**Water Policy in the USA and the EU**

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**Case Study:**

**Total Maximum Daily Load and Water Framework Directive**

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## 1.0 Comparison of US and EU Approaches

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## 2.0 The Role of Uncertainty Analysis in the USEPA Total Maximum Load (TMDL) Program

### 2.1 Introduction

Since the early 1990s, the USEPA Total Maximum Daily Load (TMDL) program has emerged as the most important element of the federal and state strategy to improve the quality of surface waters. The program actually has its origin in Section 303d of the 1972 Clean Water Act which required the states to identify waterbodies not meeting state water quality standards, determine the allowable pollutant load (the TMDL) to achieve compliance, and finally to oversee implementation of the necessary pollutant load reductions. However, the program was largely dormant for the first twenty years following passage of the Clean Water Act, as water quality improvements were focused on a schedule of upgrades in public and private wastewater treatment plants.

In the late 1980s and early 1990s, the realization that, despite substantial improvements in wastewater treatment plants, thousands of waterbodies were in violation of ambient water quality standards led to the growth of the TMDL program (fueled, in part, by numerous lawsuits filed by environmental organizations). It was recently estimated that there are over 40,000 ambient water quality standard violations to be addressed nationwide.

### 2.2 How is the TMDL Defined?

The total maximum daily load estimated to achieve compliance with a water quality standard has three components:

TMDL = WLA + LA + MOS

where:

> WLA = waste load allocation, or the amount of pollutant load reduction required from point sources
>
> LA = load allocation, or the amount of pollutant load reduction required from nonpoint sources
>
> MOS = margin of safety, which is an additional pollutant load reduction (hedging in the direction of greater water quality protection) that is intended to reflect the uncertainty in the estimated TMDL.

Thus, the margin of safety is the point at which uncertainty in TMDL forecasting is supposed to be considered. In fact, however, uncertainty analysis is almost never undertaken during a TMDL assessment; in a recent study, Dilks and Freedman (2004) reviewed 172 TMDLs and found that only one included uncertainty analysis as the basis for the MOS. Instead, the most common practices, permitted by EPA, were to assess the TMDL margin of safety using an arbitrarily chosen percentage (typically 10%) of the pollutant load, or base the MOS on so-called "conservative" model assumptions.

Despite the EPA guidance that the MOS reflect TMDL model uncertainty, it appears that the other practices (labeled "explicit" and "implicit") have been accepted by EPA for a few reasons. One, uncertainty analysis is not that easy to do, particularly for large models, and water quality modelers typically have little experience in this area. In addition, however, EPA Office of Water staff may have substantially underestimated water quality model prediction error and apparently actually believed that ±10% was a reasonable estimate of error.

So, EPA now confronts a dilemma because the actual forecast error for many of the models used for TMDLs can be extremely large (±50% or more; NRC 2001). If an error term of this magnitude becomes the basis for the MOS, the result is a TMDL that will require major reductions in pollutant loads, likely at substantial cost. The resultant uproar from those who must bear the cost could well undermine the program. Of course, the large uncertainty could mean that substantial pollutant load reductions are indeed necessary; however, it also could mean that only a relatively small pollutant load reduction is needed. The consequence of these two possible, but quite different, outcomes was a major reason for a recommendation for adaptive management.

### 2.3 An Example: The Neuse Estuary TMDL

In the mid/late 1990s, The Neuse Estuary in North Carolina experienced several massive fishkills. Public outcry resulted in the appropriation of NC funds to support a modeling and monitoring study to address the issue, and it was determined that a nitrogen TMDL was needed to address chlorophyll a water quality standard violations. Disagreements among modelers led to the development and application of three distinctly different models:

(1) a two-dimensional, laterally-averaged model was initially selected by state scientists (based on CE-QUAL W2),
(2) EPA, noting that the fishkills tended to be observed first in the shore zone, opted for a three-dimensional model (based on the EPA WASP model), and
(3) Duke University scientists, pessimistic that the data would support these elaborate models, developed a Bayesian network model that provided a probabilistic statement of uncertainty.

Citizen and Agency stakeholders met regularly with the three modeling groups to discuss progress; as a result, these people developed a higher than normal understanding of the complexity of the problem and the difficulty of achieving reliable predictions.

