Uncertainty in the Water Framework Directive: Implications for Economic Analysis

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Abstract: The Water Framework Directive (WFD) imposes a new approach to water resource management in the EU states. Uncertainty surrounding its implementation, however, could badly affect the achievement of the objectives set by the Directive. Although not directly linked to a set of techniques to deal with it, the WFD and accompanying guideline documents identify uncertainty as a factor likely to play a significant role in assessing the risk of failing to achieve the objectives and setting up the required programmes of measures. In this paper, by addressing the initial description of a river basin we analyse uncertainty in socioeconomic descriptors such as demographic and water-use data. Socioeconomic data, models and evaluation techniques supporting the economic analysis of water uses are crucial parts of a Decision Support System (DSS) aimed at facilitating the WFD implementation.

Keywords: Water resources; Decision Support System; Catchment; Modelling; Economic Analysis

1. INTRODUCTION

The Water Framework Directive (WFD) is a piece of environmental legislation which is unprecedented in the history of the EU. As well as imposing environmental objectives to be achieved, the WFD also lays down a set of instruments and procedures to analyse the socioeconomic and environmental impacts of current water uses and to help implement measures to achieve the objectives. To support the implementation of the WFD, a series of guideline documents have been developed under the *Common Implementation Strategy of the WFD* (CIS) to explain the novel concepts and guide the application of the WFD's instruments. However, none of them – nor indeed WFD itself – addresses the issue of uncertainty. However, uncertainty is likely to be an important factor in guiding activities designed to achieve the WFD's objectives and effectively allocate the resources available. Indeed, ignoring uncertainty could, in many cases, result in the desired status of water resources not being achieved because the available information (uncertainty being a piece of information) has not been sufficiently exploited. Excessive demands for certainty on the other hand can lead to unnecessarily expensive measures being implemented while valuable resources, which could be more effectively allocated to other catchment locations, are wasted.

Economic analysis in connection with the WFD is designed to analyse the importance of water to the economy and the socioeconomic development of river basins (WATECO 2003). Several Decision Support Systems (DSS) have been developed to facilitate the economic analysis of water resources, especially to (i) analyse the socioeconomic drivers which exert pressures on water resources and are thus responsible for the water's current status; (ii) investigate the dynamics of water uses and contributes to the development of a baseline scenario; (iii) assess the cost recovery level of water services; (iv) select the most cost-effective programme of measures to achieve the WFD's objectives.

In all these tasks, uncertainty is likely to play an important role. As a conclusion drawn from the initial description of a river basin, the analysis of current water uses and the prediction of future development (baseline scenario), the 'risk' (in the sense of likelihood) of the WFD's objectives not being met needs to be assessed. This is crucial, because once the likelihood of failure is known, suitable measures can be adopted. Uncertainties from different sources are summed up in this assessment, e.g. uncertainty in data collection, transformation (from the original spatial units for which they are collected to the hydrological boundaries where they are required), and forecast models. These uncertainties may vary and interact differently at various spatial levels: e.g. the transformation of demographic data to a river basin district is normally less uncertain than to sub-basin survey areas.

In this paper, we analyse the uncertainty in the assessment of key economic drivers likely to influence pressures on water resources. We focus on demographic development (and domestic water supply) as a representative socioeconomic data set for several reasons: (i) demographic development is regarded as one of the main driving forces behind the pressures on water resources (IMPRESS 2003); (ii) the population size and especially age structure determine a number of other economic indicators such as inflation, national saving rates, investment rates, gross domestic product growth rates, etc. (Lindh and Malberg, 2000); and (iii) these data are best available from the data required to perform economic analysis, meaning a number of uncertainty sources which are common to any other socioeconomic data may be demonstrated. The analysis and the case study presented in the paper were developed to aid the development of a DSS for the White Elster River to analyse pressures and impacts and subsequently to compile a programme of measures designed to achieve the WFD's objectives.

2. UNCERTAINTY IN THE WFD

Although the WFD recognises uncertainty as a relevant factor, it does not contain a comprehensive framework for describing and handling it. In fact, the term 'uncertainty' is not used by the WFD; instead, two other expressions in the context of uncertainty can be found: "Adequate level of confidence and precision" and "risk". The former is used in relation to: (i) the process of establishing the reference conditions for surface water body types; (ii) monitoring the ecological and chemical status of surface waters and (iii) the identification of trends in groundwater pollution. Presumably these three domains should be regarded as representative because the problem of uncertainty also arises in other domains. Instead of the term 'adequate' (as applied to the level of confidence and precision), the WFD uses the expressions 'sufficient' and 'acceptable'. The simultaneous employment of the terms 'confidence' and 'precision' expresses the subjective (confidence) and objective (precision) character of uncertainty.

