Expert judgement on the lower limit for project-specific calculations of nitrogen depositions

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20 January 2025

Summary
When using a model for a specific (policy) goal, it must first be determined what the scientific application range of a model is. The application range indicates where the model can be used to make reliable statements (given the purpose for which the calculation results are used). If the results are too uncertain (there is a 'false certainty'), then the model is insufficiently reliable (not valid) for use. There is always a limit to a model. In the context of deposition modelling of individual sources, the limit below which results are insufficiently reliable is 1 mol/ha/year, based on the best available scientific knowledge, taking into account the measurement detection limit. Below 1 mol/ha/year, a deposition cannot be distinguished from zero with sufficient certainty and a calculated deposition contribution cannot therefore be related to an individual source with sufficient scientific certainty (no causal relationship can be established). Calculation results lower than 1 mol/ha/year are scientifically insufficiently reliable for use in decision-making about specific projects (the model system is then not fit for purpose).
Theoretical and empirical considerations, the agreement with other models and peer consensus do not scientifically allow room – due to false certainty – to calculate nitrogen depositions from individual sources and to attribute effects where the deposition is lower than 1 mol/ha/year. The current calculation's lower limit of 0.005 mol/ha/year (0.01 mol/ha/year after rounding) cannot therefore be maintained from a scientific perspective; the calculation's lower limit is two orders of magnitude higher.

Introduction

I have been asked by the Ministry of Agriculture, Fisheries, Food Security and Nature for an independent expert judgement on the magnitude of the lower limit in project-specific calculations of nitrogen depositions.[1] First of all, I must state that although my broad scientific background also includes boundary layer meteorology, atmospheric chemistry and (large-scale) dispersion modelling, the requested expertise on my part here is mainly on methodology of science.[2] Naturally, my background in natural sciences does help with the discussion on the calculation's lower limit.

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[1] This independent expert judgement on the calculation's lower limit, written on behalf of the Ministry of Agriculture, Fisheries, Food Security and Nature (LVVN in Dutch) is partly based on a peer review by 15 institutes and individuals (organised by LVVN) of my expert opinion published on 28 August 2024, which had been updated following the research carried out by TNO and UvA on behalf of the IPO–Association of Provinces of the Netherlands (https://www.ipo.nl/nieuws/rekenkundige-ondergrens) and was originally delivered on 22 July 2023 on behalf of De Nieuwe Denktank. It is a variation on an earlier independent expert judgement (Petersen 2022), which was written on behalf of the Ministry of Infrastructure and Water Management on the substantiation of the maximum calculation distance. The current expert judgement is analogous to my previous expert judgement on the maximum calculation distance (and section 1 is largely identical) – after all, the reasoning is the same: scientifically, this file must avoid calculating with false certainty.
[2] I have had no involvement in my career with the development of the models under discussion here (mainly because these models are not managed by the PBL Netherlands Environmental Assessment Agency).

In my expert judgement on the lower limit in project-specific calculations of nitrogen depositions, I will, as transparently as possible:

1. Reflect on the importance of delineating the application range of scientific models, especially when they are used in decision-making. I place this in the context of dealing responsibly with uncertainties as codified in the Guidance for Uncertainty Assessment and Communication.
2. Scientifically substantiate what the magnitude of the lower limit should be for project-specific calculations of nitrogen depositions (given that calculating with the current lower limit of 0.005 mol/ha/year leads to false certainty).
3. Respond (briefly) to the points about 'cumulation' and 'precaution' raised by the Hordijk Committee (Advisory Committee on Measuring and Calculating Nitrogen 2020) and TNO (2022), in the light of 1 and 2.

The impact of using a scientifically substantiated calculation's lower limit and the legal aspects are not part of this expert judgement. This also applies to the ecological sciences. This expert judgement, like TNO (2024), concerns the (atmospheric) modelling sciences and is a direct follow-up to the IPO exploration that was carried out in the first half of 2024. In addition to TNO (2024), this IPO exploration also produced an impact analysis and a legal analysis. For information about the impact and legal aspects of a calculation's lower limit, I therefore refer to the aforementioned analyses.[3] However, as an introduction, I will provide a brief explanation of the difference between a calculation's lower limit and a threshold or limit value as used in the Programmatic Approach to Nitrogen:

How does a calculation's lower limit differ from a threshold or limit value as used in the Programmatic Approach to Nitrogen (PAS in Dutch)?

