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Scientific models in legal judgements: The relationship between law and environmental science as problem-feeding

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ABSTRACT

Legal decision-making often relies on scientific knowledge and information of other kinds, not least in environmental law where legal institutions use environmental modeling to, for example, project expected effects of projects when approving or denying permits. In this paper, using use the problem-feeding model of interdisciplinarity, we analyze this relationship as an exchange of problems and solutions between different communities of expertise. Drawing on recent examples from Finland, we use the problem-feeding model to explore the conditions under which problem-solution coordination breaks down. We argue that tensions between the notions of uncertainty used by the different communities of expertise can lead to differing understandings of the way the relationship between legal institutions and scientific experts works, and that this may disrupt the orderly exchange of problems and solutions. We illustrate our views in a fictional discussion between a lawyer and a modeler.

1. Introduction

The law often turns on scientific knowledge (Feldman, 2009). This can be seen both in the legislative phase, where scientific information is used by law-makers trying to assess what should be regulated and how, and in the application of the law in individual cases. Nowhere is this relationship more evident than in environmental law, where the legislature relies on scientific guidance and where legal judgements are often conditional, in part or in whole, on scientific assessments (Rose, 2005; Ruhl, 2007; Fisher et al., 2017; Bjornlund et al., 2018). Thus, whether or not a new infrastructural or industrial operation is authorized will often depend on a range of long-term risk and damage assessments focusing on various environmental values. Where legal protections for the environment have been established (e.g., an obligation in law not to pollute the environment), those tasked with deciding whether to grant permits or other authorizations for a project tend to base their decisions largely on scientific evidence.

This raises familiar issues about the appropriate relationship between legal decision-making and the production and transfer of scientific knowledge. How does this division of labor work? How should it? As Robin Feldman (2009), J. B. Ruhl (2007) and Carol Rose (2005) have pointed out, the relationship is not without its share of problems and challenges. A recurring issue is the failure to maintain appropriate boundaries between legal and policy matters, on the one hand, and science, on the other (Feldman, 2009; Ruhl, 2007). Legal problems are often, as Feldman puts it, inappropriately *externalized* as scientific problems, when the source of the problem is actually normative. Another issue arises from a lack of question-answer coordination between legal and scientific collaborators (Wahlberg, 2010). Key concepts, such as adaptivity, uncertainty, and even causality, are interpreted differently in legal and scientific contexts in subtle but consequential ways. This can lead to what some have called *Type-III errors*, where the right answer is provided to the wrong question (Mitroff and Featheringham, 1974; Kriebel et al., 2001; Wahlberg and Persson, 2017).

The purpose of this paper is to structure the problem situation according to the problem-feeding model of interdisciplinarity (Thorén and Persson, 2013). We use this model to provide some analytical clarity and to generate normative conclusions about how to structure the relationship between environmental law and natural science appropriately and effectively. For context, we refer to the implementation of the EU Water Framework Directive (WFD, 2000/60/EC) in Finland and case law from the Supreme Administrative Court of Finland.

The structure of the paper is as follows. We first illustrate the challenge of communicating effectively across the law and natural science

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divide by describing a case from the Supreme Administrative Court of Finland. We then introduce the problem-feeding concept. The aim here is to highlight problem-solving dynamics and problem-solution coordination between different communities of expertise, and the general challenges involved with that. We then discuss variation in understandings of uncertainty. We explain that this variation can result in the usual way of organizing the boundary between legal and scientific institutions breaking down. In the section that follows we illustrate these problems in more concrete terms by setting out a fictional conversation between a legal scholar and a natural scientist. The aim is to apply the philosophical, problem-feeding framework in a way that helps to explain the successes and failures of an interdisciplinary exchange in a real-life decision-making context. Finally, we speculate about the underlying reasons for the (potential) breakdown of the problem-feeding structure. Here we rely on some recent (and not so recent) discussions of inductive risks and the science-policy interface in the philosophy of science.

