Ministry of Environment
of Denmark
Department

Derogation Report 2021

Danish Report in accordance with the Commission Decisions 2005/294/EC, 2008/664/EC, 2012/659/EU, 2017/847/EU, 2018/1928/EU and 2020/1074/EU

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Ministry of Environment of Denmark
Department
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Table of contents

1. Introduction

With Commission Decisions 2005/294/EC, 2008/664/EC, 2012/659/EU, 2017/847/EU, 2018/1928/EU, and 2020/1074/EU Danish cattle holdings are allowed to derogate from the general rules in the Nitrates Directive (91/676/EEC).

The relevant decisions for the data reported in this report are 2018/1928/EU and 2020/1074/EU. According to these decisions, cattle holdings could apply for authorisations to apply livestock manure corresponding to up to 230 kg N per hectare per year if more than 80 per cent of the area available for manure application was cultivated with beets, grass or grass catch crops. Furthermore, derogation holdings have to comply with several other conditions laid down in the decision.

The aim of this report is to present maps showing the percentage of farms and percentage of agricultural land encompassed by the derogation in each Danish municipality for the planning period 2019/2020.

According to the decisions 2018/1928/EU and 2020/1074/EU, the Danish authorities shall submit the following information to the Commission for the derogation period 2019/2020:

- According to Article 10 (1) and 12 (a): maps, showing the percentage of cattle farms, percentage of livestock and percentage of agricultural land covered by the derogation for each municipality of Denmark.
- According to Article 12 (g), an evaluation of the implementation of the derogation conditions, on the basis of controls at farm level and information on non-compliant farms, based on the results of the administrative and field inspections.
- According to Article 12 (b, c, e), the results on ground and surface water monitoring as regards nitrate and phosphate, including information on water quality trends as well as the impact of derogation on water quality. Further results of model-based calculations from farms benefiting from an individual derogation.
- According to Article 12 (d and f), the results of the surveys on local land use, crop rotations and agricultural practices including tables showing the percentage of agricultural land under derogation covered by clover or alfalfa in grassland and by barley/pea, undersown with grass.
- According to article 12 (h), trends in livestock numbers and manure production for each livestock category in Denmark and in derogation farms.

The derogation decision 2018/1928/EU and 2020/1074/EU requires according to Articles 10 (2) and 12 (b), reporting of water quality data from reinforced monitoring on sandy soils and in an area, where at least 3% of all derogation farms are located. The monitoring data is updated with data from 2020 in this report.

Various Danish authorities and institutions have contributed to this report, edited by the Ministry of Environment of Denmark. The respective authors, and hence responsible institutions for the different chapters, can be found under the heading to the respective chapters.

2. Maps of cattle holdings, arable land and livestock in kg N in 2019/2020

Lars Paulsen & Lene Kragh Møller, the Danish Agricultural Agency, Ministry of Food, Agriculture and Fisheries of Denmark, January 2022

For the planning period 2019/2020, the Danish Agricultural Agency received 32,164 fertilizer accounts containing key figures on the use of nitrogen (commercial fertilizer and livestock manure). The accounts were registered and reviewed. The maps (**Figure 2.1 – Figure 2.3**) are based on the number of agricultural holdings, kg N per hectare per year and arable land used by derogation farms in 2019/2020. The fertilizer accounting year runs from 1st of August to 31st of July. Accounts for 2019/2020 were to be submitted to the Danish Agricultural Agency no later than 31st of March 2021.

In the fertilizer account, the farmer states whether the derogation was used.
This means that the individual farmer needs to apply for the use of the derogation when the farmer submits the fertilizer quota and catch crops plan (at the latest 21st of April each year). The information about the application is automatically transferred to the fertilizer accounting system. The maps of cattle holdings, arable land and kg N from organic fertilisers per hectare per year are based on the data reported by the farmers. In reports before 2019, a map with livestock units per year was presented. This has from 2019 been replaced by a map showing kg N from organic fertilisers, including livestock manure per hectare and year at municipal level. In Danish regulation, it has generally from 2019 been changed to limit livestock density at farm level via a maximum allowable N application from organic fertilisers (instead of number of livestock). However, since one livestock unit corresponds to 100 kg N (ex storage), the data is directly convertible and hence does not present any change in the limitation per area.

2.1 Map of derogation holdings 2019/2020

The map (**Fig 2.1**) shows derogation holdings in percentage of the total number of agricultural holdings registered in each respective Danish municipality.

In 2019/2020, 1,197 derogation holdings were encompassed by the derogation. This corresponds to 3.7 % of all registered fertilizer accounts. The applied amount of manure on these farms ranged from 170 to 230 kg N per hectare per year. If the production of manure on a derogation farm corresponds to more than 230 kg N per hectare, the farmer is obliged to deliver the excess manure to one or more contractual partner-farmers.

2.2 Map of arable land 2019/2020

The map (**Figure 2.2**) shows the share of arable land on derogation holdings in relation to the total agricultural area in each Danish municipality.

In 2019/2020, the arable land on cattle holdings encompassed by the derogation was 182,950 hectare at national scale. This corresponded to 7.6 % of the registered area used for agriculture in Denmark.

2.3 Map of livestock in kg N in 2019/2020

The map (**Figure 2.3**) shows the share of kg N distributed from cattle holdings encompassed by the derogation holdings in relation to the total kg N from organic fertilisers in each Danish municipality.

In 2019/2020, the kg N from organic fertilisers distributed from cattle holdings encompassed by the derogation was 36.8 million kg N in total. This corresponded to 16.8 % of all kg N in organic fertilisers distributed on the agricultural area in Denmark.

2.4 Use of the derogation

Over the first three planning periods in which the derogation was used, i.e. 2002/2003, 2003/2004 and 2004/2005, an increase in the use of the derogation was registered both regarding the number of farms, the number of hectares and the number of livestock units (**Table 2.1**). This tendency was broken in 2005/2006, where a decrease was observed for all three measured parameters and the decreasing trend continued until the period 2008/2009. Between 2009/2010 and 2015/2016, an overall increase in the agricultural area using the derogation was observed, whereas the number of farms remained at a more constant level. The general trend of Danish farms becoming bigger is reflected in these numbers and from 2016/2017 there has been a decrease in the number of farms and the number of hectares encompassed by the derogation. From 2017/2018, the number of livestock unit was replaced by produced kg N per year in the Danish legislation.

Table 2.1: Development in use of the derogation for number of farms, agricultural area and kg N in organic fertilisers per year (livestock units (LU) until 2016/2017) from 2002/2003 until 2019/2020 (One LU=100 kg N (ex storage)).

Year	Number of derogation farms	Share of total farms (%)	Area of derogation (hectare)	Share of total Area (%)	Number of LUs	Share of total LUs (%)
2002/2003	1,845	4.0	123,068	5.0	213,617	10.6
2003/2004	1,927	4.0	128,523	5.0	225,586	10.6
2004/2005	2,331	5.0	134,780	5.0	277,330	12.9
2005/2006	1,779	3.4	115,336	4.2	220,839	10.3
2006/2007	1,610	3.2	111,845	4.0	211,765	9.5
2007/2008	1,296	2.8	92,282	3.9	186,313	8.3
2008/2009	1,115	2.4	90,647	3.6	176,588	8.2
2009/2010	1,507	3.3	134,698	6.1	276,765	11.9
2010/2011	1,607	3.9	164,353	7.4	341,781	14.1
2011/2012	1,652	4.0	175,783	7.1	365,887	15.5
2012/2013	1,481	3.7	162,176	6.7	334,508	14.5
2013/2014	1,482	3.8	189,495	7.7	397,014	17.1
2014/2015	1,500	4.0	205,165	8.2	425,102	18.6
2015/2016	1,466	4.2	210,061	8.6	443,134	19.4
2016/2017	1,378	3.9	205,874	8.4	439,114	19.3
					Mill. kg N (org. fert.)	**Share of total kg N (%)**
2017/2018	1,312	3.9	198,195	8.2	39.6	18.1
2018/2019	1,284	3.9	195,804	8.1	39.1	17.8
2019/2020	1,197	3.7	182,950	7.6	36.8	16.8

The livestock density on derogation farms has remained at an approximately constant level, compared to the periods 2009/2010-2016/2017 and the average number of livestock units per farm has increased over the same period. From 2017/2018, the average livestock size and the average livestock density were measured in kg N (from organic fertilisers) per holding and in kg N (from organic fertilisers) per hectare per year.

By comparison, a total number of 9,839 Danish agricultural holdings had cattle as livestock in 2019/2020. These holdings housed in total 117.2 million kg N from organic fertilisers and covered an agricultural area of 811,062 hectare. This gave an average of 11,910 kg N from organic fertilisers per cattle holding and an average livestock density of 144 kg N from organic fertilisers per hectare on all Danish cattle farms. Consequently, approximately 12.2 % of all cattle farms were derogation farms in 2019/2020, and the derogation (cattle) farms housed 31.4 % of all cattle-kg N in Denmark, covering 22.6 % of the total Danish cattle farm area.

Table 2.2: Average number of spread livestock units[1] (LU) per holding and per hectare under the derogation until 2016/2017. From 2017/2018 the number of livestock is expressed by kg N from organic fertilisers (One LU = 100 kg N (ex storage)).

Year	Average livestock size (LU/holding)	Average livestock density (LU/ha)
2002/2003	115.78	1.74
2003/2004	117.07	1.76
2004/2005	118.97	2.06
2005/2006	124.14	1.91
2006/2007	131.53	1.89
2007/2008	143.76	2.02
2008/2009	158.37	1.95
2009/2010	183.65	2.05
2010/2011	212.68	2.08
2011/2012	221.48	2.08
2012/2013	225.86	2.06
2013/2014	267.89	2.10
2014/2015	283.40	2.07
2015/2016	302.27	2.11
2016/2017	318.66	2.13
	Average livestock size (kg N/holding)[2]	**Average livestock density (kg N/ha)**
2017/2018	30.171	199
2018/2019	30.475	200

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[1] “Spread LU” is the term used to describe the amount of livestock manure, which is being applied to agricultural land within the farm, as this amount can be different from the amount of livestock manure produced at farm level due to import or export of livestock manure from/to other farms. One LU corresponds to 100 kg manure-N (ex storage) in the Danish system.

[2] From 2017/2018, the number of livestock units (LU) is replaced by produced kg N from organic fertilisers per year in the Danish legislation (One LU = 100 kg N).

2019/2020	30.769	201

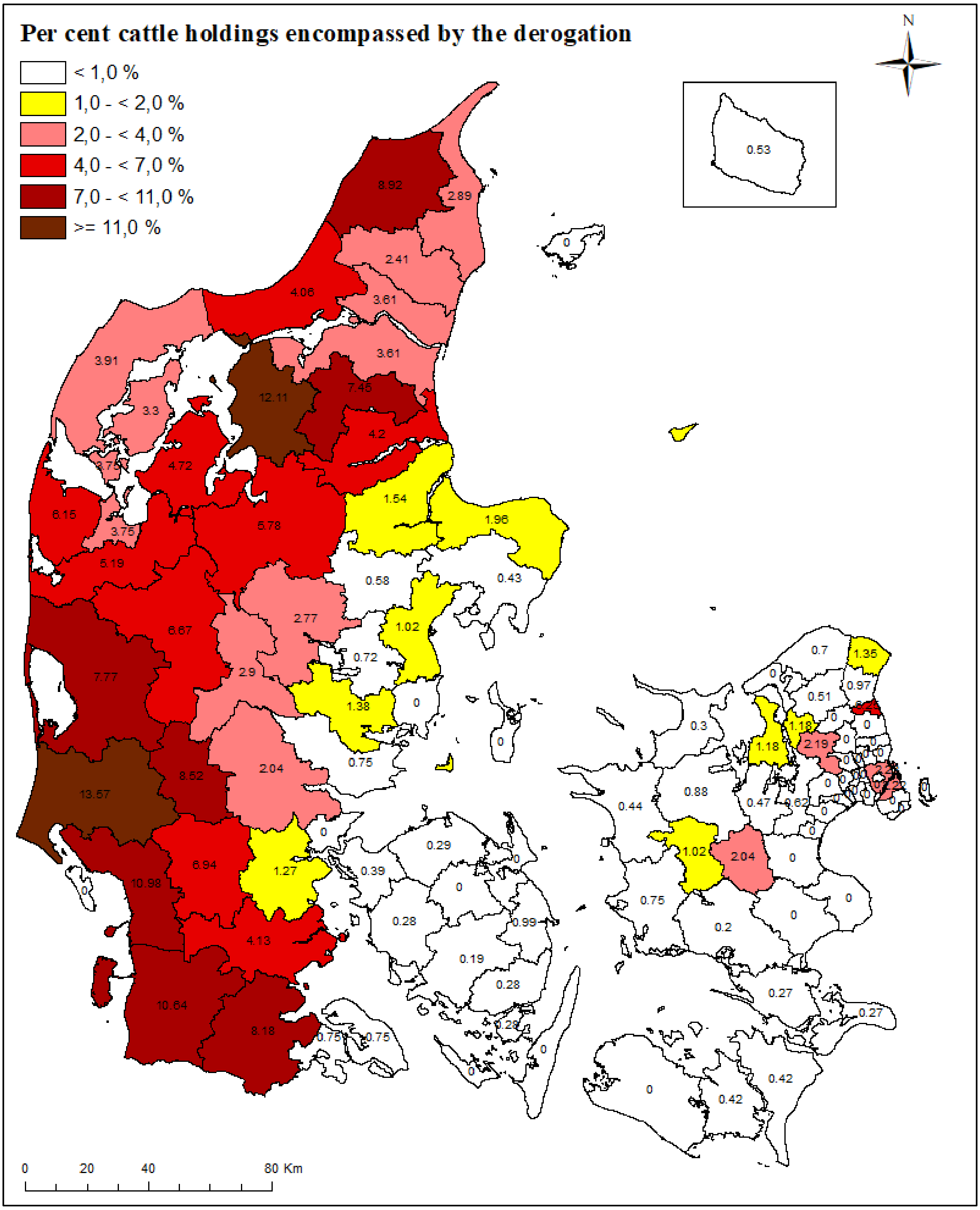

Figure 2.1: Derogation holdings in percent of total number of agricultural holdings in Denmark in 2019/2020. The location of each holding is determined by address of the owner.

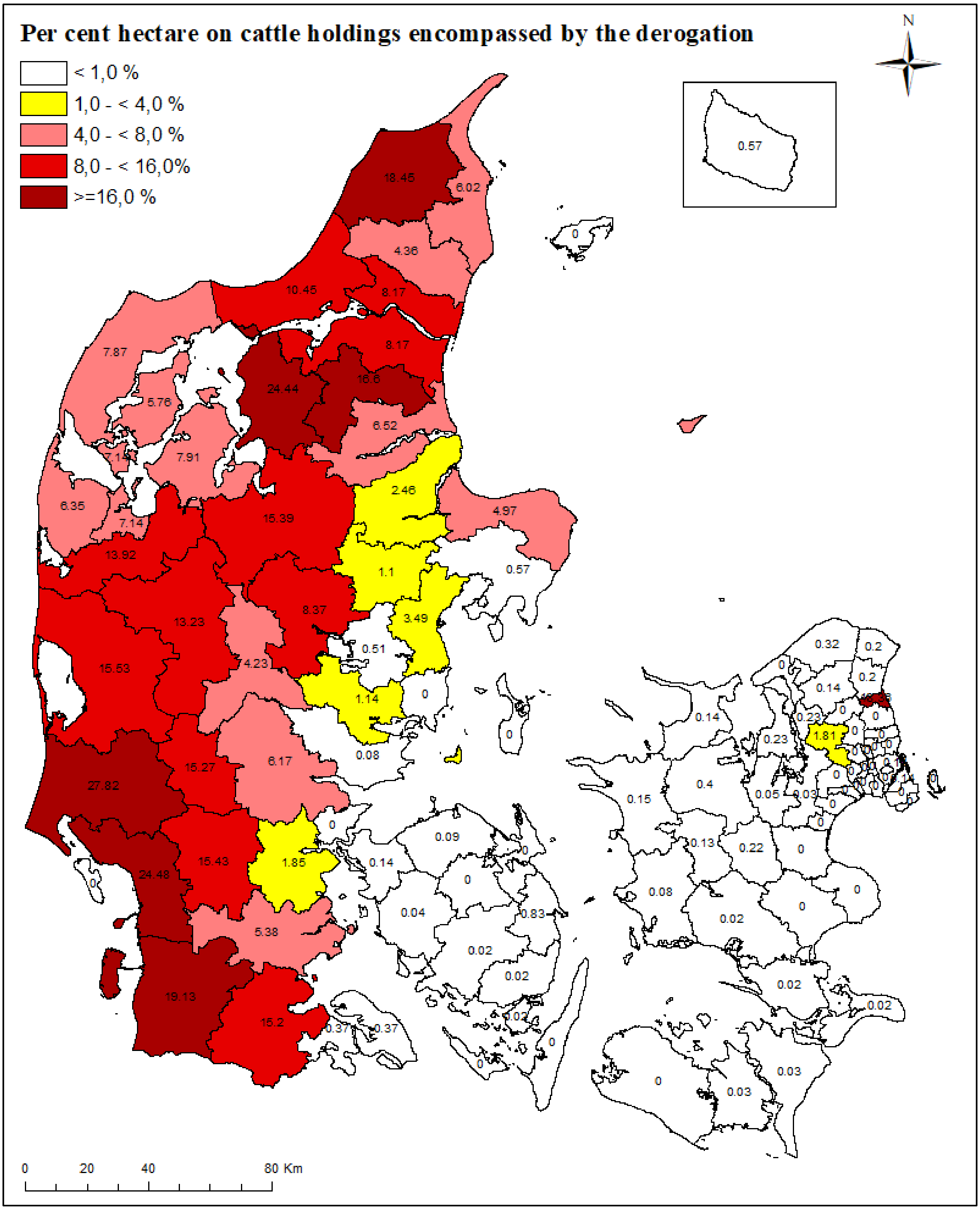

Figure 2.2: Agricultural land encompassed by the derogation in 2019/2020 in percent of the total agricultural area in Denmark. The location of each holding is determined by address of the owner.

The maps (**Figure 2.1 – Figure 2.3**) illustrate that derogation cattle holdings are concentrated in the western parts of Jutland. A few holdings are located on Zealand and even fewer on Funen and the island of Bornholm.

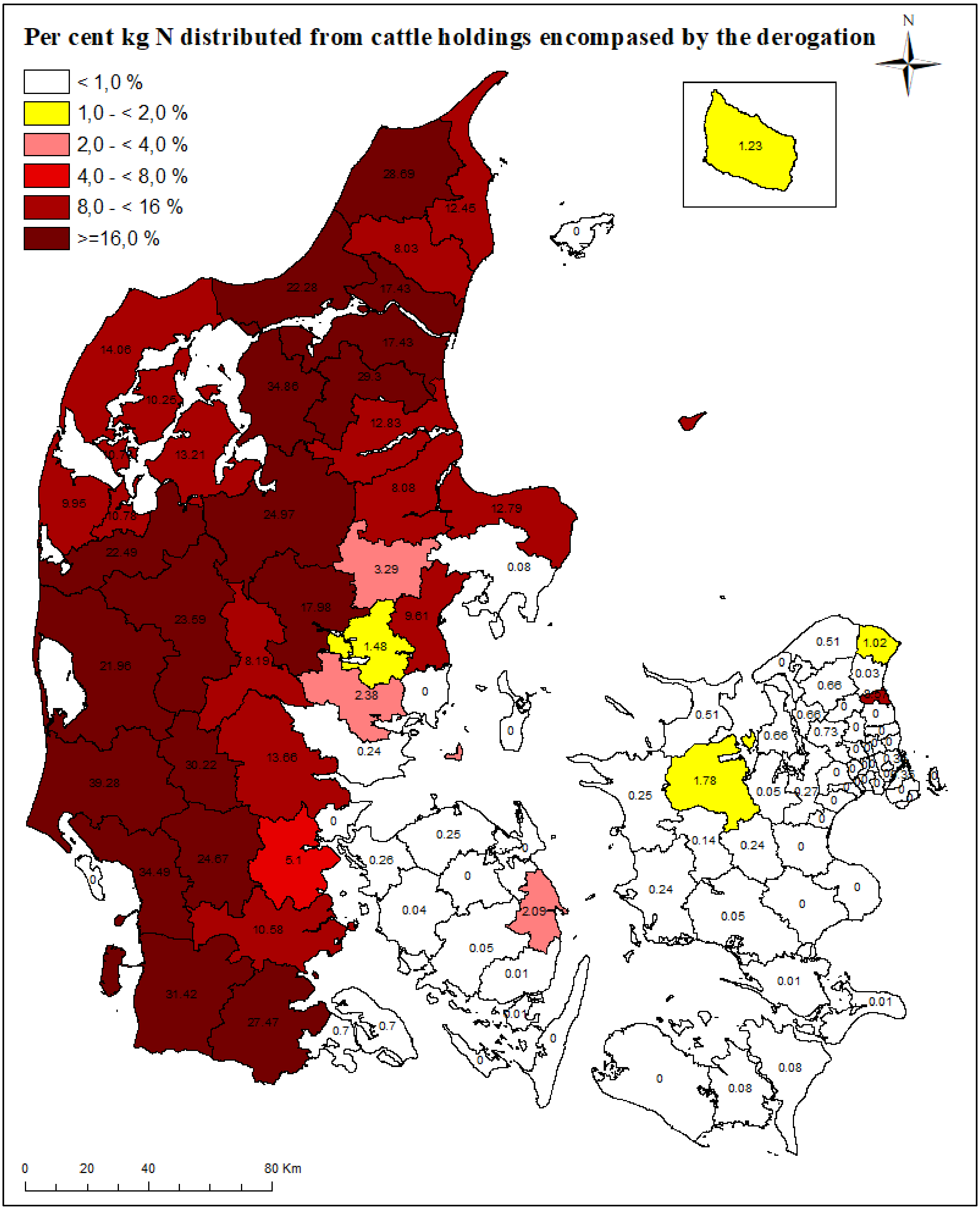

Figure 2.3: Kg N from organic fertilisers per hectare per year spread on derogation farms in percent of total kg N from organic fertilisers in 2019/2020 in Denmark. The location of each holding is determined by address of the owner.

