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Research Question: How can the value of implementing the European Union Water Framework Directive be evaluated?

System Science Method(s): System Dynamics & Networks

Things to Notice:

- Combination of system dynamics and other models using networks
- (Challenges in) using system science methods to evaluate public policy

The term "integrated valuation" is defined and its relevance is discussed in terms of bridging the gap between cost-effectiveness analysis and economic valuation in the implementation of the European Union Water Framework Directive. We demonstrate how to integrate benefit valuation with the ecosystem services cascade framework using an Object-Oriented Bayesian Network (OOBN). The OOBN is then used to assess the benefits of nutrient abatement measures across a cascade of submodels of the driver-pressure-state-impact-response (DPSIR) chain for the Vanemfjord lake in Morsa catchment in south-eastern Norway. The lake is part of a complex lake system in a semi-urbanized catchment dominated by forest and agriculture. The catchment has highly variable seasonal climatic conditions affecting nutrient run-off and algal blooms. It has been one of the most eutrophic lakes in Norway with periodic cyanobacteria blooms, but continues to attract a large recreational user population, despite the large variations in water quality. The "DPSIR-OOBN" model is used as a case study of "integrated valuation" and evaluated for its applicability for decision support in nutrient abatement. We find that the DPSIR-OOBN model meets seven of the nine criteria we propose for "integrated valuation". The model struggles to meet the criteria that ecological, social and economic values should be defined consistently in relation to impacts on lake quality. While the DPSIR-OOBN integrates from valuation methods across an ecosystem cascade to management alternatives, it is neither a full benefit-cost analysis, nor a multi-criteria analysis. However, we demonstrate how the DPSIR-OOBN can be used to explore issues of consistency in scaling and weighting of different ecological, social and economic values in the catchment system. Bayesian belief networks offer a consistent approach to analysing how management implementation probability may determine economic valuation. We discuss the implication of our integrated valuation not being able to account for farmer responses, in particular

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the incentive effects of the model not being able to predict abatement effectiveness and value. The resolution of the nutrient monitoring data and modeling technologies that were at our disposal are probably better in the Morsa catchment than for any other catchment of this size in Norway. We therefore conclude that using our integrated valuation model for assessing benefits of eutrophication abatement measures as part of the EU Water Framework Directive still lies in the realm of utopia – euphemistically speaking a "eutropia".

Freshwater eutrophication is one of the major environmental challenges around the world. There is a range of known factors that are responsible for water eutrophication, though the increased flux of nutrients from the sources to the water bodies is a key factor. This loading of nutrients occurs both from point sources and non-point sources. Point sources, such as sewage water, were historically the most important sources of nutrients to surface waters. With the advancement of sewage treatment technologies the culprit nutrients in the sewage are removed effectively before discharged into the water bodies. Now scientists and policy makers in most developed countries are turning their attention to the remaining non-point sources, such as from agricultural land (Parry, 1998). The challenge lies in that the mechanisms of mobilization and transport of nutrients from agricultural land are not adequately understood (Tong et al., 2003; Yang et al., 2008). Eutrophication is still a problem in many rivers and lakes in Norway despite the introduction of best management practice and numerous abatement measures in recent years. Environmental monitoring shows that the situation has remained largely unchanged during the last ten years. Norway adhered voluntarily to the EU Water Framework Directive (WFD). It was implemented in 2009 in a number of pilot river basins, with the EU objective of achieving "good ecological status" by 2015. In defining a programme of measures for a river basin, a river basin authority should assess whether costs of achieving "good ecological status" are disproportionate to benefits of measures (EC, 2003, 2009). If costs are disproportionate to benefits, a delayed and/or lower ecological status objectives may be justified for the water body under the WFD rules. While a benefit–cost rule is a relevant approach for evaluating disproportionate costs, there are few operational examples of integrating valuation of benefits with cost-effectiveness assessment of measures (Galioto et al., 2013).

A recent review of economics and ecosystem services analysis in support of the Water Framework Directive Martin-Ortega (2012) identifies five requirements for more sophisticated approaches to dealing with uncertainty:

- to address multiple stressors acting simultaneously;
- technical improvements in the valuation of ecosystem services from water bodies;
- adequate reflection of trade-offs between environmental and social objectives;
- quantification of multiple benefits;
- co-construction of knowledge and practice with stakeholders at multiple levels.

These recommendations for improving economic analysis in the WFD have many commonalities with Gómez-Baggethun et al. (2014) proposal for "integrated valuation", which we discuss in detail below.

The aim of this study is to operationalize "integrated valuation" as a way of bridging the gap between cost-effectiveness analysis and economic valuation of benefits in the implementation of the Water Framework Directive. We illustrate how Bayesian networks (Jensen and Nielsen, 2007; Kjaerulff and Madsen, 2007) offer an operational approach to integrating benefit valuation with the ecosystem services cascade framework (Haines-Young and Potschin, 2010). More specifically we use an object-oriented Bayesian network (OOBN) to show how uncertainty can be analysed consistently across a casual chain of submodels of driver–pressure–state–impact–responses (DPSIR) in a catchment and lake system (Barton et al., 2012; Tscherning et al., 2012). We demonstrate the use of Bayesian network software by assessing eutrophication abatement decisions in the Lake Vanemfjorden within the Morsa watershed in south-eastern Norway. Lake Vanemfjorden has periodically been one of the most eutrophic lakes in Norway (Bechmann and Øgaard, 2013; Bechmann et al., 2007). Notwithstanding its periodically substandard water quality, it continues to attract a large population of recreational users (Barton et al., 2009). An evaluation of the extent to which the DPSIR-OOBN model meets criteria for "integrated valuation", defined tentatively by Gómez-Baggethun et al. (2014), is conducted. We also discuss the limitations of the integrated valuation model from a systems perspective, and how these limitations may define the role the proposed model plays as a mediator in WFD policy implementation (Morrison and Morgan, 1999). This study is an integral part of the transdisciplinary Eutropia project which aims at understanding processes and pressures governing the P-flux into the eutrophic lake Vansjø, as well as thresholds and barriers in society apposing abatement actions (Orderud and Vogt, 2013).

We begin below with a definition of integrated valuation of ecosystem services as a type of systems analysis, after which we discuss the lake and catchment system boundaries. Next we discuss the modeled system boundaries as defined by different submodel domains. We demonstrate how the submodels are linked together in a driver–pressure–state–impact–response object oriented Bayesian network (DPSIR-OOBN), and we evaluate whether the model meets the definition of integrated valuation. We discuss whether the model boundaries could be extended to capture stakeholder responses to regulation, incentives and the model findings themselves. Finally, we draw conclusions on the applicability of the DPSIR-OOBN model for "integrated valuation."

Integrated Valuation of Ecosystem Services as Systems Analysis

Gómez-Baggethun et al. (2014) propose a tentative operational definition of integrated valuation as "the process of synthesizing relevant sources of knowledge and information to elicit the various ways in which people conceptualize and appraise ecosystem service values, resulting in different valuation frames that are the basis for informed deliberation, agreement and decision". They argue that measuring multiple values, which are simply assessed independently to inform environmental decisions, without a consistent and coherent evaluation, is *hybrid* valuation. The distinction between *integrated* and *hybrid* valuation contrasts a systems approach evaluating causal relationships between components of social-ecological systems, with an approach that merely combines components that have been assessed independently.

Gómez-Baggethun et al. (2014) offer four tentative criteria to evaluate whether a method can be defined as a fully *integrated* valuation approach, versus a *hybrid* valuation approach. They start by underlining the importance of specifying the decision context of valuation, although this is not seen as part of the definition of integrated valuation. In the discussion of "ecological value" they point out that value is not merely a biophysical indicator, but needs to be a measure of subjective "importance". It is crucial that this value scaling is consistent. Furthermore, they stress the importance of explicitly addressing conflicting interests and value trade-offs in decision-making as an important feature of integrated valuation. These four tentative criteria are in this study developed into nine criteria for assessing the integrated valuation of the DPSIR-OOBN.

