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Opportunities for reducing the diffuse phosphorus input to Ringkøbing Fjord

Hans Estrup Andersen

Institute for Ecoscience

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Foreword

The report is the result of a coastal water council project under Ringkøbing-Skjern Municipality, which is part of the project "Locally Based Analyses". The purpose of the locally based analyses is to identify whether there are other ways to achieve target fulfillment, as defined in the EU Water Framework Directive.

Ringkøbing-Skjern Municipality has entered into an agreement with the Department of Ecoscience, Aarhus University, for expert support to conduct a thorough review of the relevant sub-basins in order to identify potentials and measures for reducing phosphorus input.

This report describes measures and potentials for measures to reduce the diffuse phosphorus transport to Ringkøbing Fjord, as well as the effects of the measures in terms of a reduction in phosphorus transport.

Executive summary

This project focuses on providing options for reducing diffuse phosphorus loss from risk areas in the catchment of Ringkøbing Fjord by combining detailed mapping of phosphorus loss with different measures. Phosphorus loss is primarily from five diffuse sources: erosion, leaching, macropore loss, loss from cultivated organic soil and bank erosion. The mapping shows that these sources account for 94% of the total diffuse phosphorus loss at a national level.

Various methods and models are used to calculate the effect of different measures such as afforestation, buffer zones, trees on riverbanks, sand traps, small-scale reach-based restoration, river meandering, mini-wetlands, integrated buffer zones, GLM 5 and phosphorus wetlands. Potential areas for these measures are mapped and the effects of the implementation of these measures on the reduction of phosphorus loss are calculated.

First, the project calculates the effect of the measures when the potentials are fully utilized. Next, the effect of locally based scenarios regarding phosphorus wetlands, tree planting on riverbanks and mini-wetlands are calculated.

The total phosphorus input to Ringkøbing Fjord averaged 112.1 tons P per year over the period 2016-2018, of which the diffuse contribution amounts to 83.5 tons P. The most significant diffuse loss pathways for phosphorus are bank erosion and losses from cultivated organic soil, which account for 60% and 24% of the total diffuse input, respectively.

The locally based policy scenarios include tree planting on 10% of the banks along all watercourses outside planned wetlands with an effect in the form of a reduced phosphorus transport to Ringkøbing Fjord of 5.2 tons P. Furthermore, it is assumed that 25% of the planned areas are constructed as phosphorus wetlands, where periodic flooding of the areas close to the watercourses is allowed. The effect of this is a reduction in phosphorus transport of 79.7 tons P. Finally, the local scenario includes the construction of a total of 18 sand traps and 14 ochre plants, which will reduce phosphorus transport by 0.4 tons P and 2.7 tons P, respectively.

Sammendrag

Dette projekt fokuserer på at anvise muligheder for at reducere diffust fosfortab fra risikoområder i oplandet til Ringkøbing Fjord ved at kombinere detaljeret kortlægning af fosfortab med forskellige virkemidler. Fosfortabet stammer primært fra fem diffuse kilder: erosion, udvaskning til dræn, makroporetab til dræn, tab fra dyrket organisk jord og brinkerosion. Kortlægningen viser, at disse kilder udgør 94% af det samlede diffuse fosfortab på nationalt niveau.

For at beregne effekten af forskellige virkemidler som skovrejsning, randzoner, træer på vandløbsbrinker, sandfang, mindre strækningsbaserede restaureringer, genslyngning af vandløb, mini-vådområder, integrerede bufferzoner, GLM 5 og fosfor-vådområder, anvendes forskellige metoder og modeller. Potentialeområder for disse virkemidler er kortlagt, og effekterne af implementeringen af disse virkemidler på reduktionen af fosfortab er beregnet.

Projektet beregner indledningsvist virkemidlernes effekt ved fuld udnyttelse af potentialerne. Dernæst beregnes effekten af lokalt baserede scenarier vedrørende fosfor-vådområder, træplantning på vandløbsbrinker og mini-vådområder.