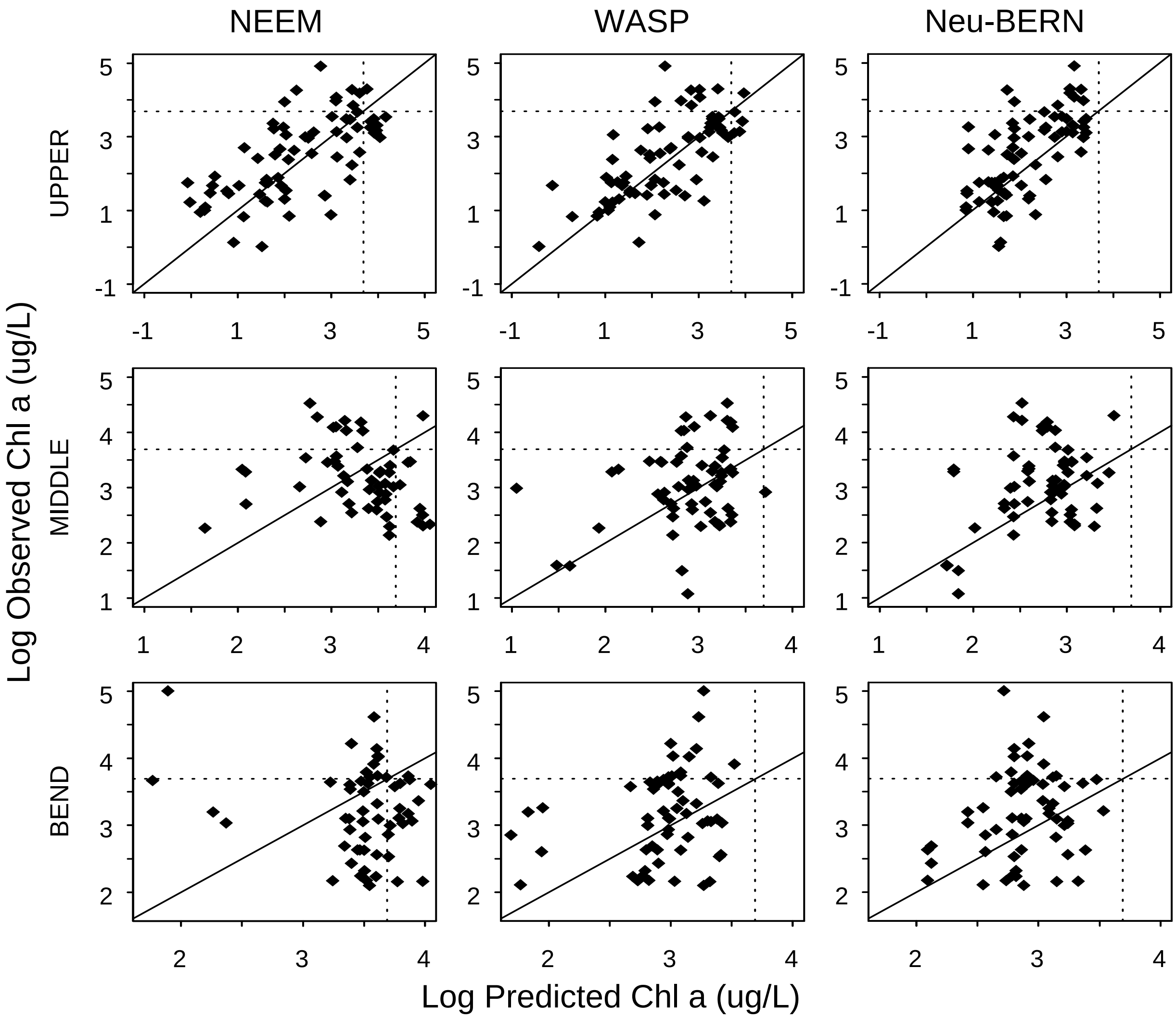


*Figure 1. A comparison of predictions versus observations for log chlorophyll a in three segments of the Neuse Estuary. NEEM is the 2-D model, WASP is the 3-D model, and Neu-BERN is the Bayes network model.*

The problem with unreliable predictions is evident in Figure 1 (Stow et al. 2003). A good model would yield predictions and observations tightly along the 1:1 line; in contrast, these points on the graphs appear distressingly random (particularly in the lowest panel of graphs).

The actual conclusion of this case study underscores the value of cooperative modeling (Cockerill et al. 2006), bringing modelers together with stakeholders. Over time, the Bayes network model (Figure 2; Borsuk et al. 2004) became increasingly useful for communication and analysis in the modeler-stakeholder meetings. Aside from stakeholders gradually understanding the uncertainty implications of the probabilities generated by the Bayes net, they also appreciated the extension of the model to “number of fishkills" and "shellfish abundance." This provided a meaningful layperson interpretation for the chlorophyll standard.