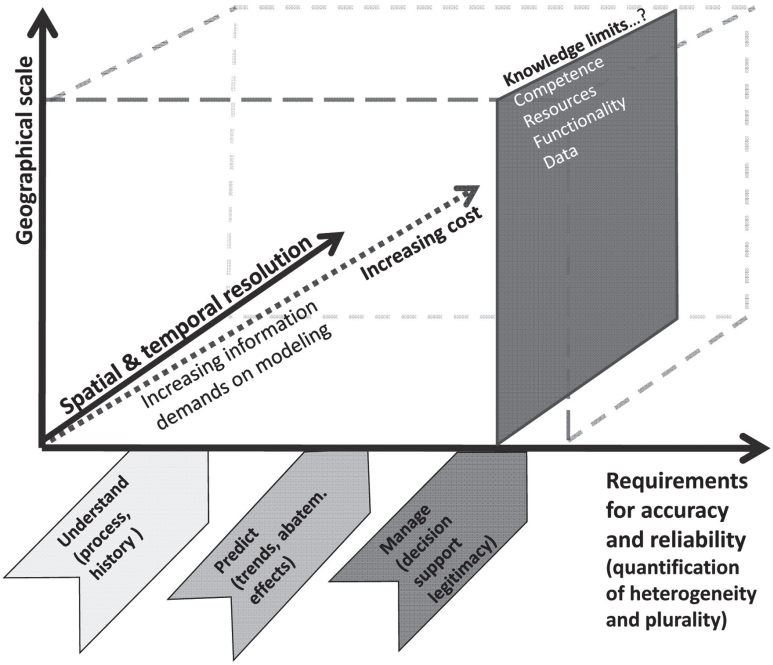

Figure 14.1 Integrated modeling can be carried out to understand or predict ecosystem function. Our definition of integrated valuation requires management decisions. Information costs of describing spatial and temporal heterogeneity of the natural system to be managed, combined with limits to knowledge may call into question the legitimacy of using integrated valuation models to inform policy.

Criterion 1. Management relevance. The ability to discern between decision alternatives and thus provide support for decisions about policy is our first criteria for integrated valuation. Integrated valuation goes beyond understanding or predicting a system, to discerning between alternative courses of management action based on the "importance" of their consequences for people. It faces information costs and knowledge limits. If the feasible accuracy and reliability of integrated valuation models is insufficient to discern between management actions, its legitimacy as a decision-support tool may be called into question (Figure 14.1).

Criterion 2. Value plurality. Integrated valuation should address ecological, social and economic value dimensions held by stakeholders. Integrated valuation thus identifies conflicts of interest across these different value dimensions.

Criterion 3. Value heterogeneity. Values vary across the time and location of decision contexts, and the location and time at which people are asked to express those values. Integrated valuation should attempt to describe systemic features of this heterogeneity by using a consistent modelling approach to describe temporal and spatial heterogeneity – or uncertainty – across submodels of the system.

Criterion 4: Interdisciplinarity. Integrated valuation should be based on contributions from several disciplines, including multiple expert domains from both social and natural sciences. Interdisciplinarity, transdisciplinarity (adding policy-makers and stakeholders), and methodological pluralism are thus key elements in integrated ecosystem services valuation.

Criterion 5: Knowledge systems. Integrated valuation of ecosystem services should be informed by different knowledge systems – i.e. the agents, practices, and institutions that organize the production, transfer and use of knowledge.

Criterion 6: Information types. Integrated ecosystem services valuation should be capable of dealing with both qualitative and quantitative information. Qualitative information includes what is generated in deliberative processes with locally defined metrics, description, public discourse and narration. A key feature is the consistent treatment of uncertainty across different information types.

Criterion 7: Levels of societal organization. Integrated valuation should cover values emerging at different scales of societal organization, from individuals, to communities, to nations. Individuals have different roles in these different contexts, mobilizing different rationalities and value systems (consumer, citizen, tax payer, voter, household representative, community resident, association member, public utility user, survey panel participant and so on).

Criterion 8. Consistent scaling of plural values. Any integrated valuation of importance for specific human interests requires individual scaling of changes in states of nature. Scaling is also an explicit step in multi-attribute utility theory used in multi-criteria decision analysis (MCDA). In terms of the ecosystem service cascade model, scaling is the equivalent of the transformation from ecosystem structure/state to ecosystem service. The identification of ecosystem services requires some form of importance scaling; they are *specific to the action context of a subject.* Value scaling therefore requires knowledge of ecosystem function connecting a decision to a service outcome. In that sense any scaling from an objective measure of a state of nature to a subjective measure of importance involves some form of (mathematical) integration across ecosystem function.

Criterion 9: Consistent comparison of plural values in decisions. Integrated valuation should inform and support decision-making processes on the basis of a consistent weighting of the relative importance of multiple types of value, explicitly addressing trade-offs between, e.g., ecological, cultural and monetary values. In MCDA terminology, this criterion requires explicit weighting of criteria and/or ranking of decision alternatives across different interests (depending on the MCDA method).

Study Area System Boundaries

This section provides a wide but brief description of the study area in terms of “study area system boundaries”. The “model system boundaries” of the Bayesian belief network are presented and used to analyze eutrophication abatement measures. Our aim is to encourage the reader to consider how the model boundaries sets a limit to what can be concluded regarding the eutrophication in the study area, and what limitations this also places on the understanding of our model as integrated valuation.

Study Area Extent

The study area is the Vanemfjorden Lake – also called western Vansjø – and its local watershed with a total area of 71.5 km^2 excluding the area of water bodies (Figure 14.2). This is a part of the larger Morsa catchment – also known as Vansjø-Hobøl basin with an area of 688 km^2 – situated near Oslo in the south-eastern part of Norway (59°26′N, 10°41′E). The entire Vansjø Lake covers 36 km^2 and consists of several smaller basins separated from each other by narrow straits and shallow thresholds. The lake is divided into two main parts: one eastern part

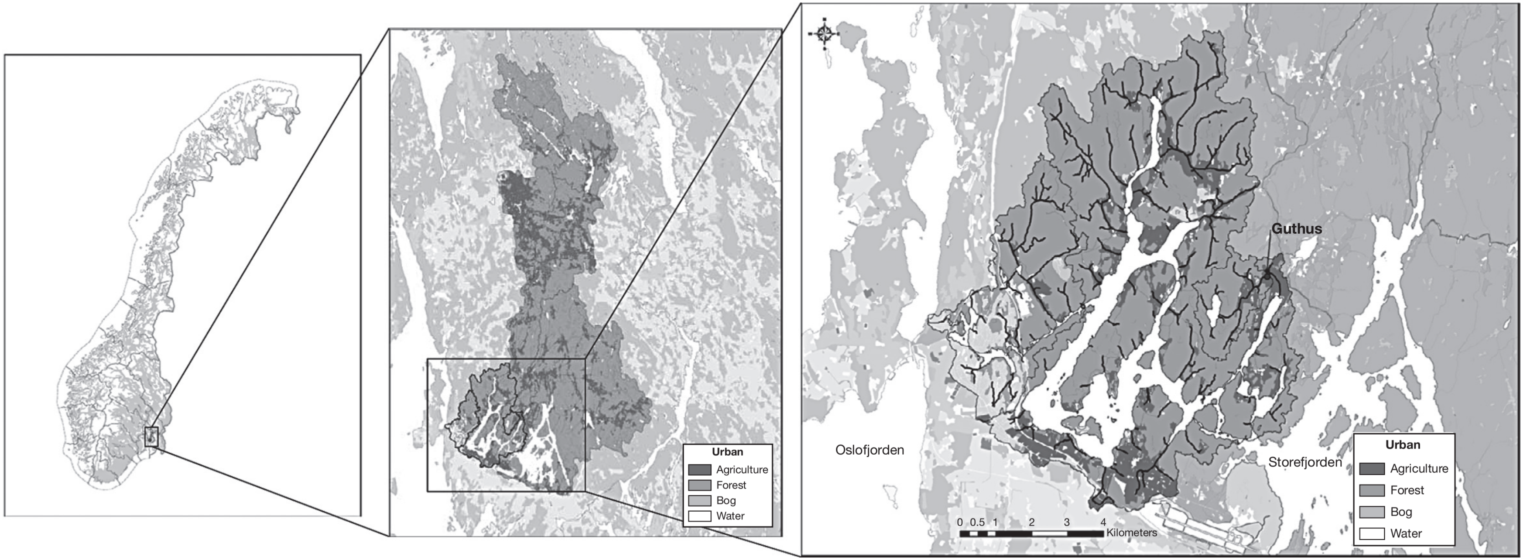

Figure 14.2 The study area of the Eutropia project lies within the Morsa catchment area, Østfold County, Norway. Integrated analysis of nutrient run-off abatement, lake eutrophication and societal response focused on the Vanemfjorden subcatchment shown in the inlay.

