3. Critical loads and dynamic modelling of nitrogen

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3.1 Introduction

Since the exceedances of critical loads of acidity have strongly declined over the last 20 years, mostly due to the substantial reductions in sulphur emissions, the emphasis has shifted to nitrogen, especially in its role as a eutrophying agent. Therefore, we look in this chapter at critical loads and dynamic modelling of nutrient N, investigate their sensitivity to the choice of critical limit and illustrate the possibilities and limitations of their use in integrated assessment modelling.

All calculations in this chapter will be done with the so-called European background database (EU-DB; see Posch and Reinds, 2005) which is maintained by the CCE to fill in for countries that have never submitted national data. Since 2005 the EU-DB has been substantially revised, making use of the recently finalised harmonised European land cover map (see chapters 5 and 6), and a comprehensive description can be found in Reinds et al. (2007).

3.2 Nutrient nitrogen critical loads and their exceedance

The European background data base (EU-DB) has been used to calculate critical loads (CLs) of nutrient nitrogen, \( CL_{\text{nutN}} \), and their exceedances (see Annex 3-A to this Chapter for the model formulation). Since the examples shown in this chapter are illustrative only, we restrict the calculations to ecosystems with an area \( >1 \text{ km}^2 \), resulting in 653,962 sites with a total area of 3.74 million km\(^2\). For forests (EUNIS code G) the long-term net growth uptake was obtained from data in EU-DB, for other vegetation classes (EUNIS codes D–F) the net uptake was set to zero; \( N_{\text{acc}} \) was set to 1 kg N ha\(^{-1}\)a\(^{-1}\) = 71.43 eq ha\(^{-1}\)a\(^{-1}\) throughout; \( f_{\text{de}} \) was derived from the drainage status of the soil (see UBA, 2004); and runoff was modelled from 30-year climatic data (Mitchell et al., 2004). The sensitivity of the CLs (and dynamic modelling results) to the choice of the chemical criterion, i.e. the acceptable N leaching which avoids ‘harmful effects’, is studied by presenting results for two values, which are characteristic of the current set of criteria (De Vries et al., 2007): \([N]_{\text{acc}}=0.3\) and \([N]_{\text{acc}}=3\) mg N L\(^{-1}\). For both criteria the 5\(^{th}\) percentiles of the computed critical loads in the EMEP50 grid cells covering Europe are shown in Figure 3-1.

\[ \text{Figure 3-1. 5^{th} percentile of the critical loads of nutrient nitrogen, } CL_{\text{nutN}}, \text{ on the EMEP50 grid computed with the European background data base (EU-DB) and two different acceptable nitrogen concentrations: 0.3 mg N L}^{-1} \text{ (left) and 3 mg N L}^{-1} \text{ (right).} \]
Obviously, the magnitude of the critical loads is strongly influenced by the choice of criterion. The influence is the stronger the greater the runoff $Q$ and or $f_{de}$ are, and the relative difference is greatest if $N_{e}+N_{i}$ is small (see eq.A7 in Annex 3-A). The overall distribution of nutrient CLs in Europe for the two criteria is shown in Figure 3-2; it shows that, e.g., the median is about 350 eq ha$^{-1}$a$^{-1}$ for the low and about 1000 for the high criterion.

![Figure 3-2](image)

*Figure 3-2. Cumulative distribution functions (cdfs) of the European nutrient N critical loads (653,962 sites) computed with EU-DB and two different acceptable nitrogen concentrations: 0.3 mg N L$^{-1}$ (red cdf) and 3 mg N L$^{-1}$ (blue cdf).*

The regional distribution of critical loads, i.e. the sensitivity of ecosystems, is needed to determine whether the deposition of N needs (further) reductions so that ‘harmful effects’ are avoided. The quantity expressing that the deposition is, on average, too high, is the so-called ‘average accumulated exceedance’ (AAE; see Posch et al. (2001) and UBA (2004) for definitions and technical details). In Figure 3-3 the exceedance (AAE) is shown for the year 2020 and two deposition scenarios, the Current LEgislation (CLE) and the Maximum Feasible Reductions (MFR) scenario and for the two chemical criteria (0.3 and 3 mg N L$^{-1}$). As is to be expected, exceedances are higher for the lower criterion, but even for the high criterion exceedance is fairly widespread in Europe and only for the MFR scenario it becomes quite low.