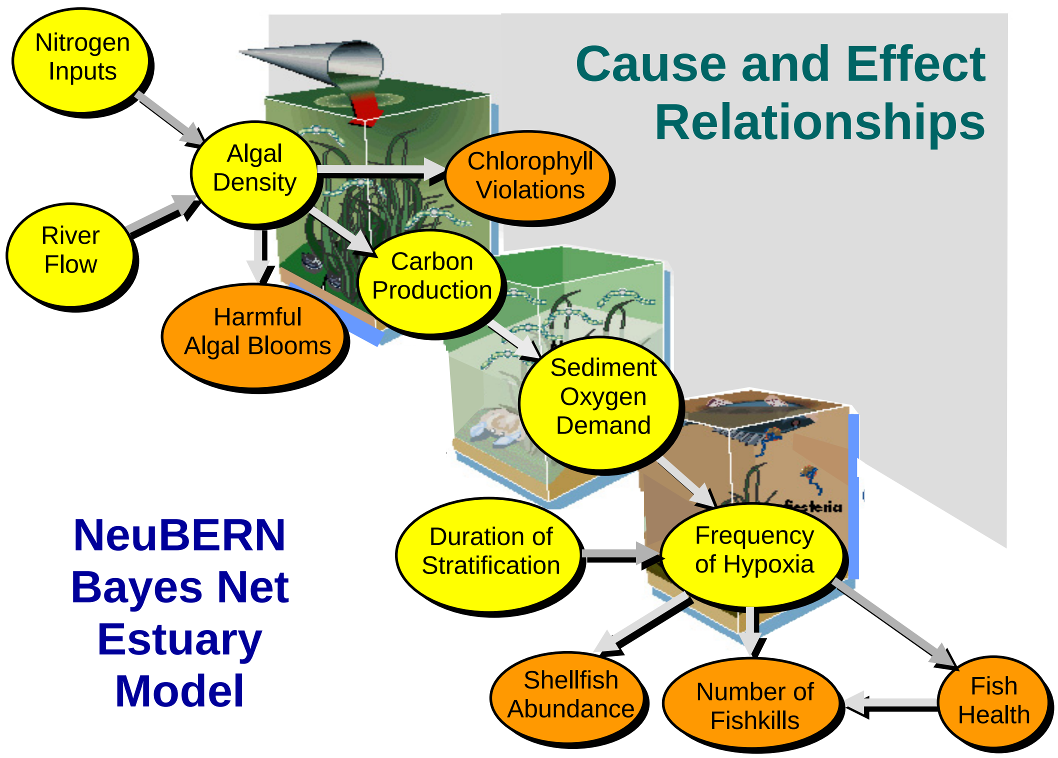


*Figure 2. Neuse Estuary Bayes Network Model*

Finally it should be noted that the error analysis provided by the Bayes net model indicated that a 68% nitrogen load reduction was needed in order to provide 95% assurance of compliance with the water quality standard; under strict EPA guidance this would be the MOS. Despite this substantial uncertainty, all stakeholders were willing to accept a TMDL submittal calling for only a 30% MOS. In addition, EPA Region 4 approved this TMDL application with the understanding that the TMDL would be "revisited" (analogous to adaptive implementation). In many respects, this particular cooperative model building experience has become a notable success in TMDL development, as compliance with the chlorophyll a standard in the Neuse Estuary was achieved in 2001.

### 2.4 Adaptive Management

In 2001, a National Academy of Sciences (NAS) committee was established to assess the scientific basis of the TMDL program. In the resultant report (NRC 2001), the NAS committee recommended that adaptive management (or "adaptive implementation") provide a basis for TMDL assessment and implementation in situations of high uncertainty. Adaptive implementation was viewed as “learning while doing” through a process with initial management actions followed by monitoring to assess progress, and then additional actions if necessary. Thus, the uncertainty would be addressed by observing how the actual waterbody responded and then adaptively implementing (or modifying, if necessary) further pollutant load controls until compliance is observed.