An calculation's lower limit (*rekenkundige ondergrens*) is not an (ecological) threshold (*drempelwaarde*) or limit value (*grenswaarde*) but follows imperatively from atmospheric science in combination with the legal standard of proof in the context of permitting, namely that a causal relationship must be detectable between the emission from an individual source and the calculated deposition before a preliminary test or appropriate assessment is carried out. The difference is that below the calculation's lower limit, causality between emission and deposition cannot be detected, which results in false certainty; therefore, calculated depositions below that limit must be rounded off to zero. In the case of a threshold or limit value higher than a scientifically substantiated calculation's lower limit, the cumulative nitrogen deposition of all exempted activities must be offset by a package of measures that ensure that the maintenance objectives are achieved. This is not necessary for a calculation's lower limit, at least not as a condition for use in the context of art 6.3 HD (Habitat Directive). In the context of art 6.2 HD, the government is of course still obliged to prevent habitat deterioration and to achieve the improvement and expansion objectives in the long term.[4] The current calculation's lower limit of 0.005 mol/y/year is not scientifically substantiated but does work the same (calculations below the lower limit are rounded off to zero) and has the same legal consequences. See also the legal analysis of the IPO exploration.

[3] These can be found at https://www.ipo.nl/nieuws/rekenkundige-ondergrens.

[4] The calculation's lower limit for the use of a model in the granting of permits (art 6.3 HD) does not automatically apply when using a model for another purpose (such as in the context of art 6.1 and art 6.1 HD). To obtain estimates of the total deposition in the context of art 6.1 HD and art 6.2 HD, contributions below 1 mol/ha/year (and also all contributions beyond 25 km) remain included.

1. Guidance for Uncertainty Assessment and Communication: Scope of application of scientific models

A good starting point for the discussion on how to deal with uncertainty at the interface between science and decision-making in the context of policy-making or permitting can be found in the *Guidance for Uncertainty Assessment and Communication*, originally published in 2003 (RIVM 2003a; RIVM 2003b; PBL 2013) and in the report *Dealing with Uncertainty in Policymaking* (CPB/MNP/Rand Europe [2007] 2008). These documents represent the state-of-the-art in dealing with uncertainties in science and policy. The Guidance for Uncertainty Assessment and Communication has been developed for use by scientists in the environmental domain,[5] in the Netherlands and abroad.[6] The Group of Chief Scientific Advisors of the European Commission's Scientific Advice Mechanism has explicitly recommended the Guidance approach for wide use in decision-making based on scientific input (European Commission 2019, 46–49). The European Food Safety Authority also refers to the *Guidance for Uncertainty Assessment and Communication* in its own uncertainty guidance (EFSA 2018a, 2018b, 2019).

The scientist-focused Guidance for Uncertainty Assessment and Communication pays particular attention to the following six key points:

1. How is the problem framed; which contextual factors are included/excluded?
2. What are the main parties (stakeholders/ actors) involved; what are their views, roles, stakes and involvement with respect to the problem, and what would be the added value of involving certain stakeholders in the study?
3. What are the main indicators/visualisations used in this study and how do these relate to the problem definition?
4. How adequate is the knowledge base that is available for the study?
5. What are the uncertainties relevant to this problem and what is their nature and location?
6. How is uncertainty information communicated?

All these points are important for scientists who develop models in the context of policy-making or permitting and use them to make calculations in order to arrive at reliable statements.[7] There is no general 'guidance' available for policy-makers and other decision-makers, although there is a need for one:

> Policymakers are faced with a dilemma: on the one hand, they are expected to base their decisions on clear, measurable facts, while, on the other hand, they are confronted with developments that give rise to uncertainties as a result of variable and unpredictable processes. (CPB/MNP/Rand Europe [2007] 2008, 9)

[5] The Guidance for Uncertainty Assessment and Communication can be applied more broadly than just in the environmental domain.

[6] The first phase of development took place at the RIVM and further development took place later at the PBL.

[7] 'Reliability' has three dimensions: (1) statistical reliability ('confidence intervals'), (2) methodological reliability, and (3) public reliability (Smith and Petersen 2014, 142–47). Each of these three dimensions plays a role in public discussions about 'the' reliability of models for policy-making or permitting. I will discuss methodological reliability in more detail below.

> The exchange of experiences and best practices [in the conference 'Dealing with Uncertainty in Policymaking' of 16 and 17 May 2006] was expected to provide some guidance for dealing with uncertainty in policymaking. It turned out that we were aiming too high, because of the complexity of the issues involved and the great diversity in policy environments, policy questions, types of uncertainty and experiences. (Don [2007] 2008, 5)

Of course, the complexity of decision-making does not absolve decision-makers and other parties involved from the duty to ascertain, in particular, the scope of application of the models used. They should require scientists to deal responsibly with uncertainty in the context of decision-making. One of those responsibilities is not basing decisions or having them based on results that are too uncertain according to the scientists involved (where that limit lies is exactly what the discussion is about, see the next section).