2. Setting the Stage: cross-disciplinary expectations

In a recent decision, the Supreme Administrative Court of Finland (SACF 2019:166) ruled against the pulp manufacturer Finnpulp. The company had intended to make a 1.4 billion euro investment into a new bioeconomy operation producing pulp and renewable energy from timber. Section 27 of the Environmental Protection Act of Finland (527/2014) required Finnpulp to obtain an environmental permit. The permit would ensure that the negative environmental impacts of emissions to air, soil and water would be controlled. The company had submitted a permit application to the relevant national authority, which had granted the permit provided that the company followed certain requirements mitigating emissions to the environment. The Supreme Administrative Court was asked to review the legality of this permit decision. Its job, in other words, was to determine whether or not the Finnpulp operation should be issued with an environmental permit. In order to decide the legality of the permit application, the court was invited to assess the long-term environmental impact of the operation on the ecological functioning of the lake that would hold the project's nutrient (especially phosphorus) and sulfate rich wastewaters. Finnpulp had conducted an environmental impact assessment using computer models designed to predict how the water quality and ecological functioning of the nearby lake would change as a consequence of the proposed project.

The court rejected Finnpulp's permit application, affirming that Finnpulp had a strict legal obligation not to reduce the ecological quality of the lake and citing significant model uncertainties regarding the ecological condition of the lake over the long term (Belinskij and Soininen, 2020; Paloniitty and Kotamäki, 2021). Without the permit, the project could not proceed. The conditions for granting an environmental permit are that the activity, alone or in combination with other activities, taking permit regulations and the location of the activity into account, does not cause significant pollution of the environment (Environmental Protection Act, Section 49 and 5). This provision is interpreted in the light of art. 4 of the EU Water Framework Directive stipulating that "Member States shall implement the necessary measures to prevent deterioration of the status of all bodies of surface water". The Court of Justice of the European Union clarified in the *Weser* case (C-461/13) that WFD art. 4 applies to permits for operations causing environmental pollution. According to the Supreme Administrative Court of Finland, an environmental permit must be denied if there is a risk that the ecological status of the water body would deteriorate within the timespan of the proposed project (40–50 years into the future). While the court does not explicitly discuss tolerable risk levels in quantitative terms, in the *Finnpulp* case the best available water quality models were not able to meet the legal standard of scientific certainty. Consequently, the permit was denied in line with the precautionary principle.

In light of the *Finnpulp* case we can ask: What are the more general prospects of scientific models meeting legal standards and tolerances for (un)certainty? Does legal regulation of environmental quality ask too much of science? It is also interesting to ask whether the scientific modelers tasked with predicting the aquatic impact of the project 40–50 years into the future regarded the legal requirements for models to be scientifically feasible. Were they persuaded that the legal standard for certainty would not be entirely beyond their reach? We shall now set out the philosophical framework of problem-feeding that we believe illuminates the law and natural science interface, both in the *Finnpulp* case and in environmental law more broadly.

3. The problem-feeding model

The pattern the Finnpulp example illustrates is as follows. Questions are formulated (when problems arise) in one context, or community, that cannot be addressed without expertise from some other community. The questions are therefore put to the relevant community, with the expectation that this will solve the problem, and in this sense the problem is "transferred". Such an exchange of problems and solutions has been called *problem-feeding*—or *bilateral* problem-feeding, to be more precise (Persson et al., 2018; Thorén, 2015; Thorén and Persson, 2013). It has been applied in analysis of the dependence relationship that obtains between law and science (Wahlberg and Persson, 2017).

The issue is that actors, or communities, that differ in a number of relevant dimensions need to collaborate towards specific goals. In the *Finnpulp* case there are legal actors (the courts) and scientific actors (modelers). In this paper, we will use the terms *discipline* and *community of expertise*, depending on the context. We shall treat these terms as largely interchangeable—both refer to groups bound together by technical and theoretical expertise, shared theories, models, concepts, and values (Bechtel, 1986; Kuhn, 1993). Among other things, this makes a community of expertise suitable to solve particular sets of problems.[1]

3.1. The basic structure

Problem-feeding involves the exchange of problems and solutions. The structure of the exchange is as follows. We have two disciplines, D_1 and D_2, that are assumed to be different and complementary with respect to the knowledge they can produce such that one can be dependent on another. That is to say, a problem or question may arise in one discipline that can only be addressed or answered in the other. The overall pattern is simple:

(1) A problem P arises in D_1 such that it can only be solved in D_2.
(2) D_2 proceeds to provide a solution S to P.
(3) S is implemented in D_1.

