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# 30 YEARS OF NUTRIENT MANAGEMENT LEARNINGS FROM DENMARK: A SUCCESFUL TURNAROUND AND NOVEL IDEAS FOR THE NEXT GENERATION

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## Abstract

Excess nitrogen (N) and phosphorus (P) emissions to surface waters are a high priority environmental problem worldwide for protection of water resources in times of population growth and climate change. As clean water is a scarce resource the struggle for reducing nutrient emissions are an ongoing issue for many countries and regions. In Denmark, a wide range of national regulatory measures have been implemented since the mid1980 all with the aim to reduce land based N and P loadings of the Danish aquatic environment. These measures have addressed both point source emissions and especially also been devoted to reducing emissions from diffuse sources especially from agricultural production. Common to the agricultural measures is that they until now are general, i.e. they have been applied uniformly everywhere irrespective of, for instance, geology and the natural nitrate reducing capacity in the subsoil and irrespective of the vulnerability of the receiving water body to eutrophication. Following nearly 3 decades of combating nutrient pollution our surface waters such as lakes and estuaries are, however, only slowly responding on the 50% reduction in N and 56% reduction in P loadings However, the implementation of the EU Water Framework Directive in Danish surface waters still call for further reductions of N and P loadings from both point and diffuse sources. A new era of changing from national regulatory measures to targeted implemented measures was the outcome of a Commission on Nature and Agriculture established by the Danish Government in 2013. The Commission pointed to the need of increased agricultural growth along with an improved environment achieved through a more targeted and efficient regulation by applying advanced technological mitigation methods that have to be implemented according to the local attenuation capacity for nutrients in the landscape. As a follow up a national consensus model for N was established chaining existing leaching, 3D groundwater and surface water models that enable a calculation of the N dynamics and attenuation capacity within a catchment scale of 15 $km^2$. Moreover, several research projects have been conducted to investigate the effect of a suite of targeted mitigation measures such as restored natural wetlands, constructed wetlands, controlled drainage, buffer strips and intelligent buffer strips. Lastly, the Danish Government has in 2016 passed a new regulation of agricultural production allowing farmers to apply economic optimum levels of nitrogen to crops after nearly 18 years of regulation below economic optimum (1998: 10%; 2015: 21%).

**Description of Denmark**

Denmark has a land area of 43,100 km2 of which ca. 60% is in agricultural land with more than 90% as arable farming. Mean annual precipitation is around 700 mm and mean annual runoff in rivers around 300 mm. Most crops are cereals and mostly grown as winter cereals. We have ca. 12.3 million pigs, 1.6 million cattle, 9.7 million of broilers and 2.8 million minks. Our export of agricultural products amounts to ca. 20% of the Danish export.

**The history of nutrient regulation in Denmark**

Since the late 1980's, Denmark has yielded a comprehensive and efficient effort towards reductions in N and P emissions from both point sources and diffuse sources to improve the environmental state of groundwater and surface water regarding nutrient concentrations, [being directed] (Fig. 1). The first Action Plan on the Aquatic Environment (VMP I in Figure 1) was adopted in 1987 setting the goal for all other plans with a 50% reduction goal for nitrogen discharges from point sources and leaching from diffuse sources and a 80% reduction of phosphorus discharges from point sources. This Action Plan has since then been followed by subsequent National Action Programmes to ensure that sufficient efforts were made to reduce the loss of nitrogen and phosphorus to the aquatic environment. With the aim of fulfilling the obligations pursuant to the EU Nitrates Directive, the Plan for Sustainable Agriculture and the National Action Plan II 1999-2003 (Action Plan II (VMP II) for the Aquatic Environment) was adopted in, respectively, 1991 and 1998. In 2003, a final evaluation of the agricultural measures in the Action Plan I, Action Plan for a Sustainable Agriculture and Action Plan II showed that the annual nitrate leaching from the root zone water from agriculture was reduced from 311,000 to 162,000 t N during the period 1985-2003, corresponding to a reduction of 48%, which fulfilled the reduction target set in 1987.