The term 'risk' is used in two different meanings in the WFD. In the context of "risk to or via the aquatic environment", 'risk' is used in the sense of danger (hazardous substances). One common approach for dealing with this kind of risk is to establish a link between the negative outcomes and the likelihood of these outcomes occurring. In the case of hazardous substances, the WFD dictates that two strategies be followed: scientific risk assessment and the precautionary principle. In the context of "risk (of water bodies) failing to meet the environmental quality objectives" the term 'risk' could firstly be interpreted as 'possibility'. However, from the context it can be concluded that the WFD here implicitly refers to the sum of pressures affecting the water body. Hence 'risk' becomes a negative meaning increased by the negative wording ('failing to achieve').

Concerning *strategies for dealing with uncertainty*, the WFD states that the "level of confidence and precision" has to be "estimated" and has to be "adequate". These two steps, estimating and evaluating uncertainty, can be designated as central components of any kind of strategy for dealing with uncertainty. In addition, the WFD contains several elements which may play an important role for dealing with uncertainty as they influence the way in which information and (imperfect) knowledge are generated and handled in the implementation process of the WFD, e.g. designed and targeted monitoring programmes, participation, adaptation and review of the WFD. These elements, although not explicitly linked to uncertainty, are very important as they focus on a multitude of types and sources of uncertainty.

3. UNCERTAINTY IN ECONOMIC ANALYSIS

A variety of socioeconomic descriptors is required at some stage of the WFD implementation process. A comprehensive list of socioeconomic descriptors has been produced by the WATECO (2003), LAWA (2002) and the Economics Sub-Group of the International Commission for the Protection of the Danube River (ICPDR). In the latter, the descriptors are structured into (i) general socioeconomic indicators (e.g. population, gross domestic product, rate of economic growth, employment), (ii) characteristics of water services (e.g. total water production, water supply, water demand, wastewater treatment, irrigation water supply), and (iii) characteristics of water uses (e.g. agriculture, industry, hydropower). In addition, the forecast of future development with regard to these descriptors has to be integrated into the baseline scenario, which describes the dynamics of the river basin without any additional provisions resulting from the WFD.

Many general socioeconomic descriptors are collected by statistical offices which guarantee (albeit not totally, as shown below) the uniform methodology of data acquisition, data comparability, the constancy of data upgrade, and the basic assessment of uncertain components of the data. These data are normally non-confident and available at the municipal or higher aggregated district level. On the other hand, some other data (e.g. water abstraction payments, waste water charges) not normally collected by statistical bureaux is either not available at all or (at least) partly confidential, available only on demand and accessible at a higher aggregation level (Interwies et al., 2003).

The socioeconomic data have an uncertain component, the magnitude of which depends on a variety of factors including (i) the quality of measurements, (ii) the quality of models from which they are derived, (ii) the scale at which the data are collected or made publicly available (data confidence issue), (iv) the upgrade frequency and (v) the quality of metadata documenting the descriptors, to name but a few. Generally speaking, uncertainty in economic analysis is caused (and accumulated) through (i) the conceptualisation of the phenomena analysed; (ii) measurement and representation; and (iii) data conversion and analysis (Fig. 1). Below we address the issues related to the quality of the general socioeconomic descriptors using the example of the demographic data and domestic water supply.

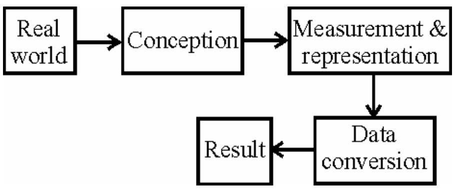

Figure 1: Uncertainty and error propagation.

The case study area is the River White Elster catchment, a tributary of the River Saale that eventually flows into the River Elbe. Most of the White Elster area (5200 km2) is in Germany, although a small upland part is situated in the Czech Republic. The structural diversity of the local government units for which socioeconomic data is normally collected makes the case study an ideal place to investigate the availability and quality of socioeconomic data.