2.5 Trends in livestock

According to decision 2018/1928/EU, and 2020/1074/EU the Danish authorities shall submit information about trends in livestock numbers and manure production for each livestock category in Denmark and in derogation farms according to Article 12 (h). All numbers have been brought to a round number in order to have a clearer picture.

The trends in livestock numbers (i.e. number of herds[3]) and manure production in kg N (until 2016/2017 in number of LUs[4]) for each livestock category and in derogation farms can be derived from the data shown in **Table 2.3**. Over the planning periods from 2014/2015 to 2019/2020, the number of herds have decreased for each livestock category. The total number of Danish herds of livestock has decreased by ca. 20 % in between the planning periods of 2014/2015 and 2019/2020. From 2017/2018 the LUs is replaced by kg N.

Table 2.3: Number of Danish herds of livestock and production of manure in livestock units (LUs) or in kg N per livestock category, rounded to the closest unit of 100 (1 LU=100 kg N (ex storage))

Livestock category Year	Cattle total	Derogation cattle[5]	Pigs	Fur and poultry	Sheep and goats	Others	Total
2014/2015							
No. herds	12,300	1,500	4,100	2,000	2,400	6,100	26,900
No. LUs	1,164,700	425,100	905,300	190,500	12,200	19,100	2,291,800
2015/2016							
No. herds	11,800	1,500	3,900	2,000	2,300	5,800	25,800
No. LUs	1,193,400	443,100	881,300	178,000	10,500	18,800	2,282,000
2016/2017							
No. herds	11,500	1,400	3,600	2,100	2,200	5,600	25,000
No. LUs	1,186,800	439,100	883,700	183,000	10,600	18,100	2,282,200
2017/2018							
No. herds	10,800	1,300	3,400	2,000	2,000	5,500	23,700
kg N, mill.	115.2	39.6	80.0	20.2	1.0	2.2	218.6
2018/2019							
No. herds	10,200	1,300	3,300	1,900	2,000	5,300	22,700
kg N, mill.	116.4	39.1	78.5	18.6	1.0	2.2	216.7
2019/2020							

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[3] The total number of herds does not coincide with total number of holdings in Denmark. A herd includes only one type of livestock and some holdings keep more than one herd, e.g. cattle and pigs.

[4] One livestock unit is defined as 100 kg nitrogen in the livestock manure ex storage.

[5] The amount of derogation cattle herds and LUs/kg N (organic fertiliser) are a part of “cattle total” and, thus, is not included in the summarization of herds and LUs/kg N (organic fertiliser) in “total”.

No. herds	9,800	1,200	3,000	1,700	1,900	5,100	21,500
kg N, mill.	117.2	36.8	80.2	16.7	1.0	2.1	217.2

3. Controls at farm level

Lars Paulsen & Lene Kragh Møller, the Danish Agricultural Agency, Ministry of Food, Agriculture and Fisheries of Denmark, January 2022

3.1 Control of compliance with the Danish derogation

According to Article 12 of Commission Decisions 2018/1928/EU, and 2020/1074/EU Denmark must submit a concise report on the evaluation practice, i.e. control at farm level, to the Commission every year.

The control of compliance with the Commission Decisions 2018/1928/EU and 2020/1074/EU follows two strategies:

1. Inspection of compliance with farm management, which is carried out during the year the farmer uses the derogation. This includes field inspections.
2. Control of the amount of livestock manure applied per hectare per year (control of compliance with the harmony rules), which is carried out after the derogation year has ended. This control is carried out as an administrative inspection of submitted fertilizer accounts.

3.2 Summary of inspection results 2021

Compliance with management conditions:

- Inspection at the farm in January and February 2021: 79 inspections were carried out. 79 holdings complied with the derogation management conditions, no holdings got a remark in 2021 (**Table 3.1**).

Compliance with the harmony rules for holdings using the derogation:

- Administrative inspections of the submitted fertilizer accounts for 85 inspected farms in January and February 2020: 9 holdings complied with the specific rules for derogation holdings. No holdings had minor violations. 76 holdings are still under investigation (**Table 3.2**).
- Administrative control of the submitted fertilizer accounts: 48 inspections were carried out, out of which 33 holdings complied with the rules. Two holdings had minor violations and 13 holdings are still under investigation (**Table 3.5**).

3.3 Inspection of compliance within the derogation year

The farmers are required to fulfil certain conditions in order to use the derogation. The Danish Agricultural Agency has inspected the fulfilment of the Danish derogation conditions on derogation holdings from 2002/2003 through 2020/2021. Some conditions have to be checked on site at the farm (physical inspection), for example certain ploughing conditions, which are checked in January and February.

During the inspection at the farm, the inspector asks the following questions:

1. Does the farm have a yearly production of nitrogen in livestock manure above 300 kg of which at least 2/3 are from cattle (2/3 of the livestock units), i.e. is the farm mainly a cattle holding?
2. Has a plan been made for crops grown in the actual planning period?
3. Has the manager stated that the farm intends to comply with the 230 kg nitrogen per hectare per year derogation in the crop rotation plan?
4. Does the plan contain leguminous crops, e.g. red and white clover?
5. Has a declaration about (omitted) manure application been made?
6. Does the plan include ploughing grassland or grass catch crops in the planning period?
7. If the answer is "yes" in question 6: Have the fields already been ploughed by the time of inspection?
8. Does 80 % or more of the acreage available for manure application cultivated with crops with high nitrogen uptake and long growing season?

The inspection is based on 1) an interview with the farmer, 2) an inspection of the farms crop rotation plan for the previous and coming growing season and 3) a visual inspection of fields designated for ploughing.

At the inspection, the inspector draws up a report, which includes answers to the abovementioned questions. At the end of the inspection, the farmer is informed whether the holding is allowed to apply manure corresponding to 230 kg N/ha/year, i.e. whether the derogation can be used or not. If the holding is not complying with the derogation conditions, the holding is only allowed to apply livestock manure up to 170 kg N/ha/year. In this case, the farmer has to find other legal means of disposing the surplus manure produced on the farm.

If a farmer informs the inspector that the derogation will not be used, the field inspection is not carried out. An administrative control of the farm is carried out instead by the time the fertilizer account has been submitted. This control is carried out to secure that no more than 170 kg N/ha/year was applied.

The inspection report is submitted by the inspector to the headquarters of the Danish Agricultural Agency for possible further administrative inspection. The Danish Agricultural Agency verifies the data. Additional remarks made by the inspector, if any, are examined. This includes a process where the parties of interest are allowed to make statements on the case if an infringement is discovered.

3.4 Results

From 1st of January until 1st of March 2021, the Danish Agricultural Agency carried out 79 inspections on derogation holdings to inspect whether the conditions requirements were met. The control refers to the fertilizer accounts for the planning year 2019/2020 where some conditions are controlled in the next planning period 2020/2021. **Table 3.1** shows the results of the inspection for the last 18 years. Only very few remarks have been given and in general a good compliance with the rules has been noted.

Table 3.1: Results of on-site inspection of compliance within the derogation years during winter.

Control planning-period[6]	Total number of inspections	Inspections without remarks	Inspections with remarks
2003/2004	35	29	6
2004/2005	46	46	0
2005/2006	50	49	1
2006/2007	50	49	1
2007/2008	54	54	0
2008/2009	47	46	1
2009/2010	51	49	2
2010/2011	50	50	0
2011/2012	54	52	2
2012/2013	49	49	0
2013/2014	47	46	1
2014/2015	49	49	0
2015/2016	48	48	0
2016/2017	49	48	1
2017/2018	90	87	3
2018/2019	86	86	0
2019/2020	85	85	0
2020/2021	79	79	0

3.5 General inspection of the harmony rules

Harmony rules

Control of the harmony rules (i.e. the amount of livestock manure applied per hectare per year) on derogation farms is carried out after the derogation year has ended. This control is carried out within the general inspection of the Danish harmony rules. The inspector visits the farm to inspect the production based on various production and fertilizer account documents. Violation of the harmony rules is sanctioned. For minor violations, the farmer receives a notification and recommendation or a warning. For more severe violations, the farmer is reports to the police and receives a fine. Farmers that receive a warning or a fine are reported for not complying with the cross compliance criteria.

Administrative inspection included submitted fertilizer accounts concerning the year 2018/2019, for 85 inspected farms in January and February 2020 for violation of the harmony rules. The holdings were automatically selected for inspection, based on a previously agreed set of “risk criteria”. The Danish Agricultural Agency has therefore no direct influence on how many derogation holdings ware selected for “harmony rules inspection”. Out of these administrative inspections, 9 holdings (10.6 %)

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[6] The respective controls during the planning period 2020/2021, which have been performed in January and February 2021 are related to the fact that the farmer has made use of the derogation in the previous planning period, i.e. 2019/2020. This applies also to all previous control years.

complied with the specific rules for derogation holdings. 76 holdings (89.4 %) are still under investigation and no holdings had minor violations (**Table 3.2**).

Table 3.2 Results of administrative inspection of compliance with the harmony rules for farms using the derogation.

Control planning-period	Total number of inspections	Inspections without remarks	Inspections with minor violations	Inspections with fines	Inspections still under investigation[7]
2006/2007	65	59	0	5	1
2007/2008	27	22	2	2	1
2008/2009	32	26	1	5	0
2009/2010	27	24	1	2	0
2010/2011	37	35	0	0	2
2011/2012	52	50	0	2	0
2012/2013	43	40	0	3	0
2013/2014	29	27	0	1	1
2014/2015	30	29	0	0	1
2015/2016	28	24	0	2	2
2016/2017	86	85	0	0	1
2017/2018	84	60	3	0	21
2018/2019[1]	85	9	0	0	76

[1] Administrative inspections of the submitted fertilizer accounts for 85 inspected farms in January and February 2020 (Table 3.1)

Soil analysis

If the derogation is used for four consecutive years, the farmer must provide a soil analysis where phosphorous and nitrogen levels in the soil are examined. One sample per five hectares must be provided.

In Denmark, the soil analysis for phosphorus (the ”P-tal”) indicates the soil's phosphorus status and hence approximates the level of phosphorus in the soil available for uptake by the crop. Internationally, the soil analysis is referred to as “Olsen-P”. Olsen-P is often expressed in mg P per kg soil. In Denmark, however, the “P-tal” is expressed in mg P per 100 g soil. Olsen-P in Danish agricultural soil is in average around 40 mg P per kg soil (P-tal = 4.0). Only a part of the inorganic phosphorus available for the crop is extracted from the soil sample, when the phosphorus status is determined. This extractable part accounts for approximately 5 to 10 per cent of the total phosphorous content of the soil. A P-tal between 2 and 4 is generally accepted as a sufficient level for most crops and 2-2.5 is the lower critical soil P level. A P-tal above 6 is considered very high.

The N-total analysis is used to determine the amount of extra fertilizer to be added to meet the nutrient demand of the crop. The total soil N content (N-total) describes the N pool in the soil, which potentially is available to the crops as a result of slow mineralization. In Denmark, depending on the C/N ratio in the soil, the standard N-total is

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[7] I.e. inspections still under investigation at time of reporting. Numbers of inspections still under investigation prior to 2017/2018 are not updated. Thus, these inspections may have been finalized.

0.13 %. The farmer cannot expect any N-supply from mineralization, if the level of 0.13 % N-total is found. If the value is above 0.22 %, the level is high and expected mineralization is (accounted for with) 40 kg N in maize and cereals per hectare.
The N-total standard for grass fields is 0.18-0.22 %, and if the value is above 0.22 %, the expected mineralization is (accounted for with) 10 kg N per hectare.

Results of soil analyses from derogation farms

The sampling and analyses must be carried out at least once every four years (prior to 2012/2013, the requirement was at least once every three years). The results of the development of compliance with the requirement of soil analysis are shown in **Table 3.3**.

The inspection of derogation farms for 2018/2019 showed that four holdings out of the nine (44.4 %) inspected holdings had to provide soil analysis. No holdings got a remark regarding soil analysis.

Table 3.3: Results of inspection of compliance with the soil analysis requirement.

Control planning-period	Number of inspections for soil analysis	Inspections without remarks	Inspections with remarks/still under investigation
2004/2005	74	71	3
2005/2006	18	16	2
2006/2007	39	34	5
2007/2008	16	12	4
2008/2009	22	18	4
2009/2010	11	9	2
2010/2011	14	13	1
2011/2012	35	35	0
2012/2013	30	27	3
2013/2014	15	14	1
2014/2015	22	21	1
2015/2016	11	11	0
2016/2017	41	41	0
2017/2018	39	39	0
2018/2019	9	9	0

The results of the soil analyses for phosphorus and nitrogen on derogation farms are shown in **Table 3.4**.

Table 3.4: Phosphorus ("P-tal" after Olsen-P-extraction) and nitrogen levels in soil analyses, given as average of all inspected holdings (n=4 in 2018/2019) and with the lowest and highest average values at holding scale, respectively.

Control planning-period		2011/ 2012	2012/ 2013	2013/ 2014	2014/ 2015	2015/ 2016	2016/ 2017	2017/ 2018	2018/ 2019
P tal (mg P/100 g soil)	Average	4.36	4.60	4.33	4.60	4.62	4.29	4.22	3.98
	Minimum	2.00	2.90	2.90	2.87	3.10	2.39	2.20	3.26
	Maximum	6.40	6.10	8.40	6.08	6.14	6.95	7.05	4.47
N-total (%)	Average	0.60	0.33	0.25	0.25	0.23	0.21	0.20	0.23
	Minimum	0.11	0.12	0.15	0.13	0.13	0.11	0.12	0.11
	Maximum	2.39	1.71	0.41	0.58	0.41	0.59	0.34	0.36
N in grass (%)	Average	0.36	0.24	0.48	0.24	0.24	0.22	-	-
	Minimum	0.01	0.17	0.16	0.16	0.17	0.13	-	-
	Maximum	1.10	0.35	2.00	0.51	0.33	0.36	-	-

3.6 Control of fertilizer accounts

Each year, the farmers submit their fertilizer accounts to the Danish Agricultural Agency. The accounts include key data on:

- total arable land on the farm
- arable land available for application of livestock manure
- data on catch crops
- type and number of livestock
- production of livestock manure (kg N and P)
- usage of livestock manure including manure from contractors
- usage of fertilizers and organic matter other than livestock manure
- the farms nitrogen quota and the average phosphorus ceilings for different livestock manure, fertilizers and organic matter other than livestock manure
- information on whether the farmer has used the derogation or not

For the year 2018/2019, 645 (2.0 %) of the submitted fertilizer accounts were subject to administrative control. 129 fertilizer accounts remain to be investigated. The data was verified and the parties of interest were allowed to comment on their cases.
The accounts were selected based on different risk criteria. In 2018/2019, 48 (7.4 %) derogation holdings were selected for control. The holdings were asked to submit their updated and valid fertilization plan and to state their manure application. It was

checked whether the crop rotation plan included at least 80 % crops with high N-uptake and long growing season as well as whether leguminous plants were included. If the derogation had been used for four consecutive years, the farmer also had to submit the results of the soil analysis. The share of cattle- and other animal kg N on the farm was also controlled.

Results

Out of the 48 harmony controls, 33 holdings (68.8 %) were closed without remarks. Two holdings (4.2 %) were closed with remarks and 16 (27.1 %) inspections are still under investigation (**Table 3.5**).

Table 3.5: Results of administrative control of compliance with the harmony rules of farms using the derogation.

Control planning-period	Number of inspections	Inspections without remarks	Inspections with remarks	Inspections still under investigation
2009/2010	38	34	0	-
2010/2011	68	68	0	-
2011/2012	40	39	1	-
2012/2013	62	58	1	3
2013/2014	34	24	4	6
2014/2015	62	30	4	28
2015/2016	61	46	6	9
2016/2017	46	31	3	12
2017/2018	55	29	0	26
2018/2019	48	33	2	13

4. Water quality

Jonas Rolighed, Gitte Blicher-Mathiesen, Department of EcoScience, Aarhus University, January 2021

4.1 Introduction

Since the late 1980s, Denmark has done a comprehensive and efficient effort to improve the environmental state of groundwater and surface water by lowering nitrate concentrations, especially through reductions of nitrate leaching from agricultural sources. The first Action Plan on the Aquatic Environment was adopted in 1987 and has since then been followed by subsequent action programmes to ensure efforts are made to reduce the loss of nitrogen and phosphorus to the aquatic environment.

In 1998, the Action Plan on the Aquatic Environment (APAE) II was accepted by the EU Commission as the Danish Nitrate Action Plan implementing the Nitrates Directive (1998-2003). In 2003, a final evaluation of Action Plan II was performed. The results showed a 48% reduction of the nitrate leaching from the agricultural sector, thus fulfilling the reduction target set in 1987. In the 5-year period 2001-2005, the total flow-normalised nitrogen load to marine waters ranged within the interval 62,000 to 70,000 t N.

In the subsequent action plans, the Green Growth Agreement from 2009, the first and the second River Basin Management Plan from 2014 and 2016 as well as the Food and Agricultural Agreement in December 2015, further mitigation measures were adopted to fulfil reduction targets for the N load to marine areas and the targets of the Water Framework Directive.

In 2015, Denmark implemented the EU Greening component under CAP direct payments (REG EU 1307/2013), implying that at least 5% of the arable land of farms shall be appointed as ecological focus areas with a greening element such as set-aside, catch crops etc.

Establishment of 50,000 ha of obligatory buffer zone placed approximately 10 m from the edge of open streams and lakes larger than 100 m^2 was decided to be implemented from autumn 2012. In these buffer zones, application of fertiliser is prohibited, and soil cultivation must not take place. The area with buffer zones was adjusted from 50,000 to 25,000 ha later in 2014, and from the beginning of 2016 the additional buffer zones are no longer mandatory and restricted to the former requirements of 2 m buffer zones along target streams and lakes larger than 100 m^2, amounting to approximately 6,000 ha.

The Political Agreement on Food and Agricultural Package from December 2015 includes a diverse selection of measures aimed to change the environmental regulation of the agricultural sector. The first part of this political agreement was implemented from 2016.

In 2016, farmers were allowed to use more fertiliser. According to the APAE II agreement, farmers were restricted in the application of fertiliser at a level that was lower than the economic optimum. This measure in APAE II was set to reduce the fertiliser application of nitrogen to 10% below this optimum. This rule was regulated so that the total national nitrogen quota was set to a fixed level but with the possibility of an adjustment relative to changes in crop cover. This adjustment made sense as crops having a high application standard also have a higher nitrogen uptake. If crops such as grass increase in cover, then the fertiliser application and N quota will increase as well. However, due to the suspension of set-aside in 2008, higher yields and increases in the prices of cereals and proteins, the gap between the economic optimum and the national N quota increased, especially after 2008, amounting to 18% in 2015.

According to the Political Agreement on Food and Agricultural Package implemented in 2016, extra fertiliser application, amounting to 2/3 of the gap between the economic optimum and the reduced N quota, was allowed. From 2017, farmers were allowed to apply nitrogen up to the economic optimum. Additional cover of catch crops and the greening element, for instance more catch crops and set-aside, were, among other measures, introduced to counteract the potential increase in leaching due to the extra application of fertiliser from 2016 and onwards.

Additionally, targeted catch crops of 145,000 ha were implemented in 2017 to counteract the potential increase in leaching due to the extra application of fertiliser in 2017. In 2018, 2019 and 2020, the need for targeted catch crops was approximately 114,000, 139,000 and 373,000 ha, respectively. The targeted catch crops scheme was introduced to ensure that the status of coastal waters and groundwater does not deteriorate. Therefore, targeted catch crops are established in catchments where reduction of the nitrogen load is needed. Applicants for targeted catch crops could be all farmers who either own or lease fields for cultivation in such catchments.

The second River Basin Management Plans (RBMPII) was adopted in June 2016. It proposes schemes for implementation of mitigation measures, such as re-establishment of riparian areas, construction of wetlands, set-aside of organic soils, afforestation and adjustment of greening elements. The national reduction target for nitrogen in 2021 is estimated to 13,100 t N. However, the RBMPII only includes mitigation measures to obtain an annual reduction of the marine N load of 6,900 t N in the period 2015-2021 (SVANA 2016). The decision on which measures to initiate to reach a further reduction in the annual nitrogen load of 6,200 t N has been postponed to after 2021.