Figure 3-3 gives a spatial overview of the extent and, to a lesser degree, the magnitude of exceedances, but it does not tell the actual percentage of the ecosystem area exceeded; in addition, such maps provide only snapshots in time. If one does not need the spatial details, temporal traces of the ecosystem area exceeded give a comprehensive overview, and they also allow easy comparison of different deposition scenarios. In Figure 3-4 such temporal trends are shown for the CLE and the MFR scenarios. The figure shows that the ecosystem area exceeded has decreased by less than 10% since 1980, i.e. reductions in N have been modest (when compared to sulphur) and even maximum feasible reductions would not change the picture dramatically. Only with the high criterion applied everywhere would the exceeded area fall to 5% under the MFR scenario. Under the CLE scenario the exceeded area does not change much after 2010, and thus the patterns shown in Figure 3-3 for the CLE scenario are fairly representative for that period.
Figure 3-3. Exceedance (AAE) of CLnutN in 2020 computed with the EU-DB for the CLE (left) and MFR (right) scenarios and two different acceptable nitrogen concentrations: 0.3 mg N L\(^{-1}\) (top) and 3 mg N L\(^{-1}\) (bottom). Note: The size of the coloured grids is proportional to the percentage of ecosystem area exceeded in the grid.

Figure 3-4. Temporal development of the European ecosystem area exceeded (expressed as percent of total) for CLnutN using EU-DB and the CLE (red) and MFR (green) scenarios. The upper curve(s) are for \(\text{[N]}_{\text{acc}} = 0.3 \text{ mg N L}^{-1}\) and the lower ones for \(\text{[N]}_{\text{acc}} = 3 \text{ mg N L}^{-1}\).
3.3 Dynamic modelling of nitrogen pools and fluxes

Critical loads are, by definition, steady-state quantities, i.e. their (non-)exceedance does not tell when the (non-)violation of the chosen criterion will happen. In other words, once non-exceedance is achieved by a deposition reduction it may take many years before the chemical criterion is no longer violated, i.e. before the risk for ‘harmful effects’ is eliminated. The temporal aspects of recovery (and damage in case of a continuing exceedance) can only be investigated with the aid of dynamic models. Here we use the Very Simple Dynamic (VSD) model to investigate the temporal behaviour of soil chemical variables. A complete description of the nitrogen processes in the VSD model is given in Annex 3-A to this chapter.

We used the European background database as described above to run the VSD model to gain insight into the temporal development of N-related quantities. Simulations started in 1880 (assuming equilibrium with inputs) and are carried forward till 2100 for the CLE and MFR scenarios (until 2010 depositions are ‘historical’, scenarios are linearly phased in until 2020, and after that depositions are kept constant). There are two N-related variables which are of interest: the concentration of nitrate (=total inorganic N) in the soil solution and the C:N ratio in the upper layers of the soil. While the N-concentration is (still) the most widely used parameter for defining a critical chemical limit in CL calculations, the C:N ratio is an indicator for N saturation in soils. In Figure 3-5 the temporal development 1980-2100 of these two variables is displayed for the two scenarios as selected percentile traces. As can be seen, N-concentrations react strongly to changes in depositions, whereas the C:N-ratios decrease only slowly over time and they differ only slightly for the two scenarios.

![Figure 3-5.](image)

**Figure 3-5.** 25\(^{th}\), median and 75\(^{th}\) percentile traces of the N concentration (left) and the 5\(^{th}\), median and 95\(^{th}\) percentile traces of the C:N ratio (right) for the CLE (red) and MFR (green) scenarios.

The percentile traces in Figure 3-5 give also an indication of the percentage of ecosystems for which a chemical criterion is violated. The two criteria used here (0.3 and 3 mg N L\(^{-1}\)) are shown as horizontal black lines, and it can be seen that for the CLE scenario less than 25% of the area is violating the high criterion, but more than 50% the low criterion. The reading of these percentages is not very precise, but in Figure 3-6 we present the temporal development of the area for which the criteria are violated.