Den samlede fosfortilførsel til Ringkøbing Fjord er som gennemsnit over perioden 2016-2018 på 112,1 tons P pr. år, hvoraf det diffuse bidrag udgør 83,5 tons P. De mest betydende diffuse tabsveje for fosfor er brinkerosion og tab fra dyrket, organisk jord, som udgør hhv. 60% og 24% af den samlede, diffuse tilførsel.

De lokalt funderede virkemiddelscenarier omfatter træplantning på 10% af brinkerne langs alle vandløb udenfor planlagte vådområder med en effekt i form af en reduceret fosfortransport til Ringkøbing Fjord på 5,2 tons P. Endvidere antages det, at 25% af de planlagte områder anlægges som fosfor-vådområder, hvor periodevis oversvømmelse af de vandløbsnære arealer tillades. Effekten heraf er en reduktion i fosfortransporten på 79,7 tons P. Endelig omfatter det lokale scenario anlæggelse af i alt 18 sandfang og 14 okkeranlæg, som vil reducere fosfortransporten med hhv. 0,4 tons P og 2,7 tons P.

1 Introduction

With the "Agreement on the green transition of Danish agriculture" of October 4, 2021, it was agreed that the effort requirement and the handling of the remaining effort requirement for nitrogen removal will be reassessed in connection with the review of the agreement in 2023/24. agricultural agreement, for which the project "Locally based analyses" has been initiated to carry out locally based analyses in selected coastal waters to identify whether other ways can be found to achieve target fulfillment as defined in the EU Water Framework Directive.

The coastal water councils can investigate different types of measures to reduce the amounts of nitrogen and phosphorus added as well as other measures that can ensure goal achievement, and to investigate new or update old measures in order to prepare proposals for a professionally based program of measures that will achieve goal achievement for the coastal water.

An overall analysis and evaluation of the project must be sent to the Danish Environmental Protection Agency. Upon receipt, the coastal water councils' analyses and alternative action programs are reviewed in order to be included in the overall reassessment ("Second opinion" project) of nitrogen regulation. The primary task is to determine which pressure factors pose the most significant challenges in relation to achieving the Water Framework Directive target of good ecological status and what the baseline for these pressure factors is. The task is divided into a marine pressure factor analysis, which looks at which pressure factors are most important to address in order to achieve target achievement, and a catchment analysis, which looks at the baseline and future development in sediment transport to the water bodies.

In a project concerning Ringkøbing Fjord, Ringkøbing-Skjern Municipality has entered into an agreement with the Department of Ecoscience, Aarhus University, for expert support to conduct a thorough review of the relevant sub-basins in order to identify potentials and measures for reducing phosphorus input.

This report describes the data that AU has made available to the Coastal Water Council for the work of investigating the possibilities of reducing the diffuse phosphorus input to Ringkøbing Fjord. This includes data on transport pathways for diffuse phosphorus loss as well as potentials for and effects of phosphorus remedies.

2 Methodology

2.1 Introduction

It is well known that diffuse phosphorus loss only originates from a small part of the landscape - so-called risk areas. To be effective, measures against diffuse phosphorus loss must therefore be targeted at these risk areas. The method in this project consists of combining the detailed mapping of diffuse phosphorus loss carried out by Andersen & Heckrath (2020) with a number of measures whose effects are described in Andersen et al. (2020). The effect calculation assumes that the potential for the individual measure is known or can be estimated. As a basis for formulating locally based scenarios, the effect of utilizing the full potential is first calculated - i.e. the theoretical upper limit for reducing diffuse phosphorus loss. Next, the effect of local policy scenarios is calculated.

All effects in the form of reduction of diffuse phosphorus loss are calculated at the bank of watercourses. No retention of phosphorus transport through the catchments towards coastal waters is included. All calculations are reported at ID15 catchment level.