In the kind of case in which we are interested the law is such that courts (D_1 in the above schema) have questions that they cannot (and should not) answer on their own, such as "What are the long-term effects of activity X in environment Y?" These are transferred to the appropriate scientists (in this case, ecological modelers) who provide answers that are then used to support legal decision-making by the courts. If the risk of environmental impacts of a proposed activity rises beyond a certain threshold, it is deemed too severe and the permit is denied. In an ideal world the division of labor between the legal and the scientific communities is clear; the permit-issuing authorities and courts know what kind of scientific knowledge is needed and what the best available science can be expected to deliver, and the scientists (often consultants

[1] Legal and scientific institutions can also be differentiated in other ways. Moreover, in reality (in Finland) there is a grey area at the institutional joint that connects legal and scientific institutions most notably exemplified by the presence of expert judges that also have scientific training (see Paloniitty and Kotamäki, 2021).

conducting environmental impact assessments for the permit applicant) know what is expected of them in the legal evaluation and can live up to that expectation.

When the exchange works in this way, we call it *bilateral* problem-feeding. That is to say, it is problem-feeding plus solution-feeding (Thorén and Persson, 2013). In situations where the solution (for whatever reason) is not implemented in the intended way or is completely ignored by the discipline within which the original problem arose, we say that the problem-feeding was *unilateral.* There is nothing inherently lacking about unilateral problem-feeding as such, but a situation that *only* gives rise to this type of problem-feeding is of course a failure *if* bilateral problem-feeding was intended. It may be seriously concerning if an episode of problem-feeding is *mistakenly* understood to be bilateral – i.e., if the solution eventually produced does not address the original question, but this is not noticed for some reason.

3.2. Transfers and transformation

One important point is that, as we transfer problems and solutions between disciplines that operate with different theories or methods, and—at least, partially—on the basis of different sets of values (c.f. Kuhn, 1993), some measure of transformation or translation typically needs to take place. The point is simply that in order for scientists of any stripe to solve any problem, that problem has to be fitted to the problem-solving resources of the discipline in question (here: law) and its way of operating. There are many dimensions to this process, which involves expressing problems within the conceptual framework of the discipline in question and as varieties of problems that the discipline usually solves (see Thorén, 2015, chapter 5). The applied mathematician will understand any problem that she thinks she may be able to solve as a problem capable of being expressed in mathematical terms. Setting aside the intricacies of this process, it suffices to say that depending on how the problem is initially formulated, and whether there are already established conventions in place, this transformation can be more or less challenging. Once the problem is solved the solution needs to be transferred back with similar issues arising again.

Developing the above schema somewhat, the process looks like this:

(1) Problem P_a arises in discipline D_1
(2) Problem P_a is transferred to discipline D_2 and transformed into problem P_b
(3) Discipline D_2 produces solution S_b to P_b
(4) Sb is transferred back to discipline D_1 and transformed into solution S_a
(5) Sa is a solution to P_a and is implemented in D_1

This bilateral process can be thought of as one of problem-solution coordination. In essence, the transformation processes must ensure that the product (the solution) meets the criteria specified in (5) in the right way. First, the problems and solutions that are transformed and produced need to remain coordinated such that S_a is indeed a solution to P_a in D_1. Moreover, the process as a whole should lead to a solution of the kind generated when all of the steps in the process are actually warranted.[2]

3.3. Prerequisites and expectations

For bilateral problem-feeding to function in the intended way, a number of components need to be in place. This involves such things as aligning the values that guide inquiry, demarcating the disciplines with respect to one another (in respect of their domains of inquiry, epistemic jurisdiction, and methodological reach) and harmonizing epistemic standards, or alternatively establishing a relationship of trust between the involved parties, which ensures that the imported solutions are accepted as reliable (see Andersen and Wagenknecht, 2013; Thorén and Persson, 2013).

In what follows we shall focus on the way the boundaries between communities of expertise are organized, and on what the collaborators believe about these boundaries. These beliefs shape expectations concerning the structure of the problem-feeding exchange itself that will, if the beliefs are too far removed from the actuality of the situation (and are not appropriately updated), impede progress.

Often it seems that dynamic exchanges of problems and solutions require one party to have an idea of what it needs in order to proceed, and each party to have certain expectations of the other with respect to what is forthcoming. This creates slightly more complicated problem-feeding chains. Before D_2 can proceed with solving P_a (or a successfully transformed variety of that problem) some further information is necessary such that the members of D_2 believe this information is forthcoming from D_1. The problem is that it is not forthcoming, at least in a form that is useful within D_2. In more complicated situations there can be mutual unresolved (or irresolvable) dependencies of this kind where collaborating disciplines are locked in a kind of holding pattern awaiting further instructions.

The problem here is that the collaborators are operating with a "model" of the interdisciplinary environment—the relationship between the interacting parties (here: law and environmental science) and the capabilities of their counterparts—that is at odds with the reality. Notice that, in most cases, it will require some effort to understand the capabilities and limitations of another discipline. Of course, the image of other specialties presented in a specific discipline need not be wholly accurate, but some understanding of the other discipline is required for successful problem and solution-feeding.