The N load to marine waters has been reduced incrementally along with the successful implementation of measures to reduce loadings from point sources and agriculture. Approximately half of the Danish land area is located within catchments equipped with stream water gauging stations where the N load to marine areas is regularly measured (Kronvang et al., 2008). The nitrogen load for ungauged catchments has been modelled using an empirical model (Windolf et al., 2011), and the combination of measurements and modelling shows that the total annual load to marine waters varied between 55,000 and 59,000 t N, yielding an average of 57,000 t N for the five years (2010-2014) used as reference level in the RBMPII (SVANA (2016), Wiberg-Larsen (2015)). However, the calculation of this total nitrogen load to coastal areas has been updated and now includes a higher proportion of gauged catchments as well as an improved and more detailed calculation of discharge in ungauged catchments (Thodsen et al., 2021). For the period 2015-2019, the updated calculation yields an annual flow-normalised nitrogen load ranging between 55,000 and 66,000 t N with the highest value in 2019 following a year with drought-related low crop harvest. For 2020, the normalised total nitrogen load was 51,000 t N, which is the lowest value in the monitoring period (1990-2020) (Thodsen, 2021).

The regulation and effects described in this chapter cover the period 2005-2020. Additional agricultural regulation, such as requirement to increase the utilization efficiency of nitrogen in manure, a reduced fertiliser application norm on soil with a high content of organic matter and a ban on application of solid manures in autumn, are implemented from 2020 and 2021.

The remaining part of this chapter is divided into three parts:
First, the general development in agricultural practices at national level is presented for the period 2005-2020. This analysis is based on national register datasets from the Ministry of Food, Agriculture and Fisheries, i.e. the single-payment register and the farmers' mandatory fertiliser accounts.

Second, modelled nitrate leaching, including crop distribution and nitrogen balances, is presented for various farm types (including those benefitting from an authorisation of derogation) and geographical areas. The impact of derogation farms is analysed based on a dataset derived by linking data from the single payment register, including data on the crops on each field comprised by the farms, and the fertiliser accounts. Both datasets cover agriculture in the year 2020.

Third, measurements of water quality from the National Monitoring Programme are presented for the period 1990/91-2019/20, with particular reference to the Agricultural Catchment Monitoring Programme (Blicher-Mathiesen et al., 2021). This section includes:

- Modelling of nitrate leaching in the agricultural monitoring catchments as referred to in Article 10(3).
- Measurements of nitrate and phosphorus in water leaving the root zone, including fields receiving more than 170 kg N ha^{-1} in organic manure as referred to in Article 10(2).
- Nitrogen in surface water, draining from agricultural catchments as referred to in Article 10(2).

Modelling of nitrate leaching in this report is carried out by means of the empirical model N-LES (version 4) (Kristensen et al., 2008). This model is partly based on data from the Agricultural Catchment Monitoring Programme. The model requires input data for agricultural practises (N fertilisation, cropping system), soil data and water percolation from the root zone. Percolation is calculated using the Daisy model (Abrahamsen & Hansen, 2000) and a standardised climate dataset from a 10 km grid net (Danish Meteorological Institute), representing weather measurements from the period 1990-2010. The climate dataset contains dynamic correction factors for rainfall (Refsgaard et al., 2011). Thus, modelled nitrate leaching represents the leaching in a standardised climate (water percolation). In contrast, all measurements from the Agricultural Catchment Monitoring represent nitrate leaching under the actual climatic conditions.

So far, model-based calculations of phosphorus losses from farms benefitting from an authorisation of derogation are not available, but measured phosphorus concentrations in root zone water on fields with average application of less and more than 170 kg N ha^{-1} in organic manure are presented.

4.2 Development in agricultural practices at the national level from 2005 to 2020

Crop distribution
The development in crop distribution for 2005-2020 was analysed on the basis of the single payment registration. **Figure 4.**1 presents the results for cash crops, fodder crops and non-cultivated areas. The year 2005 was the first year with single-payment, and it was anticipated that the reporting of areas for this first year would be overestimated. Hereafter, the total reported agricultural area, including set-aside, decreased from approximately 2,757,000 ha in 2006 to 2,613,000 ha in 2020.

The decrease in agricultural area of about 10,000 ha per year is due to road construction, afforestation, urbanisation etc. During the years 2006-07, set-aside comprised about 160,000 ha. As from 2008, the set-aside obligation was suspended, and in 2008 and 2009 most set-aside areas were converted to cash crops, fodder crops and nature-like areas. Set-aside covered between 23,000 and 33,000 ha in the period 2015-2020 as set-aside is an element in the Danish implementation of the EU Greening. The area with cash crops and fodder crops has decreased slightly since 2012.

Catch crops

In Action Plan III, the requirement for growing catch crops was carried over from the former Action Plan, stipulating that farmers in 2005-2009 should grow catch crops on at least 6% of the potential catch crop area if they applied less than 80 kg organic manure N ha^{-1} and on 10% of the area if they applied more than 80 kg organic manure N ha^{-1}. The potential catch crop area was defined according to crop type, including cereals, rape, maize, turnip rape, soy, faba bean, sunflower, oil flax and other rotation crops without substantial nitrogen uptake in the autumn. In 2008, the requirement for growing catch crops was raised to counterbalance the effects of the set-aside suspension. From autumn 2009, an additional catch crop area, equivalent to an extra 4% of the potential catch crop area, was implemented, yielding a total requirement for the growing of catch crops of 10% or 14%, respectively. Hence, an adjustment was made to 10.7 and 14.7% from 2020.

During this period (2005-2010), farmers growing winter crops (wheat, rye, winter barley, oilseed rape), preventing fulfilment of catch crop requirements, were granted a reduction of the required catch crop area. From 2011, this possibility ceased.

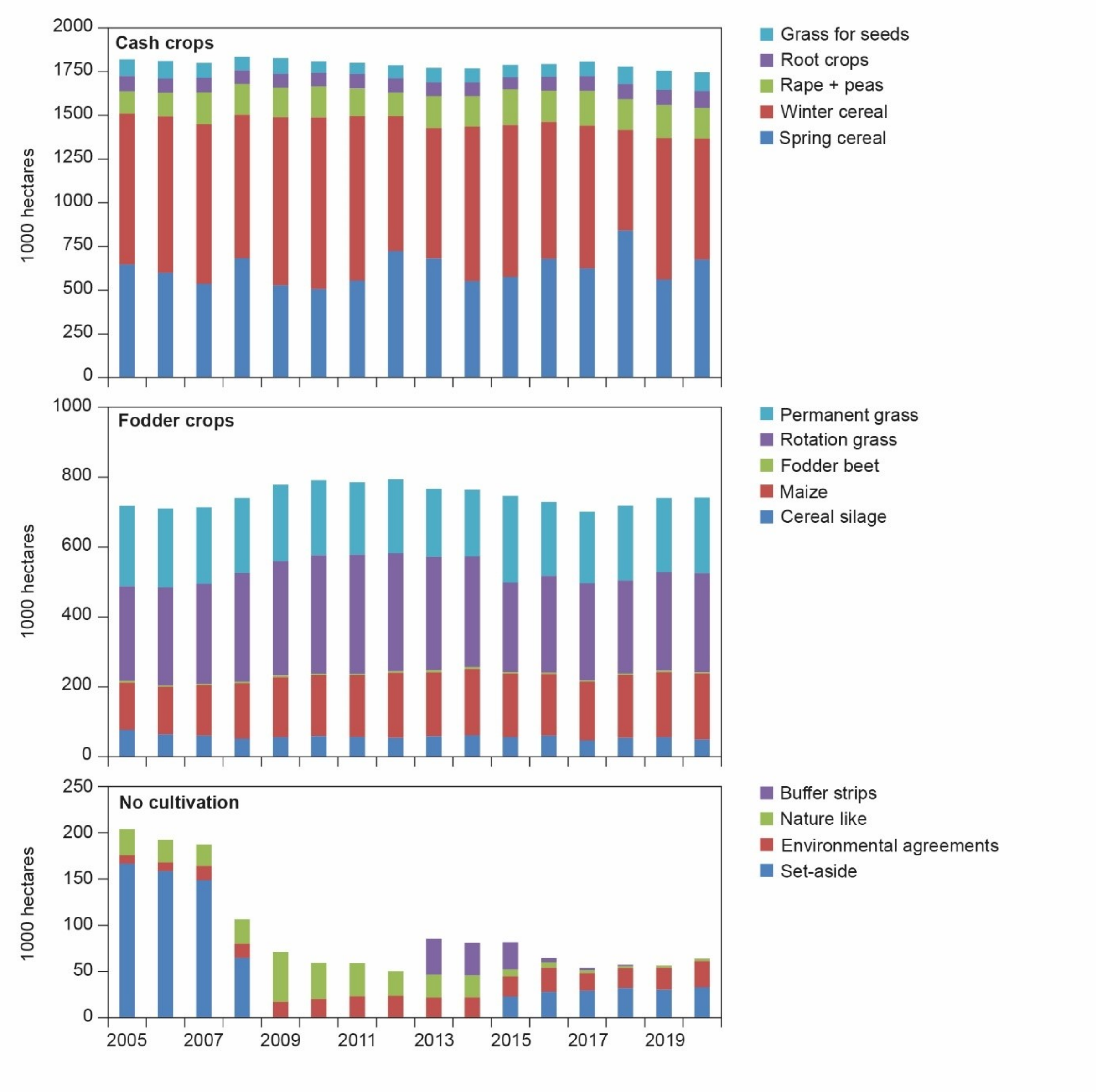

Figure 4.1 Development in crop distribution at the national level from 2005 to 2020, data from the single payment register.

At the same time, voluntary alternatives to catch crops were introduced such as:

- Reduction of the farm nitrogen fertilizer quota
- Growing of special crops between harvest and sowing of winter crops
- Growing catch crops on other farms
- Establishment of perennial energy crops
- Separation and treatment of animal manure (biogas and burning of the solid fraction of manure)
- From 2015, substitution of one ha of catch crop by four ha of set-aside near open streams and lakes larger than 100 m² and located next to agricultural areas in rotation
- From 2014, substitution of one ha of catch crop by four ha of winter cereals, if sown earlier than September 7
- From 2016, substitution of one ha of catch crop by one ha of set-aside

Data from the fertiliser accounts show that establishment of catch crops increased from about 118,600-138,000 ha in 2005/06-2007/08 to about 505,100 ha of catch crop equivalents in 2020/21 (**Table 4.1**). The introduction and use of catch crop alternatives were equivalent to the effect of 13,900-95,000 ha catch crops in the period 2011/12-2020/21.

Table 4.1 Area with catch crops and catch crop alternatives (1,000 ha of catch crop equivalents) reported by the farmers in the annual fertiliser account in the period 2005/06-2019/20.

	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21
Catch crops	138.0	118.6	127.2	196.6	183.0	211.0	211.0	224.0	295.7	321.1	390.0	353.1	415.2	366.5	355.6	505.1
Catch crop alternatives	0	0	0	0	0	0	28.6	44.0	13.9	43.3	37.6	36.1	28.5	42.8	16.2	95.0

In 2017, a new regulation of animal husbandry was implemented. With this regulation, additional catch crops, called “livestock catch crops”, were to be established in certain areas on certain farms using organic fertilisers, including livestock manure. The regulation applies only to farms cropping more than 10 ha and with the use of organic fertiliser of > 30 kg N ha^{-1}. In addition, the cropped area must be located in catchments with an increasing use of manure or other organic fertilisers that drain into nitrate sensitive types of nature habitats of the Natura 2000 area. Alternatively, to specific areas selected on a voluntary basis, which drain into near coastal waters with a need for N load reduction according to the River Basin Management Plans. The additional catch crops in certain areas on certain farms using manure or other organic fertilisers can replace all or a part of the need for 80% fodder crops on derogation farms and catch crops grown to fulfil the EU greening requirements.

Consumption of nitrogen fertiliser and nitrogen in manure

Data on the annual use of inorganic fertilisers and the use of nitrogen in animal manure are obtained from the fertiliser accounts (**Table 4.2**). The application of animal manure N varied between 216.000 and 227.000 t N from 2005 to 2020. The use of inorganic fertilisers amounted to about 181,000-202,000 t N year^{-1} in 2005-2007 and increased to 205,000 and 209,300 t N year^{-1} in 2008 and 2009, probably due to the cultivation of previous set-aside areas. This was expected to be a temporary effect as the procedure for setting the crop nitrogen standards implies that an increase in agricultural area with fertiliser requirements must be followed by an equivalent reduction in nitrogen standards. Administratively, however, this reduction is based on statistical data on the cultivated area, resulting in a delay of two years. Thus, in 2010-2014, the use of inorganic fertilisers decreased again, reaching the same level as in 2005-2007. The use of inorganic fertiliser increased from 210,000 t N in 2015 to 242,000, 237,000 and 224,000 t N in 2016, 2017 and 2018, respectively, after the implementation of the Food and Agricultural Package, according to which farmers were allowed to use more fertiliser after 2015. The lower use of inorganic fertiliser in 2018 compared to the two former years is caused by an increase in organic farming, farms that do not use inorganic fertiliser, as well as a decrease in the cultivated area. A change in the crop distribution with higher cover of spring cereals at the expense of winter cereals also contribute to a lower use of inorganic fertiliser of approximately

20,000 t N in 2018 as winter cereals have a higher N uptake, higher harvest yield and therefore a higher economic optimal standard than spring cereals. The use of inorganic fertilisers amounted to 223,000 t N in 2019, which is almost the same level as in 2018. For the growing season 2019, farmers were recommended to apply app. 4 kg N ha^{-1} less as a significant amount of nitrogen still remained in the soil in spring due to a very dry autumn and winter. A wet autumn in 2019 made the establishment of winter cereals difficult. This resulted in a decrease in the 2020 winter cereal area compared to 2019.

Table 4.2 Development in the use of inorganic nitrogen fertiliser and of nitrogen in animal manure as reported by the farmers in the annual fertiliser accounts for the period 2005-2020 (1,000 t N a^{-1}).

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Fertiliser	191	181	202	205	209	198	203	198	199	203	210	242	237	224	223	230
Animal manure	227	218	236	230	226	224	223	220	215	212	216	219	218	224	219	216

However, the use of N in inorganic fertiliser increased to 230,000 t N, partly due to a recommended higher application rate to compensate for a low soil N content prior to the growing season of 2020 in some parts of the country.

4.3 Modelled nitrate leaching for farm types and geographical areas and the impact of derogation farms at the national level – 2020 data

Modelled nitrate leaching demonstrates the effect of crop distribution, nitrogen input, soil type and water percolation through the soil. This section includes a presentation of all of these parameters. Regarding crop distribution and nitrogen input, the analyses are based on the national datasets from the single payment register and the fertiliser accounts. However, before the data can be used for this purpose, a detailed compilation of the two datasets must be made (Børgesen et al., 2009). The single payment register contains information on crops at field-block level, and the fertiliser accounts contain information on the use of nitrogen (inorganic fertiliser and organic manure) at farm level. The two datasets are linked by means of the common farm identity number or a common farm address, and the reported amounts of fertiliser and manure from the individual accounts are distributed on the fields of each farm according to the crop nitrogen standards. Hereby, we obtain a dataset with coherent data on crops and nitrogen application at field level. We have no information on grass-ley from either dataset. Therefore, we estimate this parameter based on the area with rotation grass, assuming a conversion rate of three years. If there is not sufficient space in the crop rotation, the area with grass-ley is reduced accordingly. Data on catch crops are derived from the fertiliser accounts.

The field-blocks are geographically mapped, implying that each field can be linked to soil maps and to the meteorological grid. Having established the soil type for each field-block, the standard harvest yield may be estimated. Furthermore, nitrogen fixation is included using standard values for each crop. This final dataset now contains all information necessary for geographically distributed computation of crop coverage and field nitrogen balances and for modelling nitrate leaching.

Farm type

The data are divided into three main groups of farm type – arable farms, pig farms and cattle farms. A pig farm is defined as a farm where more than 2/3 of the used organic N including manure originate from pigs, and a cattle farm is defined as a farm where at least 2/3 of the used organic N including manure originate from cattle. An arable farm is a farm with a production of organic fertiliser including manure of less than 20 kg N ha^{-1}. The farm may import animal manure, which will appear in the fertiliser account and is therefore included in this analysis. Other farm types are not included in this analysis**.** The area occupied by organic farms constitutes about 310,000 ha in 2020 (Landbrugsstyrelsen, 2020).

Figure 4.2 shows that arable farms and pig farms grew cereals, particularly winter wheat, on most of the agricultural area (64 and 69%) in 2020. Other major cash crops were oilseed rape, peas, root crops (potatoes and sugar beet) and grass for seeds (17-24%). Cereal silage, grass and maize constituted a lesser part of the area (4-17%). Catch crops were grown on 19-21% and newly established grass-ley on 2-4% of the agricultural area on arable and pig farms as an autumn-winter plant cover.

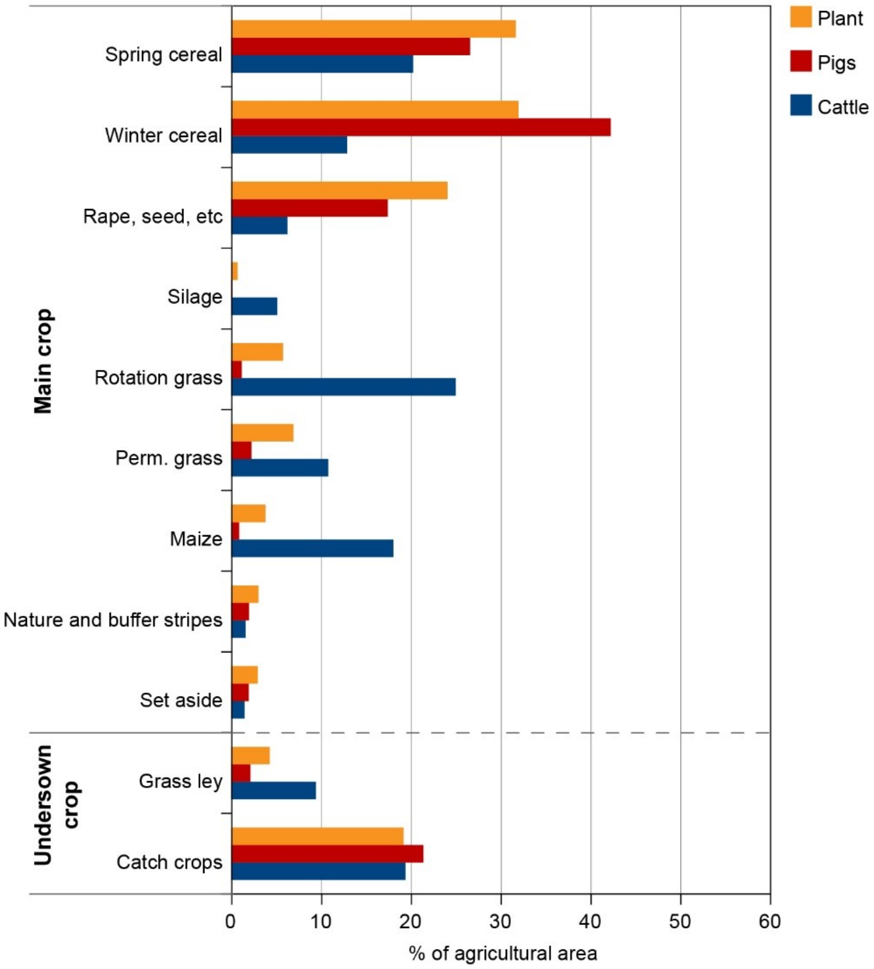

Figure 4.2: Crop distribution for three main farm types in 2020. Combined dataset from the single payment register and the fertiliser status accounts.

Cattle farms have a different crop rotation. Cereals and other cash crops were grown on 39% of the area, whereas cereal silage, grass and maize were grown on 59% of the area. Fodder beet was grown on 1.3% of the area. In addition, grass-ley was found on 9% and catch crops on 19 % of the area.

On arable farms, an average amount of about 49 kg N ha^{-1} from animal manure was applied. For pig and cattle farms, the amounts were, respectively, 103 kg N ha^{-1} and 129 kg N ha^{-1} (**Table 4.3**).

The use of inorganic fertilisers decreased with increasing application of animal manure. Total inputs of nitrogen from inorganic fertiliser, manure, other organic sources, N fixation and atmospheric deposition amounted to 186, 215 and 259 kg N ha^{-1} for arable farms, pig farms and cattle farms, respectively. N balances, calculated as the difference between the total input of nitrogen and removal by harvested crops, were 75, 102 and 106 kg N ha^{-1} for arable farms, pig farms and cattle farms, respectively. As expected, modelled nitrate leaching was lower from arable farms (on average 53 kg N ha^{-1}) than from animal husbandry farms (62 kg N ha^{-1} from pig farms and 68 kg N ha^{-1} from cattle farms). N leaching was, on average, 6 kg N ha^{-1} higher for cattle farms compared to pig farms.

Table 4.3 N inputs, N balances and nitrate leaching and nitrate concentration at the bottom of the root zone for three main farm types in 2020 based on model calculations. Combined dataset. Organic farms were not included in the analysis.