2.2 Calibration of the calculation of diffuse phosphorus loss on transport pathways

Andersen & Heckrath (2020) have mapped and calculated phosphorus transport from the five most significant diffuse sources: erosion, leaching, loss through macropores, loss from cultivated organic soil and loss via bank erosion. Phosphorus transports are calculated with several independent models. At a national level, the five diffuse sources account for 94% of the total diffuse phosphorus transport. Phosphorus losses by wind erosion and surface runoff and losses via groundwater from undrained fields make up the remaining 6%.

In this project, the model-calculated phosphorus losses via the five diffuse transport pathways are summed at the ID15 catchment level. Subsequently, the model-calculated phosphorus transport is adjusted so that the sum for each ID15 catchment is identical to 94% of the diffuse phosphorus transport calculated according to the national environmental monitoring NOVANA (Thodsen et al., 2023). The remaining 6% consists of phosphorus loss by wind erosion and surface runoff as well as losses via groundwater from undrained fields, which could not be mapped in Andersen & Heckrath (2020). An average of phosphorus transport data for the period 2012-2021 has been used. The relative distribution between the five diffuse transport pathways has been retained. This adjustment ensures consistency between results from this project at ID15 level and national figures for phosphorus loss. Figure 2.11 shows a plot of the modeled phosphorus transport at ID15 level calculated in Andersen & Heckrath (2020) before the adjustment against the corresponding phosphorus transport calculated in the national environmental monitoring. The averages for the two datasets are 387 kg P in Andersen & Heckrath (2020) and 391 kg P in the national aquatic environment monitoring. The corresponding median values are 235 kg P and 277 kg P, respectively. As shown in figure 2.1, there can be a large difference between the two phosphorus transport calculations for the individual ID15 catchment area, which is thus offset by the adjustment.

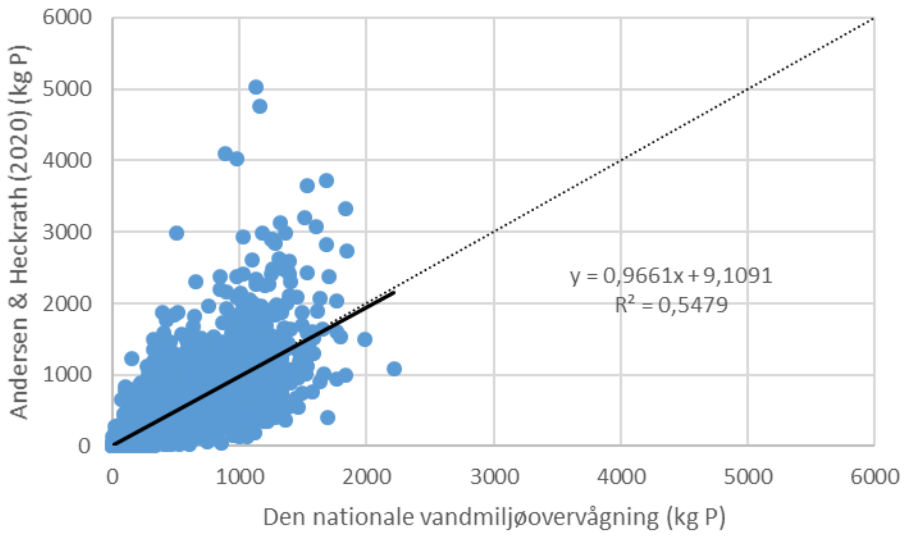


Figure 2.1. Diffuse phosphorus transport (kg P) calculated at ID15 catchment level in Andersen & Heckrath (2020) plotted against the corresponding diffuse phosphorus transport (kg P) calculated in the national environmental monitoring. The identity line is shown with a dashed signature, while the trend line is marked with a bold signature. The equation for the trend line is inserted in the figure.

2.3 Source apportionment

For each ID15 catchment in the total catchment of Ringkøbing Fjord, a source breakdown of the total diffuse phosphorus loss is made on the most significant transport pathways: erosion, leaching, loss via macropores, loss from cultivated organic soil and bank erosion. This gives an indication of which measures will be effective in each catchment area.

3 Calculation of effects when fully utilizing the potential of measures

For all measures, a brief description of the mechanism, effect and potential for use is provided below.