The recommendation in the NRC report for adaptive implementation has, until quite recently, encountered mixed response. On the one hand, EPA expects that the best science will be used to calculate a TMDL (which includes the MOS) that is then to be fully implemented and will achieve compliance with the water quality standard. Strictly speaking this does not provide flexibility for adaptive implementation, nor does it result in TMDLs that actually account for uncertainty. On the other hand, practical considerations at the state level often lead to gradual implementation of a TMDL, because state and local governments often lack the resources to fully implement a TMDL immediately upon approval. This provides an opportunity for an adaptive approach.

The EPA’s interpretation of the Clean Water Act and subsequent regulations is essentially summarized in a federal district court decision that stated that “a phased calculation that is not designed to return impaired segments to water quality standards is not in accordance with the law.” In other words, a TMDL should be approved only if it is calculated to achieve compliance with the applicable water quality standard. Thus, a problem arises because of regulatory rigidity coupled with an implied loss function that values water quality protection over the cost of pollutant control measures (the margin of safety).

Within EPA, there have existed substantially different perspectives on uncertainty in TMDL forecasting, both between the EPA Office of Water (OW) and the EPA Office of Research and Development (ORD), and between the Washington DC-based OW and the regional offices spread throughout the country. The EPA OW in Washington has insisted on a strict interpretation of the Clean Water Act with respect to TMDLs; that is, they insist that the “best science” be the basis for the TMDL and that the MOS reflect prediction uncertainty. In contrast, the ORD generally recognizes that TMDL forecast uncertainty is typically far greater than 10%, yet they seem to have little impact on this common MOS practice. At the EPA regional level, there is a major administrative burden since this is where state-based TMDLs are approved. The regional EPA offices appear to (1) accept the explicit or implicit MOS approach without concern, but (2) increasingly allow flexibility in TMDL implementation that resembles an adaptive approach. This seems to be based on recognition that the initial TMDL forecast uncertainty is large (despite the typically small MOS in approved TMDLs). At best, one may conclude that the TMDL program is in transition; at worst, one may simply conclude that various divisions of EPA are not adequately corresponding with each other.

Fortunately, there recently is reason to believe that EPA OW is beginning to recognize that the magnitude of TMDL uncertainty dictates a more flexible approach. An August 2006 memo from the EPA OW describes “phased TMDLs,” “staged implementation,” and "adaptive implementation." In the memo (B. Best-Wong, August 2006), EPA states that "By using the adaptive implementation approach, one can utilize the new information available from monitoring following initial TMDL implementation efforts to appropriately target the next suite of implementation activities." This is a substantial change for EPA OW Headquarters, yet it is not far off the pragmatic approach increasingly employed by the States and EPA regions.

Finally, in response to the NRC report calling for adaptive implementation, a second committee was recently formed to develop recommendations for how adaptive implementation might occur under the current regulatory constraints. Among the committee's recommendations (in draft form, and thus subject to change) are the following:

- Uncertainty analysis should become standard practice in the technical assessment undertaken for a TMDL. This will likely require additional training and the development or modification of software, but these are activities that already occur for the deterministic models currently used for TMDL assessment.

- For those TMDLs with relatively low uncertainty, the standard TMDL with the margin of safety based on the uncertainty should be conducted.

- However, if there is high uncertainty in the assessment, modeling, and/or in the designated water uses and water quality criteria, and large prospective costs of errors that might be made in the face of that uncertainty, then an adaptive process would likely be superior to the current approach.

- Since implementation of pollutant controls is a state (not federal) activity, there is the possibility that while the approved TMDL meets the regulatory requirement of attaining compliance, the initial implementation of the TMDL does not. This is likely to be most feasible for nonpoint, atmospheric, and legacy pollutant sources, which are outside the federal program. In this situation, adaptive implementation would involve initiation of reasonable pollutant load controls, while undertaking monitoring and experimentation to reduce uncertainty, possibly then leading to adjustments in the pollutant load allocations. This is basically phased implementation augmented by knowledge acquisition to efficiently achieve compliance with water quality standards in situations with high uncertainty.

- In the initial re-assessment of the TMDL, it is recommended that Bayesian or other information pooling approaches be used to combine the pre-TMDL model forecast with the post-implementation monitoring data. Monitoring is expensive and aquatic systems may lag in their response, so early measures of implementation success may be noisy and thus improved with information pooling.