In 2004, Action Plan III (VMP III) for the aquatic environment was adopted, the aim being a further reduction in nitrate leaching of 13% compared to the N leaching in 2003 (Table *Table*1) and a 50% reduction in the use of P in agriculture. The targets were to be obtained by 2015. The measures to reduce nitrogen losses included, among others, further restoration of wetlands, voluntary 10 m buffer strips and tightened requirements for growing of catch crops. The measures to reduce P use in agriculture were a tax on P in fodder.

In 2008, a mid-term evaluation of Action Plan III was performed, that showed that there was not yet any significant decrease in the modelled nitrate leaching during 2003-2007 and that it was unlikely that the aim in AP III would be fully attained by 2015. As a consequence, the AP III was replaced by the Green Growth Agreement in June 2009. This plan included a new concept for defining the aim of nutrient regulation. The previous Action Plans provided goals for the reduction of nitrogen leaching from the root zone water, whereas the aim of the Green Growth Agreement was to reduce the annual load of nitrogen to marine waters by 19,000 t N (Table 1). The Green Growth Agreement did also have a goal to reduce the annual emission of phosphorus from agriculture by 210 t P. Measures were implemented to ensure a planned annual reduction of the nitrogen load to the marine waters, summing up to 9,000 t N by 2015. Measures to ensure the reduction of the remaining 10,000 t N were postponed.