	N balance									Root zone water		
	Inorganic fertiliser	Animal manure	Other org.	N fix.	N depos.	Seeds	Total input	Harvest	N balance	Percol.	Nitrate leaching	NO_3^- conc.
	kg N ha^{-1} a^{-1}									mm a^{-1}	kg N ha^{-1}	mg l^{-1}
Arable	109	49	5.0	7.9	13	2.0	186	111	75	338	53	69
Pigs	91	103	1.7	4.5	14	2,2	215	114	102	372	62	74
Cattle	90	129	1.2	23.0	14	1,6	259	152	106	407	68	74

On arable farms, the modelled nitrate leaching amounted to 70% of the N balance, which is a high value relative to the 61% calculated for pig farms and the 64% for cattle farms. An explanation may be that leaching on these soils with low input of organic manure is affected by mineralisation of the soil organic pool, i.e. depletion of the total soil N content. However, the high leaching fraction may also be caused by the uncertainties associated with the two separate calculations of the N leaching and N balance.

Water percolation through the soil is considerably higher on cattle farms than on arable and pig farms. However, this is not due to the differences in farm type but the fact that the cattle farms are located mainly in the western part of the country with more sandy soil and higher rainfall and a consequently higher percolation. The higher percolation on cattle farms leads to dilution of the nitrate concentration in the soil water. Thus, the modelled average nitrate concentrations in soil water were 69 and 74 mg NO_3 l^{-1} on arable and pig farms, respectively, and 74 mg NO_3 l^{-1} on cattle farms for the year 2020.

Geographical areas

Farm types are not evenly distributed throughout the country because of variations in farming conditions. For the following analysis, Denmark has therefore been divided into five farming regions (**Figure 4.3**).

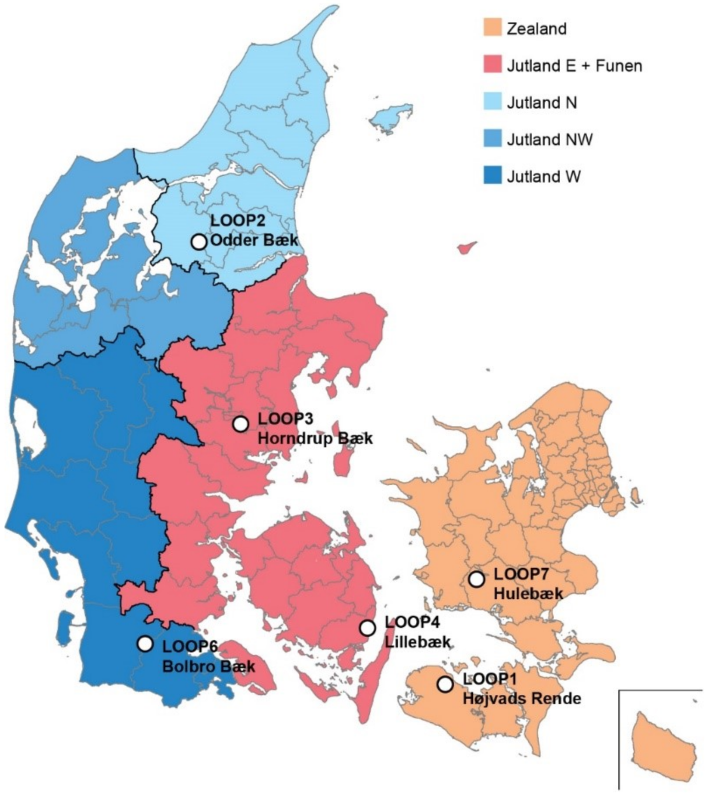

Figure 4.3 Farming regions in Denmark used in the analysis and the location of the six monitored agricultural catchments.

Table 4.4 shows that Zealand is dominated by arable farming, whereas arable farming and pig production dominate Eastern (E) Jutland and Funen. Finally, North (N), North-West (NW) and West (W) Jutland have the highest density of cattle farming. Thus, arable and pig farms are located mainly in the eastern part of Denmark on loamy soils and with low rainfall, whereas cattle farms are located mainly in the northern and western parts of Denmark on sandy soils and with higher rainfall, the rainfall increasing from north to south.

Table 4.4 Distribution of farm types and soil types in Denmark divided into five main geographical areas – 2020.

	Arable	**Pig**	**Cattle**	**Other**	**Sand**	**Loam**	**Organic soils**
	% of agricultural area				% of agricultural area		
Zealand	67	12	14	7	4	93	3
Jutland E +Funen	46	23	24	8	26	71	4
Jutland N	40	15	35	9	79	10	11
Jutland NW	33	21	39	7	61	33	6
Jutland W	37	13	43	8	75	19	6

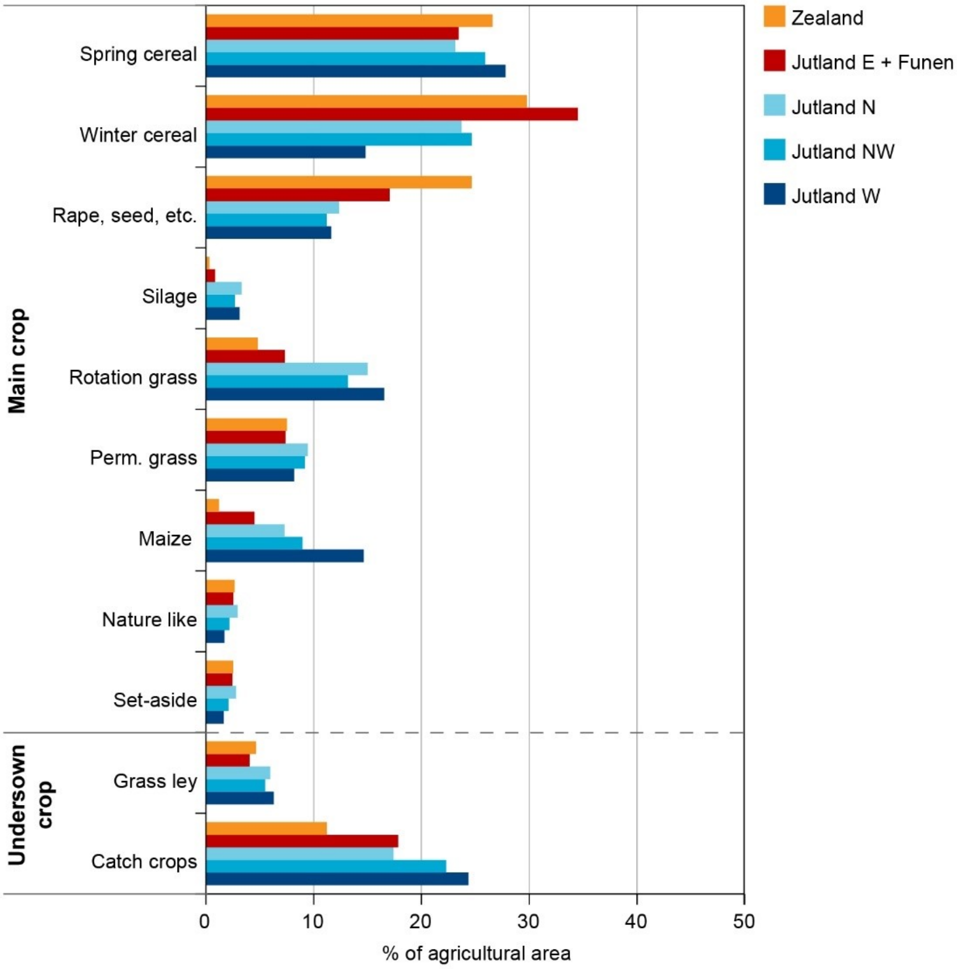

Figure 4.4 Crop distribution for five farming regions in Denmark in 2020. Combined dataset from the single payment register and the fertiliser accounts.

The crop distribution within the five farming regions of Denmark follows the same pattern as for farm types, i.e. mainly cereals and other cash crops on the islands and in Eastern Jutland and cereals and fodder crops in West and North Jutland (**Figure 4.4**).

The input of nitrogen with animal manure, the total nitrogen input and the field nitrogen balances are lowest on Zealand, higher in E Jutland and on Funen and highest in W, NW and N Jutland (**Table 4.5**). In the latter three areas, the average nitrogen input varied between 213 and 232 kg N ha^{-1}. The average modelled nitrate leaching generally increased from east to west due to increases in nitrogen input and percolation. Within the three western and northern parts of Jutland, the nitrate leaching increased from northern to southern Jutland, mainly due to increased water percolation through the root zone. Higher water percolation led to dilution of the nitrate concentrations of the soil water, resulting in an average nitrate concentration in soil water of 82, 73, 76, 69 and 63 mg NO_3 l^{-1} on Zealand, Funen + E and N Jutland, and NW and W Jutland, respectively.

Table 4.5 N inputs and N balances, nitrate leaching and nitrate concentration at the bottom of the root zone (1 m) calculated for five geographical areas in Denmark in 2020. Combined dataset from the single payment register and the fertiliser accounts. Organic farms were not included in the analysis.

	N balance									Root zone water		
	Inorganic fertiliser	**Animal manure**	**Other org. N**	**N-fix.**	**N-depos.**	**Seeds**	**Total input**	**Harvest**	**N balance**	**Percol.**	**Nitrate leaching**	**NO_3^- conc**
	kg N ha^{-1} a^{-1}									mm a^{-1}	kg N ha^{-1}	mg l^{-1}
Zealand	123	34	3.9	8.9	11	1.8	183	116	67	198	37	82
Jutl. E +Funen	104	71	3.1	9.1	13	1.9	203	118	85	329	54	73
Jutland N	81	99	2.4	15.7	14	1.7	213	121	92	364	62	76
Jutland NW	82	111	0.7	13.4	14	1.8	223	125	98	446	69	69
Jutland W	83	113	4.3	14.2	16	2.0	232	134	99	540	76	63

Derogation farms

Derogation farms are mainly located in N, NW and W Jutland where cattle farming is dominant. The effect of the derogation was evaluated for these three geographical areas. The cattle farms were grouped into four livestock density groups depending on the application of organic N including manure: 0-100, 100-140, 140-170 kg N ha^{-1} and derogation farms with the use of organic N including manure of 170-230 kg N ha^{-1}.

The crop distributions for the three geographical areas were found to be almost identical, with some differences in crop cover between spring and winter cereals as well as larger proportions of maize and catch crops in W Jutland (**Figure 4.5**). There is a clear trend indicating a decrease in areas with cereals and an increase in the areas with catch crops with increasing livestock density. In addition, the area with fodder crops increases with increasing livestock density. The area with roughage amounted to 58, 66 and 75% for the three groups, 0-100, 100-140, 140-170 use of organic N including manure ha^{-1}, respectively, whereas derogation farms grew roughage on an average of 88% of the area.

The effect of derogation on nitrate leaching was evaluated separately for the three geographical areas. The nitrogen input as well as the field nitrogen balances increased with increasing livestock density (**Table 4.6**). Modelled nitrate leaching is generally a combined effect of two opposing mechanisms – an increase in leaching due to increased nitrogen input and a decrease in leaching due to an increased area with roughage and catch crops. **Table 4.6** shows that the modelled nitrate leaching generally increased with increasing livestock density and hence with increasing nitrogen input. Thus, differences occurred in the modelled annual nitrogen leaching of 0, 6 and 6 kg N ha^{-1}, respectively, between derogation farms and farms using 140-170 kg N ha^{-1} of N in manure and other organic fertilisers in the three Jutland regions N, NW and W, respectively. Modelled nitrate concentrations in the soil water leaving the root zone were 2, 6, and 4 mg NO_3 l^{-1} higher for derogation farms than for cattle farms using 140-170 kg N ha^{-1} of N in manure and other organic fertilisers in Jutland N, NW and W, respectively.

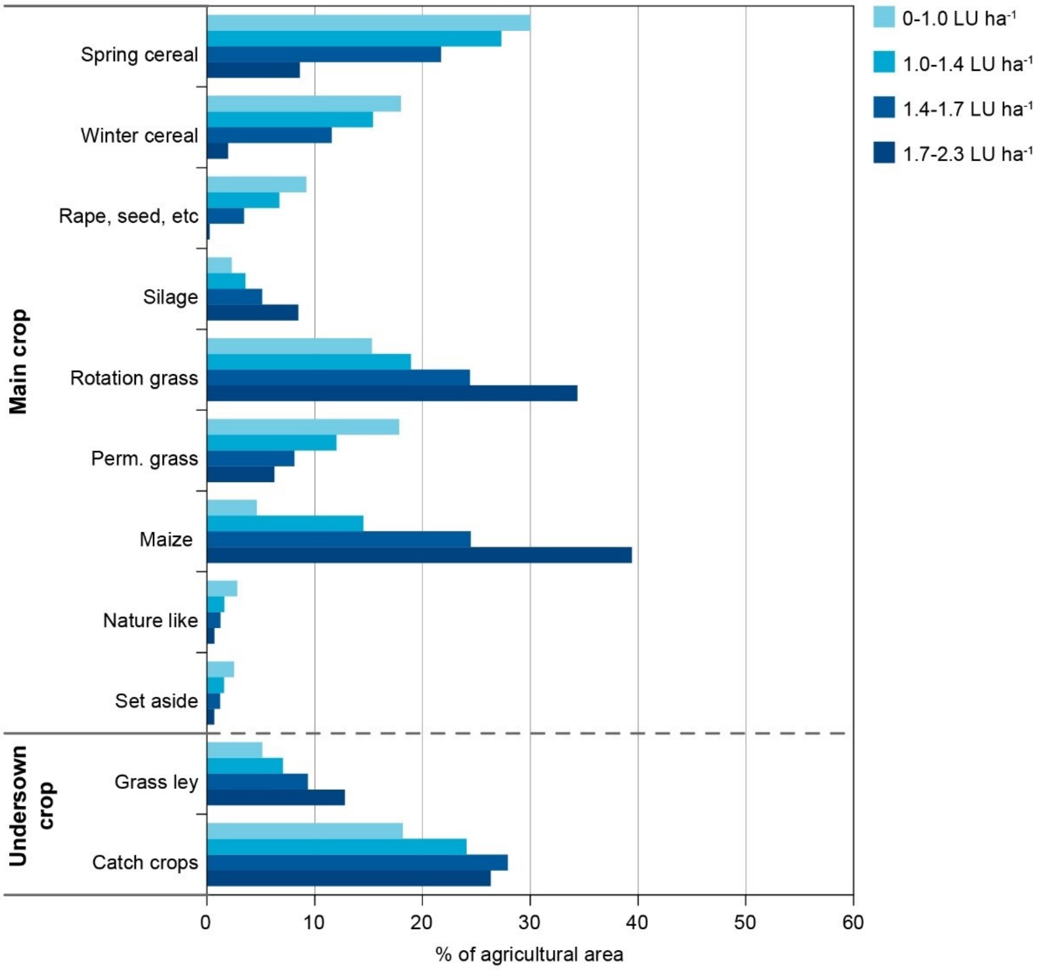

Figure 4.5 Average crop distribution for four groups of livestock density in N, NW and W Jutland in 2020. Combined dataset from the single payment register and the fertiliser accounts. Organic farms were not included in the analysis.

The use of legumes (clover, alfalfa, peas) in grass and cereal silage is shown in **Table 4.7**. The general trend is that derogation farms grow less legumes than non-derogation farms (**Table 4.7**). Thus, clover or alfalfa (max. 50% share) in rotation grass was used on 71% of the rotation grass area for derogation farms and on 76-80% for non-derogation farms. For permanent grass including legumes, the equivalent values were 21% for derogation farms and 21-38% for non-derogation farms. Cereal silage with peas amounted to 13% of the silage area for derogation farms and 13-19% for non-derogation farms.

Table 4.6 N inputs, N balances and nitrate leaching and nitrate concentration at the bottom of the root zone calculated for four groups of livestock densities at cattle farms and for three geographical areas in Jutland, Denmark, 2020. Combined dataset from the single payment register and the fertiliser accounts. Organic farms were not included in the analysis.

		N balance									Root zone water		
Region	**Annual use of organic N**	**Inorganic fertiliser**	**Animal manure**	**Other org.N**	**N fix.**	**N depos.**	**Seeds**	**Total input**	**Harvest**	**Balance**	**Percol.**	**Nitrate leaching**	**NO_3^- conc**
	kg N ha^{-1}	kg N ha^{-1} a^{-1}									mm a^{-1}	kg N ha^{-1}	mg l^{-1}
Jutland N	0-100	92	53	1.6	18	14	1.FS2	179	114	65	359	54	66
	100-140	89	119	0.2	25	14	1.4	249	141	108	358	63	78
	140-170	80	157	0.2	30	14	1.4	283	160	122	358	73	90
	170-230	80	199	0.0	40	14	1.4	334	191	143	351	73	92
Jutland NW	0-100	97	57	1.9	16	14	1.6	188	119	68	427	59	61
	100-140	85	122	0.4	21	14	1.6	245	140	105	455	75	73
	140-170	79	154	0.0	27	14	1.5	275	160	116	436	78	79
	170-230	75	196	0.1	35	14	1.5	322	186	136	439	84	85
Jutland W	0-100	83	56	5.8	18	16	1.7	179	121	58	524	59	50
	100-140	95	119	2.1	19	16	1.8	253	147	106	545	80	65
	140-170	86	156	0.6	25	16	1.7	286	166	120	543	85	70
	170-230	81	203	0.3	29	16	1.6	330	192	138	550	91	74

Table 4.7 Use of legumes in grass and cereal silage at cattle farms for derogation and non-derogation farms 2020. Organic farms were not included in the analysis.

	Use of organic N, including manure (kg N ha^{-1} a^{-1})			
	0-100	**100-140**	**140-170**	**170-230**
	share of agricultural area (%)			
Rotation grass	11.7	17.1	22.4	33.3
	share of rotation grass (%)			
No clover/alfalfa	23	20	20	29
< 50% clover/alfalfa	76	80	80	71
> 50% clover/alfalfa	1	0	0	0

Table 4.7 (continued)

		share of agricultural area (%)		
Permanent grass	15.2	11.2	7.3	5.9
		share of permanent grass (%)		
No clover/alfalfa	62	72	79	79
< 50% clover/alfalfa	38	28	21	21
> 50% clover/alfalfa	0	0	0	0
		share of agricultural area (%)		
Cereal silage	1.3	2.9	4.2	8.1
		share of cereal silage (%)		
No legumes	86	79	82	87
< 50% legumes	13	19	13	13
100% legumes	1	2	5	0

4.4 Development in modelled nitrate leaching in the Agricultural Catchment Monitoring Programme 1990-2019

This section deals with the general development in nitrate leaching from 1990/91 to 2019/2020 for measured nitrated concentrations in soil and ground water and to 2020/21 for the modelled nitrate leaching for tree loamy and two sandy agricultural-dominated catchments. Information on agricultural practises is derived from the Agricultural Catchment Monitoring Programme. This programme includes six small agricultural catchments situated in various parts of the country in order to cover the variation in soil type and rainfall and hence in agricultural practises (**Figure 4.3**). The farmers are interviewed every year about livestock, crops and fertilisation and cultivation practises. Nitrate leaching is modelled with the NLES4 model for all fields in the catchments based on the information from farmers on agricultural practises and standard percolation values that are calculated on the basis of the climate for 1990-2010.

In 2020, 124 farmers participated in the investigation. 84 farms agreed to give information about part of their farming area, while 40 of the farms agreed to give information about farming on the entire farm area. Of all the investigated farms, 24 were cattle farms and 11 of the cattle farms agreed to give information about farming on the entire farm area. Two of the cattle farms were registered as derogation farms. These derogation farms covered 3.2% of the total area in the Agricultural Monitoring Catchments in 2020.

The modelled nitrate leaching from the agricultural area in the catchments was calculated for the period 1990 to 2020 (representing the hydrological years 1990/91 to 2020/21). The modelled leaching is shown in **Figure 4.6** as an average for sandy and loamy catchments, respectively.

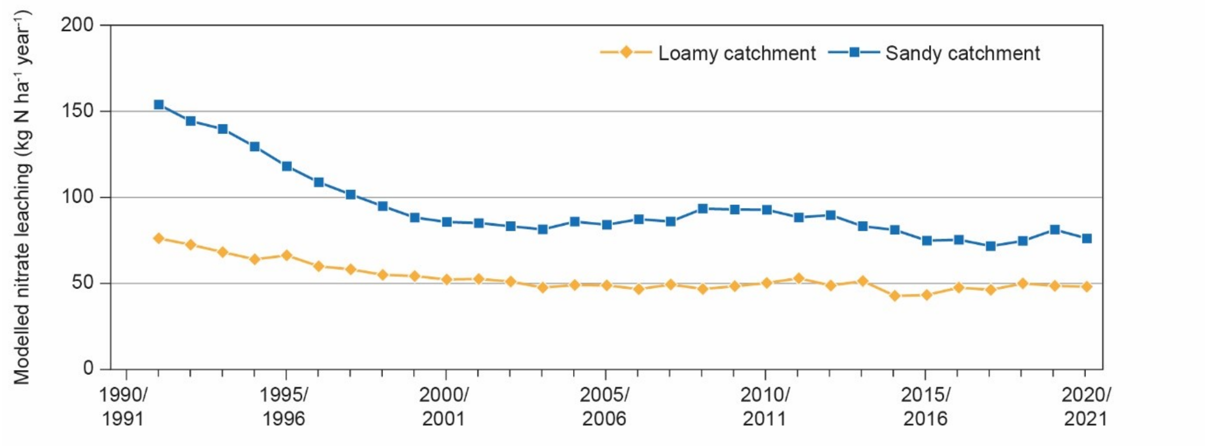

Figure 4.6 Simulation of the nitrate leaching using the NLES4 model in a standard climate for the fields of tree loamy and two sandy catchments within the Agricultural Catchment Monitoring Programme 1990/91-2020/21.