(Storefjorden), with an area of 24 km^2, which drains into a shallow western part (Vanemfjorden), with an area of 12 km^2. Modeling focus has been on the drainage area of Vanemfjorden, which faces the greatest eutrophication problems due to large contribution of nutrients from the local watershed.

Water Bodies

The bathymetry of Vanemfjorden is shallow (mean depth 5 m), yet it drains a large area. Consequently, water residence time is only 41 days. A negative aspect of this shallow water in terms of eutrophication is that it allows the water profile to easily mix to the bottom during the summer time, limiting the function of a nutrient sink by sedimentation. This is in stark contrast to the upstream, larger, and deeper Storefjorden lake basin, which removes most of the runoff nutrients via sedimentation, before water flows into Vanemfjorden. A positive aspect from eutrophication point of view is that water contribution from Storefjorden effectively works as a fast diluting medium for Vanemfjorden's local runoff, without which Vanemfjorden would be even more eutrophic. Long-term monitoring data for water quality in these basins exists during the ice-free seasons. Other details about the lake have been published elsewhere (Andersen and Færøvig, 2008; Saloranta, 2006; Skarbøvik et al., 2013).

Land Use

For the total Morsa catchment, 13% of the area is agricultural land, 62% is forest, 9% urban and 16% consists of lake and water (Figure 14.2). The land use distribution in the modeled Vanemfjorden subcatchment is practically the same (14% agriculture, 61% forest, 10% urban and 15% lake and water). Mostly grains and some grasslands cover 90% of the agricultural area. The northern agricultural areas in the Vanemfjorden catchment, predominantly comprising clay loam soils, are today mainly used for cereal production, whereas a narrow southern stretch consisting of sandy end-moraine has a dominance of potato and vegetable production. Animal husbandry is limited in the catchment (Bechmann and Øgaard, 2010, 2013).

There is some variation in farmers' economic characteristics within the Vanemfjorden subcatchment in terms of the type of production and the importance of farm income for households' overall well-being. These two aspects are connected in the sense that farms with more labour-intensive production, like vegetables and potatoes, also have a higher share of household income from agriculture. Off-farm employment opportunities are good in the area, implying that a large share of the farms employ less labour-intensive production that only provide a small share of household incomes. This variation has important implications for farmer responses – and presumably for attitudes – towards policies to improve the water quality, particularly because the high-income production coincides with high nutrient runoffs.

Today's farmers in the Morsa region generally have good agronomical skills, both acquired through formal education, a system of disseminating practical oriented knowledge, exchange of experiences, and ultimately learning from good farming practices (Orderud and Vogt, 2013). Most of these farmers also followed in the footsteps of their parents and are socialised into becoming a farmer and running the farm owned by the family for generations. As such, farmers might be considered conservative, but this conservatism might run counter to a political Conservatism dominated by market economics. Among the farmers there are some who are considered as models for others and running "model farms" whereas others do not perform as well. Part-time farmers are more prone to slip into the less competent category of farmers, and at the end of the day quit farming, but still live on the farm while renting out the land to other farmers.

Recreational Water Use

Vanemfjorden has experienced nuisance cyanobacteria blooms over recent decades. This has been perceived as a considerable problem by the population and municipal governments around Vansjø lakes because of significant ecosystem services provided by the lake and its surroundings (e.g., drinking-water supply, bathing, fishing, and other recreation activities, as well as an important habitat for flora and fauna) (Barton et al., 2009; Söderberg and Barton, 2013). The whole Morsa catchment draining to Vanemfjorden comprises 11 municipalities. An estimated population of approximately 40,000 households were living within the catchment in 2009. Surveys have shown that households express positive willingness to pay for nutrient abatement measures around the Storefjorden and Vanemfjorden lakes well beyond the border of municipalities intersecting the Morsa catchment (Söderberg and Barton, 2013). The largest town called Moss draws its main drinking-water supply from the Storefjorden lake. Thanks to quartiary treatment processes the plant provides some of the cleanest drinking water in the country, regardless of the quality of the raw water supplied from Vanemfjorden. About 20% of the population goes fishing and use motorized boating on about half of their trips to water bodies in the area. Almost 60% of the population goes swimming on more than half of their trips to water bodies. About 75% of the population practices some form of waterside activity on more than half their trips (walking, biking, jogging) (Barton et al., 2009).

Catchment Managers and Management Institutions

An array of management institutions define water management policies, directly or indirectly, from the local administrative level to the national level and beyond (Naustdalslid, 2014). At the local level, this can best be illustrated with those institutions represented on the board of the the Morsa Water Sub-District: the inner layer, with voting rights, is made up of mayors from the 11 municipalities; the medium layer consists of the State County Governors of the two counties Østfold and Oslo/Akershus, the two counties of Østfold and Akershus, the Norwegian Water Resources and Energy Directorate, and the Norwegian Food Safety Authority; and the outer layer (observers) comprising Oslo municipality, the Farmers' Associations in the two counties of Østfold and Akershus; the Association of Nature and Recreational Activities, the water treatment plant Movar, the Vansjø Association of Property Owners, and Moss User Rights Association. Under this structure there are two thematic groups: one on agriculture and one on sewage, both exclusively staffed by municipal officers.

The two main mitigation measures have targeted (1) diffuse runoff from farming and (2) point source sewage from dispersed settlements. Beyond general policies of establishing and enhancing public sewage system networks, farming measures were initially given the highest priority, but increasing focus has later been placed on sewage measures in dispersed settlements, with rural farmer residences facing most measures. Policies and measures are designed and implemented by departments under the Ministry of Environment, the Ministry of Agriculture and Food, and corresponding departments under the State County Governor, and lastly also at the municipal level by the agricultural offices and the water and sewage offices. Local level degrees of policy freedom are fewer than higher up in the hierarchy, but at the local level they might decide on such things as whether to connect dispersed settlements to the sewage system or demand local biological treatment. In this administrative hierarchy, the relevance and usefulness of system analyses is expected to increase the higher up one is in the policy hierarchy.

Eutrophication Management Challenges

In the Morsa catchment, and Vanemfjorden subcatchment in particular, efforts to improve lake water quality have been carried out since year 2000, but the initial mitigation efforts did not improve conditions. As a result of this, an action plan for further reducing P loads was implemented in 2007. This plan was implemented through a close collaboration between local authorities, agricultural advisors, farmers and researchers (Bechmann and Øgaard, 2013). Forty farmers in the catchment have been involved in fulfilling the action plan through contracts committing them to implement best management practices aimed at minimizing diffuse P loading from their agricultural fields. The Ministry of Food and Agriculture in Norway subsidize the farmers who participated in the project, covering expenses due to extra costs and possible loss of income, although not representing any full compensation of income losses. The farmers who signed the contract were committed to:

- Reduce P fertilizing beyond the recommended national level.
- Refrain from plowing in the autumn.
- Refrain from growing vegetable crops on fields that are at risk of being flooded.[1]
- Establish vegetative filter strips along streams.
- Plant grassed waterways in areas of high erosion risk due to surface runoff.
- Build constructed wetlands in streams draining their farmland.

The extent to which the effectiveness and benefits of such measures across the whole catchment of Vanemfjord Lake can be valued using an integrated model is a key part of the Eutropia project.