## 3.0 Water Policy – The European Framework Directive

The European Water Framework Directive (WFD) has been a major change in European Water Policy. It terminates an area characterized by directives dealing with single issues and a command and control approach to environmental policy. The WFD has the following key aims:

- expanding the scope of water protection to all waters, surface waters and groundwater
- achieving "good status" for all waters by a set deadline
- water management based on river basins
- "combined approach" of emission limit values and quality standards
- getting the prices right
- getting the citizen involved more closely
- streamlining legislation

The WFD is a formal legal document of the European Union which is a supranational structure where the member states have agreed to sacrifice part of their national sovereignty when joining this union of independent nation states. The WFD is one example of an international process where a framework directive at supra-national scale sets the overall frame and targets but where details of the legal and operational implementation are decided at national / basin scale. The European Commission has put a so-called Common Implementation Strategy in place, which involves member states, NGOs, and water management experts in the implementation process. A number of guidance documents have been developed which give recommendations but are non-binding.

The European Water Framework Directive (WFD) is a complex regulation; its implementation in the member states and river basin districts constitutes an even more complex task within the years to come. In implementing the directive, the competent authorities regularly have to make decisions many of which call for a large amount of information to provide a sound base for decision making. However, not all of the required information is or will be available and part of the information will be associated with uncertainties. And also often the deciding authorities may be in doubt what goal to pursue or what actions to take to achieve these goals.

Take, for instance, the description of the status of all water bodies that all member states must have carried out according to Annex II WFD until December 2004. This not only involves uncertainties in measurements of environmental variables but also uncertainties in assessing the sources of pressures (Annex II 1.4 WFD) as well as the uncertainties regarding the probability that water bodies will not reach good status. Or take the requirement to decide which particular water bodies with intensive human activities will be exempt from the overall goal to reach ‘good’ status and thus only need to reach less stringent environmental goals (Art. 4(5) WFD). Often, information concerning the properties of these water bodies and their deterioration by human activities is lacking; furthermore, of what level should the less stringent goals be? Or take, finally, the measures that will be decided upon to reach the goals of the directive. Mostly, their effectiveness which are the base for economic considerations can only be guessed – for reasons of scientific nature but also concerning the willingness of the addressees to comply with the rules.

In summary the following kinds of uncertainties arise during the implementation process:

- Ambiguity exists in defining operational targets for the different management goals to be achieved and conflicts of interests require participatory goal setting and a clear recognition of uncertainties in this process.
- Outcomes of management measures are uncertain due to the complexity of the system to be managed and due to uncertainties in environmental and socio-economic developments influencing the performance of implemented management strategies.
- New knowledge about system behaviour (e.g. response of ecosystems to measures or compliance of actors with rules) may suggest options for change in management strategies.
- Changes in environmental (e.g. climate change) and/or in socio-economic conditions (e.g. agricultural policy) may demand change in management strategies and may alter entirely the base for economic analyses.

Overall, we identify a clear need for a more coherent and comprehensive approach based on sound conceptual foundations to deal with uncertainties in the implementation of the WFD.

In addition problems of fit and interplay have arisen during the process of implementation. The nation states have very different structures in place to implement integrated water management at basin scale, most with a very long history. Hence, many European countries have to deal with a key problem to moving from an administrative to a hydrological principle, a problem that is currently paramount in many countries in the world. Such problems of fit and interplay are often linked to friction and loss in efficiency due to the complex structure of the implemented institutional settings (e.g. new authorities, working groups with representatives from different administrative bodies). Some argue that such changes might facilitate innovation in management approaches and cross-sectional integration.

## 3.1 Current approaches to deal with uncertainties in the WFD

In principle the WFD provides a flexible framework for implementation that would allow innovative, participatory and adaptive approaches to water management. However, the current implementation process of the WFD seems to follow largely a traditional command and control approach where operational targets are defined to be able to "quantify" the good ecological state of water bodies – e.g. European wide binding water quality targets. One may argue if this approach will really lead to the goals envisaged by the WFD. In the following some issues are addressed that highlight the challenges of this new water policy for water management regimes that have largely been shaped by a control approach to policy.

The European Water Framework Directive is novel in that it leaves far more opportunities for member states to adapt the implementation of the Directive to national and regional specificities. Whereas the time schedule is narrowly prescribed, the relative vagueness of the goal of a “good ecological status” leaves a lot of freedom for interpretation.