There are several examples of scientists and consultants who have contributed to dealing irresponsibly with uncertainties, for example by offering quasi-certainties ('false certainties'), quantifying non-quantifiable uncertainties, providing point estimates instead of ranges, believing in their own models and analyses and applying knowledge outside the range of phenomena for which it has been validated (Petersen and van Asselt [2007] 2008, 64). From a scientific point of view, this needs to change.

The Guidance for Uncertainty Assessment and Communication is intended as an 'antidote' to this tendency of scientists (which, incidentally, they mainly give in to under pressure from decision-makers seeking certainty)[8] and thus forms the basis for carefully dealing with uncertainties in decision-oriented scientific research (PBL 2013, 6). It is not only important for scientific research itself to know where uncertainties are located (in model studies, for example, in the 'model structure', the 'model parameters', the 'model inputs' or the 'technical model', see table 1). At the interface between science and decision-making, this then mainly concerns assessing the impact of uncertainties on specific model results and (policy) conclusions based thereon (including on the scope of application of the models in the specific decision-making context). And that is why it is important to have an idea of the reliability of a model *for a certain (policy) purpose* (see Knuuttila et al. 2025; Smith and Petersen 2014, 137). And even before that: 'When building the model, it is important when selecting model components to take into account the policy-related requirements and the circumstances of the specific policy problem' (Hordijk [2007] 2008, 54).

In Guidance terminology, the assessment of the methodological reliability of a scientific model involves giving a 'qualification of the knowledge base (backing)' (see table 1). This concerns 'the degree of underpinning of the established results and statements' (PBL 2013, 31). If the underpinning is qualified as 'weak', then this is an indication 'that the statement of concern is surrounded by much (knowledge-related) uncertainty, and deserves further attention' (PBL 2013, 31).[9] To determine the qualification of the knowledge base, '[c]riteria such as empirical, theoretical or methodological underpinning, and acceptance/support

[8] Fear of decision-makers to be held responsible for something may play a role here. However, scientists have a social responsibility to monitor what decision-makers do with their results, to advise on this and to warn against misuse.

[9] The Guidance emphasises that the qualification of the knowledge base is always given in the context of the purpose of using the knowledge and therefore never about a model detached from the context.

UNCERTAINTY MATRIX			Level of uncertainty *(from determinism, through probability and possibility, to ignorance)*			Nature of uncertainty		Qualification of knowledge base (backing)			Value-ladenness of choices		
Location ↓			Statistical uncertainty (range+ chance)	Scenario uncertainty (range as 'what-if' option)	Recognized ignorance	Knowledge-related uncertainty	Variability-related uncertainty	Weak −	Fair 0	Strong +	Small −	Medium 0	Large +
Context		Ecological, technological, economic, social and political representation											
Expert judgement		Narratives; storylines; advices											
Model	Model structure	Relations											
Model	Technical model	Software & hardware implementation											
Model	Model parameters												
Model	Model inputs	Input data; driving forces; input scenarios											
Data (in general sense)		Measurements; monitoring data; survey data											
Outputs		Indicators; statements											

Table 1. Uncertainty matrix (RIVM 2003b, 16; Petersen [2007] 2008, 17; PBL 2013, 27). See Walker et al. (2003) and PBL (2013, 29–32) for a concise explanation of all dimensions in the uncertainty matrix and Petersen ([2006] 2012) for a philosophical discussion.

within and outside the peer community may be used' (PBL 2013, 32). A so-called 'pedigree analysis' can be used for this:

> Pedigree analysis is an analysis that evaluates the 'strength' or scientific status of a figure [number, ap]. Pedigree literally means 'genealogy', 'origin' or 'background': how did the figure originate and does it have a good background? Two aspects are considered here: how does a figure (in a conclusion) come about and what is its scientific status, and how is it substantiated?
>
> Criteria that may be used in the pedigree analysis for evaluating a model include 'proxy' (degree of directness of the indicator applied), 'quality and quantity of empirical basis', 'theoretical basis', 'representation of the system's underlying causal mechanisms', 'plausibility' and 'degree of consensus'. (van der Sluijs [2007] 2008, 25–26)

Pragmatic choices also play a role in determining whether a model is 'good enough' for a particular (policy) purpose (for example, the budget and time available must be used efficiently). In terms of the 'uncertainty matrix' this can be seen as one of the dimensions of the value-ladenness of choices regarding the model.[10]