To take a practical example, legal frameworks are deeply intertwined with science and scientific knowledge in many ways, and it is easy to see why the boundaries here might become hazy or unclear. A good illustration of this is the Water Framework Directive mentioned earlier. The directive seeks to 1) prevent deterioration of the status of ground, surface and coastal waters within the EU, and 2) achieve good status in the said waters (art. 4). WFD deploys scientific criteria for classifying ecological status—what Feldman would call *internalization.* Ecological status has three quality elements: biological (BQEs), physico-chemical and hydro-morphological. Good Ecological Status requires, at a general level, that the BQEs show only a low level of distortion resulting from human activity. With regard to fish fauna, for instance, Good Ecological Status requires that there are only slight changes in species composition and abundance attributable to anthropogenic impacts (WFD Annex V).

The Water Framework Directive and the national laws implementing it also externalize legal problems about ecological status, transferring them to science (Hering et al., 2010a,b; Carvalho et al., 2019). In 2015, the EU Court of Justice ruled that national authorities shall not grant environmental permits to projects that would lead to a deterioration in water status or jeopardize the achievement of good status as measured by the directive (C-461/13). This ruling resulted in the denial of a permit in the SACF *Finnpulp* case. When national permit-issuing authorities and courts are asked to establish whether a project satisfies the directive's requirements, ecological modelers are asked to simulate and predict how the project would alter the biological, physico-chemical and hydro-morphological quality elements of the water body. The models are decisive in establishing whether the project can be legally approved, and, if so, with what conditions (Belinskij and Soininen, 2020; Paloniitty and Kotamäki, 2021). Unsurprisingly, the SACF *Finnpulp* ruling hinged largely on whether the scientific water quality models were fit for

[2] For example, the transformation process by which solutions are re-interpreted within the framework of the discipline or community of expertise in which the original problem arose shouldn't be such that it will transform anything into something that counts as a solution P_a which would render the whole exercise superfluous as well as violate some of our initial stipulations (i.e., that D_1 is not *able* to solve the problem on its own).

purpose, and whether they could predict the future ecological condition of the lake with sufficient certainty. The court seems, then, to have externalized a legal question about whether to grant a permit, and whether the project would infringe the requirements of the Water Framework Directive and the CJEU *Weser* ruling, to scientific experts, both within the court (expert judges) and without the court (modelers). Interestingly, the *Finnpulp* case illustrates the way in which problem-feeding fails when the problem-feeding is not connected to solution-feeding. The ruling left the scientific modelers deeply confused as to what is expected of them in terms of model certainty, and how they could ever achieve such high standards given environmental complexities and change, and scientific uncertainty. In the next section, we try to clarify where and how, exactly, the failure of problem-feeding and solution-feeding originates.

4. A dialogue between a legal scholar and an ecological modeler

The previous sections have established that legal texts, such as the Water Framework Directive and the Environmental Protection Act of Finland, and legal institutions, such as the permit-issuing authorities and courts, proceed on the basis that science, in this case aquatic ecosystem modelling, can provide answers concerning environmental quality with sufficient certainty. Our point is that laws are drafted with a particular idea of what environmental science as a discipline can provide in terms of knowledge. But the way in which ecology operates, and how it deals with uncertainties, often makes it unable to offer this product—there is a lack of problem-solution coordination that, we shall suggest, flows from discrepancies in the way in which uncertainties are managed.

Before we turn to the fictional exchange between a legal scholar and a natural scientist, based on the SACF Finnpulp-case, let us remind the reader of the kind of situation in which we are interested. Project developer X has scoped various locations in Finland to set up a sizable bioeconomy operation producing pulp and renewable energy. X has finalized the engineering plans for the operation, conducted an Environmental Impact Assessment and discusses suitable locations for the operation with a municipality responsible for land-use planning. Section 27 of the Environmental Protection Act of Finland requires such a project to have an environmental (pollution control) permit. The permit can only be granted if the project is not likely to cause significant pollution of the environment (sections 49 and 5).