The European legislator should not reasonably prescribe every detail of implementation – particularly not within a ‘framework’ (sic!) directive, but leave many decisions regarding the operationalization of goals and measures to the member states and the river basin authorities (Newig, Pahl-Wostl and Sigel, 2005). The rationale of this applied subsidiarity principle (cf. Collier, 1997; Kraemer, 1998) is, of course, that despite the overall goal to reach good water status, regional conditions differ in terms of culture, water uses, waterrelated problems and so forth. However, the openness of the directive is also partly a product of watereddown compromises (Kaika, 2003, p. 311). In any case, it is both sensible and requisite that a considerable amount of decisions are made on a regional level by authorities familiar with regional conditions. This extended discretionary scope on the part of the authorities entails normative uncertainty (Arentsen *et al.*, 2000), i.e. normative considerations of goals and tastes (cf. March, 1978). Such uncertainty about the final targets to be achieved may be perceived as a problem for effective and efficient implementation (inability to act prior to having agreed on binding targets) or as an opportunity to negotiate goals that can really be achieved.

An actor may be in doubt (or a group of actors may be undecided – which on a collective level amounts to the same) as to what goal to pursue and what actions to take in order to achieve these goals. Both aspects are captured by normative uncertainty (Newig, Pahl-Wostl and Sigel, 2005). This calls for the participation of the different societal actors that have an interest in the decision of the goal setting process (Arentsen *et al.*, 2000, p. 601). One example that illustrates the spectrum of possible stakeholders is the so-called ‘area cooperations’, which are currently (summer 2005) being put into place in the German federal state of Lower Saxony with the aim of involving actors in the implementation of the WFD on the level of each local working district (sub-basin).

These groups are composed of 10 people representing the local municipalities, water suppliers and the local and the regional water administration as well as the local associations of agriculture, industry, fishery, navigation and nature conservation, calling in additional actors, such as land owners or forest officials, as needed in specific phases and contexts.

### 3.2 How is uncertainty addressed in the guidance documents of the implementation process of the WFD

In order to examine how the directive and the implementation process deal with the issue of uncertainty, a text analysis of the WFD as well as three ‘guidance documents’ has been conducted (Sigel, in prep). These guidance documents are part of the common implementation strategy for the WFD[1], namely *Economics and the Environment* (Wateco, 2002), *Guidance for the Analysis of Pressures and Impacts* (Impress, 2003) and *Guidance on the Planning Process* (Proclan, 2003). The analyse comprises (i) the overall understanding of uncertainty and (ii) the main strategies for dealing with uncertainty, and then discuss the potential shortcomings and suggestions for improvement.

The *WFD* does not refer to 'uncertainty' as such. Instead, the converse expression 'adequate level of confidence and precision' is used in relation to (i) the process of establishing the reference conditions for surface water body types (Annex II 1.3 WFD), (ii) monitoring the ecological and chemical status of surface waters (Annex V 1.3 WFD) and (iii) the identification of trends in groundwater pollution (Annex V 2.4 WFD). The three-pronged demand in the Annex of the directive for an 'adequate level of confidence and precision' should presumably be regarded as merely an example, because the problem of uncertainty also arises in other domains of the implementation process. Instead of the term 'adequate' (as applied to the level of confidence and precision), the WFD also uses the expressions 'sufficient' and 'acceptable'.

Although the *guidance documents* analysed all refer explicitly to 'uncertainty', the way in which this term is understood varies greatly between the different documents. Wateco deals in great detail with 'uncertainty' because it covers the subjects 'decision-making' and 'information management'. The main 'sources for uncertainty' throughout the process of identifying measures and developing river basin management plans according to Wateco are 'the assessment of pressures, impacts, baseline, costs or effectiveness' (Wateco, 2002, p. 40). However, Wateco does not describe these sources of uncertainty in detail. Only one special type of uncertainty is mentioned: 'Gaps in information and knowledge' (Wateco, 2002, p. 47). Since these gaps have to be filled over time, Wateco refers here to a form of reducible ignorance.

Impress points out that uncertainties have to be taken into account in the initial state when analysing pressures and impacts and in the environmental conditions required to meet the directive's objectives (Impress, 2003, p. 19). Thus, according to Impress, the problem of uncertainty is initial rather than fundamental.

Proclan defines uncertainty as 'the occurrence of events that are beyond our control' (Proclan, 2003, p. 20). The cause is the complexity of the many factors involved in planning processes, such as meteorological, demographic, social, technical and political conditions. According to Proclan, uncertainty is always an element in planning processes.
Concerning strategies for dealing with uncertainty, the WFD states that the 'level of confidence and precision' has to be 'estimated' and 'adequate'. These two steps,

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[1] The CIS constitutes an up to now unparalleled institution to foster and ensure the coherent implementation of an EU directive. Within its scope, 14 thematic guidance documents have been produced until 2003, which have been 'adopted' by the 'water directors' of the member states and the commission. Since these documents constitute neither legal rules nor decisions of the commission, they remain legally unbinding. It may however be expected that they will be of significant importance in the course of interpreting the WFD by the European Court of Justice in the event of a lawsuit. Because the member states anticipate this, the CIS guidance documents may *de facto* have considerable influence on the actual implementation of the WFD.