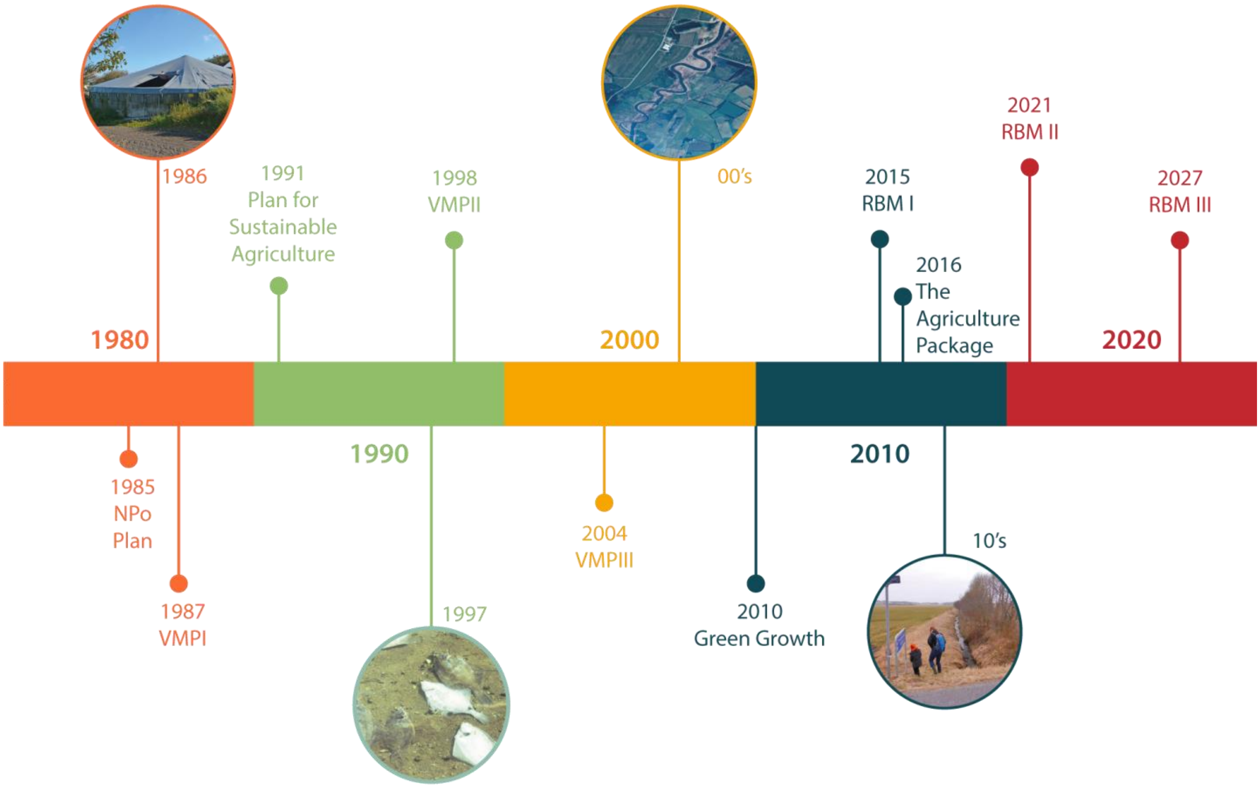


Figure 1: The timeline of the Danish National Nutrient Action Plans. VMP: National Environmental Action Plans. RBM: River Basin Management Plans under the EU Water Framework Directive (see text for further explanation).

Modelled nitrate leaching from the root zone water was calculated to be 163,000 – 165,000 t N in the period 2007-2011, thus giving no further reduction for this period (Børgesen et al., 2013). For the same period, the annual N surplus for the agricultural production decreased by 32,000 t N. The differences between the two estimates are mainly ascribed to an actual increase in harvested yields from the agricultural crops during this period.

The first River Basin Management Plan for 2009-2015 to fulfil the targets in the Water Framework Directive was adopted in 2014. The reduction target for the marine nitrogen load was set to be 6,600 t N. However, this reduction target has since been altered, partly due to the decision not to obligatorily establish further catch crops and the annulment of the act on mandatory buffer strips. The second River Basement Management Plan was adopted in June 2016. The decision on which measures will be included in the second River Basin Management Plan is not yet final.

The N load to marine waters has stepwise been reduced, as planned measures for point sources and agriculture were implemented successfully. Approximately half of the Danish land area lies within catchments, equipped with stream water gauging stations, where N load to marine areas are regularly measured (Kronvang et al., 2008). Nitrogen load for the ungauged catchments has been modelled using an empirical model (Windolf et al., 2011). The annual load to marine waters varies between 55.000 and 59.000 t N which gives an average of 57,000 t N for the last five years 2010-2014 (Thodsen et al., 2017).

Table 1: Reduction target in Action Plan (APAE) I, II and III for nitrogen in root zone water and reduction target in Green Growth Agreement (GGA), River Basin Management Plans and the Food and Agricultural Agreement for the N loading to marine coastal waters (Blicher-Mathiesen et al., 2017).

| | | **Reduction targets** | |
|---|---|---|---|
| | | in root zone water (%) | in N load to marine waters (t N) |
| 1987 | Action plan for Aquatic waters (APAE) I | 48 | |
| 1998 | APAE II | | |
| 2004 | APAE III | 13 | |
| 2009 | Green Growth Agreement, 2009-2015 | | 9,000 |
| | Green Growth Agreement, postponed | | 10,000 |
| 2014 | River Basin Management Plan I | | 6,600 |
| | (Implementation of GGA) | | |
| 2016 | Food and Agricultural Agreement | | 8,000 |
| | (Total effect from new regulation, new measures and baseline 2021) | | |
| 2016 | River Basin Management Plan II (2015-2021) | | 6,900 |
| | River Basin Management Plan after 2021 | | 6,200 |

In January 2016, a majority in the Danish parliament adopted the Food and Agricultural Agreement. The agreement includes a diverse package of measures aimed to change environmental regulation of the agricultural sector from general to targeted regulation and allowed Danish farmers to fertilize to the economic optimum after having been ca. 21% below economic optimum fertilization in 2015. The first parts of this political agreement were implemented during 2016 and will be fully implemented in 2017.