The dialogue opens with the interlocutors considering the following question: Is the granting of an environmental permit for a project emitting nutrient and sulfite rich waste waters into a lake legally justified? This question then extends to a problem-solution dialogue between the court (the "legal scholar") and the environmental scientist (the "modeler").[3]

QUESTION Legal Scholar: Is the project likely to cause significant pollution of the lake? In environmental cases like this, the permit-issuing authority and the courts reviewing permit decisions are interested in whether the proposed project is likely to cause significant pollution of waters (section 49) within the timespan of the project (here: 40–50 years). According to section 5 of the Environmental Protection Act, "environmental pollution means such emissions that either alone or together with other emissions: a) cause harm to health; b) are detrimental to nature and how it functions; c) prevent or materially hinder the use of natural resources; d) cause a loss of general amenity of the environment or of special cultural values; e) reduce the suitability of the environment for general recreational use; f) cause damage or harm to property or impairment of use; or g) constitute a comparable violation of the public or private interest." In this case, the interest is in "emissions that are detrimental to nature and how it functions". This is evaluated in light, especially, of whether the project is likely to reduce the ecological status of the water or jeopardize the achievement of good status as explained by the Water Framework Directive.

ANSWER Modeler: The project's impacts on the water body have been assessed and quantified with pressure-impact models. The reason the legal institution turns to modelers in the first place is that mathematical models are the dominant scientific method for assessing, predicting and understanding the links between human actions and the state of an ecological system (Schmolke et al., 2010). They are widely used in water management planning and permissions (Fisher et al., 2015; Hering et al., 2010a; Rekolainen et al., 2003). In the impact assessment, the modeler quantitatively links the indicators of interest and the pressures that affect these indicators. The established model will be used for simulating a range of options: assessing the water quality without the planned project, and then with the alternative sizes and locations for the project. In this way it is possible to distinguish between the impacts of the proposed project and other natural and anthropogenic pressures. However, what, exactly, the modeler is capable of delivering is constrained by the models that are available, the representativeness of the local calibration/validation data, and the resources that are available for making the assessments (time, money and experience).

QUESTION Legal Scholar: I'm expecting your model to clarify long-term effects on the lake's ecological status. Is this possible? To quantitatively assess impacts on an ecosystem in various situations we need simple and easily interpreted proxies of the environment, i.e., ecological indicators (Jackson et al., 2000). The guidelines for selecting such indicators are set by legislation, here in the Water Framework Directive. In practice, they are a co-production of science and policy, as they are shaped by both scientific knowledge and political considerations and priorities (Turnhout et al., 2007). In lakes, the ecological status indicators are metrics of biological quality elements describing the amount and community composition of phytoplankton, macrophytes, benthic invertebrates and fish. The prescribed limits of Good Ecological Status must not be exceeded. The selection of the ecological indicators and their quality standards are defined in Annex V of WFD.

ANSWER Modeler: To some extent, yes. However, the 40–50-year timescale is challenging and often not feasible. In addition, models and data seldom allow us to assess all the ecological quality metrics. The difficulty with the long-term predictions arises from the fact that the relationship between the functioning of the ecosystem and the physical environment is complex. Often there is not enough information (e.g., historical data) to track trends, and the annual and seasonal variations, and their drivers. Different parts of the ecosystem can react in different phases, and the changes can be slow or rapid. Therefore, long-term impacts are often assessed with multiple model simulations that vary in respect of biophysical conditions (with changes, for example, in temperature and precipitation, and in nutrient and oxygen availability). The worst-case scenario then sets the level of maximum impact. In addition, in the impact assessment there is rarely enough data and knowledge on the biological quality metrics. The models were developed and applied only for easily measurable physico-chemical parameters such as nutrient concentration and chlorophyll-a (Andersen et al., 2016; Hjerppe et al., 2017). Moreover, the complexity, and thus the uncertainty, of the ecological, biogeochemical models is much higher than those of hydrodynamic, purely physical models. For these reasons, the impact assessments perhaps only partly deliver what the legal scholar requires.

QUESTION Legal Scholar: Okay, but how reliable are the available model results? What is the risk of jeopardizing the Good Ecological Status of this waterbody? WFD art. 4 and the CJEU *Weser* ruling require there to be sufficient certainty that permitted projects will not reduce or jeopardize Good Ecological Status.