![Figure 3-6.](image)

**Figure 3-6.** Temporal development of the European ecosystem area (expressed as percent of total area) for which the N concentration violates two criteria ([N]\(_{acc}\)=0.3 and [N]\(_{acc}\)=3 mg N L\(^{-1}\)) for the CLE (red) and MFR (green) scenarios.
Comparing Figure 3-6 with Figure 3-4 shows that N concentrations follow the deposition path quite closely. The slow increase in the N-concentration after 2030 is caused by the slow filling-up of the N-pool, resulting in a diminishing N immobilisation and thus more leaching (until the C:N-ratio \( C_{\text{N}} \) is reached; see eq.A9 in Annex 3-A).

That the N-concentration is a ‘fast’ variable can also be seen from the model equations (see Annex 3-A): Assuming a constant input \( N_{\text{in}} \), eq.A1 can be solved analytically, yielding for the concentration at time \( t \):

\[
(N)(t) = [N]_{ss}e^{-t/\tau} + ([N]_{ss} - [N]_{0})(1 - e^{-t/\tau})
\]

where \( [N]_{ss} = N_{\text{in}}/Q \) is the steady-state concentration and \( [N]_{0} \) is the initial concentration; furthermore the characteristic time \( \tau \) is given by:

\[
\tau = \frac{Q}{\theta \cdot z}
\]

The time \( \tau \) measures the time needed to replace the soil water with net precipitation and is thus mostly in the order of a few years only. Consequently, the N-concentration equilibrates rather quickly with a constant N input. The filling-up of the N pool, on the other hand, is a slow process since the amounts immobilised per year (in the order of grams) is small compared to the pools themselves (in the order of kilograms); and this can bee seen in the small change of the C:N ratio in Figure 3-5 (\( \text{CN}_{\text{seq}} = 0 \) was used in all simulations).

There are four possible cases an ecosystem can fall into with respect to CL (non-)exceedance and criterion (non-)violation. They are summarised for nutrient N in Figure 3-7; and this figure should be compared with a similar scheme for acidification (Figure 2-16 in Posch et al., 2005).

**Figure 3-7. Possible combinations of critical load (non-)exceedance and criterion (non-)violation.**

These four cases are investigated in combination with two different critical limit values for nitrogen concentration, 0.3 and 3 mg N L\(^{-1}\). The critical limit of 0.3 mg N L\(^{-1}\) is associated with vegetation changes such as the substitution of lichens by cranberries but also with nutrient imbalances in deciduous forests. This critical limit leads to relatively low critical loads and relatively high exceedances. Conversely, the critical limit of 3 mg N L\(^{-1}\) leads to relatively high critical loads and low exceedances. The latter limit is associated with vegetation changes in coniferous forests, grass lands and heathlands, and with impacts on fine root biomass and sensitivity to fungal diseases (de Vries et al., 2007; Table 24). The use of low and high critical limits yields different combinations of European ecosystem areas with exceedances of critical loads and violations of critical limits. Table 3.1 shows the percent ecosystem area in 2020 falling into the four categories listed in Figure 3-7 for simulations with the EU-DB using the CLE and MFR scenarios. As can be seen, the majority of cases (more than about 89%) fall into either category 1 (no exceedance of CLs and no violation of criterion) or 4 (exceedance and violation) for both scenarios. This means that in the case of nutrient N the VSD model is not needed to compute target loads or recovery delay times; with VSD, non-exceedances
rapidly lead to non-violation. MFR in combination with a critical limit of 3 mg N t\(^{-1}\) yields the highest percentage of safe ecosystem areas (95.5%) and lowest percentage of non-safe areas (1.5%).

Category 2 (no exceedance and criterion violated) is hardly occurring (except in case of steep deposition changes before the implementation year) and recovery times are short since concentrations react fast to deposition changes (see above). This leaves those areas in which the CL is exceeded but the criterion is not (yet) violated (category 3). In our simulations this covers between 2.1 and 9.4 percent of the total ecosystem area, which – in absolute terms – is still a sizeable area.