The new era of changing from national regulatory measures to targeted implemented measures was the outcome of a Commission on Nature and Agriculture established by the Danish Government in 2013. The Commission pointed to the need of increased growth and improved environment through a more targeted and efficient regulation by applying advanced technological mitigation methods that have to be implemented according to the local attenuation capacity for nutrients in the landscape. As a follow up a national consensus model for N was established chaining existing leaching, 3D groundwater and surface water models that enable a calculation of the N dynamics and attenuation capacity within a catchment scale of 15 km2. Moreover, several research projects have been conducted to investigate the effect of a suite of targeted mitigation measures such as restored natural wetlands, constructed wetlands, controlled drainage, buffer strips and intelligent buffer strips.

## Trends in nutrients in Denmark

*Nutrient surplus and leaching*

The nutrient surplus and the nutrient cycling in agro-ecosystems are monitored under the national monitoring programme (NOVANA) in Denmark within 5 small agricultural micro-catchments. Surveys of farming practices at field scale and concentrations of nutrients in soil water, groundwater, tile drainage water and surface waters are followed every year.

The national nitrogen surplus has decreased nearly 45% since 1990 (Fig. 2). As comparison, the nitrogen surplus and modelled nitrate leaching has decreased considerably (46%) in 5 monitored micro-catchments since 1991 (Blicher-Mathiesen, 2017).

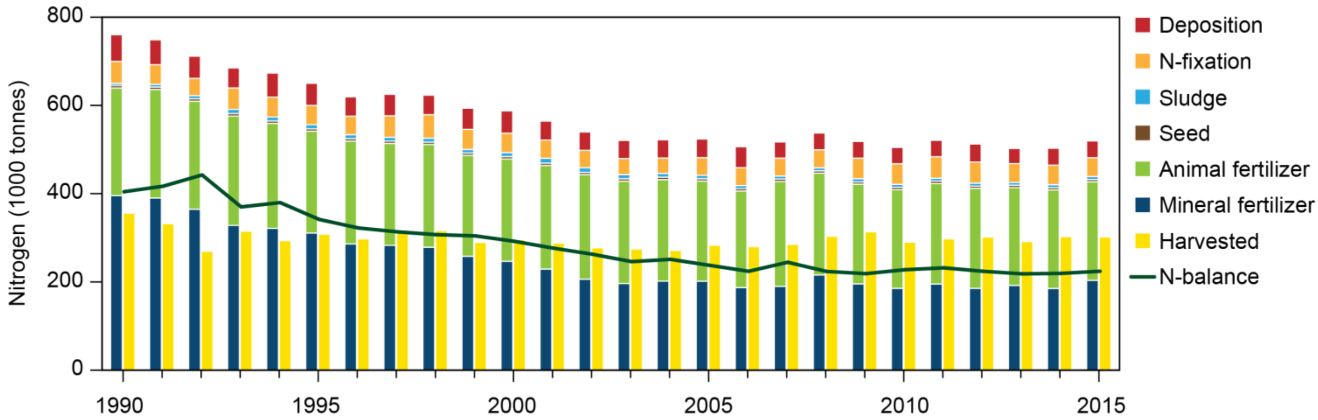


Figure 2: The nitrogen input, output and surplus within Danish agriculture during the period 1990-2015.

Similarly, a large change has occurred in the input and surplus of phosphorus in Danish agriculture where the decrease in surplus has amounted to 69% during 1990-2015 (Fig. 3).