System Boundaries of the Integrated Valuation Model

We set up a system or "meta-model" spanning different temporal and spatial resolutions of submodels of the driver–pressure–state–impact–response (DPSIR) of eutrophication in the Vanemfjorden (Figure 14.3). Our systems modelling approach involved linking different models in the DPSIR chain together in an OOBN. The OOBN methodology is discussed in the next section.

A challenge for this system modelling approach lies in the confrontation of stakeholders with the uncertainty of the system described by the different scientific submodels coupled together in the OOBN. As the modelled causal chain is extended, the modelled uncertainty regarding integrated model response is expected to increase, while stakeholder comprehension of effects of abatement measures is expected to decrease (Figure 14.3).

Integrating submodels from different domains faces the challenge of different temporal and spatial resolutions. Temporal and spatial resolution defines the heterogeneity and variance that each submodel can render. For example, management measures are drivers that are implemented on an annual time scale, specific to subcatchments. Their combined effect is aggregated spatially at catchment level by the SWAT model (Arnold et al., 1998) with temporal distribution driven by daily meteorological data. As the SWAT catchment model and the MyLake model (Saloranta and Andersen, 2007) work at the same temporal resolution they can be calibrated simultaneously (see Supplementary Material S3). Based on simulation of the joint SWAT-MyLake models, daily predictions of Tot-P and Algal-P at different lake depths in June–August are summarized as probability distributions of expected lake water quality for the summer recreation season. The suitability for summer recreational use at recreational sites along the lakeshore is interpreted based on water quality provided by the Mylake model. Finally, households are asked to provide

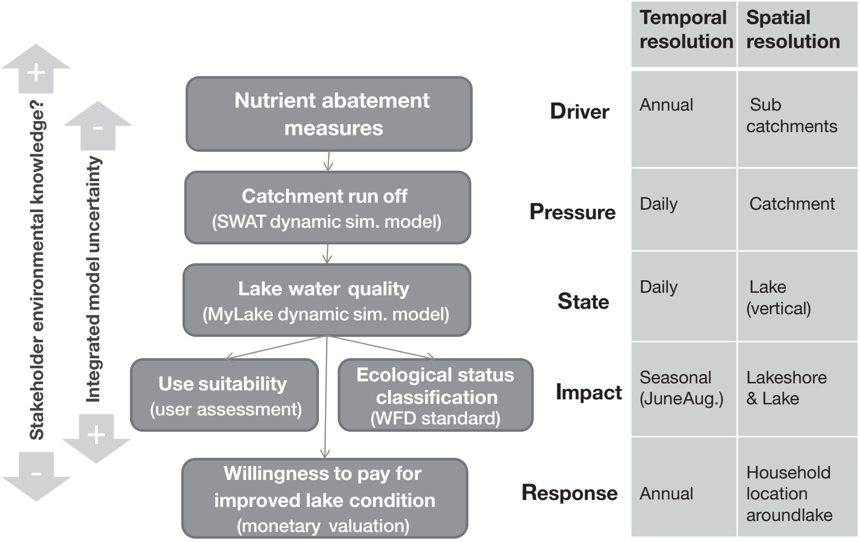

Figure 14.3 Conceptual overview of a systems modelling approach linking a series of model domains along a driver-pressure-state-impact-response causal chain

estimates of willingness-to-pay (WTP) annual sewage fees based on scenarios of summer lake condition across major lakes in the region, including Vanemfjorden. Probability distributions of WTP are generated based on household location round the lake, also extending beyond catchment boundaries. Interfacing heterogeneous temporal and spatial resolutions introduces variance due to different data aggregation procedures at model interfaces, which is additional to the variance in the data themselves. This is one possible explanation for so-called smudging or signal attenuation effects observed in serially integrated cause-effect models (Barton et al., 2008).

Presented below are the constituent submodels for nutrient abatement measures: catchment runoff; lake water quality; classification of ecological status; use suitability and willingness-to-pay for improved lake condition. From here on *italics* are used when referring to *node names* and *node states* in the object oriented Bayesian network (Figure 14.4).

Catchment Runoff Model

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) is a semi-distributed watershed-scale model based on physical processes that runs in continuous time, on a daily time step. Watershed heterogeneities are represented by dividing the catchment into smaller sub-basins that are spatially connected. Each sub-basin is further apportioned into hydrologic response units or HRUs. HRUs are lumped land areas comprising unique land-use, soil type and management practice combinations. Effects of management practices on hydrological processes, nutrient cycles, erosion processes and crop growth are quantified for each HRU and aggregated for each sub-basin. Water movement through the watershed (infiltration, redistribution, surface runoff, lateral subsurface flow and base flow) is modeled after deducting evapotranspiration (ET), potential ET and canopy storage (water intercepted by vegetative surfaces). Nutrient abatement measures included: (1) reduced fertilization; (2) changed plowing practices; (3) constructed wetlands; (4) vegetation buffers; and (5) reduction of point sources from dispersed settlements (septic and farm sludge tanks). Expert judgment was used to organize these measures into alternative scenarios or programs of measures which described the historical, current, and hypothetical future extreme management regimes.

Lake Water Quality Model

Among many lake ecosystem models (Mooij et al., 2010), the MyLake model (Saloranta and Andersen, 2007) was chosen due to researchers' familiarity with the model, and its documented applications to phenomena describing central mechanisms of eutrophication in Vanemfjorden. MyLake is a one-dimensional model code for the simulation of the daily vertical distribution of lake water temperature and thus density stratification, the evolution of seasonal lake ice and snow cover, and most importantly the sediment–water interactions, and phosphorus–phytoplankton dynamics. The basic idea behind MyLake has been to include only the significant physical, chemical and biological processes in a well-balanced and robust way.

Because of the unidirectional flow of water from the catchment to the lake, catchment loading simulated by SWAT is used as an important part of the input to MyLake. Thus, the downstream model MyLake depends on non-uniquely identified input before calibration is conducted. This problem was circumvented by calibrating *SWAT* and *MyLake* sequentially using monitoring data from streams and lake basins. Conditional probability tables (CPTs) for the key model interface variables were produced by running MyLake repeatedly with different parameter and input factor values from SWAT in a Monte Carlo Markov chain calibration. The resulting subnetwork and further documentation on the joint calibration of SWAT-MyLake can be found in Supplementary Material S3.

Ecological Status Classification Model

The European Union's Water Framework Directive (WFD) mandates "good ecological status" as an environmental objective for all water bodies in Member States. Norway adhered to this standard voluntarily. In the present study a classification model, developed by Moe et al. (2014), was adapted to also describe classification uncertainty. Lake ecological status is classified as "poor", "moderate", "good" or "very good" according to the classification standards for Tot-P and Algal-P defined for lakes in the marine zone. A regulatory definition of (un)acceptable chemical and biological indicator levels from a societal point of view can be interpreted as an importance scoring of lake status, i.e. as an "ecological valuation" as defined by Gómez-Baggethun et al. (2014). In MCDA terminology, this is valuation interpreted as scaling a single criterion, but without weighting relative to other criteria. The resulting subnetwork for ecological status classification is explained further in Supplementary Material S4.

Use Suitability Model

A household web-based survey conducted in 2008 presented questions about lake recreational habits and perceptions (Barton et al., 2009). The survey asked for water users' perceptions of the lake's suitability for different water uses at different eutrophication levels, using a series of illustrations of the lakeshore. A challenge in the integrated valuation was determining the water quality parameters of Algal-P and Tot-P that corresponded to the illustration of the water quality scenarios presented in the survey. This was solved by consulting three independent limnologists familiar with the Vansjø lakes, and asking each of them to evaluate the four ecological status illustrations in terms of ranges of Algal-P and Tot-P with 95% confidence. A combination of the three judgments was used for the Bayesian network, giving each expert equal weight. The lake condition illustrations and subnetwork generated by experts are explained further in Supplementary Material S5.