3.1 Uncertainty due to Conceptualisation and Measurement

The demographic data are collected by statistical offices relatively infrequently, normally once every 5 or 10 years. The last census took place in the states that were previously part of the GDR (East Germany) in 1981 and were technically updated in 1991. Since then the number of inhabitants has been updated with data from registry offices. In demographic analysis the population size may be the subject of uncertainty analysis as there is a variety of quantities which may be referred to (i.e. who are counted). Statistical bureaux normally count inhabitants according to their main place of residence rather than the inhabitants actually living in a local authority. Especially in the bigger cities with a university (e.g. Leipzig with about 30,000 students and Halle with about 17,000 students, the former being nearly completely included and the latter included by 1/3 in the river basin district) where many students are registered under their second place of residence, the actual number of inhabitants is understated. For example, for the city of Leipzig the difference between the estimated total population in Leipzig and the number of inhabitants with their main residence in the city accounts for 28,500 inhabitants (~6%). In addition, a high number of commuters (different place of residence and place of work) represent another source of uncertainty. People commute to work between local authorities, districts or even federal states. Depending on the region, these migrations may account for quite large uncertainty, especially when the demographic data is used as an input to predict the future water supply demand. In Saxony the share of commuters accounts for 10%.

3.2 Uncertainty due to Data Analysis and Transformation

The socioeconomic data, unlike environmental data like land cover, are collected and aggregated for spatial units which are not readily compatible with river basins districts. The data are often available for statistical and/or administrative units such as local authorities, districts, federal states or the national level. Other data are collected primarily for different spatial units such as water supply districts, wastewater disposal districts, areas of high population concentrations, etc. To perform the economic analysis, this data have to be restructured to hydrological spatial units such as river basin districts or even more detailed water sub-basin survey areas. In Germany, federal states' statistical bureaux assigned the water management relevant data (e.g. abstraction) to river basin districts according to the statistical units' centre of gravity. A more precise algorithm is based on a weighted average of the geographic and settlement shares of the local authorities' segment covered by the river basin district (LAWA 2002).

Data transformation is a considerable source of uncertainty whose importance increases with the number of administrative units intersected by the boundary of the river basin district. The *White Elster* river basin passes through four German federal states, four Government regions, 22 districts and 334 local authorities. Since each of the four states has its own Department of Statistics, there are four different data providers for basic statistical information about the river basin district. The river basin completely contains 194 municipalities (with a total area of about 3200 km^2) and intersects another 140 municipalities (with a total area of about 3800 km^2). The local authorities completely contained within the river basin districts are on average smaller (mean ~16 km^2, standard deviation ~18 km^2) and more homogeneous than the intersected local authorities (mean ~27 km^2, standard deviation ~31 km^2), which means a rather high uncertain component for example in the assessed number of inhabitants living in the river basin district. Indeed, the total population living in the intersected local authorities (and who are thus more problematic for assigning to the river basin districts) accounts for 1.6 million (in 2001), which is more than double the population living in the local authorities completely within the hydrological boundary of the river basin district (0.76 million).

Different approaches to restructuring the demographic data to the hydrological boundaries of the river basin yield different results. For example, the transformation of the local authority based population data among the respective river basin districts is often based on the percentage of populated area concerned. To calculate the perceptual share of the settled area in each local authority, the CORINE Land Cover (CLC) data recommended by LAWA (reference date 1997, reference scale 1:100,000) and a more precise biotope map (based on CIR images, reference date 1992-93, reference scale 1: 10 000, see Rosenberg 2003) were used. While at the river district level the CLC and biotope map based assessments performed equally, at the more disaggregated (district) level the differences between them ranged from –23% to 15%. Although both data sets differ in terms of their resolution and quality of classification, the transformation based on them assumes a perfect correlation between the inhabited area and the number of inhabitants which does not hold, as the following example shows. For other socioeconomic descriptors such as the number of households or age structure, this relationship is even lower or non-existent.

In the main urban centres, transformation based on settlement shares can cause higher uncertainty as the different population density (dwelling houses with different numbers of floors) in different parts of the city cannot be considered by using the settlement land cover data. To assess this uncertainty we analysed the population and settlement land cover data for the city of Leipzig. We found that the difference between the estimated and the actual population size in our test area ranged from –300 % (in the periphery of the city where the actual population size is lower than a proportional share derived from the settlement area) to +70% with the lowest difference (~0) being close to the city centre (Fig. 2).