*estimating* and *evaluating uncertainty*, can be designated as central components of any kind of strategy for dealing with uncertainty. In addition, the WFD provides several regulations that play a potentially important role in dealing with uncertainty as they influence the way in which information and (imperfect) knowledge are handled. Whereas these provisions are not explicitly designed to deal with uncertainty, some of them are mentioned with regard to this function in the *guidance documents*. Examples include public participation, planning styles and monitoring. These provisions are designed to deal with more than just uncertainty, which is why they can be referred to as multifunctional or general.

The role of *public participation* in the economic process is stated by Wateco as follows: ‘To integrate stakeholders into the economic analysis can prove very useful as it brings expertise and information, it provides opportunities to discuss and validate key assumptions and it increases the ownership and acceptance of the results of the economic analysis’ (Wateco, 2002, p. 9). The direct link with uncertainty is made in the statement that public participation needs an adequate way of communicating uncertainty to the public and stakeholders (Wateco, 2002, p. 65). There is, however, neither guidance to support a judgement of what the term ‘adequate’ could imply, nor on potential consequences of uncertainty, in particular in the case of conflicts.

The strategy introduced by Proclan takes a similar track, arguing that *planning strategies* are crucial for managing uncertainty. The more ‘interactive’, ‘discursive’ and ‘adaptive’ planning processes are designed to be, the more important uncertainties are judged to be (Proclan, 2003, pp. 19, 21). However, the document remains quite vague regarding more specific recommendations.

Impress aims to boost confidence in the assessments of pressures and impacts by *designed and targeted monitoring programmes*. Whenever the assessments nevertheless contain significant uncertainty, these water bodies should – by way of precaution – be classified as at risk of failing to meet their objectives (Impress, 2003, p. 19).

The fact that the WFD and all the guidance documents analysed raise the issue of uncertainty emphasizes its relevance. The guidance documents give important clues about where uncertainty occurs and how it could be dealt with, each focusing on specific parts of the implementation process, the various sources and types of uncertainty and how they affect development and implementation of river basin management plans. Because of the different understandings, the various descriptions of uncertainty cannot be put together to form a complete framework for the whole process. The manner in which uncertainty is described is rather rough and fragmentary. Moreover, although important strategies are identified, the concrete role they may play to reduce or manage uncertainty has yet to be defined.

### 3.3 The role of models and participation

Water management has a long tradition in using hydrological models for planning processes. Due to the increased recognition for the importance of economic and social factors, the development of decision support systems has enjoyed considerable interest. However, the application of models and decision support tools by water management practitioners has been far less than anticipated by the research community. Under the umbrella of the European project HarmoniCA a profound analysis has been conducted to elicit user requirements concerning models and IC tools and modellers expectations of user requirements. Borowski and Hare (in press) summarized the main findings of the two year process. They identified a gap between water managers and research community that is evidence of a mutual misunderstanding of the fundamental activities of both communities. They recommended among others things to improve researchers' understanding of water management processes and the role their tools play within such a process and to identify for both communities the importance that such tools can play as part of social learning-oriented management processes. Brugnach et al (in press) came to similar findings in their analysis of the role of uncertainty in using models and the science-policy interface. They highlighted that the use of computer models offered a general and flexible framework that could help to deal with some of the complexities and difficulties associated with the development of water management plans as prescribed by the Water Framework Directive. However, despite the advantages modelling presents, they judged that the integration of information derived from models into policy was far away from being trivial or the norm and that part of the difficulties of this integration was rooted in the lack of confidence policy makers have on the incorporation of modelling information into policy formulation. They concluded that public confidence in models is highly dependent on the way uncertainties are addressed.

The findings support the elaborations by Pahl-Wostl (2002, in press) that in order to develop models for application in policy and management the whole model development process has to be embedded in a process of social learning involving different stakeholder groups (including science). However, the findings also show that the water management community is still far from fully embracing complexity and acknowledging the importance of learning processes.