ANSWER Modeler: The uncertainty is high. It is partly unavoidable and accumulates from several sources. Scientific

[3] This dialogue is based on the actual Finnish Supreme Administrative Court case referred to in the article (SACF 2019:166) and all the questions and answers are based on sound existing research. The actual dialogue is, however, fictional and used here to explain and highlight what the problem between law and natural science is by using the problem-feeding model.

knowledge, including model assessments, always contain uncertainty (Uusitalo et al., 2015; Popper, 1959). Following the framework provided by, for example, Refsgaard et al. (2007), this ineliminable uncertainty can be divided into roughly two types, depending on its cause. The first is so-called aleatory, or stochastic, uncertainty, which is inherent in nature. Genuine aleatory uncertainty cannot be reduced, as it resides within the system itself. Often enough, however, this kind of uncertainty will produce stable frequencies, and it allows probabilistic treatment and can, if appropriate conditions obtain, be at least partly quantified and communicated to decision makers (Uusitalo et al., 2015). The other type of uncertainty is epistemic. In the case of modelling, this stems from insufficient knowledge of the system's behavior, or inadequate empirical measurements, among other things. Uncertainties in modelling are connected with issues including: i) complexity of the model structure (what is the appropriate level of simplicity when describing the real world with a model?), ii) spatio-temporal scale (what is the appropriate timeline and geographical resolution?), iii) availability and quality of data (is there enough input and output data to verify, calibrate and validate the model?), iv) numerical approximations (which arise especially in complex modelling of issues that cannot be solved analytically). In addition, issues with the confidence of the status assessment of the water body, and with complexities in the WFD classification system, introduce further uncertainty (Sigel et al., 2010).

QUESTION Legal Scholar: Is it possible to reduce the uncertainty, and consequently the risk, in the decision-making? Decision-making is easier when the certainty of the outcome is higher. The permit-issuing authority needs to know that the project is highly unlikely to cause ecological deterioration or jeopardize the water's good status, otherwise the permit decision may prove to be unlawful in the future. The legal standard of risk cannot, however, be established in quantifiable terms. What level of risk can be tolerated must be decided on a case-by-case basis.

ANSWER Modeler: Yes, at least some of it. Some uncertainties can be reduced by improving the model structure and utilizing more (and more representative) measurement data. Modelling and data always go hand in hand, and local data are the basis of the model's parametrization, calibration and validation (Rykiel, 1996). Data availability is also critical in model evaluation, i.e., when we are comparing the model-based predictions with empirically collected data from the project site (Nichols et al., 2011; Carmona et al., 2013). To reduce uncertainty, models can be updated whenever new data is available. The model assessment outputs will then become more accurate every time (but they can also change). Uncertainty in the model can be reduced somewhat, but it cannot be entirely eliminated. Significant uncertainty remains even after the model has been loaded with local data. Aleatory/stochastic uncertainty can be mitigated with more data but not removed. What we get with more data is a better understanding of the probabilities involved. Moreover, sometimes there are higher-order uncertainties—uncertainties about the uncertainties themselves—that can be difficult to capture within a simple framework for reporting uncertainty (e.g., Douglas, 2009; Frank, 2017).

QUESTION Legal Scholar: How much uncertainty will remain if the permit applicant is required to gather more local data and update the model runs with these data? The system issuing in permissions contains some legal mechanisms for dealing with uncertainty. These include temporary permits, enhanced monitoring obligations and periodic modelling, coupled with a review of the permit conditions (e.g., Best Available Technology for water purification) (Paloniitty and Kotamäki, 2021). The problem is that in many cases (such as in mining operations and large industrial operations) the proposed project requires significant economic investment at the construction and set-up phase. Under the established constitutional and administrative law doctrine, the permit cannot be entirely revoked once the original go-ahead has been granted. This creates a risk that the project will end up infringing the requirements of WFD. The operation can, however, be down-scaled or required to obtain new technologies for purifying waste waters and the like. However, these may not be sufficient to meet WFD art. 4 requirements. We would need scientific certainty, or at least confirmation that it is highly unlikely that the project will infringe WFD art. 4, for the models to deliver an answer that is fully justified in law to the question whether a permit should be granted.

ANSWER Modeler: It is very hard to know the level of certainty prior to the assessments. Actually, it seems that the law has excessively high expectations about what our models can and should do. The requirement of producing long-term, cumulative and holistic assessments with enough certainty is not realistic. Modelers also struggle with qualitative expressions describing tolerable levels of risk and confidence. Moreover, it seems that although evaluative questions of "sufficiency" and "tolerability" need to be answered on legal grounds, modelers can only give the assessment results and explain the different sources of uncertainty. The modelers cannot, and should not, make the permit decision for the legal scholar, even if the decision seems to hinge on a scientific assessment of future ecological quality.