**Table 3-1. Percent of ecosystem area for the CLE and MFR scenarios in 2020 in the four categories defined in Figure 3-7.**

<table>
<thead>
<tr>
<th>Category (see Fig.3-7)</th>
<th>CLE scenario ([N_{acc}=0.3=3 \text{ mg N L}^{-1}])</th>
<th>MFR scenario ([N_{acc}=0.3=3 \text{ mg N L}^{-1}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38.9</td>
<td>62.5</td>
</tr>
<tr>
<td>2</td>
<td>78.2</td>
<td>95.5</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.4</td>
</tr>
<tr>
<td>4</td>
<td>6.8</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>10.9</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>54.3</td>
<td>31.7</td>
</tr>
<tr>
<td></td>
<td>10.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 3-1 gives only a snapshot in time (here 2020); in Figure 3-8 we show the temporal development of the areal share of the four categories defined in Figure 3-7 for the two scenarios (CLE and MFR) and two criteria \((N_{acc}=0.3 \text{ and } N_{acc}=3 \text{ mg N L}^{-1})\). As Table 3-1 indicates, there are no (or hardly any) ecosystems in category 2, i.e. ecosystems recover (almost) immediately. The line separating the orange and blue colour gives the percentage of the exceeded area over time (and thus the same information as Figure 3-4).

The time delay between first occurrence of CL exceedance and first violation of the criterion – which exists if we are in a category 3 situation (see Table 3-1) – is called Damage Delay Time (DDT). In Figure 3-9 the cumulative distributions of the DDTs for those cases are shown for the two scenarios and two criteria. By 2100 the critical limit will be violated under CLE by about 15% (at 0.3 mg N L\(^{-1}\)) and by about 17% (at 3 mg N L\(^{-1}\)) of the areas of which critical loads were exceeded in 2010. Under MFR this percentage is reduce to about 7% and 6%, respectively. The order of the graphs depends on the percentage area in category 3 which varies over deposition scenarios and critical limits (see Table 3-1). The figure shows that DDTs are, in general, (very) long. This is due to the fact that only the slow filling-up of the N pool and consequent decrease in N immobilisation leads eventually to a violation of the criterion.
Figure 3-9. Cumulative distribution of Damage Delay Times (DDTs) for the CLE (red) and MFR (green) scenarios and two criteria ([N]_{acc}=0.3 and [N]_{acc}=3 mg N L^{-1}). Note that the percentages in this figure are relative to the percentages for category 3 in Table 3-1.

The spatial distribution of DDTs is illustrated in Figure 3-10 for the two scenarios and two criteria. It shows in which time range the minimum DDT in a grid square lies (if it exists); grid cells in which there is no ecosystem with a DDT are shown in pink if there is exceedance, otherwise they are shaded grey. Figure 3-10 shows that low critical loads (corresponding to low critical limits) result in a large area (pink) where critical loads are exceeded and critical limits already violated in 2020 under CLE (upper left map). At the same time areas with a DDT before 2030 (red shaded) are concentrated in Portugal, Austria and Switzerland. Under MFR (upper right map) the non-safe area is reduced and substituted by areas with a DDT beyond 2100 (grey shaded), while the areas with a DDT before 2030 are scattered over a few grid cells. For the high criterion, if there is exceedance there is a damage delay for the majority of grids. In that case many areas have a DDT before 2030 (red shaded) under CLE (lower left map), while under MFR most of the areas have a DDT beyond 2100. Areas that become non-safe already before 2030 under MFR are mostly located around the border area of the Netherlands and Germany.

Figure 3-10: Minimum Damage Delay Time (DDT) after 2020 in every EMEP grid cell. The pink area indicates grid cells with exceedance but no DDT, the white areas where there is no exceedance or no data (see also Figure 3-3).
3.4 Interpolation of scenarios

NFCs were requested to provide dynamic modelling output for a number of scenarios, i.e. pairs of future N- and S-deposition. These scenarios are chosen such that any reasonable future scenario lies within the rectangle defined in the \((N_{dep}, S_{dep})\)-plane by the pre-defined scenarios (see Figure 1 in Appendix B). The European Background Database (EU-DB; see above), for which scenario runs according to the Call for Data as well as random other simulations are available for testing, has been used to check how good such interpolations perform in practice. Figure 3-11 shows examples of such comparisons for the N concentration in soil solution and the Al/Bc-ratio, a derived variable. While for Al:Bc the result is almost perfect, the (very) small interpolated N concentrations tend to be higher than the exact ones. The reason is that the interpolation cannot exactly catch when a concentration becomes zero, since this is inherently a non-linear process. Note that for \([N]\) the S-scenarios do not play any role, the interpolation is actually one-dimensional. Overall, results are very encouraging – also for the other variables not shown here – and suggest that in many cases even less scenarios are sufficient for reasonable interpolations.