3.1 Afforestation

Afforestation can counteract phosphorus loss through erosion and can also reduce the risk of phosphorus loss via macropores, as the mobility of dissolved and particle-bound phosphorus in the soil is reduced when the soil is no longer cultivated and fertilized. In other words, it can have an effect in areas at risk of erosion and in areas at risk of macropore flow to drains. It is estimated that phosphorus loss through erosion is reduced by 100% and that phosphorus loss via macropores to drains is reduced by 25-50% (Andersen & Rubæk, 2020).

Risk areas for phosphorus loss via erosion and via macropores to drains are mapped in Andersen & Heckrath (2020). As potential afforestation areas, municipalities' reports of areas where afforestation is desired have been used (figure 3.1). The theme is downloaded from Miljøgis (mim.dk). The afforestation area amounts to approx. 60,000 ha in the catchment area of Ringkøbing Fjord.

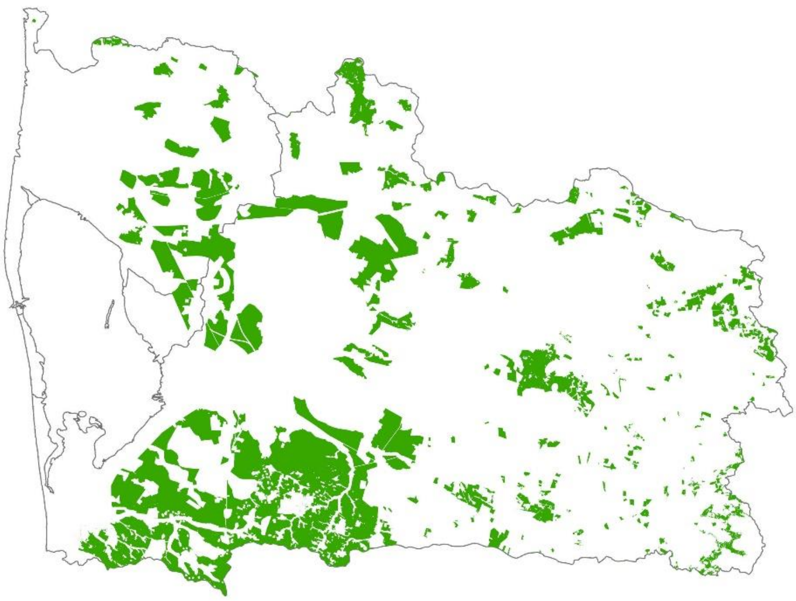


Figure 3.1. The municipalities' reports on where afforestation is desired in the area covered by the Ringkøbing Fjord Coastal Water Council.

3.2 Buffer zones

Targeted, wide and dry riparian buffer zones are designed to match the surface runoff flowing through the riparian zone from the overlying field towards the stream or lake. This means that the width of the riparian zone from the crown edge of the watercourse can be varied from, for example, the mandatory 2 meter strips to a width determined by local topographic and soil conditions. The wide riparian buffer zones can typically be placed along small and medium-sized watercourses where the river valley is narrow. The width will typically vary between 10 and 30 meters. The significant effect of an uncultivated, wide and dry buffer zone will be an expected greater infiltration capacity in a buffer zone than in a cultivated area. The greater infiltration in the buffer zone is due to the permanent vegetation, which increases the infiltration capacity of the soil with its roots. When surface runoff with its content of soil particles and associated phosphorus meets the buffer zone, there will be both a reduced water flow velocity (due to the roughness of the vegetation) and an infiltration of water into the zone. Both mechanisms lead to sedimentation and retention of soil and phosphorus. In addition, dissolved inorganic phosphorus can be sorbed to the free binding surfaces of the soil when water infiltrates into the buffer zone. Thus, the retention of phosphorus in riparian zones occurs through three processes: 1) sedimentation of soil and associated phosphorus in the riparian zone; 2) sorption of dissolved phosphate in the riparian zone in the soil matrix; 3) infiltration and uptake of dissolved phosphorus compounds in the vegetation in the riparian zone. Kronvang et al. (2020) describe the effect of the buffer zone on phosphorus transport as a function of the width of the buffer zone. A 20 m wide buffer zone can thus retain 60% of the total phosphorus input.