Seen relative to the distribution of the main soil types in Denmark, the modelled nitrate leaching decreased by 43% during the period 1991 to 2003 due to the general improvement in agriculture and fertilisation practises (Action Plan I+II) (Blicher-Mathiesen et al., 2021 ; Grant et al., 2006). From 2003 to 2020, the modelled nitrate leaching decreased significantly in the two sandy catchments ($p<0.01$ and 0.02), whereas no significant trend could be detected in either of the loamy catchments. For the loamy catchments, modelled annual nitrate leaching was relatively stable around 50 kg N ha^{-1} during the period 2003-2020, with the exception of the years 2014 and 2015, where the modelled annual nitrate leaching was approximately 8 kg N ha^{-1} lower than this level. For the sandy catchments, the annual leaching of 81 kg N ha^{-1} in 2003 was relatively low. After this year, the leaching increased to an interval of 81-93 kg N ha^{-1} in the period 2004-2014. In the period 2015-2020, the annual leaching decreased to a lower level than in 2003 (76-82 kg N ha^{-1}). The lower leaching in these five years is mainly due to a higher share of catch crops after cereals and maize.

The purpose of the root zone modelling is to show the effects of measures introduced to mitigate nutrient losses from agriculture. The modelling is therefore carried out for normalised growth conditions, i.e. averaging the model output for a 20-year period: The model is run for each year in the 20-year period and model outputs are then averaged for the period. The climatic data used cover the period 1990-2010. Actual measurements of nitrate leaching will show higher annual variations than the climatic average of the modelled values as the measurements depend on the actual climate.

Certain forms of soil cultivation and ploughing of grass fields in autumn were prohibited as from autumn 2011. This circumstance is not considered in the leaching model due to lack of actual measurements that could otherwise have been applied in the model development. It is estimated that postponed soil tillage will reduce root zone leaching by 2,400 t N at the national level, corresponding to an average effect of about 1 kg N ha^{-1} (Børgesen et al., 2013).

4.5 Measurements of nitrate in water leaving the root zone

In five of the six Agricultural Monitoring Catchments, soil water samples are collected regularly at 30 sites. One of the sites is covered by forest and is therefore not

included in the data on nitrate concentrations measured in agricultural areas. Measurements were ceased on a sandy site in 2011 as the farmers did not want to participate in the monitoring. Two sites on a loamy catchment are located very close to the edge of the field, and tractor transport in and out of the fields, results in high damage to crops, possible uneven fertiliser application and very high values of measured nitrate leaching in some of the monitored years. Out of the remaining 27 sites on agricultural areas, 14 are located on loamy soils and 13 on sandy soils, and the data on these are considered valid for use in the trend analysis of the loamy and sandy catchments. The samples represent the root zone water (approx. 1 m depth – 30 samples per year) and the upper oxic groundwater (1.5-5 m depth – 6 samples per year).
To obtain an annual representative value for the nitrate leaching, the measured nitrate concentration is multiplied by the percolation in the sampling period. Samples are taken weekly in periods with percolation (autumn, winter and spring) and monthly in summer time when percolation is scarce or zero. Percolation values are modelled as measurements of soil water content and flow in soil, covering soil variability at field level, are difficult to perform (Blicher-Mathiesen et al., 2014). The annual flow-weighted nitrate concentration is calculated by dividing the annual percolation by the annual nitrate leaching.

Since the publication of the annual derogation report for 2018, inconsistencies in the precipitation time series have been detected. These inconsistencies affect the reported flow-weighted concentrations as the precipitation time series are used for the calculation of percolation. Specifically, it was found that the relation between precipitation and stream runoff in the monitoring catchments was inconsistent before and after 2010, respectively. The precipitation is measured at several rain gauge stations and distributed to cover 10x10 km^2 grids by the Danish Meteorological Institute (DMI). The type of rain gauge station was changed from 2011, and also the number of stations decreased significantly. This explains some of the inconsistency related to measured discharge. DMI has delivered new precipitation data for the period after 2010, but all inconsistency in the data has not yet been resolved. In order to address the possible bias or inconsistency in the precipitation time series, we included an uncertainty in the precipitation data, which is reflected in the calculated percolation and flow-weighted nitrate concentration. This uncertainty was derived from an analysis of radar-detected precipitation in five subplots within ten precipitation grids of 10x10 km^2. The standard error bars on the flow-weighted nitrate concentration in **Figure 4.7** and **Figure 4.10** represent this uncertainty from variation in precipitation on field level but tabulated as an average uncertainty from ten precipitation grids (Blicher-Mathiesen et al., 2021).

The flow-weighted nitrate concentrations are shown as annual average values for loamy and sandy soils, respectively, for the period 1990/91-2019/20 (**Figure 4.7**).

Generally, measured data on nitrate leaching from the root zone at only 27 sites cannot be used directly for estimating the effect of a single variable as the input of fertiliser or manure because of the high variability in actual fertiliser and manure practice and climate between the monitoring fields and the measured years. Instead, the measured nitrate leaching data, together with other leaching data, were used for the development of the nitrate leaching model, N-LES4, which was subsequently used for calculating the leaching from all the fields in the catchments relative to agricultural practises.

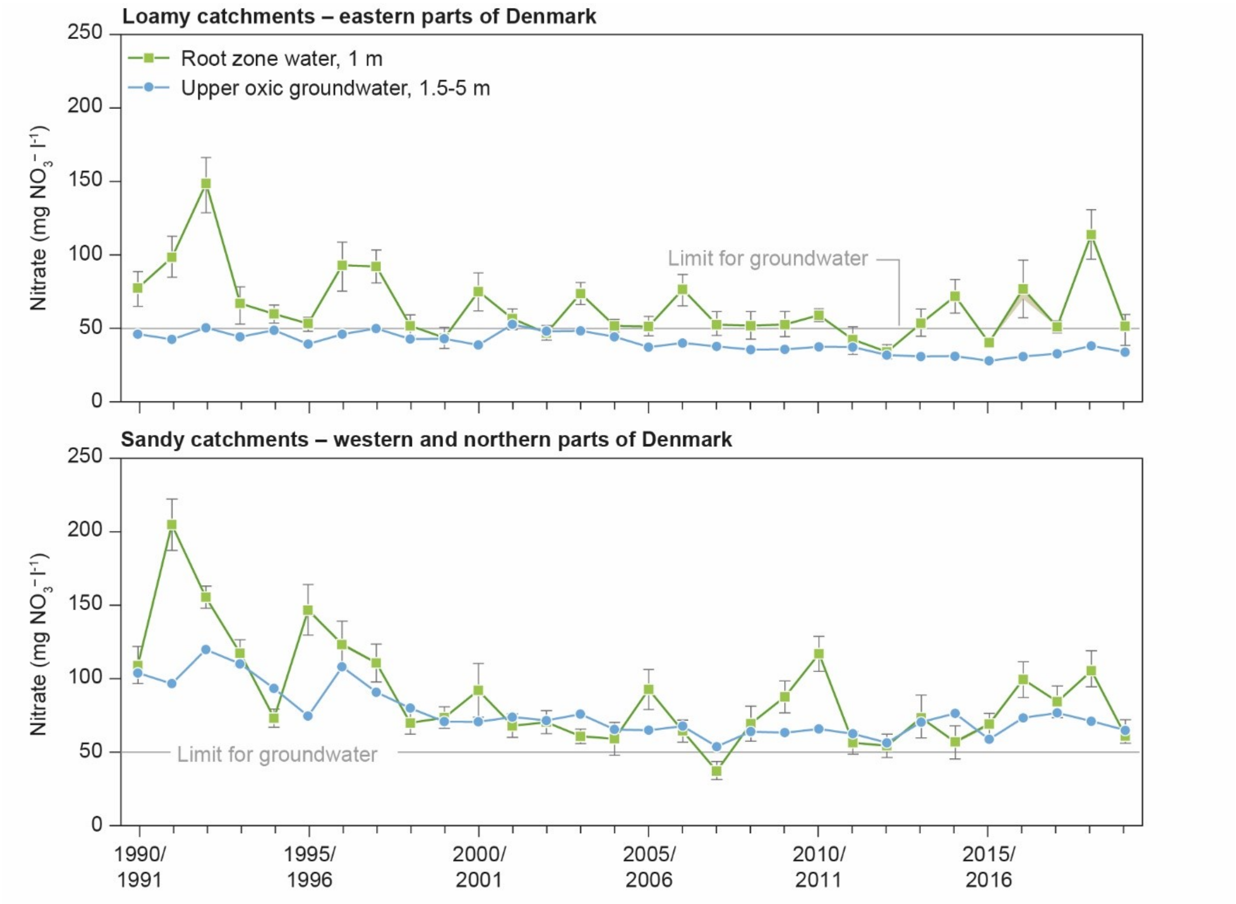

Figure 4.7 Annual flow-weighted nitrate concentrations measured in root zone water (1 m below ground level) and annual average nitrate concentrations measured in upper oxic groundwater (1.5-5 m below ground level), the Agricultural Catchment Monitoring Programme 1990/91-2019/20. Error bars indicate variation in percolation as precipitation variated on local scale within a DMI 10 x 10 km² precipitation grid.

General trend for nitrate concentrations in water leaving the root zone

There is strong inter-annual variation in the measured nitrate concentrations due to differences in rainfall and temperature. Therefore, a long time series and a large number of measuring points are needed to detect any statistically significant trend. Such data series are available from the Danish Monitoring Programme. A statistical trend analysis – a Mann-Kendall test, incorporating annual variations in the mean annual flow-weighted nitrate concentrations for water leaving the root zone – showed that concentrations decreased significantly by 1.2 and 2.6 mg NO_3 l^{-1} a^{-1} for the measured sites on loamy and sandy soils, respectively, and for the whole 26-year monitoring period from 1990/91 to 2015/16.

In loamy catchments, the measured nitrate concentrations in root zone water decreased from 61-155 mg NO_3 l^{-1} in the 5-year period 1990/91-1994/95 to 37-66 mg NO_3 l^{-1} in the 5-year period 2011/12-2015/16. After this period, the concentrations were 72, 48, 107 and 48 mg NO_3 l^{-1} in the four years 2016/17, 2017/18, 2018/19 and 2019/20, respectively. The high nitrate concentrations are seen in years with low percolation– as observed on loamy soils in 2004/05, 2010/11, in 2016/17 and in 2018/19. In sandy catchments, the nitrate concentration decreased from 73-192 mg NO_3 l^{-1} in the 5-year period 1990/91-1994/95 to 54-73 mg NO_3 l^{-1} in the 5-year period 2011/12-2015/16 and were 93, 79, 99 and 57 mg NO_3 l^{-1} the four years

2016/17, 2017/18, 2018/19 and 2019/20, respectively (**Figure 4.7**). Low nitrate concentrations were measured in 2019/20 due very high percolation diluting the nitrate in the root zone.

After 2003/04 (Action Plan III + Green Growth), no statistically significant change in measured nitrate concentrations in soil water leaving the root zone has been recorded. However, before 2011/12, high concentrations were temporarily observed for sandy soils. This is most likely due to growth of crops with high leaching potential on these fields, such as turnover of grassland followed by cereals with no catch crops the following years, growing of maize and winter rape etc.

It should be noted that the measurements of nitrate leaching originate from a small number of sampling stations (27 stations). Furthermore, the measurements are affected by high crop yields, in particular in 2009, and effects of crop rotation, especially of grass in rotation. These conditions induce higher inter-annual variations than seen in the average modelled nitrate leaching, which covers a larger area including approx. 124 farms.

In the upper groundwater (1.5-5.0 m below ground level), nitrate concentrations were lower than in the root zone water, indicating nitrate reduction in the aquifer between the bottom of the root zone and the uppermost groundwater (**Figure 4.7**).

In loamy catchments, the measured annual mean of nitrate concentrations in the upper oxic groundwater decreased from 41-47 mg NO_3 l^{-1} in the 5-year period 1990/91-1994/95 to 28-38 mg NO_3 l^{-1} in the 5-year period 2015/16-2019/20. In sandy catchments, the nitrate concentration decreased from 87-112 mg NO_3 l^{-1} in the 5-year period 1990/91-1994/95 to 59-77 mg NO_3 l^{-1} in the 5-year period 2015/16-2019/20.

Nitrate concentrations in water leaving the root zone from cattle farms with manure N applications below and above 170 kg N ha^{-1}.

Two to three of the monitoring sites received an average between 130 and 170 kg organic manure N ha^{-1} in the period 2000/01 -2019/20, and four to six sites received an average of more than 170 kg organic manure N ha^{-1}. Measurements of nitrate in water leaving the root zone are shown annually for each site for the period 2000/01-2019/20 (**Figure 4.8A** and **B**).

At one of the sites, station “st 604”, the manure input changed from a high annual input (>170 kg N ha^{-1}) in the period 2000-2008 to a lower input (<170 kg N ha^{-1}) in the following years (**Figure 4.8A** and **B**). With an annual average manure application of more than 170 kg N ha^{-1}, nitrate concentrations were very high at “st 604”. This is seen in five out of six years between 2004/05 and 2009/10. However, other sites with manure applications of 170-230 kg N ha^{-1} had relatively lower soil water concentrations (**Figure 4.8B**). Suction cups at site “st 203” were re-established in 2012, which entails that no nitrate concentration measurements in the root zone were available for this site in 2012/13 and 2013/14. However, manure application on “st 203” increased to >170 kg N ha^{-1}, on average, for a five year period monitored from 2012 and onwards. The annual manure application at site “st 202” changed to a much lower level from 2014, and the nitrate concentration in the root zone water is therefore included in **Figure 4.8A** and **B** from 2014 and onwards. For the site “st 206”. The average five-year manure input increased from <130 kg N ha^{-1} to >170 kg N ha^{-1} in 2013 and is included in **Figure 4.8A** and **B**. Manure application changed to a higher level for “st 608” in 2019/20. The relatively low nitrate concentration of 0.01 mg Nitrate l^{-1} is therefore shown in **Figure 4.8B** with 170-230 kg N ha^{-1} for this year. In 2019/20, “st 203 received no manure input, and no nitrate concentration is therefore shown for this year in. **Figure 4.8B**. The manure application at site “st 201” increased from 2013 and is included in **Figure 4.8B** and **D** from this year. At one site, “st 406”, the farmer stopped livestock production from 2017, and this site is therefore not included in the data from this year and onwards in **Figure 4.8**.

The average flow-weighted nitrate concentrations in root zone water at four-five specific sites with an average manure application within 170-230 kg N ha^{-1} varied between 64 and 103 mg NO_3 l^{-1} for the recent five hydrological years (2015/16-2019/20) (**Figure 4.8D**).

The average flow-weighted nitrate concentrations in root zone water at two-three specific sites with an average manure application within 140-170 kg N ha^{-1} varied between 40 and 135 mg NO_3 l^{-1} for the recent five hydrological years (2015/16-2019/20) (**Figure 4.8C**). Thus, there was no clear difference in flow-weighted nitrate concentration between monitored fields with application of 140-170 kg N ha^{-1} and 170-230 kg N ha^{-1} in manures.

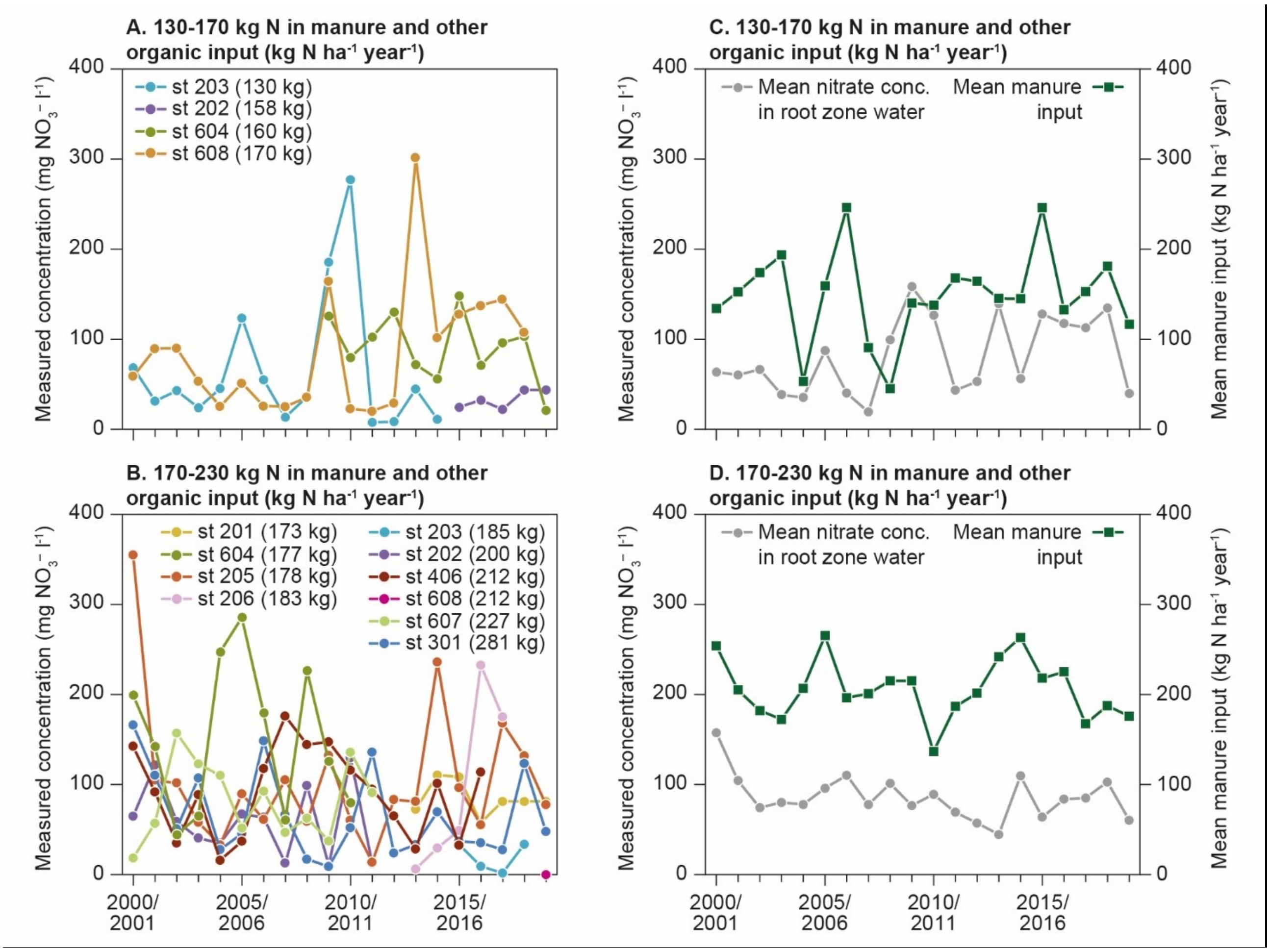

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Figure 4.8 Measured nitrate concentrations in root zone water (1 m depth) with average application of 130-170 N ha^{-1} (A) and more than 170 kg N ha^{-1} in manure and other organic fertilisers (B) at the sites (average application of organic manure N is shown in brackets). Annual averages for the measured stations, average application of 130-170 kg ha^{-1} (C) and more than 170 kg N ha^{-1} in manure and other organic fertilisers (D). All data from the period 2000/01-2019/20 are shown.

Annual variations in measured concentrations at the individual monitoring stations were expected, partly due to crop rotation and variations in yield and meteorological conditions.

The sites that annually received an average of 130-170 kg N in manure ha^{-1} in the period 2000/01-2019/20 had high average nitrate concentrations in the six years 2005/06, 2008/09-2010/11, 2013/14 and 2015/16-2018/19 (**Figure 4.8**).

High nitrate concentrations are most likely a result of crop rotation, especially turnover of clover grass in rotation, followed by cereals without catch crops or high N input to maize, and they cannot be linked to the level of manure input alone.

Phosphorus concentrations in the water leaving the root zone are shown in **Figure 4.9**. Generally, the concentrations varied between 0.005 and 0.050 mg PO_4-P l^{-1}, irrespective of the use of organic manure. However, in one field receiving an average of 148 kg organic N ha^{-1} ("st 608"), P concentrations were much more variable. The soil texture in this field is coarse sand, and it is located in an area with high rainfall.