ANSWER Lawyer: I agree. The evaluative decisions need to be made on legal grounds using legal criteria. This means that the permit-issuing authority, and the court reviewing the permit, are left without clear legal guidance on risk tolerance. Either the permit-issuing authority declines to grant the permit based on the precautionary principle (too much uncertainty to grant a permit), or it grants the permit based on its view that there is sufficient certainty and seeks to mitigate the remaining uncertainty with permit conditions, such as monitoring, modelling and BAT requirements. It is frustrating that there are no clear-cut answers.

5. Uncertainty, values and inductive risks

The above dialogue is fictional. It is descriptive in the sense that (in our view) it is reflective of the actual issues that arise as legal institutions and scientists attempt to set in motion problem-feeding exchanges. It also serves normatively as an illustration of the way uncertainties in models and their use in law can be interrogated by the involved parties—a process which itself can aid the successful exchange of problems and solutions.

The dialogue helps to make explicit some considerations regarding uncertainty. Obviously when expectations among the parties fail to map onto the actual situation, and when, moreover, these discrepancies are not appropriately recognized, the risk of the bilateral problem-feeding failure increases.

Let us examine this kind of situation from a more general perspective. The "standard" model of the sharing of labor between legal and scientific institutions involves a somewhat sharp fact/value distinction. Although there are plenty of technical ways of defining the notions of risk and uncertainty in precise ways, we can generally separate two components that are important in decision-making situations. One is the probability of some outcome coming about. This may be expressed as an "objective" or "subjective" probability. The other part has to do with the value, or disvalue, of that outcome—how good or bad it is. In a conventional decision framework such as expected utility theory we simply multiply the probability of an outcome with its value in order to compare uncertain (or better, risky) outcomes with one another.

Where the science-policy interface is concerned, a traditional way of describing the relationship between scientific institutions, on the one hand, and decision makers (in the present case, legal institutions), on the other, is that the scientists provide the probabilities—which are taken to be matters of fact—and the decision makers provide the utilities, as these reflect values. Although much has been written about the various limitations of this model of the science-policy interface, it is quite clear that it very often serves as a model for organizing the division of labor in such a way as to both keep the science free of values (to the extent this is possible) and render the decision-making democratically legitimate.

In the case we are focusing on, we can think of this as the model of the interdisciplinary/science-policy arrangement around which the problem-feeding exchange is organized. Often enough, and perhaps especially if adequate institutional arrangements function to stabilize concepts and conventions, the model works well. In other words, it allows for the appropriate exchange of problems. In some situations, however, the model fails to approximate the relationship between the different communities of expertise, and this can lead to failures of bilateral problem-feeding.

The challenge the lawyer and the scientists are discussing in our fictional account revolves around the uncertainties themselves. On the standard model, these should be provided, or set out, by the scientists, but the form in which they are set out here fails to live up to the expectations of the lawyers. The two communities are operating with slightly different understandings of what counts as an adequate way of reporting uncertainties and maintaining the appropriate coupling between the respective communities of expertise. This in turn challenges the standard fact/value model of the science-policy interface through which our presumed discussants are operating.

To find the reason for this, we can turn to the philosophical literature on inductive risk. The so-called argument from inductive risk was first formulated by Richard Rudner (1953). It states that when scientists are accepting and rejecting hypotheses in conditions of uncertainty they are effectively—and indeed should be—making value judgements by setting epistemic standards. The threshold of acceptance for a hypothesis is arbitrary, and the kind of error one prefers countenance (false positives or false negatives) should depend on what the practical consequences are. This argument was famously criticized by Richard Jeffreys (1956), who denied the premise that it is the task of scientists to accept or reject hypotheses. Instead they should merely report the (subjective) probability of some hypothesis being true. In this way, scientists leave value judgements to the decision makers with whom they rightly belong.

Jeffreys proposal has by all accounts been widely influential, and it appears that often enough this is how, as a matter fact, we understand and structure exchanges between scientists and decision makers. The Jeffreyan model, however, appears to have limitations. A common counter-argument, and one that was to some extent anticipated by Rudner (see also Douglas, 2009; Frank, 2017), is that a statement to the effect that some hypothesis has a certain probability of being true is indeed also a hypothesis that needs to be accepted or rejected, and as such also subject to inductive risk considerations.[4] As David Frank (2017) points out, the model only holds given that specific conditions apply. These are:

(i) There must be an understanding of the way uncertainties are represented by decision makers.
(ii) Scientists must not try to manipulate uncertainty representations in order to forward some particular agenda.
(iii) It must be the case that the higher-order uncertainties are limited, and that the scientists are transparent about them.