As we shall see below, the model calculations of nitrogen deposition resulting from individual projects quickly lead to false certainty. In the remainder of this expert judgement, I will focus on finding an answer to the question at hand, namely what the magnitude of the lower limit should be when calculating nitrogen deposition in the context of granting permits

[10] The following dimensions of 'value-ladenness of choices' can be distinguished: general epistemic values, discipline-bound epistemic values, sociopolitical values and practical values (Petersen 2006, 50; 2012, 51).

for individual projects, whereby false certainty is prevented. As an alternative to the current 0.005 mol/ha/year, which leads to false certainty and is not fit for purpose. In the following section, the Guidance for Uncertainty Assessment and Communication is used as a tool to assess the reliability of the knowledge required for determining the calculation's lower limit, including value-ladenness. However, the strength of the argument given below does not depend on the explicit use of this guidance.

2. Expert judgement on the magnitude of the lower limit for project-specific calculations of nitrogen depositions

The Hordijk Committee (the Advisory Committee on Measuring and Calculating Nitrogen) published its final report on 15 June 2020 (*Measure More, Calculate More Robustly*). The summary discusses the reliability of high-resolution deposition modelling in more detail and the committee indicates

> that the calculation tool AERIUS Calculator is not fit for purpose. There are two reasons for this: 1. the imbalance between the detail required by policy and the degree of scientific uncertainty in calculating the deposition on a small area and 2. the unequal treatment of different sectors due to the use of different models (SRM- 2, OPS) when granting a permit. (Advisory Committee on Measuring and Calculating Nitrogen 2020b, 4)

This is further specified in the conclusions of the report:

> Two considerations play a role in the assessment of AERIUS calculations for permitting. In the first place, the reliability of the prediction is insufficient due to the use of a very low assessment threshold [the current calculation's lower limit of 0.005 mol/ha/year, ap], and this approach leads to false certainty. AERIUS Calculator (hereinafter referred to as AERIUS for short) calculates small contributions to concentrations and deposition based on emissions from a project. The uncertainty of this extra deposition on Natura 2000 areas is many times higher than the assessment threshold [the current calculation's lower limit of 0.005 mol/ha/year, ap] at the spatial scale used (hexagons the size of one hectare). Science cannot provide what policy demands here.
>
> A second consideration is that it is indefensible that a different calculation system (SRM-2) is used in AERIUS when granting permits for the construction of a road than for the construction of a stable (OPS), whereby also the deposition of nitrogen oxides at more than five km from the source is not included. (Advisory Committee on Measuring and Calculating Nitrogen 2020b, 9)

To date, the government has not followed the method that the Hordijk Committee advised to make the models more suitable for the granting of permits. This concerns calculating the deposition not on a hexagon but on a cluster of hexagons, classified according to habitat type. This would reduce the false certainty in deposition calculations at a great distance from the source. However, in 2021, the government has opted for a different method to make the models more fit for purpose. This involves using a uniform maximum calculation distance of 25 km,[11] to prevent unreliable calculation results based on hexagon level beyond that calculation distance.[12] Using a maximum calculation distance, while still calculating at the hexagon level within 25 km, solves part of the problem of false certainty. But the problem of false certainty linked to the use of a calculation's lower limit of 0.005 mol/ha/year has not yet been solved. I share the opinion of the Hordijk Committee on this point that the current system is not fit for purpose. The calculation's lower limit of 0.005 mol/ha/year concerns a pragmatic, computer-technical choice made by RIVM experts that does not have any substantive scientific meaning.[13]

Below, I will discuss in more detail the justification provided by TNO for delineating the application range of the model used for project-specific calculations by the use of a much higher calculation's lower limit. I do this in the light of what is said in science about methodological reliability and what has been laid down about this in the Guidance for Uncertainty Assessment and Communication. But first the possible deliberate use of false certainty in the context of the precautionary principle must be considered, which is scientifically problematic when this is not done transparently and is in any case difficult to maintain legally and policy-wise (see also section 3). The Hordijk Committee sheds light on this issue as follows for the choice of the calculation's lower limit of 0.005 mol/ha/year:

> For the time being, the precautionary principle calls for a strict threshold value [the current calculation's lower limit of 0.005 mol/ha/ year, ap] when granting permits. An ambitious source policy with established national objectives has the advantage that the threshold values [lower then, equal to or higher than a scientifically substantiated calculation's lower limit, ap][14] could be increased when granting permits, so that the uncertainties in the calculations for the permits become less critical and false certainty becomes less prominent. (Advisory Committee on Measuring and Calculating Nitrogen 2020b, 10)

