceiving and describing uncertainty may be applied to other public, or even private, decision-making processes. Our guess is that it would be possible to apply our framework more generally, but we leave the issue open because the framework has been primarily developed for and empirically tested in the field of environmental decision-making, and the authors have no overview of all the relevant specific aspects of other fields of application.

Now, after getting a detailed picture of uncertainty in environmental decision-making the question remains how this information about uncertainty (and pure ignorance) can be used fruitfully in the decision-making process (stage 2). Of course, an extensive discussion of this issue needs to be undertaken elsewhere. Nevertheless a few conclusions can already be drawn here.

Formal, science-based methods that are limited to calculating probabilities in order to conceptualise uncertainty – such as cost-benefit analysis, cost-effectiveness analysis or optimisation approaches – do not systematically take account of the uncertainty information associated with the other perspectives on uncertainty.[12] It is left to the decision-makers to bring together the formal results and recommendations with the remaining (mostly qualitative) information in order to reach a final decision – and this is not satisfactory. We see a great need for scientific decision support methods that are able to process the diversity of uncertainty information that exists, as we have shown to be possible in our framework for perceiving and describing uncertainty.

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[12] It should be mentioned that several alternatives to probability theory are discussed in the literature on decision support. One example is the use of fuzzy set theory in multicriteria analysis (e.g. Munda 1995; Zimmermann 1986, 1990). A common technique that is able to make use of qualitative information on uncertainties is scenario analysis (e.g. Messner *et al.* 2001; Schoute *et al.* 1995). In contrast to (most) formal decision support methods, the results of a scenario analysis are not clear recommendations but projections and predictions of what changes if the general conditions develop in different ways. However, scenario analysis does not address the core of a decision-making problem, i.e. balancing the advantages and disadvantages of alternative actions.

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