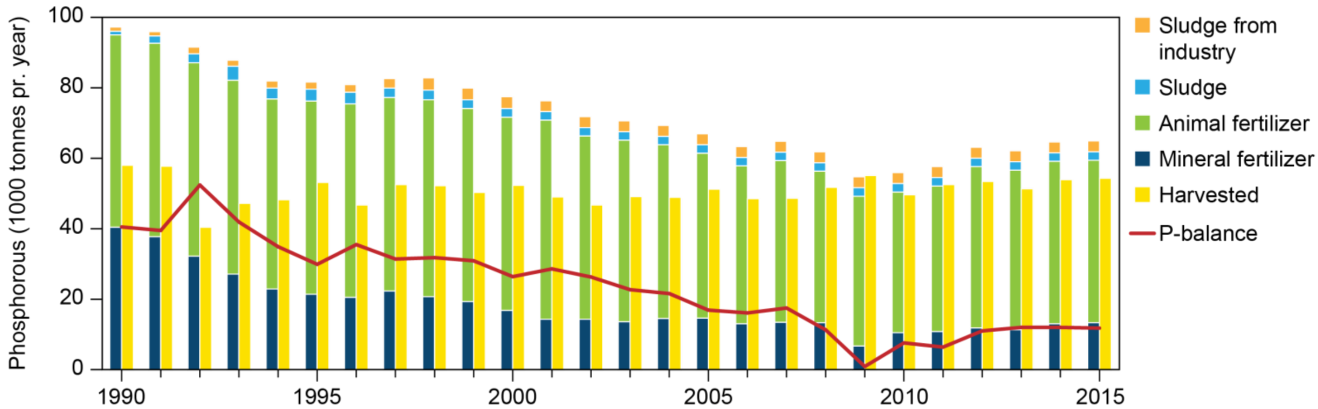


Figure 3: The phosphorus input, output and surplus within Danish agriculture during the period 1990-2015.

*Nutrient loadings to coastal waters in Denmark*

The nutrient loading to coastal waters in Denmark are monitored at ca. 160 gauging stations in major rivers around the country. The nutrient loading programme has been enlarged in 2016 with 200 extra gauging stations whereof 100 is included in the nutrient loading programme to coastal waters. During 1990-2016 around 50% of the country has been covered with gauging stations the remaining part being modelled utilizing a national model DK-QNP (Windolf et al., 2011).

The main sources of nitrogen to coastal waters in Denmark are today diffuse sources as huge reductions have been obtained in the discharges of nitrogen from point sources (70%) from 1990-2015 (Fig. 4). The reduction in nitrogen from diffuse sources has also been high amounting to 44% during the same period (Fig. 4). Diffuse sources are today accounting for 90% of the nitrogen loading to coastal waters in Denmark.

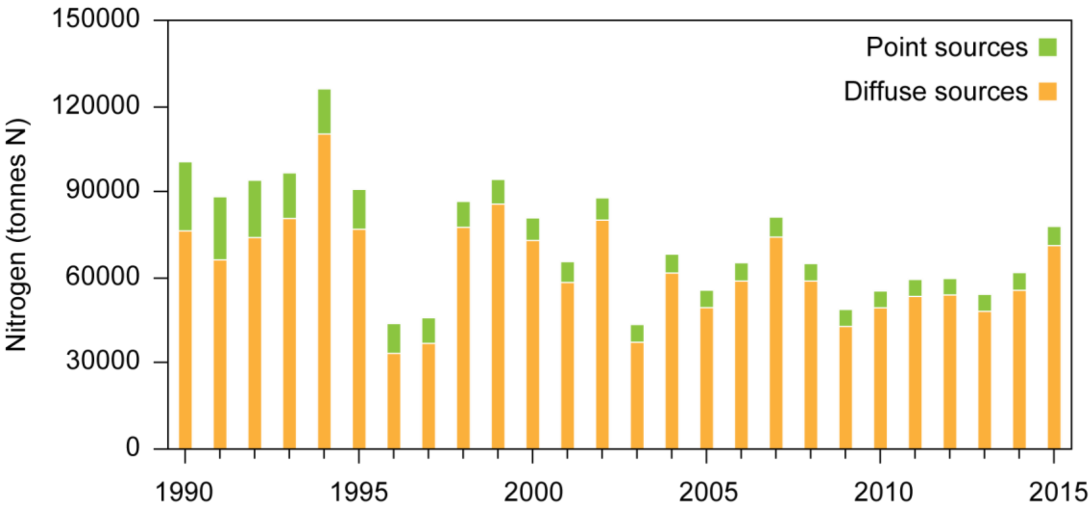


Figure 4: Total nitrogen loadings to Danish coastal waters from point sources and diffuse sources during the period 1990-2015.