A tension in the quote above is that limiting false certainties – for example, by increasing the calculation's lower limit – is scientifically required. The fact that this limitation, which is necessary from a scientific point of view, does not always happen (and that calculations are still based on false certainties) has to do, among other things, with the value-laden nature of the choices made by the experts.[15] Modellers can choose to accept false certainties based on an assumption (which is not always factually correct in terms of the effect)[16] that this is necessary because of a 'precautionary principle'. It is important to make such a mixture of epistemic values (focused on knowledge) and non-epistemic values (focused on ethics and

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[11] Five times larger than the 5 km previously used for road traffic and much smaller than the unlimited calculation distance used for all sources. This means that different types of emission sources are treated equally in the context of granting permission.

[12] Both ways of making the models more fit for purpose are not mutually exclusive and can be combined (i.e., calculations with clusters of hexagons within the maximum calculation distance).

[13] AERIUS Calculator can calculate to many more decimal places, but this led to system instability with unmanageably long calculation times.

[14] The wording chosen by the Hordijk Committee here indicates that this concerns a threshold value (*drempelwaarde*), even if it is lower than or equal to a scientifically substantiated calculation's lower limit (see the box on page 2 of this expert judgement for the difference between a threshold or limit value and a calculation's lower limit).

[15] See the uncertainty matrix (in table 1) and footnote 8.

[16] Decisions made on the basis of false certainties need not have the (negative or positive) effect that is modelled.

policy) transparent in the systematics of the model and also to indicate on which aspects of science the non-epistemic values focus and in that sense are limited (Douglas 2009, 2023; zie ook Harding 1991 en Longino 1995, 2001). Thus, a proper balance must be found between the role of epistemic values and non-epistemic values in the assessment of models' fitness for purpose. This expert judgement aims to do this in a transparent manner when substantiating a calculation's lower limit.

In scientific practice there are standards for determining the reliability of knowledge. In the Guidance for Uncertainty Assessment and Communication, these standards have been crystallised into the various dimensions that are (in parallel) important in determining the qualification of the knowledge base (see the previous section). The dimensions of methodological reliability can be grouped as follows: (i) the theoretical basis, (ii) the empirical basis, iii) the agreement between different models and (iv) peer consensus (Petersen 2006, 57–62; 2012, 58–62). Before I explicitly discuss the value-ladenness of various expert judgements (including my own expert judgement) on the magnitude of the calculation's lower limit, I first provide the scientific substantiation of a calculation's lower limit along these four dimensions:

- *Theoretical basis:* Below a scientifically determined calculation's lower limit, the model is theoretically not valid. The current calculation's lower limit of 0.005 mol/ha/year itself has no basis in any scientific theory. From a scientific point of view, it is theoretically relevant to derive the calculation's lower limit from physical, chemical and biological considerations in the (atmospheric) modelling sciences. The fact that there is a calculation's lower limit, i.e., that a lower limit can be determined from the (atmospheric) modelling sciences below which a calculated deposition contribution cannot be related to an individual source with sufficient scientific certainty (no causal relationship can be established), can be theoretically substantiated (see also TNO 2024). After all, a model is used that is only an approximation of reality. In modelling scientific theory behind the detection of a causal relationship, the empirical measurement detection limit forms a 'complement' (cf. Schlüter et al. 2023) of the model (the empirical measurement detection limit provides an anchor for the theoretical detection limit, that is, the calculation's lower limit). A theoretical detection limit must be determined because it is empirically not possible to actually detect project-specific depositions via measurements. The measurement detection limit is currently in the order of 10 mol/ha/year (see below under 'empirical basis'). The model may not be used below the theoretical detection limit because it must then be assumed that it is too uncertain that there is a causal relationship between emission and deposition. It requires expert judgement to determine what is a 'safe' value for the calculation's lower limit in this respect, i.e., a value that can last for years: the empirical measurement detection limit must in any case not fall below the theoretical detection limit, that is, calculation's lower limit. It does not appear that the empirical measurement detection limit will fall by more than one order of magnitude in the coming years – or even decades (see below under empirical basis). From this theoretical consideration, in which the empirical measurement detection limit (currently in the order of 10 mol/ha/year) theoretically completes the model, the judgement therefore follows that the calculation's lower limit (theoretical detection limit) is in the order of 1 mol/ha/year; the calculation's lower limit cannot be determined more precisely than by an order of magnitude[17] (see TNO 2024). The value of 1 mol/ha/year for the calculation's lower limit is scientifically a safe value for use over a period of many years.[18]