Willingness to Pay Model

The web-based household survey also mapped the respondents' willingness-to-pay increased water and sewage fees to finance nutrient abatement measures in the catchment. The survey conducted monetary valuation using the contingent valuation and choice experiment methods (Barton et al., 2009; Söderberg and Barton, 2013). The results from the choice experiment valuation were used in the DPSIR-OOBN model. The choice experiment asked households to compare and choose between pairwise scenarios of ecological status of Vanemfjorden and other major lakes in the region. The ecological status of the lakes was varied using an experimental design combining different lake conditions with different annual sewage fees. An econometric model was used to estimate the willingness-to-pay in Norwegian kroner (NOK) per household per year for incremental improvements in the condition of each lake. The quality of neighboring lakes was also included in order to control for respondents who prefer two or more adjacent lakes, so-called substitution effects. The choice experiment scenario maps of lake water quality and the subnetwork for household willingness-to-pay is explained further in Supplementary Material S6.

Integrated Valuation Using an Object Oriented Bayesian Network (OOBN)

Causal networks, conditional probability distributions and Bayesian statistics constitute a consistent framework for evaluating spatial and temporal variance across linked submodels (Barton et al., 2008). The Bayesian Belief Network (BBN) methodology is used to study how integrated model uncertainty increases in this causal chain due to heterogeneity in the respective sub-models. There is a substantial literature on the use of BBNs to integrate knowledge domains in environmental and resource management (Barton et al., 2012; Cain, 2001; Darwiche, 2009; Henriksen et al., 2011; Jensen and Nielsen, 2007; Kuikka et al., 1999; Marcot et al., 2006; McCann et al., 2006; Nyberg et al., 2006; Uusitalo, 2007; Varis and Kuikka, 1999). BBNs are models that graphically and probabilistically represent relationships among variables. They can be used diagnostically to study the probability of outcomes given specific causes, reasoning "top-down" through the causal chain of drivers-pressures-states-impacts- responses (DPSIR). BBNs also facilitate using Bayes' theorem for inductive or "bottom-up" reasoning in the causal chain, to determine the likelihood of different valuation outcomes given knowledge about the states of the lake, the management and context variables (Barton et al., 2012). Figure 14.4 describes the modelled system as it is represented in the Bayesian belief network software Hugin Expert.

In Figure 14.4 the network "nodes" (ovals) represent conditional probability tables, with conditional relationships represented by edges (arrows). Individual domain models are represented as subnetworks (white rectangles). Subnetworks contain a number of model variables which are nested in an OOBN in order to reduce the complexity of the visual representation of the model chain. The lake eutrophication system is represented by a cascade of driver–pressure–state–impact–response models in the object-oriented Bayesian network, hence the abbreviation "DPSIR-OOBN".

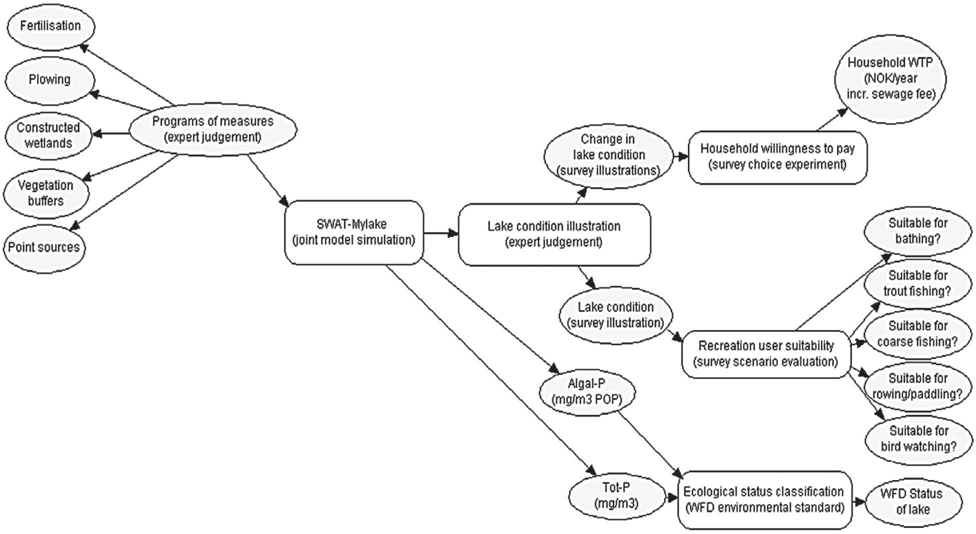

Figure 14.4 DPSIR model chain of nutrient abatement measures and their impacts modelled in an object oriented Bayesian network (OOBN) as represented in Hugin Expert software's graphical user interface

Five types of farm and point source nutrient abatement measures make up alternative "*programs of measures*" in the DPSIR-OOBN. In Figure 14.4 the representation of the SWAT and MyLake calibrated models is condensed into a single node, visualising only two key variables from the simulation (Algal-P and Tot-P). The expert judgment of the link between lake parameters and visual representation of lake condition is complex and it has been condensed here, showing only the outcome of expert judgment on the change in lake condition. Three different valuation methods are identified in the network: (1) Change in lake condition relative to the current condition determines *household willingness-to-pay*, which is a multivariate model that has been visually condensed into a single outcome variable. (2) *Recreational user suitability* is conditional on visual representation of lake condition. Suitability is disaggregated for different types of water users. (3) *Ecological status classification* is directly conditional on Algal-P and Tot-P concentration predicted by SWAT-MyLake.

The OOBN uses a "utility node" in the willingness-to-pay subnetwork to enable evaluation of any node state in the DPSIR model chain in terms of its marginal monetary importance for households. This is explained further in Supplementary Material S6. Because large non-linear integrals cannot be solved analytically, Monte Carlo simulation and Bayes' rule are used across multiple conditional probability tables in the network to assess how values "downstream" in the DPSIR causal chain *scale* to different biophysical states "upstream".

Results and Discussion

Figure 14.5 shows how the Hugin Expert software is used to calculate expected utilities of all nodes and states in the network. Using utility nodes it is technically possible to integrate any chosen "importance score" or value dimension across the whole network. However, in this section the main focus will be on whether the DPSIR-OOBN for Vanemfjorden catchments passes our proposed set of criteria for defining integrated valuation.