![Figure 3-11.](image)

The scenarios provided by NFCs can not only be used to interpolate the chemical parameters (or combinations thereof) for any given reasonable future deposition, but also allows to estimate more involved quantities such as target loads and delay times. Obviously, not the full target load function can be reconstructed, but only the parts which lie within the rectangle defined by the scenarios. Thus, also target loads lower than the MFR scenario cannot be computed (only identified that they exist). As an example, Figure 3-12 shows the S-value of target loads entering that rectangle ('TLS', black crosses) and the N-value of those leaving it ('TLN', red crosses). While the TLS-values are reproduced quite well, the TLN-values are, for a certain cluster of sites, mostly underestimated. Nevertheless, given the complex nature of TL calculations and their sensitivity to certain parameters, the approximate determination of target loads from dynamic model simulations looks quite promising.
Concluding remarks

It has to be emphasized that all conclusions above are drawn from simulations with the VSD model. There are several points in which the model could be amended (if deemed necessary). For example, in the current version the N pool can only increase (and the C:N ratio decrease), which limits the possibility of recovery. Also, a (simple) description of the nutrient cycle might be useful to better capture the relationship with biota. In general, results presented here might have to be revised if more sophisticated models, such as described in De Vries et al. (2007), are employed.

As with critical loads, the use of dynamic modelling results has to be seen in the context of integrated assessments. In general, results of dynamic models provide insights in the spatial distribution of target loads, recovery delay times and damage delay times. Theoretically, these distributions could be used as (additional) constraints in optimization exercises of, e.g., the RAINS model. This chapter has illustrated that the use of VSD for the description of eutrophication does not yield (meaningful) recovery delay times nor target loads. The reason is that non-exceedance rapidly results in non-violation of the criterion. This may change when more sophisticated models are used, as planned in the work plan under the Working Group on Effects and the European Consortium for Modelling Air Pollution and Climate Strategies (EC4MACS). Meanwhile, the VSD exercise described here illustrates how the spatial distribution of DDT varies both with scenarios and with critical limits. This can also become relevant information in the future context of robustness analyses as described in chapter 4.

References

Annex 3-A: Nitrogen processes in VSD

Here we describe the nitrogen processes as currently implemented in the VSD model. A basic assumption in the VSD model is that there is complete nitrification, i.e. all incoming (deposited) ammonium is converted into nitrate, i.e. it makes sense to use total N fluxes, and the only ion seen in the soil solution is nitrate, i.e. \([N] = [NO_3]\).

As for all other ions considered in the VSD model, the mass balance equation for N is given by:

(A1) \[
\frac{d}{dt} N_{\text{tot}} = N_{\text{in}} - Q \cdot [N]
\]

where \(N_{\text{tot}}\) (eq m\(^{-2}\)) is the total amount of N in the soil (per unit area), \(N_{\text{in}}\) (eq m\(^{-2}\)a\(^{-1}\)) is the net input flux into the soil, \([N] = [NO_3]\) is the concentration in soil solution (eq m\(^{-3}\)) and \(Q\) is the water leaving the root zone (m a\(^{-1}\)). N interactions between soil and soil solution are not modelled in the VSD model and therefore the total amount equals the amount in the soil water:

(A2) \[
N_{\text{tot}} = z \cdot \theta \cdot [N]
\]

where \(z\) the thickness of the soil compartment (m) and \(\theta\) is the volumetric water content of the soil (m\(^3\) m\(^{-3}\)). In the VSD model the net input flux is due to N deposition, \(N_{\text{dep}}\), reduced by net growth uptake by plants, \(N_u\), net immobilisation, \(N_i\), and denitrification, \(N_{de}\):

(A3) \[
N_{\text{in}} = N_{\text{dep}} - N_u - N_i - N_{de}
\]

Denitrification is modelled as fraction of the remaining N input:

(A4) \[
N_{de} = f_{de} \cdot \left(N_{\text{dep}} - N_u - N_i\right)
\]

where \(f_{de}\) is the denitrification fraction (0 \(\leq f_{de} \leq 1\)); thus we get for \(N_{in}\):