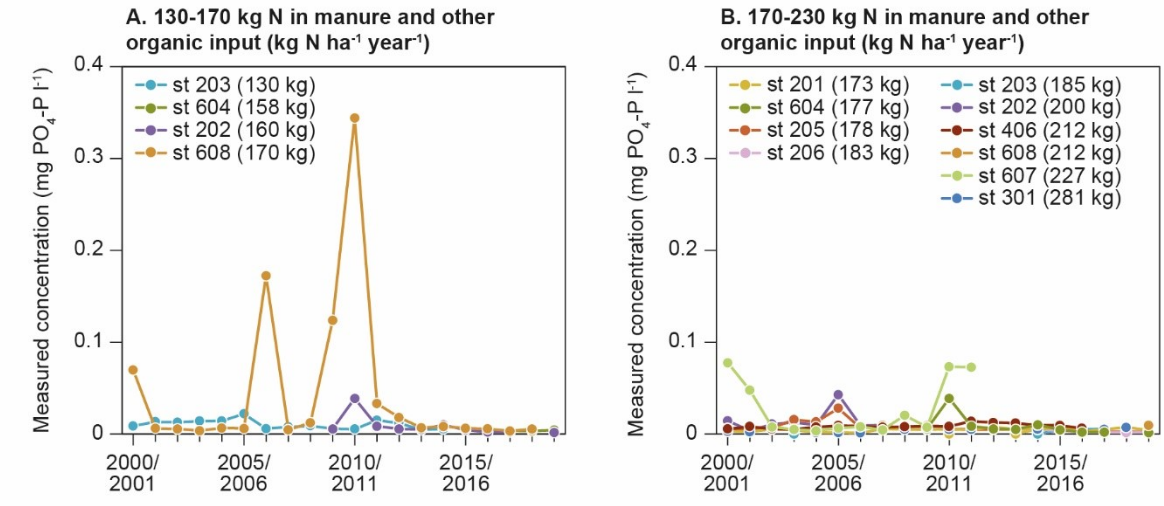

Figure 4.9 Measured phosphorus concentrations as dissolved orthophosphate (PO_4-P) at soil water stations (1 m depth) with average application of 130-170 (A) and more than 170 kg organic N ha^{-1} (B) at the sites (average application of organic manure N is shown in brackets). All data for the period 2000/01-2019/20 are shown.

4.6 The nitrogen flow to surface water in agricultural catchments

This chapter gives an overview of the nitrogen pathways in the hydrological cycle and describes the trends for nitrate in water for the period 1990-2020. Continued monitoring within the framework of the Agricultural Catchment Programme and the Stream Programme will provide indicators for the future development.

When percolating water leaves the root zone, it can conceptually be partitioned into a component that discharges directly to surface water and a component that discharges to groundwater from where it will eventually – often some years later – discharge into the streams. In Denmark, the pathways for water and nutrients in agricultural catchments are analysed in the Agricultural Catchment Monitoring Programme. Nitrate concentrations are measured in soil water, water from tile drains, upper groundwater and surface water from three loamy catchments and two sandy catchments.

The monitoring programme does not allow a specific evaluation of the effect of derogation farms on the nitrate transport in the streams since measurements at the catchment outlet integrate the effects of all activities in the catchment. However, the monitoring programme will provide an overview of the general trend for surface water, including the effect of any derogation farms in the catchment.

The hydrological pathways

An analysis of the water flow in the streams of the five agricultural catchments has shown that it can be conceptually divided into three components – rapid, intermediate and slow response to precipitation (**Figure 4.8**) (Blicher-Mathiesen et al., 2021). These components may be regarded as flow from the upper soil layers (including tile drainage), from the upper oxic groundwater and from deep reduced groundwater.

Table 4.8 Partitioning of water flow in streams into three components – rapid, intermediate and slow responding water. The analysis included three loamy catchments and two sandy catchments (1989/90-2002/03).

		Flow response	
	Rapid	**Intermediate**	**Slow**
Loamy catchments	41%	16%	43%
Sandy catchments	20%	23%	57%

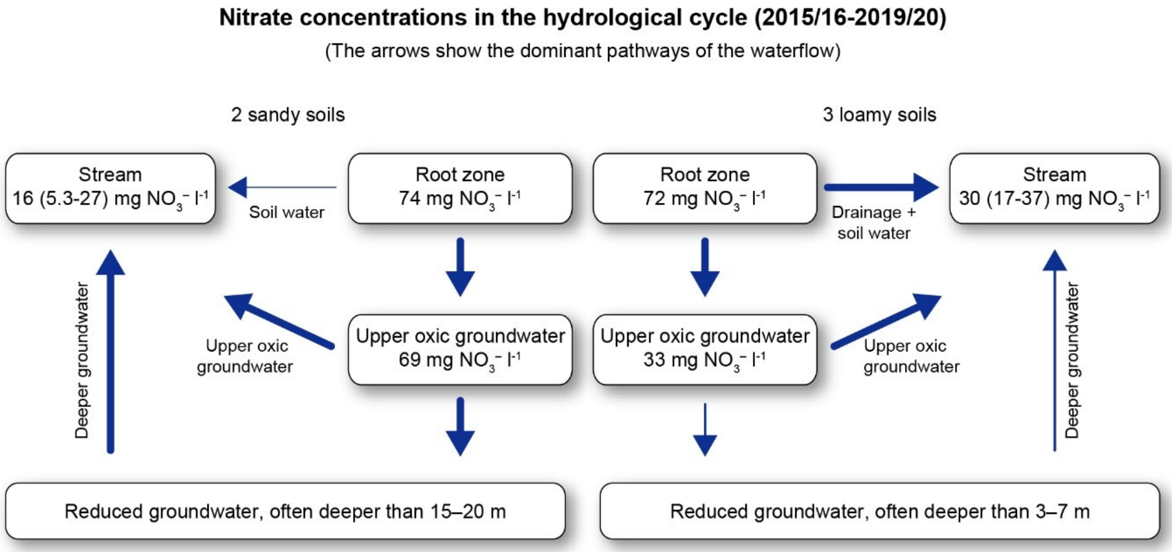

Figure 4.10 Measured means of nitrate concentrations in the hydrological cycle in three loamy catchments and two sandy catchments included in the Agricultural Catchment Monitoring Programme. Stream values for the two sandy catchments are means, and data on the two individual stream outlets are given in brackets. For the three loamy catchments, mean, min. and max. values are given in brackets. The values are calculated as an annual mean for the period 2015/16-2019/20.

In loamy catchments, the flow path is characterised by relatively rapidly responding water (from upper soil layers), whereas there is a larger proportion of slowly responding water (from deeper groundwater) in sandy catchments (**Figure 4.10**) (Blicher-Mathiesen et al., 2021).

Figure 4.11 illustrates measurements of nitrate concentrations (mg NO3 l^{-1}) in soil root zone water, upper oxic groundwater (1.5-5 m below ground level) and in streams. When water percolates from the root zone to the upper groundwater, denitrification processes take place. Thus, nitrate concentrations in the upper groundwater are lower than in the root zone water. When the water passes through the deeper aquifers, it will usually reach the deepest redox interface where the remaining nitrate will be removed by biological and geo-chemical reduction processes.

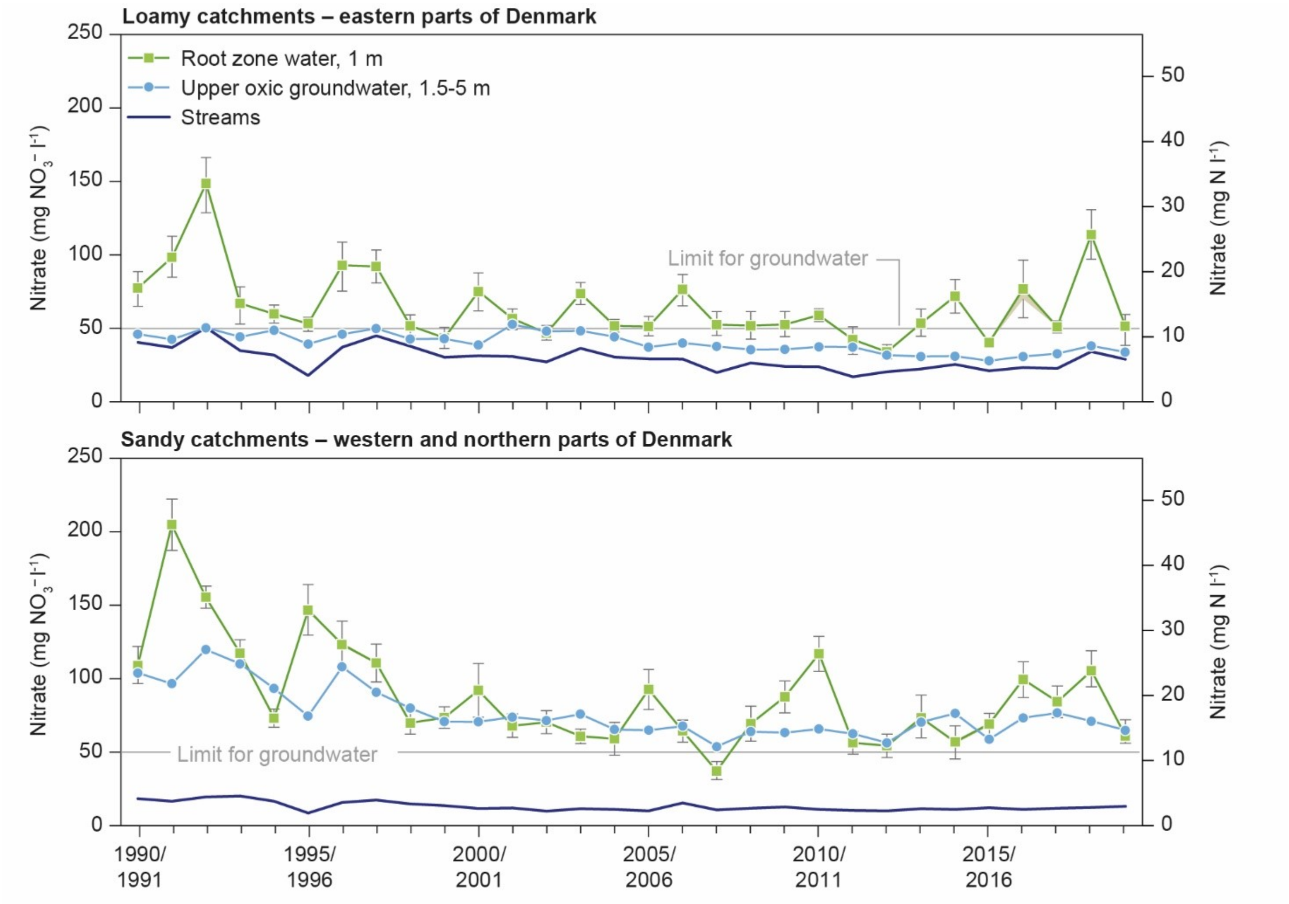

Figure 4.11 Nitrate concentrations measured in root zone water, upper groundwater and in streams for three loamy catchments and two sandy catchments according to the Agricultural Catchment Monitoring Programme, 1990/91-2019/20.

As streams in sandy catchments are dominated by deeper groundwater flow, the groundwater discharging to the streams has often been exposed to reduction processes. Thus, nitrate concentrations in the stream water are relatively low. In loamy catchments, the discharging water has mainly passed through the upper soil layers and through the drainage system where there is less nitrate reduction. Hence, nitrate concentrations in the streams on loamy soils are higher than in sandy catchments.

In this context, it should be noted that cattle farms, i.e. the derogations farms, are mainly located in the western and northern parts of Jutland that are characterised by sandy soils and deep groundwater flow, leading to high nitrate removal and lower nitrogen concentrations in the streams.

Trends in nitrate concentrations in the hydrological cycle

The development in nitrate concentrations in root zone water, upper oxic groundwater and stream water is shown in **Figure 4.11**. Statistical analyses incorporating the annual variations showed that the nitrate concentration in water leaving the root zone decreased significantly by 1.2 and 2.6 mg NO_3 l^{-1} a^{-1} at the measured sites on loamy and sandy soils, respectively, for the 26-year monitoring period from 1990/91 to 2015/16. However, as mentioned before, nitrate concentrations were 72, 48, 107 and 48 mg NO_3 l^{-1} in the four years 2016/17, 2017/18, 2018/19 and 2019/20, respectively, on loamy soils and 93, 79, 99 and 57 mg NO_3 l^{-1} in the corresponding four years, respectively, on sandy soils (see section 4.5). In the Stream Monitoring Programme, the development is analysed for a larger number of streams. This programme reported that during the period 1989-2020, in 49 agriculturally dominated catchments representing both loamy and sandy soils, there was an average reduction of 51% (95% confidence interval: 47-55) of the total nitrogen transport (Thodsen et al., 2021).

References

Blicher-Mathiesen, G., Houlborg, T., Petersen, R.J., Rolighed, J., Andersen, H.E., Jensen, P.G., Wienke, J., Hansen, B. & Thorling, L. (2021). Landovervågningsoplande 2020. NOVANA. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 262 s. - Videnskabelig rapport nr., 472

Blicher-Mathiesen, G., Andersen, H.E. & Larsen, S.E. (2014). Nitrogen field balances and suction cup-measured N leaching in Danish catchments. Agriculture, Ecosystems and Environment 196, 69-75.

Grant, R., Nielsen, K. & Waagepetersen, J. (2006) Reducing nitrogen loading of inland and marine waters – evaluation of Danish policy measures to reduce nitrogen loss from farmland. Ambio 35, 117-123.

Kristensen, K., Waagepetersen, J., Børgesen, C.D., Vinther, F.P., Grant, R. & Blicher-Mathiesen, G. (2008). Reestimation and further development in the model N-LES - N-LES_3 to N-LES_4. DJF Plant Science No. 139.

Kronvang, B., Andersen, H.E., Børgesen, C., Dalgaard, T., Larsen, S.E., Bøgestrand, J. & Blicher-Mathiasen, G., (2008). Effects of policy measures implemented in Denmark on nitrogen pollution of the aquatic environment. Environmental Science & Policy 11, 144-152.

Landbrugsstyrelsen (2020). Statistik over økologiske jordbrugsbedrifter 2020. Landbrugsstyrelsen, Ministeriet for Fødevarer, Landbrug og Fiskeri. https://lbst.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Oekologi/Statistik/Statistik_over_oekologiske_jordbrugsbedrifter_2020_.pdf

Thodsen, H., Tornbjerg, H., Bøgestrand, J., Larsen, S.E., Ovesen, N.B., Blicher-Mathiesen, G., Rolighed, J., Holm, H. & Kjeldgaard, A. 2021. Vandløb 2019 - Kemisk vandkvalitet og stoftransport. NOVANA. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 74 s. - Videnskabelig rapport nr. 452

SVANA (2016). Vandområdeplaner 2015-2021. Styrelsen for Vand og Naturforvaltning. Miljø- og Fødevareministeriet. https://mst.dk/natur-vand/vandmiljoe/vandomraadeplaner/vandomraadeplaner-2015-2021/vandomraadeplaner-2015-2021/

Wiberg-Larsen, P., Windolf, J., Bøgestrand, J., Larsen, S.E., Thodsen, H., Ovesen, N.B., Bjerring, R., Kronvang, B. & Kjeldgaard, A. (2015). Vandløb 2013. NOVANA. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 50 s. - Videnskabelig rapport fra DCE - Nationalt Center for Miljø og Energi nr. 121 http://dce2.au.dk/pub/SR121.pdf

Windolf, J., Larsen, S.E., Thodsen, H., Bøgestrand, J., Ovesen, N. & Kronvang, B. (2011). A distributed modelling system for simulation of monthly runoff and nitrogen sources, loads and sinks for ungauged catchments in Denmark. Journal of Environmental Monitoring 13, 2645-2658.

5. Reinforced monitoring in areas characterized by sandy soils

This chapter is based on selected data from the National Monitoring Programme of Water and Nature (NOVANA), provided by the Danish Environmental Protection Agency, and data on derogation farm location, provided by the Danish Agricultural Agency.

5.1 Introduction

Prior to 2018, data on water quality in the derogation report was based on data from the national agricultural catchment monitoring programme. This programme combines detailed information on both agricultural practice and crop rotation as well as data on water quality in root zone water, uppermost groundwater and small local streams. Monitoring takes place in five agricultural catchments throughout the country, of which three are located in parts of Denmark characterized by loamy soils and two in the western part, where sandy soils predominate. The latest, relevant results from the programme are reported in chapter 4 of this report.

Due to the limited size of the area monitored within the national agricultural catchment monitoring programme, only very few derogation farms are located in the five catchments. The majority of derogation farms are found in the western part of Denmark, especially in the western part of middle and southern Jutland, as shown on the maps in chapter 2 of this report. This part of Denmark is also characterized by predominantly sandy soils.

The derogation decision from 2017 (2017/847/EU) introduced the requirement that water quality should be reported using data from reinforced monitoring. The reinforced monitoring is carried out on sandy soils and in an area that comprises fields belonging to at least 3% of all derogation farms. The derogation decision from 2018 (2018/1928/EU) and the latest derogation decision from 2020 (2020/1074/EU) specifies in Article 10 (2) that, in addition to the monitoring obligations in prior derogation decisions, "[...] *Reinforced monitoring of water quality shall be carried out in areas with sandy soils. In addition, nitrates concentrations in surface and groundwater shall be monitored in at least 3 % of all holdings covered by an authorisation.*"

5.2 Method

Selection of relevant monitoring stations
Besides the results from the national agricultural catchment monitoring programme (see chapter 4), which previously has formed the basis for annual reporting according to the derogation decision, Danish authorities also collect data through a number of other national monitoring programmes. As part of the “National Monitoring Programme of Water and Nature” (NOVANA), data from approximately 500 water quality stations in streams and rivers are collected on a regular basis. The primary purpose is to determine nutrient loads to sensitive recipients, i.e., coastal waters and lakes. Water samples from more than 1,000 groundwater monitoring stations are also analysed on a regular basis; the sampling frequency varies from several times annually to once during a multi-year period, according to the monitoring and reporting requirements of the Nitrates Directive and the Water Framework Directive.
One of the usual parameters that both groundwater and surface water samples are analysed for is nitrate concentration.

Simultaneously, the Danish Agricultural Agency registers which fields belong to derogation farms.

The approach is based on the identification of either surface water or groundwater monitoring stations located in close proximity to a field belonging to a derogation farm. More precisely, the GIS-analysis is based on the coordinates of the surface water or groundwater monitoring station as well as the surrounding area within a fixed 15-metre radius. This circle allows for an overlap between the position of the monitoring station and any fields in close proximity.

Only water course and groundwater monitoring stations located within 15 metres of a field registered to a derogation farm are selected. To determine whether this criterion is met, the latest registry data from the Danish Agricultural Agency is used.

If a groundwater monitoring well fulfils the location criterion but contains several monitoring stations at different depth ("multi-filter wells"), only one of these stations is selected; typically, the station that has the largest number of prior nitrate concentration samples.

Groundwater monitoring stations at a depth of 80 metres or more have been excluded from the data set, as data from the national groundwater monitoring ("GRUMO") programme shows that nitrate levels are no longer quantifiable (<1 mg/L) at these depths.

Only surface water monitoring stations that are part of the national programme monitoring "Transport of nutrients in streams" have been considered for the reinforced monitoring. A few mobile stations used for lake monitoring that would have fulfilled the proximity criterion have been excluded from the data set, as their locations typically change every year, making it impossible to create time series. Monitoring stations that have been installed in water courses to monitor the outflow from constructed wetlands have also been excluded.

In all, this selection method has identified a total of 38 monitoring stations. 20 stations of these (53 %) are groundwater monitoring stations, while 18 stations (47 %) are located in water courses (**Figure 5.1**). The distribution between station types is a direct consequence of the higher density of groundwater as opposed to surface water monitoring stations throughout Denmark.

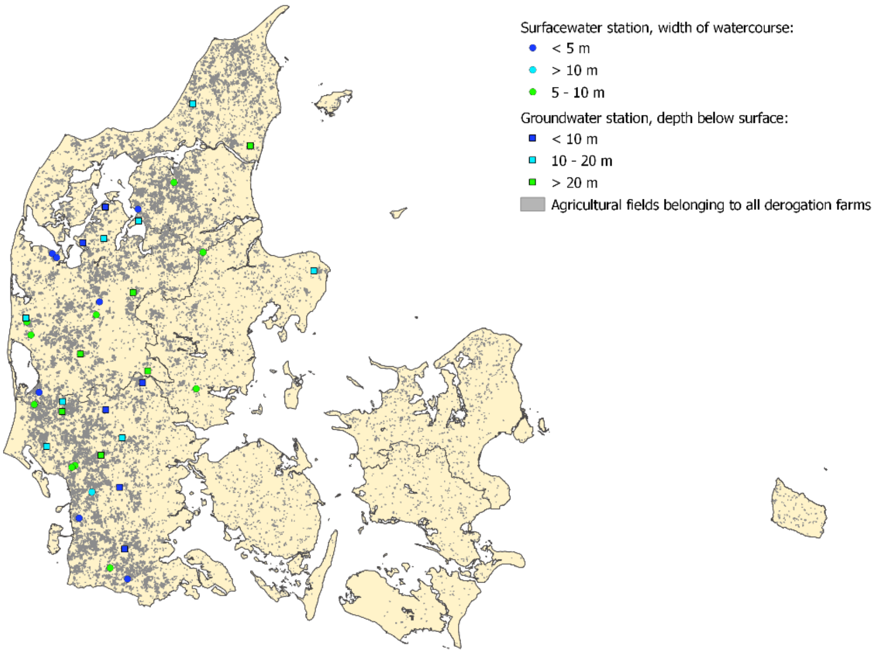

Figure 5.1: Map showing the locations of the 38 monitoring stations selected as the reporting basis for the reinforced monitoring. The squares show the location of in total 20 groundwater monitoring stations at different depths – these may overlap due to the scale of the map. The circles show the location of the 18 water course monitoring stations. Grey shading indicates all fields belonging to Danish derogation farms.