Risk areas for phosphorus loss via erosion and via macropores to drains are mapped in Andersen & Heckrath (2020). The map spatially indicates where sediment transport with associated phosphorus to watercourses takes place. Based on the mapping, all 50 m river reaches where sediment transport exceeds 1 ton of sediment per year are identified. With an assumed phosphorus content of 600 mg phosphorus per kg sediment, a sediment transport of 1 ton corresponds to 0.6 kg phosphorus. In the calculations in this project, it is assumed that 20 m wide buffer zones are placed along all the identified 50 m river sections.

3.3 Trees on river banks

In many studies, trees along the banks of watercourses have been shown to help stabilize the stream bank, thereby reducing bank erosion and the addition of sediment and particle-bound phosphorus. The roots of the trees penetrate the bank and thus help to retain the soil in the bank. This reduces the ongoing erosion of the banks by the forces of water and also maintains the bank, so the period between major bank collapses is expected to be significantly extended.

Kronvang & Larsen (2023) have developed a method for calculating the effect of trees on the stream bank. Calculating the effect requires information on the location of the stream in the landscape type (moraine or alluvial plain landscape) and in the georegion, as well as information on the size of the stream (width less than 2 m, 2-10 m or greater than 10 m). The effect of trees is a 27-53% reduction in bank erosion.

Bank erosion in all Danish watercourses is mapped in Andersen & Heckrath (2020) on 100 m watercourse sections. The mapping also contains information about the location of the watercourse in the landscape type and georegion, as well as the width of the watercourse. Furthermore, the vegetation in a 2 m zone on each side of the watercourse is mapped and divided into low vegetation (grass, herbs, small shrubs) and high vegetation (trees) (figure 3.2). The potential for tree planting on riverbanks is thus made up of the stretches of river where there is currently low vegetation.

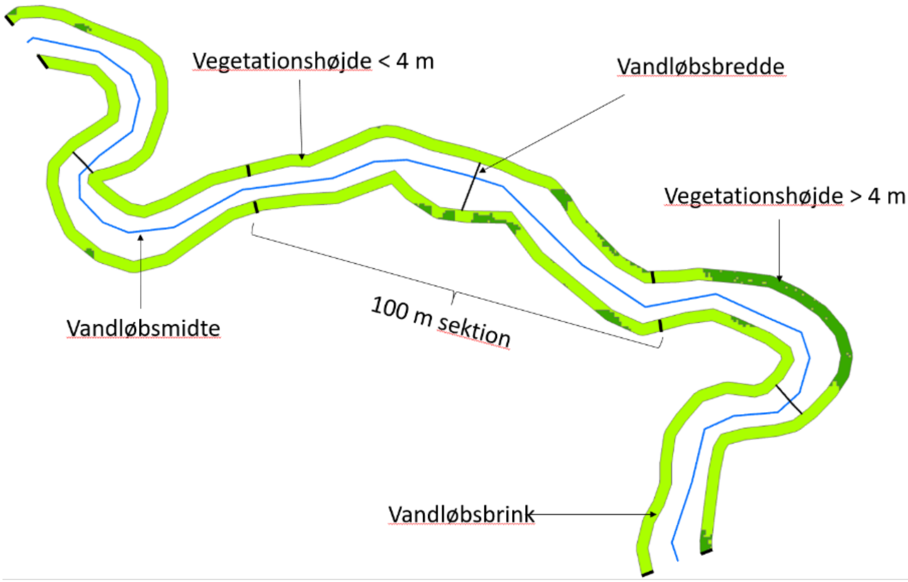


Figure 3.2. Division of streams into 100 m reaches and classification of vegetation heights in the riparian zones. Dark green color indicates vegetation higher than 4 m and thus interpreted as woody vegetation, while light green color indicates vegetation lower than 4 m, interpreted as shrub, grass and herbaceous vegetation.