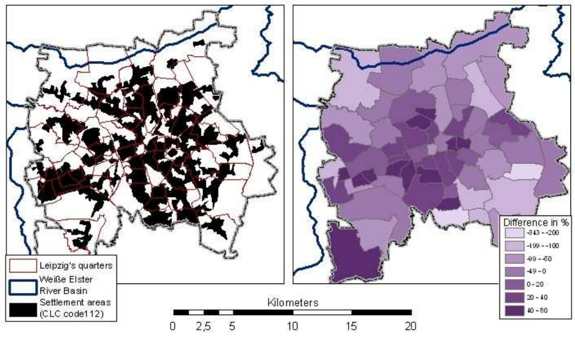

Figure 2: Differences between actual and calculated population size in the boroughs of the city of Leipzig when transformation is based on the CLC data.

Administrative reforms are another source of (in some cases considerable) uncertainty. In Saxony, for instance during the reforms carried out between 1991– 2001, the number of local authorities was reduced from 1623 to 539, while the number of districts decreased from 48 to 29. Although this caused only little uncertainty in population data (which has been correspondingly adjusted for the past periods), this makes it largely impossible to compare data about water services and analyse past trends. Water management data are collected for spatial units corresponding to the areas supplied by an enterprise. Originally corresponding to the local government areas, due to the administrative reform this data differs from the current administrative units and must be restructured to fit the river basin districts. The magnitude of uncertainty caused by administrative reforms varies considerably among the data required for economic analysis, being lower for data aggregated at district level and higher for data available at the lower level. Finally, the uncertainty of boundaries of river basin/ subbasins and administrative boundaries exacerbate the above-described uncertainties.

3.3 Uncertainty due to Prediction – Base Line Scenario

The Directive stipulates the development of a baseline scenario which frames the forecast and assessment in key economic drivers likely to influence water status until 2015. Forecasting demographic development is a task for each state's statistical bureau. The current forecasts are available for 2002–20 in Saxony, 1997–2015 in Thuringia and 2000–15 in Saxony-Anhalt. These forecasts are based on different models and assumptions and are thus only partly comparable. The smallest administrative unit for which the forecast is available is district. For Saxony and Thuringia there are two different scenarios of further demographic development available, based on different assumptions for (i) the mortality rate and migration between the German states (in Saxony and (ii) immigration from other European countries, especially EU Associated States (in Thuringia). In Saxony-Anhalt and Thuringia, the available forecasts are being updated as the current forecasts have performed poorly in predicting the demographic development of past years. Another demographic prediction (INKAR) available at district level has been developed by the Federal Department of Construction and Regional Planning (BBR) for all German states. This prediction consists of just one scenario. The differences between the predictions of states' statistical bureaux and INCAR predictions are up to 49 and 47 per cent (scenario 1 and scenario 2) in Saxony, 19 and 16 per cent in Thuringia, and 43 per cent in Saxony-Anhalt. An analysis of variance revealed significant differences between how the Inkar prediction fits the states' forecasts ($p < 0.01$, Fig. 3). The different scenarios differ not only with regard to the absolute numbers of expected inhabitants but also in the sign of the expected trend in development. The differences between available forecasts differ considerably across the districts (spatial variability).

One considerable source of uncertainty in the predictions considered is the fact that future economic development in the region is largely neglected. This is an important factor considering the vast economically motivated emigration from the states in eastern Germany in the early 1990s. In those years, for example, Saxony lost some 11% of its population. This emigration is still continuing, albeit less significantly, and Saxony's population is expected to decline by 14–17% by 2020. Although the long-term predictions may include a significant uncertainty which increases towards later periods, frequent updates help to keep the actual level of uncertainty manageable. For example, the differences between the different predictions and scenarios does not exceed 10% in the first five predicted years. In Saxony, the latest demographic forecast tallies well with current development (differences < 1%) at the state level despite the mismatch (>10%) in the individual parameters of the model.