### 3.4 Experience from the implementation process

In his analysis whether the Framework Directive (WFD) builds resilience, i.e. the capacity of freshwater systems to deal with change and perturbations, Galaz (2005) concluded that the current realization of the WFD in Sweden raises some considerable issues, and might at worst reduce the resilience of nested social-ecological freshwater systems. In particular he highlighted that:

- Collective Action and Analytical Deliberation is Highly Limited
- Water Management Institutions Disregard Complexity and Uncertainty
- Water Policy is Poorly Prepared to Tackle Global Environmental Change

Such insights are not limited to Sweden. Despite the stated policy goals by government to foster innovation and more flexible and adaptive management approaches, one observes a lack of change at the operational level. In the Netherlands, for example, the government asks for a radical rethinking of water management – more space for rivers and living with water rather than control. However, management practice is very slow in adopting new strategies. Currently, adaptive management seems to limited in prevailing designs, practices and ideas surrounding river basin management (Pahl-Wostl, Berkamp and Cross, 2006; Pahl-Wostl, in press).

### 3.5 Prospects for adaptive management in the implementation of European Water Policy[2]

What are now the requirements for adaptive management in river basins:

(1) New information must be available and/or consciously collected (e.g. indicators of performance of management regimes, indicators for change that may lead to desirable or undesirable effects) and monitored over appropriate time scales (longer than those mandated by short-term political objectives).

(2) The actors in the management system must be able to process this information and draw meaningful conclusions from it. This can be best achieved if a learning cycle and negotiation process unites actors in all phases of assessment, policy implementation and monitoring. Actors pursue different and changing political

[2] Currently the prospects of and requirements for adaptive water management are investigated in the European project NeWater: New Approaches to Water Management under Uncertainty (www.newater.info).

interests. Hence transparency and leadership are of major importance to make such processes work.

(3) Change must be possible in ways that are open and understandable to all actors. Management must have the ability to implement change based on processing new information in a transparent process where it is clear as to who decides how and when to change management practices, based on which evidence and why. Doing so requires to strike a balance between continuity (some management strategies may take one or more decades to be implemented and tested) and flexibility. Without transparency and trust there is a danger that some actors may abuse such an open process to pursue their vested interests.

One has to be aware that one current water management regimes show a certain degree of path dependence and one cannot expect that it would be straightforward to implement a radically new management approach. A management regime is here referred to as the whole complex of technologies, institutions (= formal and informal rules), environmental factors and paradigms that are highly interconnected and together form the base for the functioning of the management system targeted to fulfil a societal function. Due to the high interconnectedness and internal logic, individual elements of a regime cannot be exchanged arbitrarily. Regulatory frameworks, good rules of practice of engineers, expectations of citizens, characteristics of technologies have co-evolved over time and do stabilize each other. The often quite rigidly prescribed planning procedures do not foresee experiments as part of the planning and implementation process. The whole issue of accountability is on open problem? Who is to be held accountable for failed management notions within such loose frameworks of actors and polycentric governance systems?

Hence the implementation of adaptive management needs what one may call integrated system design. Taking into account uncertainties and the need to revise management strategies based on new insights requires a major paradigm shift in water management where still a technocratic and expert culture dominates and where certain expert knowledge that provides the base for prediction and control is also related to dominance and power. Having to acknowledge that their assumptions about management strategies were wrong is still perceived by quite a few water management authorities as a loss in credibility in the public. Processes of social learning will play here a major role.

As pointed out, technical infrastructure (e.g. large technical infrastructure for flood protection), citizen behaviour (expectations regarding safety in floodplains, risk perception) and habits, and engineering rules of good practice are often mutually dependent and stabilize each other. In many cases they have co-evolved over a long periods of time. Hence one observes so-called lock-in situations with the effect that changes towards new resource management schemes are blocked and require collective learning and decision making processes (Pahl-Wostl, 2002). Actors need to learn to recognize how their own frame of reference influences and constrains their thinking and that other legitimate frames of reference exist. Collective action and the resolution of conflicts require that people recognize their interdependence and their differences and learn to deal with them constructively. The different groups need to learn and increase their awareness about their biophysical environment and about the complexity of social interactions. This does not imply that a consensus is achieved but what is required is the development of a minimum level of trust as base for transparent and efficient communication. It is claimed that social learning in river basin management is needed to develop and sustain the capacity of different authorities, experts, interest groups and the public to manage their river basins in a sustainable way and balance multiple and competing interests to the benefit of the socio-ecological system as a whole.

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