3.4 Sand traps

A sand trap is constructed by increasing the width and depth of the watercourse for a short stretch. This reduces the velocity of the water and sand is not transported through the sand trap under normal runoff conditions. As a rule of thumb, the bottom width of the watercourse is widened to 2-3 times the normal width and the bottom is lowered to approx. 1 m below the normal bottom. The length of the sand trap is excavated to approx. 10 times the width of the watercourse, depending on the amount of sand transport (Wandall et al., 2000).

In order to maintain its functionality, the sand trap must be regularly emptied of deposited sediment. The sediment contains phosphorus, which is why sand traps have a reducing effect on phosphorus transport in the watercourse. In a study of the effect of sand traps on phosphorus transport in streams (Andersen & Nilsson, 2023), it was shown that the average size of a sand trap is 75 m^2 , but with great variation, and that the sediment removal rate ($m^3\ m^{-2}\ year^{-1}$) varies between georegions: georegion 2 (North Jutland) 1.1 m m^{3-2} $years^{-1}$, georegion 3 (West Jutland) 0.5 m m^{3-2} $years^{-1}$, other georegions 0.3 m m^{3-2} $years^{-1}$. There is no statistically significant difference between georegions on sediment bulk density (average 1.41 kg l^{-1}) or sediment total phosphorus content (average 221 mg P kg).$^{-1}$

The phosphorus effect of a sand trap is found by first multiplying the area of the sand trap by the sediment removal rate. The calculated sediment volume is converted to a weight by multiplying by the volume weight (average 1.41 t m^{-3}). The amount of phosphorus removed by the sediment is found by multiplying the phosphorus concentration of the sediment (average 221 mg P kg^{-1} = 0.221 kg P t^{-1}) by the weight of the sediment. A sand trap with a size of 75 m^2 located in North Jutland will thus be able to remove approx. 26 kg P per $year^{-1}$ from the watercourse, while the corresponding figures for sand traps of the same size in West Jutland and in the other georegions are approx. 12 kg P per year^{-1} and approx. 7 kg P per year^{-1} .

In principle, sand traps can be installed in all watercourses and at any distance. Thus, there is no theoretical upper limit to the number of sand traps. There are already more than 1000 sand traps in Danish watercourses (Andersen & Nilsson, 2023). The potential for establishing new sand traps is based on the proposed initiatives in the river basin management plans for the third planning period (figure 3.3) (data downloaded from https://miljoegis.mim.dk/spatialmap?profile=vandrammedirektiv3-2022). For the Ringkøbing Fjord catchment area, 12 sand traps are planned.

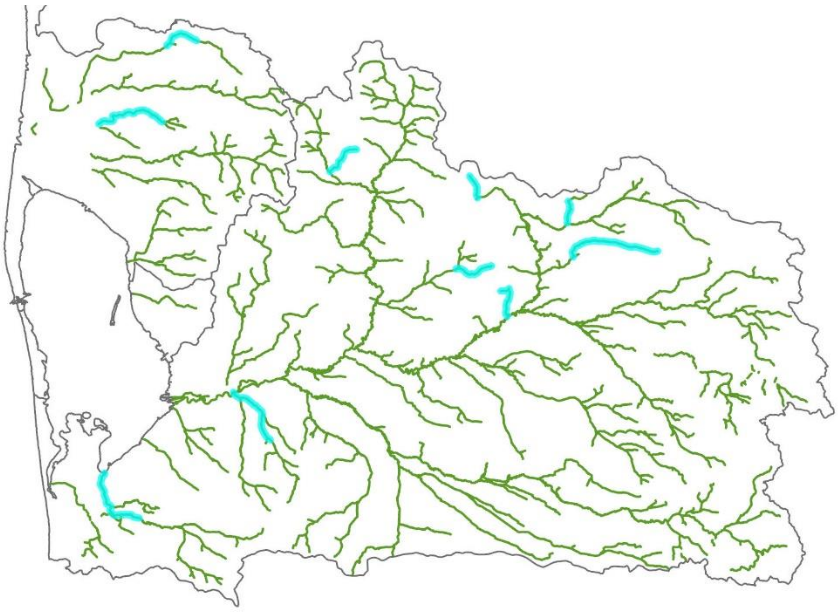


Figure 3.3. Location of proposed sand traps in the river basin management plans for the third planning period.