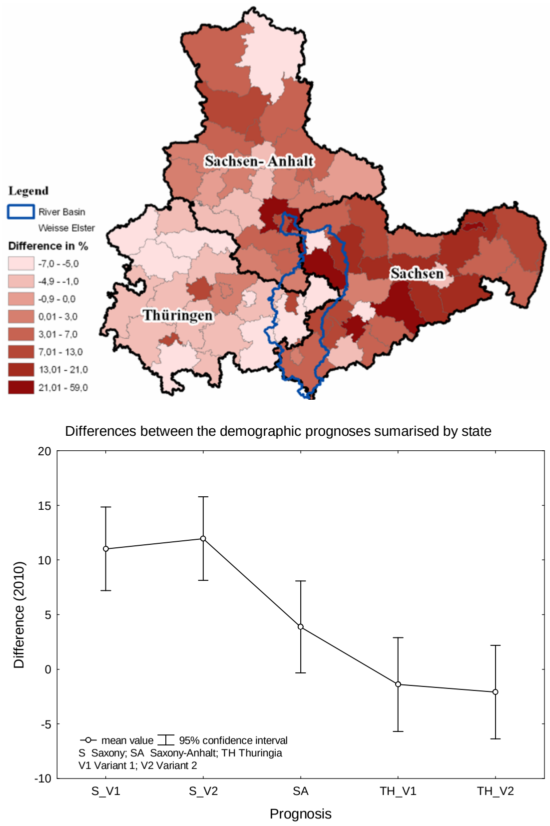

Figure 3: Differences between the demographic prognoses in the districts (above) and summarised by state (below).

Socioeconomic drivers predicted in the baseline scenario have to be linked to water demand and wastewater disposal to assess their impact on water resources. Demographic data (population size, number of households, age structure, etc.) alone is not sufficient to explain the water consumption pattern as documented by low (and non-significant) correlations between population size and water consumptions, or by the reduction of water consumption per capita in Saxony by 6% (1995–98). A significant source of uncertainty in water demand prediction, besides the uncertainties discussed above, is the fact that factors such as technological development, shifts in social values, globalisation and also climate change (on the supply side) are largely neglected. Although LAWA recognises these uncertainty factors as potentially significant for the future development of water uses and services, instruments for assessing these uncertainties are lacking and river basin authorities are not expected to address these issues (LAWA 2002). Unlike the demographic prediction, the forecast of future water demand is not being pursued by the statistical bureaux. A practical impediment to the development of such predictions is a lack of larger time series data for the calibration of the forecast models. Currently this data about water consumption and wastewater disposal are available for four previous periods with a collecting interval of three years. Additionally, the records available are not comparable because of the complex administrative reform carried out in the past ten years.

4. CONCLUSIONS AND DISCUSSION

Although a considerable amount of uncertainty was identified in the demographic development and future water demand requirements, these assessments must be considered cautiously. It is not solely the level of uncertainty that indicates the significance of driving forces and pressures. Negative developments of pressures (albeit with an uncertain magnitude of decline) and/or non-significant impacts of the pressure considered may lead to the assessment of a pressure as not being significant for river and riverine ecosystems. In the White Elster case study, we conclude that (i) little to moderate uncertainty is included in the description of current population (which is higher in large cities and in the areas with a high proportion of commuters), (ii) high uncertainty accompanies the prediction of further demographic development (uncertainty being larger for more distant periods), and (iii) moderate to high uncertainty is caused by restructuring the population data to the river basin district (depending on the structural diversity of the local authorities intersected by the river basin district boundary). Although because of the progressing population decline in the river basin district, the population may be regarded as a non-significant driving force behind pressures on water resources, because of the high spatial variability of the data analysed, higher caution is advised at the level of sub-basin survey areas.

Furthermore, the predictions of future water demand and wastewater disposal are moderately to highly uncertain in the long term because of the relevant uncertainty sources such as climate change or technological development and innovation, in addition to uncertain demographic prediction.

Other places where uncertainty plays an important role include estimating the current level of cost recovery for water services and selecting programmes of measures to achieve the WFD objectives. In both cases, the estimation of environmental and resource costs may include large uncertain components. In the latter case, the application of economic appraisal and multicriteria decision methods may be surrounded by uncertainty resulting for example (i) from the choice of a method, (ii) from restricting the number of participants and thus the preferences modelled, (iii) from monetising non-marked goods (e.g. wetland values); and (iv) from aggregating preferences about a multitude of conflicting objectives. Although not addressed here, they are the subject of another paper being prepared by Mysiak et al. (in preparation).

5. ACKNOWLEDGMENTS

This research was kindly supported by the EC under contract no. EVK1-2000-22089 and HPMD -CT-2001-00117. The authors gratefully acknowledge the help of Matthias Rosenberg in analysing the settlement areas using a biotope map.

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