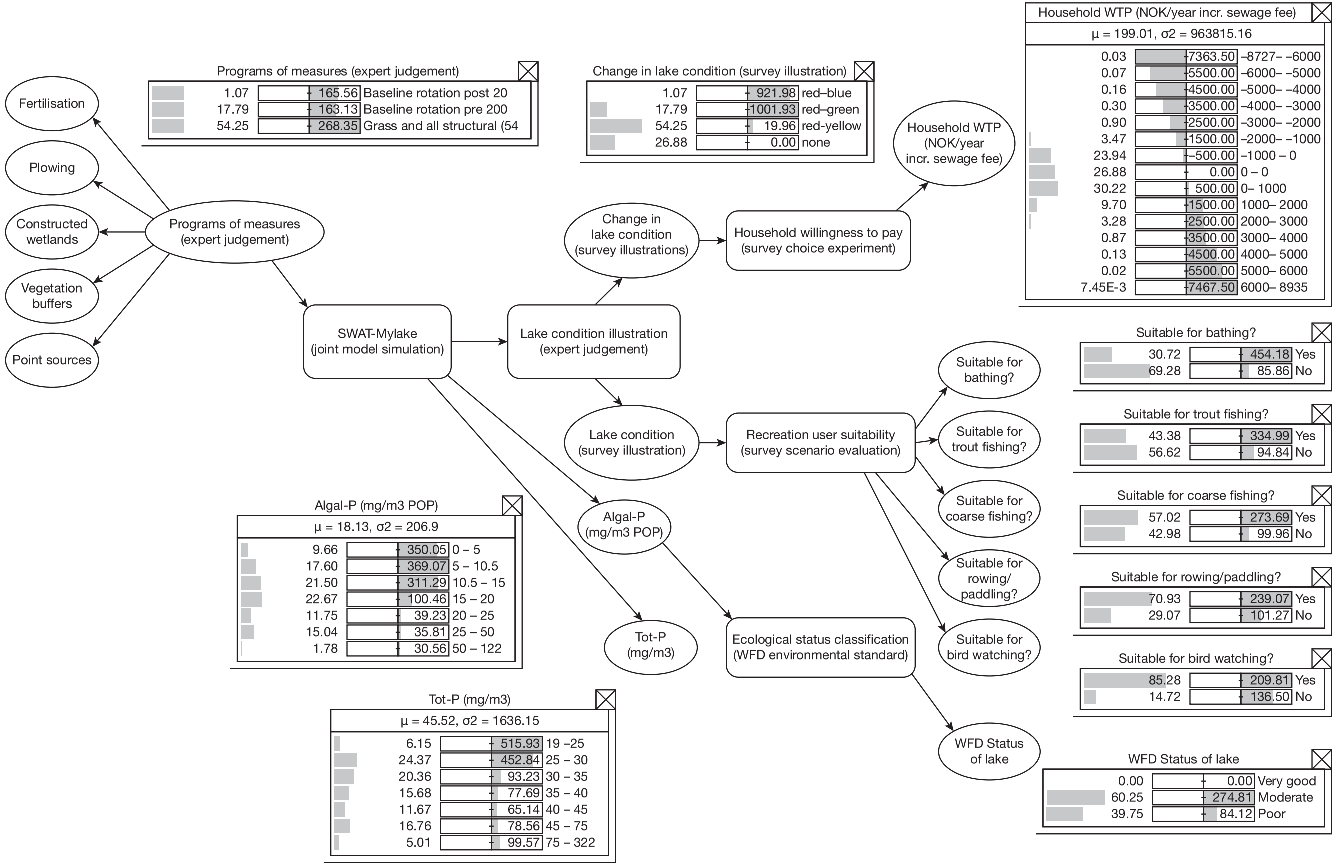

Figure 14.5 Bayesian belief network showing the probability distribution of selected variables (gray columns and number of left-hand side of the node monitors). Node resolution is shown on the right-hand side of the monitors. The gray bars in the middle of the node monitors show the expected WTP of each node state, based on integration (scaling) across the causal chain from the household WTP node (upper left hand of network). For example, the expected WTP of "Grass and all structural" abatement measures in the "programs of measures" (upper left hand of the network) is computed as 268.35 NOK/year per household.

Management Relevance

The network does not qualify fully as integrated valuation by Criterion 1, listed on page 300, because it does not specify (1) the monetary costs of measures, nor (2) the geographical and social distribution of costs and benefits across different upstream and downstream stakeholder interests. While the DPSIR-OOBN is not a full benefit-cost analysis tool with distributional impacts it can still be used to discuss management alternatives and whether model predictions are sufficiently accurate and constitute a reliable basis for action. The DPSIR-OOBN can be used for reasoning deductively about the expected benefits in and around the lake of the alternative programs of measures in the catchment. For example, converting the whole catchment to grass and implementing all nutrient abatement structures computes to an expected willingness-to-pay of 268 NOK/year per household, while baseline crop rotations post or pre 2007 only have an expected willingness-to-pay of 163 or 166 NOK/year, respectively. Apparently, only the radical land use conversion measure has a discernable effect in terms of household willingness-to-pay. Even without knowing monetary management costs, this integrated valuation also gives the impression that the predicted benefits across the other value dimensions – ecological status and recreational suitability – are relatively small compared to the physical magnitude of the abatement measures. The DPSIR-OOBN can also be used to reason inductively, or in diagnostic mode. For example, one may ask "if our management target is lake water that is 100% suitable for bathing (the most quality demanding recreational use), what is the likelihood that any of the programs of measures on the table can attain this?" The integrated valuation shows that with conversion to grass and all structural abatement measures, it is only about 6.5% more likely to achieve this than the baseline crop rotations post-2007. See Supplementary Material S7 for further explanation.

Value Plurality

The DPSIR-OOBN is an integrated valuation method with regard to Criterion 2 because it involves several different measures of the importance of lake condition. The DPSIR-OOBN explicitly handles ecological values in the node "ecological status classification", defining a regulatory threshold for good versus moderate status. Monetary values are defined in terms of household WTP for improved ecological status. Finally, it could be argued that social values are also represented in the network through the evaluation of suitability for different recreational uses.

Value Heterogeneity

The DPSIR-OOBN adheres to Criterion 3 by addressing uncertainty consistently across submodels, using conditional probability tables and Bayes' Theorem to reason across the network of beliefs. Temporal and spatial heterogeneity of runoff and lake phenomena are captured at the resolution and scale considered most appropriate to represent the different ecological, economic, social phenomena. While the difference in temporal and spatial resolutions and scales is not technically consistent, the use of conditional probability tables for defining the interfaces between submodels is consistent. The resolution of the interface nodes (i.e. how finely continuous variables are disaggregated into intervals) was not determined by a consistent statistical rule, instead it depended on modelers' judgments. Independent of the chosen resolution method, some information reflecting heterogeneity is lost at each interface, reducing the sensitivity of ecological, economic and social value responses to different programs of measures in the model.

Interdisciplinarity

The DPSIR-OOBN qualifies as an integrated valuation method based on Criterion 4 because it involved interdisciplinary research. Expert domains spanned agronomy, chemistry, hydrology, limnology, human geography, environmental economics and systems modeling. Interdisciplinarity was required in (1) the joint specification of the driver–pressure–state–impact–responses causal network; (2) specification of interfaces between submodels in the network in terms of the ranges and resolution of variables along the DPSIR chain (specification of conditional probability tables in the network). Finally (3), simultaneous calibration was carried out with two dynamic models, where the lake eutrophication model MyLake was calibrated across all predicted states of the runoff model SWAT.

Knowledge Systems

The DPSIR-OOBN is also an integrated valuation in terms of combining different knowledge systems adhering to Criterion 5. In the terminology of Bayesian belief networks, all the different knowledge systems are called beliefs, whether coded models or expert opinion. Beliefs are specified as a causal network structure and consistently described using conditional probability distributions. Scientific knowledge was used in specifying (1) the alternative eutrophication management decisions, (2) defining the system boundaries in terms of eutrophication and (3) specifying the causal network as a driver–pressure–state–impact–response system. At the level of system drivers both scientific and lay knowledge held by local practitioners was used to point out the relevant management measures to be analysed. The DPSIR-OOBN uses scientific knowledge in terms of the rules/code in the dynamic simulation models SWAT and MyLake. Expert scientific opinion of visual lake condition in terms of Tot-P and Algal-P indicators represents another form of scientific knowledge. An online web-based survey is used to collect lay knowledge held by local household representatives in their role as recreational users. The survey asks for an interpretation by recreational uses of the subject specific suitability of different visual lake conditions. A choice experiment in the survey also consults local household representatives in their role as individual consumers of lake recreational amenities.

The DPSIR-OOBN does not include traditional ecological knowledge in the sense held by local indigenous or peasant communities. The dynamic catchment run-off and lake models are in place of any traditional knowledge about algal blooms that might be found in local communities around Vanemfjorden. Notably, local farmer knowledge of the effectiveness of agricultural measures in controlling nutrient run-off is replaced by experimental scientific knowledge as part of the SWAT model.

Information Types

The DPSIR-OOBN is an example of integrated valuation according to Criterion 6 because it deals with both qualitative and quantitative information. Management measures, catchment and lake, hydrology, limnology and biochemistry processes are described as quantitative dynamic simulation models. In the BBN model results are implemented as interval conditional probability tables. Visualization of lake condition (red, yellow, green, blue scenarios) and WFD classification (very good, good, moderate, poor) are implemented as discrete categorical conditional probability tables, while the suitability for use (suitable, not suitable) is binary. Common to all the information types in the network is their specification in terms of conditional probabilities of each state (whether interval, numerical, categorical, binary). While many cultural ecosystem services may not be quantifiable numerically, they can be evaluated in a causal structure if they can be described in terms of states, and if beliefs about the conditional probability of each state can be obtained from someone. In that sense BBNs treat both quantitative and qualitative information as subjective beliefs. The BBN is not designed to deal with textual narration nor discourse, unless arguments can be simplified to a network of causal relationships, described as discrete states with conditional probabilities.