- *Empirical basis:* The current calculation's lower limit of 0.005 mol/ha/year has no empirical basis and is well below the empirical measurement detection limit. Balla et al. (2014) estimate the empirical measurement detection limit for nitrogen deposition based on the smallest measurable quantities of NO_x and NH_3 (0.4 and 0.1 µg/m^3 respectively) at 35 mol/ha/year. RIVM (2021, 17) estimates the detection limit (as a calculation's lower limit) as follows: 'To provide an indication of the lower limit of the demonstrability of a source contribution based on measurements, the sensitivity of the measurement methods for measuring the air concentrations of NO_x and NH_3 can be used. This sensitivity is approximately around 0.2 micrograms per cubic meter (Berkhout et al. 2017; Teledyne 2016). Based on an average deposition rate in the Netherlands, these concentrations translate into depositions of the order of 20 mol N per hectare per year.' TNO (2021) confirms RIVM (2021), with the same references. TNO (2022, 28) concludes: 'A major validation study comparing calculated concentrations resulting from emissions from a single source with measured values shows that a deposition between 6 and 12 mol/ha/year is not measurable.' And TNO (2024), referring to the method of TNO (2022, 21), states under the heading 'The deviation of measurements forms a measure for the lower limit': 'The detection limit of measuring instruments forms a technical barrier to validating small calculated depositions. The standard deviation of the measurements compared to modelled concentration values is 0.05 µg/m^3 for NH_3. Assuming an average deposition rate of 1 cm/s without taking into account additional uncertainties in the deposition rate, this can be translated to an order of 10 mol/ha/year.'[19] This estimate for the measurement detection limit of an order of 10 mol/ha/year also encompasses the estimates of RIVM (2021)/TNO (2021) of 20 mol/ha/year and of TNO (2022) of 6 mol/ha/year. Based on uncertainty in the deposition rate modelling (a factor of 3), TNO (2024, 22) estimates the maximum measurement detection limit at 30 mol/ha/year (and – by implication – the minimum measurement detection limit at 3.3 mol/ha/year). Given the values mentioned, which have been in the order of 10 mol/ha/year for more than a decade but which, given the presence of estimates of the average measurement detection limit of 6 mol/ha/year (TNO 2022), could possibly end up in the order of 1 mol/ha/year in the future, 1 mol/ha/year is a safe value for the calculation's lower limit as a theoretical detection limit for many years (again, I emphasise, with TNO 2024, that the calculation's lower limit cannot be determined more precisely than to an order of magnitude).

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[17] The order of magnitude of a number is a term used in the exact sciences to indicate the integer exponent of a power of 10 – e.g. 10^{-1} (0.1), 10^0 (1) and 10^1 (10) form a series with three consecutive orders of magnitude –, where the power of 10 is considered an approximation of a number. Roughly speaking, you can say that values that fall within a factor of √10 (which is approximately 3.16) of 0.1, 1, 10, etc. are of order 0.1, 1, 10, etc., respectively.

[18] This can be implemented in different ways, e.g., rounding to 1.00 mol/ha/year at 0.995 mol/ha/year and higher, rounding to 1.0 mol/ha/year at 0.95 mol/ha/year and higher or rounding to 1 mol/ha/year at 0.5 mol/ha/year and higher. The calculation's lower limit before rounding would then be 0.995, 0.95 or 0.5 mol/ha/year, respectively (the current calculation's lower limit before rounding is 0.005 mol/ha/year and the current calculation's lower limit after rounding is 0.01 mol/ha/year).

[19] The exact result for the multiplication of this concentration and deposition rate is 9.3 mol/ha/year.

- *Agreement between different (versions of) models:* A calculation's lower limit of 0.005 mol/ha/year or comparable order of magnitude is not used in foreign calculations of depositions in permitting. The above theoretical and empirical arguments for using the measurement detection limit to determine a lower limit in calculations do not depend on the precise way in which (model) calculations are performed. In Germany, the calculation's lower limit is determined on the basis of the smallest measurable amounts of NO_x and NH_3 (corresponding to a nitrogen deposition of 35 mol/ha/year – for safety reasons the theoretical detection limit or calculation's lower limit is set at 21 mol/ha/year, see Balla et al. 2014). In Ireland too, a calculation's lower limit of 21 mol/ha/year is prescribed for use in modelling instruments for permitting (Irish Environmental Protection Agency 2023). In both countries, no specific model is prescribed for use.
- *Peer consensus:* All experts involved agree that the calculation's lower limit of 0.005 mol/ha/year is not a scientifically based calculation's lower limit. This also applies to the experts in the Hordijk Committee and at RIVM and TNO. Experts from RIVM (2021) and TNO (2022; 2024) support in principle the use of the measurement detection limit to determine the calculation's lower limit (for further discussion on the details of the support by RIVM and TNO see below) – and support for this was also found among the peer reviewers of an earlier version of this expert opinion, as well as for (due to possible future reduction of the measurement detection limit) safely setting the calculation's lower limit at 1 mol/ha/year (no 100% consensus on all points, but that is not to be expected given the value-laden nature of science). In Germany and Ireland, too, experts have advised using a calculation's lower limit based on the empirical measurement detection limit and this advice has been followed (see Balla et al. 2014 and Irish Environmental Protection Agency 2023)