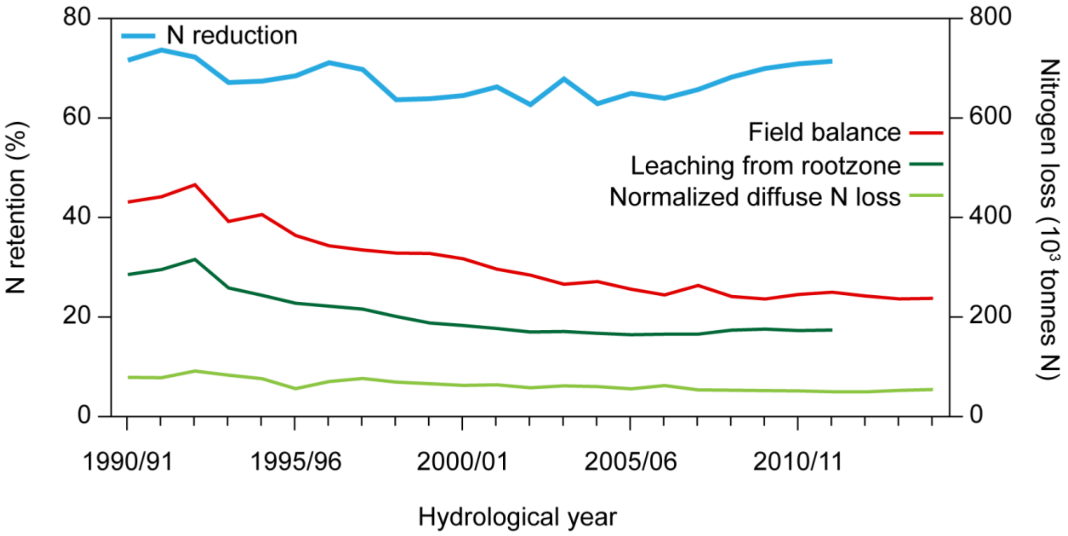


Figure 5: Nitrogen field surplus, modelled normalized leaching from root zone and total nitrogen loading to coastal waters and the nitrogen reduction (attenuation) in Denmark during the period 1990-2015.

The nitrogen field balance, the normalized modelled nitrate leaching from root zone on agricultural fields and the flow normalized total nitrogen loading to coastal waters in Denmark are shown in Figure 5 together with the nitrogen attenuation (reduction) as calculated from the root zone to coastal waters. Nitrogen attenuation in Denmark is estimated to be around 65-70% during the period 1990-2015.

The main sources of phosphorus to coastal waters in Denmark are today diffuse sources as huge reductions have been obtained in the discharges of nitrogen from point sources (80%) from 1990-2015 (Fig. 6). No reduction has, however, been detected in the loss of phosphorus from diffuse sources during the same period (Fig. 6). Diffuse losses of phosphorus are today accounting for 60-70% of the total loadings of phosphorus to coastal waters in Denmark.