Information is more than just qualitative or quantitative. Using a Bayesian belief network emphasizes that integrated valuation requires explicit treatment of the quality of information. BBNs require specifying information types (numerical, interval, categorical), the resolution (the number of states) and states' conditional probabilities, for each variable. Resolution and probability are needed to describe temporal and spatial heterogeneity of ecosystem services and are key aspects of valuation. Information types, resolution and probabilities also have costs, in terms of collection and processing. Information resolution is known to condition valuation responses. A case in point is the amount of research hours that go into finding the right balance between information resolution and cost in the number attributes and their levels in choice experiment design and multi-criteria analysis.

Finally, Gomez-Baggethun et al. (2014) suggest that integrated valuation should also account for the articulation of social and cultural values in decision-making, generally involving some sort of deliberative process, locally defined metrics, and valuation methods based on qualitative description, public discourse and narration. On this interpretation of integrated valuation, the DPSIR-OOBN does not perform so well. The management problem, the causal structure and choice of valuation metrics (environmental standard, use suitability, willingness-to-pay) were all largely defined by researchers. While focus groups, surveys and a project reference group were consulted at different stages in the research, the network was not developed as a deliberative process with stakeholders. The development of the DPSIR-OOBN spanned several different research projects (Eutropia, Aquamoney, Refesh, Openness) over almost a decade, making a consistent deliberative process with the same stakeholder representatives very difficult in practice.

Levels of Societal Organization

The DPSIR-OOBN is an example of integrated valuation with regards to Criterion 7 in that it considers multiple types of societal organization as sources of values. The willingness-to-pay values are derived from respondents consulted first and foremost in their role as household representatives, consumers of recreational amenities, public sewage utility users, and survey panel participants. Recreational use suitability is derived by respondents consulted both as individual and household representative recreational users.

The DPSIR-OOBN also qualifies as integrated valuation because it uses values from different levels of societal organization. Values at individual and household level are expressed in terms of willingness-to-pay and user suitability. The Water Framework Directive classification of ecological status of Lake Vanemfjorden is based on an environmental standards approved by the European Commission. "Good ecological status" for pilot water bodies by 2015 was adopted by the Norwegian Parliament as a policy objective, and implemented by river basin authorities and local governments.

However, the DPSIR-OOBN makes no claim of completeness regarding accounting for different societal scales, their roles and value systems. The system boundaries were defined with the aim of conducting a benefit–cost analysis of alternative management measures within the catchment boundaries. As stated above, the research design did not involve identification and participation of all affected stakeholders in the catchment in a deliberative process – i.e. a formal consultation process was not conducted as would be required by regulatory environmental impact assessment (EIA).

Consistent Scaling of Plural Values

Are we incurring double counting of values in a DPSIR cascade model? To answer this question one must first evaluate whether values were scaled independently. In the first step, illustrations of lake condition were evaluated by experts in terms of Tot-P and algal-P parameters. Recreational use suitability as interpreted by survey respondents was based on these different lake condition illustrations. The second step was to allow households to choose in an experiment between different visual representations of lake conditions in the region, versus alternative annual sewage fees. Their choice of alternative lake ecological status outcomes is a trade-off against changes in income due to different sewage fees. The choice experiment responses are then used to calculate willingness-to-pay for marginal changes in lake condition.[2] While both "willingness-to-pay" and "use suitability" are based on the same lake condition visualisations, valuation (i.e. the scaling of their importance) is independent. In the third step the WFD thresholds for ecological status (ecological value) are used to determine bad, moderate or good status based directly on water quality parameters predicted by the SWAT-MyLake model. To conclude, the network structure shows that values are scaled independently – i.e. they are not conditionally dependent on one another in the causal links of the network.

Independent scaling of economic, social and ecological values ensures value plurality, but poses problems for the consistency of values once they are all associated to specific management alternatives – i.e. to the decision context. As discussed in the methodology section, the DPSIR-OBBN is a systems approach to valuation where the expected WTP per household can be identified for all predicted states of abatement measures (driver), nutrient loading (pressure), nutrient concentration, use suitability and ecological status (state).

Below we illustrate how this value integration capability of the DPSIR-OOBN can be used to study consistency of the three different measures of the value of eutrophication abatement. We base the discussion on Figure 14.5. Turning first to the WFD standard for good ecological status as a non-monetary measure of value; the expected utility of achieving "moderate " in WFD status of lake is 275 NOK/year per household. Achieving the current "poor" ecological status calculates to an expected utility of 84 NOK/year per household. This is the result of inconsistency between (1) the experts' judgment of how well visual lake scenarios used to find WTP in the survey translate to biophysical water quality parameters, and (2) the WFD definition of ecological status relative to those same parameters.

Turning next to recreational suitability as a non-monetary measure of value: *Suitable for bathing* shows an expected WTP of 454 NOK/year per household for "yes", but also 86 NOK/year per household for "not" suitable. In fact, all nodes for suitability show a positive expected WTP for "no". This is due to a combined mismatch between (1) experts' judgment of the water quality parameters relative to the lake condition illustration in the survey, and (2) users judgement of suitability based on the same illustrations, relative to the WFD definition of ecological status.[3] In summary, inconsistent scaling is a technical way of saying that there are differences in the subjective importance of different decision criteria. The use of DPSIR-OOBN shows that consistent scaling, adhering to Criterion 8, cannot be expected, even when different criteria are made commensurate, as we have done using expected utility calculations in a Bayesian belief network.

Consistent Trade-offs Between Plural Values in Decisions

The DPSIR-OOBN specifies different types of management measures that can be implemented in the catchment in order to control nutrient input to Vanemfjorden and it addresses different decision alternatives. The network can thus be used to assess the expected willingness-to-pay per household in the catchment, suitability for different users or WFD compliance of different combinations of individual measures. The relative utility of different programs of measures can be compared as input to a decision.

Valuation methods used in the network are expected to be internally consistent, complying partly with Criterion 9. However, the DPSIR-OOBN makes no claim of consistency across value systems. As is noted above, the willingness-to-pay is not completely consistent with the WFD classification in that the combinations of beliefs in the network assign positive willingness to pay to the status quo "poor ecological status". Furthermore, respondents to the survey were encouraged to use individual consumer rationality, but the framing of the survey setting is likely to have triggered several roles at once in the respondent. It is unclear how each role affects a particular valuation metric. While respondents can be encouraged to be aware of and explain different roles using careful survey work, it seems difficult to isolate the effect of particular roles and their value systems.

In this section it is shown that it is possible to compute expected utilities of any state of the network. We have also demonstrated how to technically conduct an integrated valuation. However, the DPSIR-OOBN makes no claim to consistently integrating the values generated by different value systems, for example by explicitly weighting their relative importance. In contrast, in a multi-criteria analysis based on multi-attribute utility theory, the final step of calculating a unique utility measure across different decision alternatives would require explicit weighting of all criteria relative to one another.

Extending Systems Boundaries

Valuation, even when integrated, must have model system boundaries. Would extension of these systems boundaries for the DPSIR-OOBN for Vanemfjorden catchment better address management issues?

Farmer Response

The DPSIR-OOBN does not account for stakeholder motivations to implement land use changes and structural abatement measures. Measures are assumed to be implemented 100% within the SWAT catchment model, without any delay, lacking effectiveness or transaction costs. Farmer response could be modelled in terms of farms being profit maximising units and responding imperfectly to increased constraints on inputs.[4] However, farmer motivations and reactions extend beyond reaction to incentives or coercion. The stakeholder narratives in the following are not easily coded in a Bayesian network. Interviews with farmers revealed the basic motivations guiding the actions of today's generations of farmers (Orderud and Vogt, 2013):

1. Farmers are socialized into farming without prospects of earning a lot of money. They cultivate a family dimension of fostering an attachment to the farm, and a stewardship mentality of handing over a good farm to the next generation.
2. They have a production mentality aiming for high output and high quality by combining agronomical competence and good knowledge about their fields (soil structure, drainage,

etc.). They work with the agricultural extension service, disseminating knowledge that is trusted by farmers. However, understanding of dynamic natural processes of the catchment is relatively weak.