The majority of derogation farms are located in the western part of Denmark, especially the western, northern and southern parts of the peninsula of Jutland, also illustrated in chapter 2 of this report. These parts of the country are characterized by sandy soils, whereas loamier soils dominate the more eastern parts of the country. Consequently, the described approach of linking the locations of monitoring stations to fields belonging to derogation farms results in a considerable enlargement of the data basis for reporting of water quality in sandy areas.

The geological map in **Figure 5.2** below illustrates the soil substrates throughout Denmark.

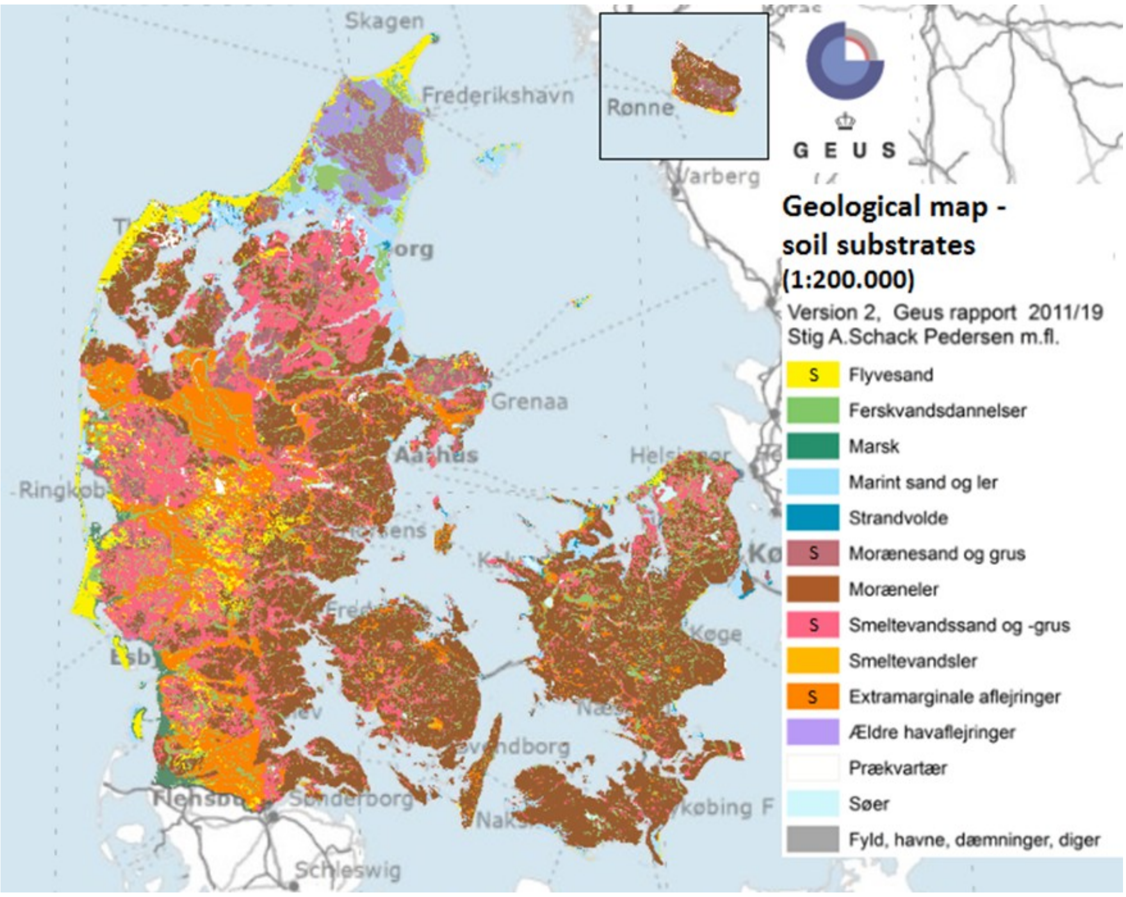

Figure 5.2 Geological map of Denmark showing the substrates that are the basis for soil development. Modified from a map produced by GEUS. The legend is only available in Danish, but the four main soil substrate types that can be categorized as "sand" have been marked with an "S" in the legend.

Coverage of Danish derogation farms

The locations of the 38 monitoring stations have been linked to 66 fields, which in turn belong to 41 different derogation farms. Out of the 41 farms, 20 are subject to the reinforced monitoring due to the proximity of their fields to a water course monitoring station, while 20 farms are included owing to proximity to groundwater monitoring stations. One farm was included due to proximity to both a water course and a groundwater monitoring station. The total number of farms encompassed by the reinforced monitoring corresponds to 3.4 % of all holdings that make use of the derogation.

5.3 Characterization of monitoring stations and data analysis

Groundwater

The selected groundwater monitoring stations are located at depths below the surface ranging from 1.75 m to 72 m[8]. The majority of the stations monitor water quality in comparatively shallow groundwater, at an average depth of 19.92 m and a median depth of 15.50 m. Of the selected groundwater monitoring stations, 32 % of the samples are of very shallow groundwater from a depth of less than 10 m. 37 % are located

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[8] Based on data available up until 2018, the deepest selected monitoring station was located at 62 m below the surface. Data from the deeper groundwater is expected to be included in future reports, when water from these selected stations will be sampled and analysed for nitrate again.

from 10-20 metre below surface and the rest 32 % of the stations are located from 20-80 metres.

All of the groundwater monitoring stations will be sampled at least once per year. Historic data since 2002 – the year Denmark obtained a derogation from the Nitrates Directive for the first time – have been included to the extent that they are available. If groundwater has been sampled more than once per year, the average annual nitrate concentration has been calculated for this station for each respective sampling year.

For the purpose of presenting the data in the results section below, the stations have been grouped into three different categories, stations at a depth of less than 10 m below surface, stations at 10 to almost 20 m depth and stations at 20 m depth or deeper. Annual average nitrate concentrations have been calculated for each depth category for each year since 2002, based on the actual number of stations sampled in the respective year.

Surface water

The monitored water courses vary considerably in size and flow rate. The widths of the water courses at the monitoring station vary from 2 m to 10.5 m. The average water course width at the monitoring station is 6 metres, while 7 out of the 18 stations are located in small streams of less than 5 metres' width.

Samples from water courses are generally analysed for Nitrite- and Nitrate-Nitrogen (N). Nitrite-N-concentrations are typically negligible, and under this assumption, nitrate concentrations in the water samples could be calculated by multiplying the Nitrate-N concentration by a factor of 4.4268. In this chapter, the surface water concentration is generally given in Nitrite- and Nitrate-Nitrogen. Historic data since 2002 is included to the extent that it is available. Only data from monitoring stations that have been sampled at least 9 times annually in the period before 2017 are displayed in the results. In 2020, each water course monitoring station has been sampled more frequently, from 16 to 21 times annually.

For the purpose of presenting the data in the results section, stations have been grouped based on the approximate width of the water course at the sampling station site into three different categories, as also displayed in **Figure 5.1**: less than 5 m, 5 to 10 m and more than 10 m width. Average nitrate concentrations have been calculated for each category for each year since 2002, based on the actual number of stations sampled in the respective year.

As a consequence of the political agreement on the Food and Agricultural Package from December 2015, the number of water course monitoring stations has been significantly increased. 9 out of the 18 water course stations selected for the reinforced monitoring were established in 2016 as a consequence of the agreement, and now, it is decided to continue the monitoring.

5.4 Results and Discussion

Groundwater

Figure 5.3 shows the nitrate concentration of each groundwater monitoring station selected for reinforced monitoring, as well as the average nitrate concentrations per sampling year for the period 2002 to 2020 for each of the depth categories. The quality limit value of 50 mg nitrate per litre is also shown.

The data generally shows great variability in nitrate concentrations from one year to another in water samples from individual monitoring stations. Especially in the shallowest groundwater (**Figure 5.3A**), absolute concentration changes of up to more than 80 mg nitrate per litre can be observed from one sampling year to the other.

The average nitrate concentration remains below the quality limit value for each depth category throughout the whole period 2002 until 2020, with the exception of 2010 for the deepest category. However, this value is only based on two monitoring stations.

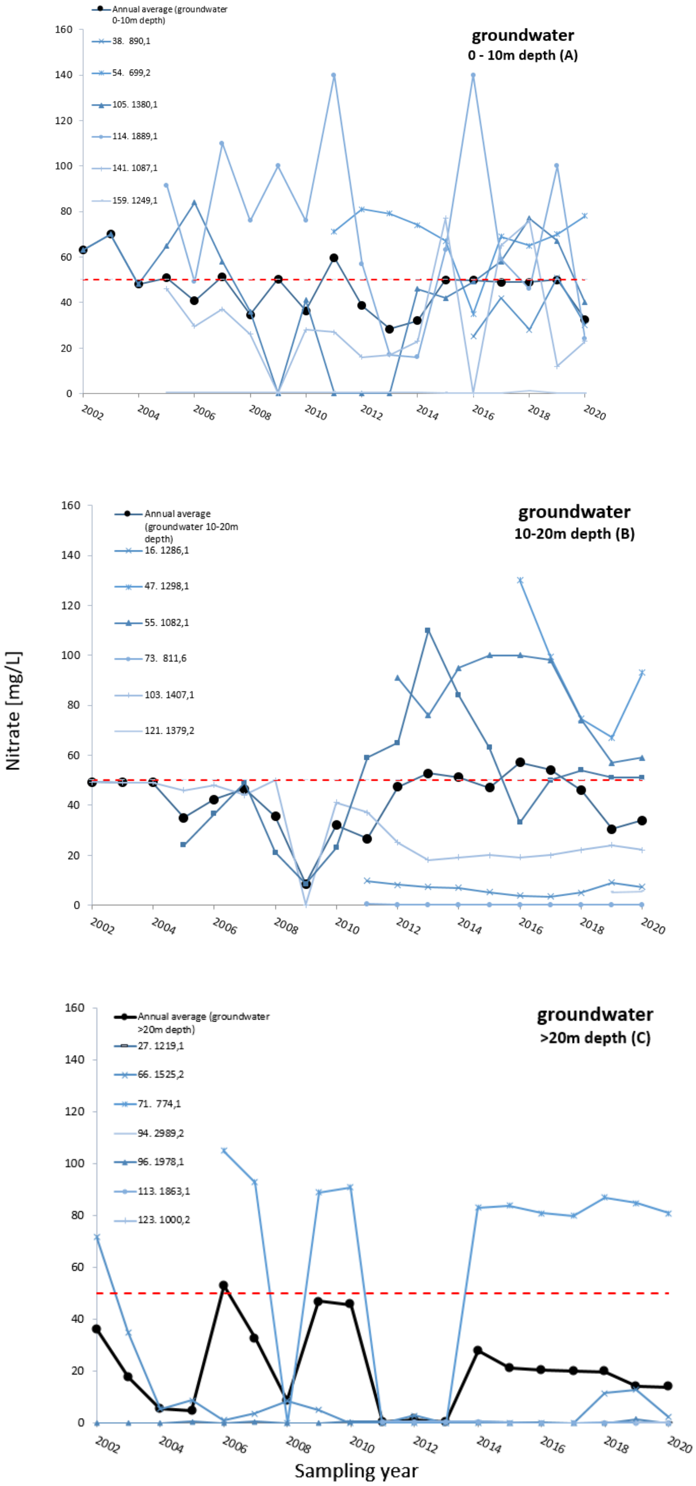


Figure 5.3: Nitrate concentration of the individual groundwater monitoring stations selected for the reinforced monitoring, as well as the average nitrate concentrations per sampling year for the period 2002 to 2020 for each of the three depth categories of groundwater stations: (A) stations at less than 10 m depth; (B) stations at 10-20 m depth and (C) stations at 20 m depth and deeper below the surface. A red dashed line at 50 mg nitrate per litre is inserted in each figure.

No clear trend in the average nitrate concentration can be observed over time for any of the three depth categories. Due to the limited number of stations and samples per year, the annual average values are highly influenced by the variability in nitrate concentration in the water sampled from some individual stations.

Table 5.1 shows the average nitrate concentration of all stations for each year in the period 2002 to 2020, irrespective of their depth and the number of stations sampled (n) in the respective year that form the basis of this calculation. The annual average nitrate concentration varies between 20.9 mg/L, as sampled in 2003 (n=11), and 41.9 mg/L in the groundwater samples from 2009 (n=13).

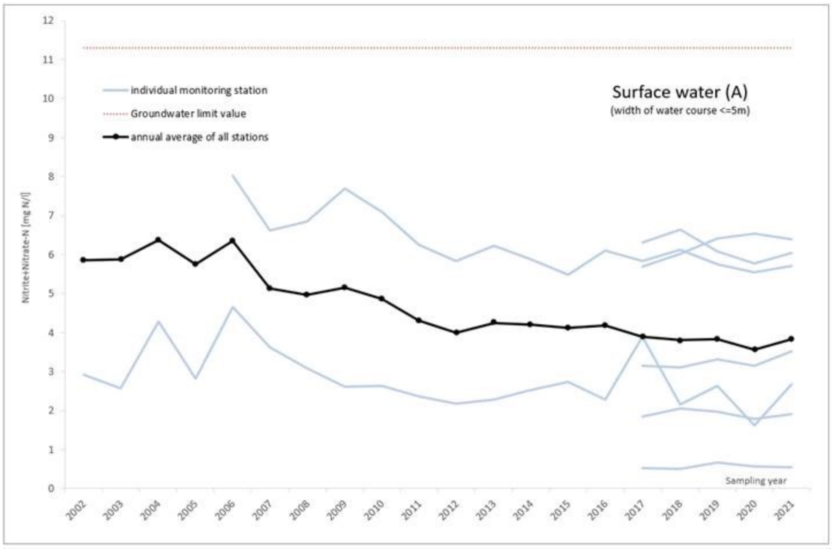
Table 5.1: Annual average nitrate concentration of all stations in reinforced monitoring in the period 2002-2020 and number of stations sampled

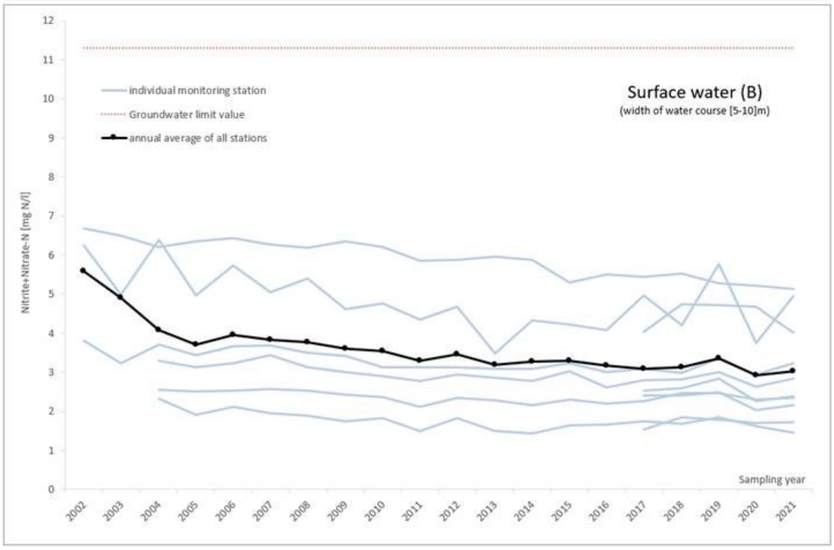
Sampling year	Average nitrate concentration [mg/L]	Number of sampled stations (n)
2002	29.2	11
2003	20.9	11
2004	27.0	10
2005	37.0	18
2006	38.1	18
2007	37.8	18
2008	32.1	16
2009	41.9	13
2010	40.7	13
2011	28.7	18
2012	28.8	23
2013	29.2	18
2014	28.8	23
2015	35.1	21
2016	35.2	22
2017	31.9	26
2018	30.5	29
2019	26.9	28
2020	27.2	19

When calculated across the entire period from 2002 to 2020, the (non-weighted) mean value of the annual average concentrations is 32.2 mg/L. The 2020 average is lower than the mean value for the whole 2002-2020 period.

Surface water

Figure 5.4 shows the Nitrite- and Nitrate-Nitrogen concentration of the individual water course monitoring stations selected for reinforced monitoring, as well as the average nitrate concentrations per sampling year for the period 2002 to 2021 for each of the width categories. The quality limit value for groundwater of 50 mg nitrate per litre, which corresponds to approximately 11.3 mg Nitrate-N per litre, is also shown.





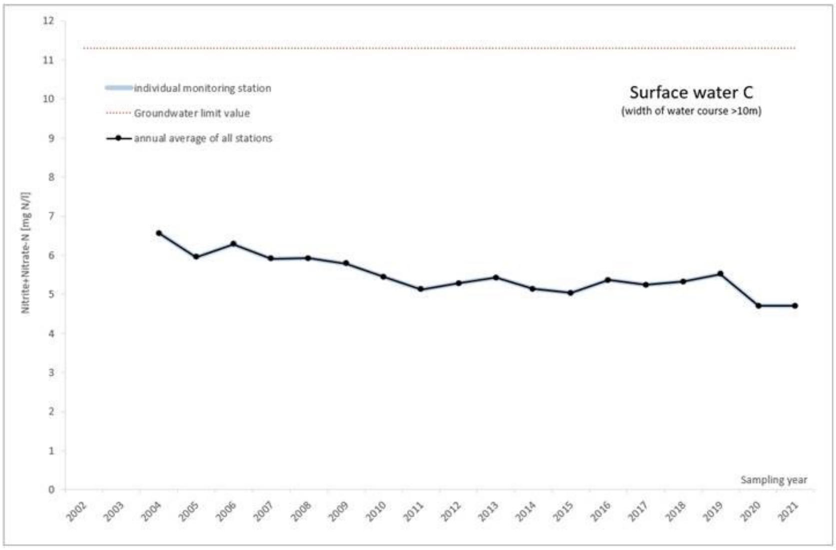


Figure 5.4: Nitrite- +Nitrate-Nitrogen (N) concentration of the individual surface water monitoring stations selected for reinforced monitoring, as well as the average nitrate concentrations per sampling year for the period 2002 to 2021 for each of the three width categories (determined at sampling site): (A) less than 5 m wide; (B) 5 to 10 m wide and (C) wider than 10 m. A red dashed line is inserted in each figure at 11.3 mg Nitrate-N/L, corresponding to approx. 50 mg nitrate per litre.

At the level of the individual monitoring station, nitrite- + nitrate-nitrogen concentrations can vary significantly from year to year mainly due to variation in amount and timing of precipitation. The standard deviation in absolute concentration are 1.84 mg/l. Nevertheless the year-to-year variations are not as pronounced as those seen in groundwater samples.

For all water course categories it is, however, important to underline that the N transport is not determined by the nitrogen concentration alone, but also by the water flow in the water course, which can significantly vary due to the specific and local weather conditions of a given year. In low flow rate situations, nitrogen levels may be relatively high while total N transport remains unchanged, and vice versa. As smaller water courses typically have a smaller catchment area than rivers, variations in local weather conditions are expected to have a greater impact on the nitrogen concentration in water sampled from small water courses.

For all individual water course monitoring stations, nitrate-N concentrations remain well below the quality limit for groundwater and drinking water throughout the whole period from 2002 to 2020. Absolute concentrations tend to be higher in the smaller water courses than in the larger ones, which is likely to be a result of nitrate being removed through natural processes along the course of the water. Overall, the annual average for each category has been steadily decreasing over the last 10 years of the period shown.

Table 5.2 shows the annual average nitrite- and nitrate-N concentration in water sampled at all water course stations – irrespective of their width – and the number of stations sampled in the respective year (n).

Table 5.2: Annual average nitrite- + nitrate-N concentration in water sampled at all stations selected for reinforced monitoring, as well as the number of stations sampled in each year

Sampling year	Average nitrite- +nitrate-N concentration [mg/L]	Number of sampled stations (n)
2002	4.1	5
2003	3.8	5
2004	4.4	7
2005	4.0	7
2006	4.4	10
2007	4.1	10
2008	3.9	10
2009	3.9	10
2010	3.8	10
2011	3.3	11
2012	3.4	11
2013	3.4	11

2014	3.3	11
2015	3.3	11
2016	3.3	11
2017	3.0	20
2018	3.0	20
2019	2.9	18
2020	3.3	18

The annual average nitrite- + nitrate-N concentration has decreased from 4.4 mg/L in the early years of the reported period (e.g. 2006, n=10) down to 3.3 mg/L in 2016 (n=11). Since 2017, 9 additional water course monitoring stations have been established, improving the data basis significantly. Hence, it is now possible to follow the development in water courses, which have been equipped with new monitoring stations as a consequence of the political agreement on the Food and Agricultural Package from December 2015. Despite the significant increase in number of monitoring stations, which are considered in the reinforced monitoring, the average nitrite- + nitrate-nitrogen concentrations for the different water course categories remains fairly constant. The average concentration in 2020 for all water course stations was 3.3 mg/L, i.e. at the same level as in 2016.