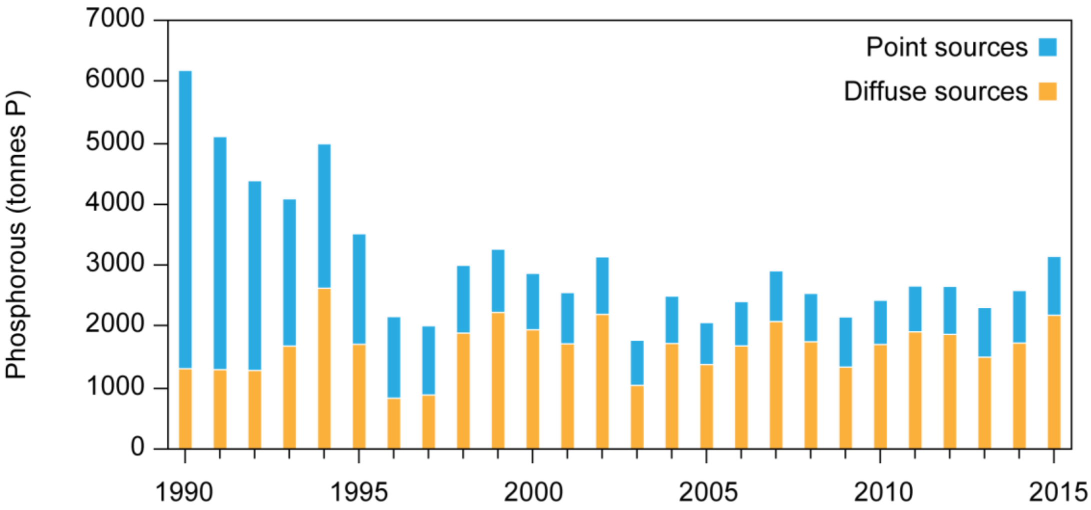


Figure 6: Total phosphorus loadings to Danish coastal waters from point sources and diffuse sources during the period 1990-2015. Diffuse sources are today accounting for 90% of the nitrogen loading to coastal waters in Denmark.

## River Basin Management Plans and the new era of targeted regulation

The River Basin Management (RBM) plans sets out a series of environmental targets for individual water bodies – such as lakes and estuaries, to be achieved through the implementation of a programme of measures to be carried out in each river basin to improve the condition. The first RBM adopted in 2014 included mitigation measures such as mandatory catch crops on a certain percentage of the agricultural area (10-14%), restoration of wetlands, mandatory buffer strips, etc..

However, the Agriculture Package was presented in December 2015 and was passed by Parliament in February 2016 after a long public debate. The main features of Agriculture Package were that the farmer must fertilize to the economic optimum and removal of the mandatory buffer strips. To compensate for the excess nitrogen leaching as caused by the Agricultural Package the plan includes voluntary collective efforts in agriculture to lower nitrogen loadings to coastal waters (mainly restored wetlands, constructed wetlands and targeted catch crops), and from 2018 a targeted regulation involving a suite of different mitigation measures that can be implemented with compensation. An attenuation map developed in 2013-2015 for the whole of Denmark is utilized in the targeted regulation but only on a relatively coarse scale (100-1000 $km^2$) meaning one number for each of 91 river basins in Denmark. The introduction of the new targeted agricultural regulation in Denmark has been named the ‘Skateboard’ model as the intend is in future to have the ‘Rolls Royce’ model implemented when science has developed a better understanding of nitrogen attenuation in the landscape and mapped it with low uncertainty to the field scale.

The Agricultural Package also allocated funds to create and run additional about 200 gauging stations for improving the monitoring efforts in measuring the emissions of nitrogen from agriculture and point sources. One thing is certain: The consequences of Agriculture Package elements and some baseline elements will be visible and the results heavily debated in the public every year when the data from the greatly expanded number of monitoring stations in the national monitoring program is being collected, processed and published in the coming years.

Table 2: National agricultural regulation in Denmark – now and in the future.

| **Nitrogen regulation in Denmark** |  |  |  |  |
|---|---|---|---|---|
| Model | Present | Skateboard | Skoda | Rolls Royce |
| Target | National | Coastal catchments | ID15 (15 $km^2$) | Farm/Field |
| Effects of mitigation measures in root zone | Animal type/crop type/soil type | Animal type/crop type/soil type | Animal type/crop type/soil type | Animal type/crop type/soil type |
| Retention | National | Coastal catchments | ID15 | Field |
| Choice of mitigation method | Nationally regulated | Farmer<br>Short list | Farmer<br>Long list | Farmer<br>Long list |

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