3.5 Minor reach-based restoration of watercourses

According to the Danish Ministry of the Environment (2021), small-scale, reach-based restoration can include the placement of coarse material, replacement of bottom material, raising the riverbed without meandering and planting trees along watercourses. We are not able to estimate any effect on phosphorus transport in watercourses from the placement of coarse material and replacement of bottom material, respectively. Planting trees along watercourses is treated in this project as an independent measure against phosphorus loss through bank erosion. Raising the stream bed also has a reducing effect on bank erosion by reducing the area that can be eroded. In the project, we have assumed that all designated reach-based restorations are carried out by raising the riverbed. This is likely to overestimate the potential, as in many cases municipalities avoid raising the riverbed to comply with river regulations.

The relative effect of raising the riverbed on phosphorus loss by bank erosion is calculated according to Andersen & Nilsson (2023) by comparing the phosphorus loss before and after raising the bed. The relative effect is applied to the pre-calculated phosphorus loss from bank erosion on the reach (calculated in Andersen & Heckrath, 2020). Information on landscape type, river width and the length of the river section where the bottom is raised is required. In this project, the effect of raising the riverbed is calculated for six combinations of landscape type and river width: moraine and alluvial plain rivers, respectively, divided into small rivers (0-2 m), medium-sized rivers (2-10 m) and large rivers (greater than 10 m). It is assumed that the riverbed is raised 40 cm.

In principle, small reach-based restorations can be installed in all watercourses and at any distance. Thus, there is no theoretical upper limit. The potential for establishing new reach-based restorations is based on the proposed initiatives in the river basin management plans for the third planning period (figure 3.4) (data downloaded from https://miljoegis.mim.dk/spatialmap?profile=vandrammedirektiv3-2022)

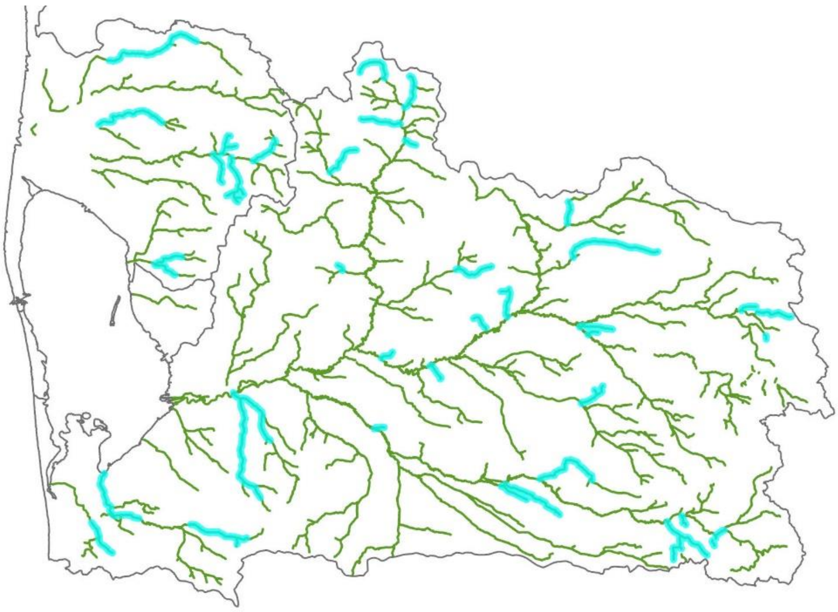


Figure 3.4. Location of proposed minor reach-based restorations in the river basin management plans for the third planning period.