(A5) \[
N_{\text{in}} = (1-f_{de}) \cdot \left(N_{\text{dep}} - N_u - N_i\right)
\]

The steady-state solution of eq.A1 is obtained by setting the time derivative to zero. Specifying an acceptable (critical) leaching of N, \([N]_{\text{acc}}\), the deposition becomes the critical load of nutrient nitrogen, \(CL_{\text{nut}}(N)\):

(A6) \[
CL_{\text{nut}}(N) = N_u + N_i + N_{de} + Q \cdot [N]_{\text{acc}}
\]

or

(A7) \[
CL_{\text{nut}}(N) = N_u + N_i + \frac{Q \cdot [N]_{\text{acc}}}{1-f_{de}}
\]

Eqs.A6/7 are the SMB model for the nutrient critical load (see UBA, 2004); and \(N_i\) is the steady-state immobilisation and \(N_u\) the long-term average uptake of N.

Net immobilisation \(N_i\) is the sum of two terms: (a) a constant (acceptable, sustainable) long-term net immobilisation \(N_{i,\text{acc}}\), which does not change the C:N ratio (i.e. a proportional amount of C is assumed to be immobilised concurrently), and (b) a time-dependent N immobilisation, \(N_{i,t}\), calculated as a fraction of the net N input, depending on the C:N ratio in the topsoil. The N flux available, \(N_{av}\), for time-dependent immobilisation is computed as:

(A8) \[
N_{av} = \max\left\{N_{\text{dep}} - N_u - N_{i,\text{acc}}, Q \cdot [N]_{\text{max}}\right\}
\]
where \([N]_{\text{min}}\) is a prescribed minimum N concentration in the soil solution. Between a maximum, \(CN_{\text{max}}\), and a minimum C:N ratio, \(CN_{\text{min}}\), the amount of N immobilised per time step is a linear function of the actual C:N ratio, \(CN_i\):

\[
(A9) \quad N_{i,t} = \begin{cases} 
N_{av,t} & \text{for } CN_i \geq CN_{\text{max}} \\
\frac{CN_i - CN_{\text{min}}}{CN_{\text{max}} - CN_{\text{min}}} \cdot N_{av,t} & \text{for } CN_{\text{min}} < CN_i < CN_{\text{max}} \\
0 & \text{for } CN_i \leq CN_{\text{min}}
\end{cases}
\]

The above equation implies that when the C:N ratio reaches \(CN_{\text{min}}\), \(N_{i,t}\) becomes zero, and the total amount of N immobilised per time step equals the constant value \(N_{i,\text{acc}}\). This formulation is thus compatible with the SMB critical load model for \(t \to \infty\) (see above).

The amount of N immobilised in every time step updates the amount of N in the topsoil, \(N_{\text{pool}}\):

\[
(A10) \quad N_{\text{pool},t} = N_{\text{pool},t-1} + N_{i,\text{acc}} + N_{i,t}
\]

The amount of C in the topsoil, \(C_{\text{pool}}\) (in g m\(^{-2}\)), is also updated by two contributions: one due to \(N_{i,\text{acc}}\) to keep the C:N ratio constant, and another which is controlled by the C:N ratio of the material immobilised according to eq. A9, \(CN_{\text{seq}}\):

\[
(A11) \quad C_{\text{pool},t} = C_{\text{pool},t-1} + CN_{i-1} \cdot N_{i,\text{acc}} + CN_{\text{seq}} \cdot N_{i,t}
\]

Earlier versions of VSD did not include \(CN_{\text{seq}}\), i.e. the C pool was not affected by time-dependent N immobilization. The new formulation follows Evans et al. (2006), who investigated the enhanced C sequestration due to elevated N inputs for some heathlands in the UK. The parameter \(CN_{\text{seq}}\) is a site-specific input for the VSD model, with default value \(CN_{\text{seq}}=0\) (thus realizing the earlier VSD version).

The updated pools, in turn, are used to update the C:N ratio:

\[
(A12) \quad CN_i = \frac{C_{\text{pool},t}}{14 \cdot N_{\text{pool},t}}
\]

where the factor 14 converts \(N_{\text{pool}}\) from eq (mol) to g.