General discussion

It is important to highlight that the reinforced monitoring does not provide data that can be used to examine any potential effect on water quality that might be the result of the use of the derogation. A range of other fluctuating factors influence nutrient concentrations in the aquatic environment, and as such, it would not be possible to identify or isolate such an effect.

Because the reinforced monitoring method is based on linking the locations of monitoring stations to fields belonging to derogation farms in a two-dimensional way: The approach does not account for the actual catchment area and subsurface water paths for the respective monitoring stations. Hence, it is only to a very limited degree possible to get a picture of the effects of land use on surface water and groundwater quality. A clearer picture would require a catchment-based approach, which takes into account that water quality in the recipient water is affected by land use in the whole catchment area.

The present method does not include a reference group of monitoring stations that are not located in proximity to fields belonging to derogation farms. However, by including the data from this selected set of the surface water and groundwater monitoring stations, the data basis for water quality in sandy areas has been considerably enlarged from the two sandy catchments within the national agricultural catchment monitoring programme (see chapter 4), which formed the basis for reporting prior to 2018 and still provides comprehensive data on land use at farm-level.

6. Indicator and monitoring system for application of phosphorus in Denmark

Ministry of Environment of Denmark

6.1 Introduction

In consultation with the European Commission, the Ministry of the Environment and Food (since November 2020 the Ministry of Environment) has agreed that Denmark must monitor the use of phosphorus (P) in organic fertilizer and commercial fertilizer, so that it is ensured that the average use does not exceed the national phosphorus ceiling. The monitoring is based on data from the fertilizer accounts, which is available approximately one year after a planning period is completed, when the farmers submit their fertilizer accounts to the Danish Agricultural Agency. The first planning period with limiting phosphorus use by specific ceilings at farm level was 2017/2018.

As a supplement to monitoring, it has been agreed that an "indicator system" must be established, where data from the NOVANA monitoring program in Agricultural Catchments (LOOP) in combination with available data on livestock production and sales of fertilizer and other phosphorus sources can provide an updated overview of the average amount of phosphorus used in Danish agriculture.

These results from the P monitoring and indicator system, respectively, should be compared with the phosphorus ceilings. In this connection, it was agreed, that the total amount of phosphorus used should be divided by the total agricultural area in order to calculate the average fertilizer rate per year per ha on agricultural land. No requirement has been set for the first planning period 2017/2018, but in 2018 (planning period 2018/2019) the average use should be below 34.7 kg P/ha, and in 2019 (planning period 2019/2020) the average use should be below 34.1 kg P/ha. In 2020 (planning period 2020/2021) the average use must be below 33.2 kg P/ha. If the average use exceeds 33.2 kg P/ha in 2020 (planning period 2020/2021), the phosphorus ceilings must be lowered.

6.2 Results from the P monitoring system

The Danish Agricultural Agency compiled data from the fertilizer accounts with data from the planning period 2019/2020. The compiled data has not been processed or checked thoroughly for exorbitant values and other "noise", e.g. typos. If there are exorbitant values, it is estimated that only extremely high values in a few fertilizer accounts can have an important influence on the overall results, so the results represent a "worst case" scenario of phosphorus use.

Table 6.1: Compiled data from fertilizer accounts 2019/2020 (rounded numbers)

	Produced P (tons)	Used P (tons)
Poultry/fur	4,700	
Finishers	10,300	
Sows and piglets	8,600	
Cattle (non-derogation)	10,900	
Cattle (derogation)	7,300	
Manure – Total	**41,800**	**41,100**

Waste and other P	3,600	3,300
Manure + waste		44,400
Chemical fertilizers		17,600
Used P – Total		**62,000**

	Mio. ha
Agricultural area	2,600
Harmony area	2,400

Average P-ceiling in 2019/2020	**33.5**
kg P/ha agricultural area	**24.1**
kg P/ha harmony area	25.8

6.3 Results from P indicator system

The following table shows the phosphorus inputs as reported in the NOVANA report "Land Surveillance Survival 2020" from December 2021[18]. The table shows an increase as expected in the use of phosphorous in 2017 due to the increase in the P-ceiling from 2016 to 2017. In the coming years the P-ceiling will be decreased back to a lower level, so the increase in the use of phosphorous is not expected to continue.

Table 6.2: The use of P-input in Danish agriculture in 2012-2020[9]

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Use of P (1,000 tons) in different inputs:									
- Chemical fertilizer	11.8	11.3	13.0	13.3	13.3	20.8	14.8	14.6	16.0
- Livestock manure	45.8	45.3	46.1	46.1	44.3	43.0	44.3	44.9	43.8
- Seed	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
- Sludge	2.4	2.4	2.4	2.4	2.4	2.4			
- Waste from industry	3.1	3.1	3.1	3.1	3.1	3.1			
- Other organic fertilizer[10]							2.8	3.1	3.1
- Deposition	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total use of P	**64.4**	**63.4**	**65.9**	**66.2**	**64.4**	**70.5**	**63.2**	**63.9**	**64.3**
Agricultural area (1,000 ha)[11]	**2,679**	**2,671**	**2,661**	**2,633**	**2,625**	**2,610**	**2,602**	**2,613**	**2,613**
kg P/ha in average	**24.0**	**23.7**	**24.7**	**25.1**	**24.4**	**27.0**	**24.3**	**24.4**	**24.1**
kg P/ha (P-ceiling)					**[32.2]**[12]	**35.2**	**34.7**	**34.1**	**33.2**

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[9] Source: Blicher-Mathiesen *et al.* (2021): *Landovervågningsoplande 2020*. Aarhus University. https://dce2.au.dk/pub/SR472.pdf

[10] From 2018 onwards, amount of other organic waste, such as sludge and waste from industry, is derived from the fertilizer accounts.

[11] Agricultural area for the years 2016, 2017 and 2018 has been updated after submission of the Derogation Report 2019.

[12] This figure indicates the average phosphorus protection level in 2016 expressed as a theoretical P-ceiling, before the P-ceilings were introduced, and is included for comparison.

In the dialogue with the EU Commission, it was expected that the development in livestock production should be monitored via data from the CHR register, since Denmark previously prepared an annual status on the size of livestock production in various catchments. This annual status is now done instead on the basis of the fertilizer accounts, which is why the best data material on the development in livestock production is the annual status of the livestock population, which is made by Statistics Denmark. Statistics Denmark's information on livestock in 2017-2020 can be seen in **Table 6.3**.

Table 6.3: The development in the livestock production according to Statistics Denmark in 2017, 2018, 2019 and 2020[13]

	Number of animals 2017	Number of animals 2018	Number of animals 2019	Number of animals 2020	% change in total number of animals 2017-2020
Number of all kinds of cattle and dairy cows on all farms	1,545,417	1,540,446	1,491,433	1,498,713	-3.02
Number of all kinds of pigs on all farms	12,307,667	12,781,247	12,298,993	13,162,627	6.95
Number of all kinds of poultry on all farms	21,483,698	19,973,164	23,059,881	22,132,858	3.02
Number of all kinds of mink on all farms	3,429,472	3,379,931	2,489,751	2,234,101	-34.86

The manure production based on data from the fertilizer accounts shows that 11 % of the total manure production comes from mink and poultry, 46 % from pigs and 43 % from cattle. The amount of mink presented in the table, is the number of mink before termination. In November 2020, all mink in Denmark were ordered to be terminated, as they were classified as a possible health risk with regards to the spread of Covid 19.[14]

There are no signs that indicate that a considerably larger amount of livestock manure will be produced in 2021, and that the average phosphorus application in Denmark will exceed 25-28 kg P/ha, as the phosphorus ceiling from 2018 onwards will be reduced continuously. This level will be well below the average phosphorus ceilings of 35.2 kg P/ha in 2017, 34.7 kg P/ha in 2018, 34.1 kg P/ha in 2019, 33.2 kg P/ha in 2020 and further reductions set for 32-33 kg P/ha in 2022 and 30-31 kg P/ha in 2025.

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[13] Data from Statistics Denmark: for cattle, pigs, poulty and mink: https://www.statistikbanken.dk/10472

[14] https://www.ft.dk/samling/20201/almdel/mof/bilag/131/2284052.pdf

7. Targeted catch crops scheme and targeted nitrogen regulation

Kari Lundsager and Marie Dam, The Danish Agricultural Agency, Ministry of Food, Agriculture and Fisheries of Denmark, October 2020. Updated by Laurits Hesselager, The Danish Agricultural Agency, Ministry of Food, Agriculture and Fisheries of Denmark, October 2021

As part of the political agreement on the Food and Agricultural Package of December 2015, the reduction of the nitrogen application standards was removed. It was also agreed to develop a new nitrogen regulation, the “targeted nitrogen regulation”, which was to be implemented in 2019.

The Danish government introduced an intermediate initiative, the “targeted catch crops scheme”, to reduce N-losses through promoting the establishment of additional catch crops in 2017 and 2018. The scheme was designed to protect both groundwater bodies and coastal waters. The scheme was targeted by assigning different requirements of nitrogen reductions for different water catchment areas, based on the calculated needed effort within each area.

The scheme consisted of a voluntary phase, where farmers applied for participation in the scheme, and a subsequent mandatory requirement for catch crops if the voluntary scheme did not reach the predefined targets within each catchment area. The latter requirement was uncompensated whereas the voluntary part was compensated with de minimis support.

In November 2017, a political agreement for targeted nitrogen regulation was reached and would be implemented from 2019. The targeted nitrogen regulation is similar to the targeted catch crops scheme in many ways. The most significant difference is the introduction of the possibility to use alternative measures to catch crops. Conversion factors are used to secure that the alternatives have the same effect as catch crop. Like the targeted catch crops scheme, the targeted nitrogen regulation is divided into a voluntary and a mandatory part. The targeted nitrogen regulation was subsidised by de minimis in 2019 and by RDP funds in 2020 and 2021.

After the application deadline in the voluntary crop scheme, the farmer is bound by any commitment made, either through catch crops or alternatives, as well as by any additional catch crop requirement imposed through the mandatory round.
The farmer will not be able to opt out of any of these requirements without consequences. The voluntary and obligatory targeted catch crops or alternatives must be additional to the national mandatory requirement for catch crops on 10.7 or 14.7% of the farm’s crop base area, and they cannot be established on the same area used for catch crops to meet the EFA requirement under direct payments.

If the farmer opts out afterwards or non-compliance is detected during control, the nitrogen quota for the farm (calculated on the basis of the composition and distribution of crops and the soil and crop-specific nitrogen standards) is reduced corresponding to the non-compliance with the voluntary and/or mandatory requirement and according to a conversion factor between the nitrogen reduction effect of catch crops and the nitrogen quota reduction for the planning period. This quota reduction will contribute to meeting the objectives of the Nitrates Directive. Furthermore, if the reduced nitrogen quota is exceeded, the farmer will be in breach of the Fertilizer Act and will be sanctioned accordingly cf. Annex III point 1.3 of the Nitrates Directive.

This is similar to the current practice for the general catch crop requirements and additional catch crop requirements for holdings using organic manure.

In 2019, the targeted nitrogen regulation contributed to a nitrogen reduction of 1,174 tons in coastal waters, including reductions of nitrogen leaching to the groundwater. Further, in 2019, it was decided by political agreement to increase the effort of the targeted nitrogen regulation in 2020 for additional contribution to meet the objectives of The Water Framework Directive. In 2020, the targeted nitrogen regulation will thus contribute to a nitrogen reduction of 3,514 tons in coastal waters. In 2021, the targeted nitrogen regulation contributes to a nitrogen reduction of 3,514 tons in coastal waters plus an additional 4 tons postponed from the previous year.

7.1 Results from 2017 to 2021

Prior to 2017 and 2018, respectively, the ministry calculated the need for further nitrates efforts for each of the years, which can be expressed as the amount of additional catch crops required in the individual water catchment areas, in terms of hectares and as a percentage of the crop base area. The calculation is based on the estimated need for reductions in the nitrates contents of groundwater bodies and coastal waters, adjusted by the estimated soil nitrates retention in the water catchment area. In 2019 and 2020, the targeted nitrogen regulation was dimensioned to comply with the Danish implementation of The Water Framework Directive.

In 2017, the need for further nitrogen efforts was calculated to 137,560 ha. By the application deadline, the farmers had applied for a total of 144,220 ha of catch crops. However, the geographical distribution of the catch crops was not optimal in relation to the efforts needed. Calculations revealed that an additional **3,253** ha catch crops were needed in order to reach the target. It was decided politically to postpone the residual effort until 2018.

In 2018, the need for further nitrogen effort was calculated to 114,300 ha catch crops (including the postponed 3,253 ha). By the application deadline, the farmers had applied for a total of 105,000 ha of catch crops. It was furthermore decided to postpone the effort related to aquaculture (fish farming, mariculture, etc.), as extensions of existing aquaculture facilities had not been approved. Calculations revealed that an additional **3,000** ha catch crops were nevertheless needed in order to reach the target. This has been implemented as a mandatory uncompensated requirement in 2018.

In 2019, the need for nitrogen efforts in targeted nitrogen regulation was calculated to 138,200 ha of catch crops. By the application deadline, the farmers had applied for 139,350 ha of catch crops (and alternatives). Calculation revealed that an additional 275 ha were needed to reach the set effort. The reason was the geographical distribution of the catch crops, which was not optimal. It was decided politically to postpone this insignificant residual effort to 2020.

In 2020 the need for nitrogen efforts in targeted nitrogen regulation was calculated to 373,000 ha of catch crops and included the residual effort from 2019. By the application deadline, the farmers had applied for 370,000 ha of catch crops (and alternatives). Some applications had to be dismissed, as the set effort for the individual water catchment areas was already reached. A total of 349,400 ha was approved for the voluntary phase. Calculations of the geographically specific retention disclosed that an additional 12,493 ha were needed to reach the set national nitrogen reduction effort. Consequently, this was implemented as a mandatory uncompensated requirement in 2020. Excluding a minor residual effort of 350 ha of catch crops, which was decided politically to postpone.

In 2020, the need for nitrogen efforts was calculated to 3,518 tons of nitrogen, which included 4 tons of residual effort postponed from the previous year. That corresponded to 373,600 ha of catch crops. By the application deadline, the farmers had applied for 359,200 ha of catch crops and alternatives. Due to suboptimal geographical placements of the catch crops in relation to the needed efforts in the individual water catchments areas, some applications had to be rejected. Some water catchment areas had too many applications, while in other areas the applications did not meet the required nitrogen targets. A total of 351,800 ha was approved. It was calculated that an additional effort corresponding to a total of **17,200** ha was needed to meet the national nitrogen effort goal. This remaining effort was implemented as a mandatory uncompensated requirement in 2021.

8. Conclusions

8.1 Cattle holdings and controls on farm level

In the planning period 2019/2020, a total of 1,197 cattle holdings made use of the derogation. This corresponds to 3.7 % of the total number of agricultural holdings in Denmark. These holdings produced 36.8 million kg N corresponding to 16.8 % of the total kg N produced. The arable land encompassed by the derogation in year 2019/2020 was 182,950 hectares corresponding to around 7.6 % of the total arable area. Compared to the previous reporting period, in 2019/2020 there has been a decrease in the number of farms and the number of hectares encompassed by the derogation. The average livestock size was 30,769 kg N/holding in 2019/2020.

In January – February 2021, 79 inspections of compliance with the derogation management conditions were carried out. All of these inspections were closed without remarks.

For the year 2018/2019, 85 inspections (0.3 % of all Danish holdings) at the holding were made concerning compliance with the harmony rules (amount of livestock manure applied per hectare). 85 of the inspected farms used the derogation. 9 of these inspections were closed without remarks. No holdings had no remarks.
76 holdings are still under investigation.

All 33,056 fertilizer accounts submitted in 2018/2019 (100 %) were automatically screened by the IT-system according to normal procedure. Of these, 645 (2.0 %) were subject to administrative control or administrative inspections. In all, 133 of these holdings used the derogation. Of the inspections of derogation farms, 42 (31.6 %) were closed without remarks, 2 (1.5 %) were closed with remarks and 89 (66.9 %) are still under investigation.

In total, approximately 7.0% of derogation farms were selected for physical inspections. In total, more derogation farms have been subject to controls due to the aforementioned administrative inspections. As holdings are automatically selected - based on a previously agreed set of risk criteria - for both physical inspections and administrative inspections, the Danish Agricultural Agency has no direct influence on the share of holdings using the derogation that are inspected each year. Therefore, the share of derogation farms that in some way has been subject to controls varies from year to year.

8.2 Water quality

General conclusions from the Agricultural Catchment Monitoring Programme

In 1998 the Action Plan for the Aquatic Environment (APAE) II was accepted by the EU Commission as the Danish Nitrate Action Plan implementing the Nitrate Directive (1998-2003). In 2003, a final evaluation of Action Plan II was performed, showing a reduction of 48% of the nitrate leaching from the agricultural sector, fulfilling the reduction target set in 1987.

Further mitigation measures were implemented in the following Action Plans.
The APAE III from 2008 were implemented to reduce N leaching from the root zone and the Green Growth Agreement from 2009. Hence, the first and second River Basin Management Plan from 2014 and 2016, respectively as well as the Food and Agricultural Agreement in December 2015 suggests mitigation measures and reductions target for N load to marine areas in order to fulfil the targets in the Water Framework Directive.

Modelling of the nitrate concentrations in the soil water leaving the root zone showed an average concentration of 74-92 mg NO_3 l^{-1} for cattle holdings using 170-230 kg organic manure N in 2020 and the concentrations were 2, 6, and 4 mg NO_3 l^{-1} higher for derogation farms than for cattle farms using 140-170 kg N ha^{-1} of N in manure and other organic fertilisers.

Measured average flow-weighted nitrate concentration in root zone water at four-five specific sites with an average manure application within 170-230 kg N ha^{-1} varied between 64 and 103 mg NO_3 l^{-1} for the recent five hydrological years (2015/16-2019/20).

The general conclusions to be drawn on trend in measured nitrate concentrations in root zone water and upper oxic ground from the Agricultural Catchment Monitoring Programme are that:

Nitrate concentrations in root zone soil water (1.0 m below soil surface) have decreased steadily from 1990/01 to 2015/16. On loamy catchments the measured nitrate concentration decreased from 61-155 mg NO_3 l^{-1} in the five year period 1990/91-1994/95 to 37-66 mg NO_3 l^{-1} in the five year period 2011/12-2015/16. On sandy catchments the nitrate concentration was 73-207 mg NO_3 l^{-1} in the five year period 1990/91-1994/95 and decreased to 54-73 mg NO_3 l^{-1} in the five year period 2011/12-2015/16. High annual variation was measured after 2015/16 until 2019/20, 48-107 mg NO_3 l^{-1} on loamy soils and 57-99 mg NO_3 l^{-1} on sandy soils with highest concentrations in years with low precipitation and subsequent percolation and lowest concentrations in years with high precipitation and subsequent percolation as seen in the latest year 2019/20.

Nitrate concentrations in the upper oxic groundwater (1.5-5.0 m below soil surface) decreased to a level well below the limit of 50 mg NO_3 l^{-1} for loamy catchments and to 59-77 mg NO_3 l^{-1} for sandy catchments in the 5-year period 2015/16-2019/20.

8.3 Targeted catch crops and targeted nitrogen regulation

For the year 2017, a total of app. 144,000 ha voluntary targeted catch crops were established, and a further effort of 3,250 ha were postponed to 2018. In 2018, a total of app. 105,000 ha voluntary catch crops were established, and in addition a mandatory effort of app. 3,000 ha has been applied (uncompensated). In 2019, first year of targeted nitrogen regulation, a total of 139,350 ha voluntary catch crops (or alternatives) were established, a further effort of 275 ha was postponed. In 2020, the targeted nitrogen regulation continued with a total of app. 349.400 ha voluntary catch crops established, and an additional mandatory effort of app. 12,500 ha applied (uncompensated). A further effort of 350 ha was postponed. In 2021, targeted nitrogen regulation continued with a total of 359,200 ha of catch crops and alternatives applied for in the voluntary phase. Of those, 351,800 ha catch crops and alternatives were approved, and a further 17,200 ha was applied through an uncompensated mandatory effort.

8.4 The reinforced monitoring

The reinforced monitoring does not provide data that can be used to examine any potential effect on water quality that might be the result of the use of the derogation. A range of other fluctuating factors than proximity to a derogation farm influence nutrient concentrations in the aquatic environment. However, by including the data from the selected set of the surface water and groundwater monitoring stations, the data basis for water quality in sandy areas is considerably enlarged. The total number of farms encompassed by the reinforced monitoring corresponds to 3.4 % of all holdings that make use of the derogation.

8.5 The phosphorus indicator and monitoring system

Neither the phosphorus indicator nor the P monitoring system indicate that the average phosphorus application in Denmark exceeds the average phosphorus ceiling of 33.2 kg P/ha. There is currently also no risk for exceeding future P-ceilings, which are reduced compared to current level.

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