In my judgement, a calculation's lower limit of 0.005 mol/ha/year cannot therefore be scientifically substantiated. Scientifically, the calculation's lower limit should be one order of magnitude below the current empirical measurement detection limit of 10 mol/ha/year, which is 1 mol/ha/year. In my view, the current model instrument, which uses a calculation's lower limit that is two orders of magnitude lower, is not fit for purpose and leads to false certainty. Furthermore, TNO (2024) rightly points out that even with a scientifically substantiated calculation's lower limit, calculations of both relatively small and relatively large depositions at ha level can be uncertain by more than a factor of 2 to 3 (so: falsely certain in the calculation of the magnitude, even if there is a decent chance that the deposition can be distinguished from zero). This confirms the previous judgement of the Hordijk (Advisory Committee on Measuring and Calculating Nitrogen 2020) and Petersen (Audit Committee RIVM Centre for Environmental Quality 2024) Committees that AERIUS Calculator is not fit for its current purpose in permitting.

The fact that it has taken so long for a more broadly scientifically supported expert opinion on the calculation's lower limit to be available in the Netherlands is related to the complexity of the subject (see TNO 2024), the value-laden nature of science and the fact that the question about the application scope of AERIUS Calculator, in the sense of a calculation's lower limit, was not put to a broader group of scientists (outside the RIVM) at an early stage. Soon after the PAS ruling in 2019, it became clear that an answer had to be found from science on the application scope of the AERIUS Calculator in the granting of permits in the new situation, in which projects are assessed individually without being able to use nitrogen accounting as under the PAS.[20] This meant that it was necessary to use both a maximum distance limit and a calculation's lower limit. The fact that the calculation's lower limit now found has the same numerical value as the limit value of the PAS, namely 1 mol/ha/year, is purely coincidental and has no meaning. After all, different quantities are involved: the 1 mol/ha/year of the PAS was a policy-based limit or threshold value to exempt small projects from the permit requirement; the current 1 mol/ha/year is a calculation's lower limit, which is one order of magnitude below the current empirical measurement/detection limit of 10 mol/ha/year.

In RIVM (2021), the necessary scientific ingredients were provided for both the maximum calculation distance and the calculation's lower limit (the measurement detection limit is elaborated as the first 'scientific technical' argument for the calculation's lower limit). The report observes that in both cases the scientific ingredients do not lead to a single number, but that a policy choice would be necessary. In other words: RIVM did not arrive at its own expert judgement in which non-epistemic values (from the policy) and epistemic values (from both 'pure' science and in connection with non-epistemic values) were balanced by scientific experts. In Petersen (2022), I have formulated a supported expert judgement for the distance limit and the current expert judgement aims to do the same for the calculation's lower limit.

This expert judgement is the result of a deliberative process with other experts over more than 1.5 years. The first version, from July 2023, provided input for a roundtable discussion with scientific experts on a lower limit in model calculations of nitrogen deposition on nature reserves on 14 December 2023 in Utrecht (I was unable to attend).[21] My membership of the scientific sounding board of the research subsequently carried out by TNO and UvA on behalf of the IPO (TNO 2024) contributed to an update of my expert judgement in August 2024. The position I formulated in my expert judgement is nothing more and nothing less than an elaboration and substantiation of 'track 3' (based on the measurement detection limit) for determining a calculation's lower limit, which was more widely shared within the scientific sounding board and played an important role in the aforementioned roundtable discussion. In the central chapter 2 ('Research carried out'), TNO (2024) specifically explores 'track 1' (based on a theoretically substantiated uncertainty analysis) and also 'track 2' (based on noise in the total deposition), whereby the ultimate conclusion must be drawn that no lower limit can yet be found along these tracks. Track 3, which also falls within the

[20] The PAS introduced a greater precision than was previously used for nitrogen depositions. The MER Commission warned in 2012: 'AERIUS suggests a very high accuracy of the calculated deposition at a detail level of 1 ha. However, many of the source data and the dispersion models used for this have a large uncertainty. The presented accuracy is therefore impossible to achieve. In current practice, calculations are also performed that incorrectly represent the deposition to an accuracy of 0.1 mol and permits are granted or refused on the basis of these figures.' The Commission already advised at the time to 'present the modelled depositions with an accuracy that does justice to the uncertainty in the data and models used' (Environmental Impact Assessment Commission 2012). This applies even more now that projects are being examined individually.