Given that we do not, in cases of the kind in which we are interested, typically suspect scientists of trying to manipulate their uncertainty reports—our point of departure is rather that scientists and modelers are generally trying to uphold what they perceive to be their part of the bargain by reporting uncertainties as objectively as possible—the most relevant conditions here are (i) and (ii).

So, in the cases we are considering, a lack of understanding on the part of the decision makers, perhaps in combination with considerable higher-order uncertainties, makes it harder to maintain the fact/value distinction in the way the involved parties deem to be appropriate. Hence, *either* the decision makers have to make epistemic judgements, *or* the scientists have to make value judgments, *or* both. However, on the assumptions we are making here, this is not how they understand their respective roles. This, we suggest, is a compelling account of why these kinds of bilateral problem-feeding relationships sometimes malfunction.

[4] This depends on whether one accepts such higher-order uncertainties. Not everyone does: see Frank (2017) for a discussion of this.

6. Concluding remarks

Let us return to the *Finnpulp* case with which we introduced this account. The failure to successfully feed problems and solutions between the law and natural science, as illustrated by the *Finnpulp* case, is at its core a matter of the overinflated expectations the law has about what ecological models can deliver. Environmental laws, such as the Water Framework Directive and the Finnish Environmental Protection Act, are based on an understanding that objective knowledge of the natural world with a broad temporal scope is attainable: it is possible to know and predict the impact of anthropogenic pressures, such as the Finnpulp operation, well into the future with sufficient certainty. And if this is not possible, a court should err on the side of precaution in granting environmental permits. Consequently, unless there is full certainty that a new project will not reduce water status or jeopardize the achievement of good water status, a permit should not be granted. This legal requirement, however, sets up an impossible task for any modeler seeking to satisfy the legal criterion of full certainty. Not understanding (or not caring enough about) the sources and scope of natural science's uncertainties, the law ends up asking the impossible. In problem-feeding terms, the legal institutions ask the right questions of natural science, but the questions are charged with such unrealistic expectations that solution-feeding fails. As we suggested in the previous section, the underlying reasons for this can be found in subtleties in the way second-order uncertainties interfere with the model of the interdisciplinary environment that the different communities of expertise are operating with.

What should be done about such mismatches? Presumably no simple or easy solution is available. The models of interdisciplinarity and science-policy relations have to be brought in line with the reality of the situation. Typically, these kinds of issue are resolved by institutionally stabilized conventions that regulate and standardize the exchanges. Indeed, there is a real effort in Finland to bridge law and science. Permit-issuing authorities and the courts both have legally trained permit officials and judges, as well as officials and judges trained in natural science or engineering. Despite such institutionalization of co-production, the *Finnpulp* case illustrates how the dialogue between law and natural science struggles (Paloniitty and Kotamäki, 2021).

Being explicit about first- and second-order uncertainties also helps, but as several philosophers have pointed out (see e.g., Frank, 2017; Steele, 2012; Elliott, 2011) there may well be real trade-offs here, and these may mean that it is not possible to approximate to the Jeffreyan, value-free ideal closely.

In practical terms, and in order to help alleviate the problem and facilitate solution-feeding between law and natural science, the legal community needs to clarify the level of certainty required, or at least establish what kinds of model can, and should, be used in assessing the potential environmental impact of the various types of project (regulation of model choice). A complementary legal pathway would involve emphasizing the different legal mechanisms, such as monitoring and permit review, that can be used to limit uncertainty (regulation of uncertainty). The scientific community, in turn, needs to be more transparent about the different sources of uncertainty in their models (transparency). Moreover, the modelers should seek to better understand the legal criteria for environmental permits, i.e., the purposes for which the models are used (matching legal criteria and models). Transparency will help the legal community to evaluate the reliability of the model outputs, and the scientists' improved understanding of the decision-making context will help scientists choose the right models, acquire sufficient data and calibrate the model they apply, so that the legal requirements are more likely to be filled. These solutions will not offer silver bullets ensuring successful problem and solution-feeding. However, they do offer a pathway for navigating the difficult interdisciplinary space between law and science.

Author statement

HT had the original idea and developed it together with NS and they developed a first preliminary draft. HT led the writing process and did most of the writing on the philosophical sections. NS developed the central examples and led the writing on those sections. NK developed the fictional exchange together with NS and NK provided substantive commentary on the rest of the manuscript. All authors contributed to structuring the text and developing the main arguments.

Declaration of Competing Interest

We hereby declare that there are no conflicts of interest to report with respect to this submission.

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