3. All other things equal, farmers will go for options providing higher income. Moreover, when taking actions, whether mandatory or not, they will prefer to use their own labour rather than pay money out of their wallet.
4. The internal interaction and status hierarchy among farmers is based on recognition of being good at farming. What the respected farmers do influences what other farmers are doing regarding production techniques, use of fertilizers, tillage, etc.
5. The interaction between farmers and local communities, as well as the wider society, shapes common norms. For example, farmers living around the Lake Vansjø and Moss consider it morally wrong to be the cause of inferior water quality.
6. The Norwegian governance structure, with policy-makers, public agencies, and farmers' organizations create a wide range of public regulations surrounding farming, making public policies a frame for what is considered acceptable farming.

On the basis of the above, we can draw the following conclusions regarding farmers' motives and the probability of actions as part of the Bayesian network analysis:

1. The farmers appear to be economic satisfiers within a bounded rationality approach displaying satisificing behaviour (Simon, 1982). They take into account a wide range of issues and concerns. For instance, they might pursue a high output without trying to maximize economic return.
2. The farmers show a high degree of compliance with agricultural policies because they have become accustomed to being part of public policies and receiving part of their income from the government. Potentially, this makes farmers internalize a societal responsibility of complying with environmental regulations, also when this might incur additional costs not automatically (fully) compensated for.
3. Most farmers possess good agronomical competence, being critical to farming techniques that run counter to what they consider "best practice", but making changes based on evidence. However, abatement measures running counter to farmers' own experiences are difficult to implement in a successful manner. Moreover, seeing that actions have an impact is part of motivation.
4. The farmers want to be an active partner in the decision-making process of designing and implementing policies at the local level due to their good agronomical competence and a generally high educational level. When farmers feel left out, they are more likely to be discontent. In turn that may have adverse impacts on willingness to take environmental-related actions beyond the required minimum.

Integrated Model Communication

How can scientific knowledge gained from the DPSIR-OOBN systems model strengthen or weaken existing stakeholder opinion regarding conflictive nutrient abatement measures? The impact on stakeholder knowledge depends on how that knowledge is communicated. An integrated monetary valuation of predicted abatement measures effectively changes the mode of communication with stakeholders. From the above narratives by farmers, we can draw the conclusion that reasonable and well-grounded policies and measure have a high likelihood of being accepted and implemented by farmers. For the farmers, trials and testing locally are crucial, but before that stage, system analyses very often will have played a role in identifying potential improvements. On the other hand, measures running counter to what is considered best practice of farming will meet resistance, often regardless of being accompanied by economic incentives or not. They will have low likelihood of being implemented and accepted. In Morsa, accepting mineral fertilizers with a lower phosphorus content is an example of a change that was accepted because "model" farmers tried it and it was proven to work on-farm. On the other hand, changing of tilling practice in areas not prone to erosion has been met with farmer resistance, causing discontent and reduced willingness to participate. The lack of significant improvements in observed water quality has also caused discontent among farmers, reducing the likelihood of accepting policies and measures (Orderud and Vogt, 2013). This is not to say that farmers deny that any improvements in the lake have taken place following the serious flooding in year 2000 and subsequent cyanobacteria blooms. However, farmers did not see that the water quality improvements had met expectations. Farmers have also understood that lake improvements cannot unequivocally be linked to the measures taken on-farm.

Opposing narratives about the effectiveness of measures live side by side. While on-farm monitoring shows that land use change, fertilizer reduction and structural measures are effective "at field's edge", the runoff and lake dynamic models have individually shown limited responses "at lake's edge" to the combined effect of farm measures. Limitations to the understanding of nutrient run-off from the large forested areas in the catchment are still substantial (Desta, 2013; Lukawska-Matuszewska et al., 2013) (see Supplementary Material S1). Lacking effectiveness of abatement measures in the DPSIR-OOBN is a combination of the heterogeneity in catchment system exceeding the signal from human intervention (variance), information loss at submodel boundaries (error), and still unexplained ecosystem function (uncertainty). See Supplementary Material S7 for further details on model power. The integrated valuation model may compound the impression farmers have already gained from previous interaction with researchers working on subcomponents of the system. The DPSIR-OOBN "story" is one of continued uncertainty about the effectiveness of measures in a complex system. This may have a negative effect on farmer motivations to implement further measures. If that is the case, the DPSIR-OOBN becomes not only a description of system dynamics, but also a mediator of those system dynamics.

Conclusions

This chapter has presented a list of criteria for defining a systems model as an "integrated valuation of ecosystem services". This refers to management relevance, value plurality, value heterogeneity, interdisciplinarity, knowledge systems, information types, levels of societal organization, consistency in scaling of plural values, and consistency in comparison of plural values in decisions.

We presented an object oriented Bayesian network (OOBN) of the valuation of eutrophication abatement measures in a catchment in South-Eastern Norway. The OOBN was used to link biophysical, social and economic models together following the framework of a driver–pressure–state–impact–response (DPSIR) model. We have shown how Bayesian networks offer a consistent meta-modeling approach to integrated model uncertainty – both in terms of spatial and temporal heterogeneity and value plurality. We argued that the Bayesian interpretation of all causal relationships as beliefs, whether lay, expert, scientific, or model-encoded knowledge is a useful framing for value plurality in environmental management. No single type of subjective scaling of the biophysical impacts takes primacy when all knowledge systems are framed as belief.

We think that the Bayesian belief network methodology can shift focus to the consistency of valuation methods within decision contexts. It helps to evaluate the causal chain linking human actions, via socio-ecological system dynamics, to perceptions. It should therefore be a practical approach to operationalizing the ecosystem services cascade framework in the economic analysis of programs of measures under the WFD.

The DPSIR-OOBN model discussed in this chapter meets most of the nine suggested criteria for "integrated valuation". The model fails to meet the criteria that ecological, social and economic values are to be defined consistently in relation to impacts on lake quality. The DPSIR-OOBN does not meet the criteria of consistent trade-off analysis as it is does not weight different impacts of eutrophication against one another. It is neither a full benefit-cost analysis, nor a full multi-criteria analysis. However, we have shown how the DPSIR-OOBN can be used to explore issues of consistency in scaling and weighting of different values. We think that Bayesian belief networks make it possible to take a consistent approach to how risk – defined as probability multiplied by impact – conditions valuation.

We also discussed how our integrated valuation is limited by model system boundaries, which exclude potentially significant explanations of lacking abatement effectiveness. We discuss farmer narratives where incentives for implementing nutrient abatement measures depend on many things, among them the power of scientific models to predict abatement effectiveness. The integrated valuation model is not merely a model, but also a mediator. The variability that continues to characterize eutrophication and human responses, at least in the complex Morsa catchment, also suggests that our integrated valuation model does not meet the accuracy and reliability requirements of a decision-support model under the WFD. For the moment it is still "eutropia".

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Notes

1. Not modeled in this study.
2. The choice experiment simultaneously weights the relative importance of different lakes and their quality, and scales the marginal changes against income. Bridging choice experiment (CE) and multi-criteria (MCD) terminology, MCA weights are equivalent to the CE beta-coefficients on the non-price choice attributes, while MCA scaling is equivalent to the CE alfa also called "scale coefficient".
3. Contributing to these inconsistencies between societal valuation systems for eutrophication, are survey responses that at first glance seem inconsistent. First, we observed from *Household WTP* that there is a probability that households have a negative WTP (there is a 24% probability that $-1000 < E(WTP) < 0$). This is due to an unexpected result in the choice experiment where respondents on average expressed negative WTP for small improvement (red-yellow lake condition), while positive WTP for larger improvements (red-green, red-blue condition). Barton et al. (2009) conjecture that respondents

expect any management measures implemented to have large effects, and react negatively to scenarios that show only small improvements (despite them being positive relative to the status quo).

4. In fact, a part of the research project addressed farm returns to different cropping patterns and fertilizer use. However, opportunity costs to farmers were not included in the DPSIR-OOBN to explore the concept of "integrated valuation", rather than benefit–cost analysis.

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