[21] 'Opbrengst Rondetafelgesprek met wetenschappelijk experts over een rekenkundige ondergrens in modelberekeningen van stikstofdepositie op natuurgebieden, 14 december 2023, Utrecht (BIJ12)' ['Outputs Roundtable discussion with scientific experts about a lower limit in model calculations of nitrogen deposition in nature areas, 14 December 2023, Utrecht (BIJ12)'] (https://www.tweedekamer.nl/downloads/document?id=2024D03194) [In Dutch].

scope of the research question, is however only mentioned as the second of three ‘possible other lines of thought’ in chapter 3 (‘Discussion’). The summary of TNO (2024) notes: ‘The Dutch lower limit of 0.005 mol/ha/year was chosen as an approximation of 0 for policy reasons, due to the precautionary principle with regard to the maintenance obligation of Natura 2000 areas. The lower limit used is not scientifically substantiated. The chosen lower limits of the order of magnitude 10 mol/ha/year that surrounding countries work with are also not purely scientifically substantiated.’ In other words: TNO (2024) also did not arrive at its own expert judgement, in which non-epistemic values (from the policy) and epistemic values (from both ‘pure’ science and related to non-epistemic values) were balanced by scientific experts.

That is why a follow-up was needed in recent months to test the possibilities of track 3 by means of a peer review based on my expert opinion. It should be noted that in various countries in the EU (e.g. Germany and Ireland) this track has already been successfully followed by scientifically substantiating a calculation’s lower limit.

3. Response to Hordijk Committee and TNO on points about ‘cumulation’ and ‘precaution’

In light of the above, I provide a brief response to some relevant points made by the Hordijk Committee (Advisory Committee on Measuring and Calculating Nitrogen 2020) and TNO (2022) about ‘cumulation’ (the addition of many small sources below the calculation’s lower limit to an effect that together can be a significant effect) and – in connection with this – ‘precaution’:

Hordijk Committee: ‘The uncertainty in the calculation is much higher than the threshold value [the current calculation’s lower limit of 0.005 mol/ha/ year, ap] that has been set. Nevertheless, this practice is necessary for application in policy, to prevent many small additional emissions from adding up to a large increase in deposition. An assessment threshold [calculation’s lower limit, ap] based on model uncertainties at a local scale is not workable for policy applications’ (Advisory Committee on Measuring and Calculating Nitrogen 2020, 14). And, as already quoted in section 2: ‘The precautionary principle calls for a strict threshold value [the current calculation’s lower limit of 0.005 mol/ha/ year, ap] when granting permits. An ambitious source policy with established national objectives has the advantage that the threshold values could be increased when granting permits, so that the uncertainties in the calculations for the permits become less critical and false certainty becomes less prominent’ (Advisory Committee on Measuring and Calculating Nitrogen 2020, 10) .

TNO: It is questionable whether the effect of cumulation may play a role when choosing a scientifically sound, higher calculation’s lower limit: ‘The contributions of all projects to the deposition below the calculation limit are added to the background. Their contribution is therefore not removed from the estimate but is included in the background’ (TNO 2022, 23). However, according to TNO, scientific considerations can be deviated from when determining a calculation’s lower limit: ‘Of course, the precautionary principle can give rise to a policy choice for a lower value’ (TNO 2022, 28).

Response: As described in the previous section, theoretical and empirical considerations, agreement with other models and peer consensus do not scientifically allow room – due to false certainty – to calculate nitrogen depositions from individual sources and to attribute effects where the deposition is lower than 1 mol/ha/year. Trying to prevent ‘cumulation’ of depositions lower than 1 mol/ha/year as a ‘precautionary measure’ cannot be scientifically substantiated in the context of evaluating the effects of an individual project – after all, no effect can be attributed to that individual project because the calculated depositions have to be rounded off to zero. From a scientific point of view, there is no room to set the calculation’s lower limit lower than 1 mol/ha/year. The argumentation here is comparable to the argumentation that applies to false certainty by calculating beyond a maximum calculation distance..

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