3.6 Re-meandering of watercourses

Re-meandering of watercourses can be carried out with the aim of allowing the natural morphological processes of the watercourse to unfold (Miljøministeriet, 2021). Re-meandering results in a longer watercourse, whereby a larger bank area can be exposed to erosion. Furthermore, the bank erosion rate (number of mm of eroded bank per year) for streams on alluvial plains is significantly higher for meandering streams than for channelized streams

(Kronvang & Larsen, 2023). Meandering streams can therefore be supplemented by raising the stream bed, changing the slope of the bank or planting trees on the bank to reduce bank erosion.

The relative effect on phosphorus loss by bank erosion of a re-meandering of the watercourse is calculated according to Andersen & Nilsson (2023) by comparing the phosphorus loss before and after re-meandering. The relative effect is applied to the pre-calculated phosphorus loss from bank erosion on the reach (calculated in Andersen & Heckrath, 2020). Information on landscape type, river width and the length of the river section to be re-meandered is required. In this project, the effect of ee-meandering rivers is calculated for six combinations of landscape type and river width: moraine and alluvial plain rivers, respectively, divided into small rivers (0-2 m), medium-sized rivers (2-10 m) and large rivers (greater than 10 m). It is assumed that the degree of meandering is 1.4, that bank construction before re-meandering is 1:1, while after re-meandering it is 1:1.25 and with construction on the inside of meander bends at 1:3, and that the river bed is raised 40 cm.

In principle, re-meandering can be carried out on all straightened watercourses. The proposed measures in the river basin management plans for the third planning period (figure 3.5) (data downloaded from https://miljoegis.mim.dk/spatialmap?profile=vandrammedirektiv3-2022)

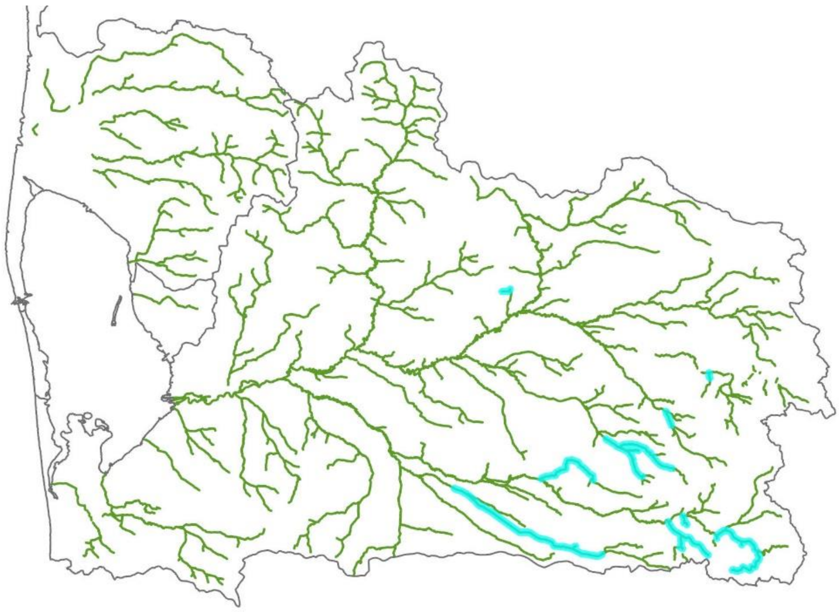


Figure 3.5. Location of proposed re-meandering of watercourses in the river basin plans for the third planning period.

3.7 Mini-wetlands

Open water surface mini-wetlands are a drainage remedy used as an *end-of-pipe solution* that is established on an area immediately before the drain outlet. Phosphorus in both dissolved and particle-bound form can be added to the drainage water via leaching and transport through macropores. An open mini-wetland consists of a sedimentation basin followed by a basin with alternating deep and shallow vegetation zones. The current design shows a good effect on phosphorus retention. Hoffmann et al. (2020) state a retention of 25-65% of the applied total phosphorus.

Risk areas for phosphorus loss via leaching to drains and via macropores to drains are mapped in Andersen & Heckrath (2020). The Department of Agroecology, Aarhus University, has prepared a potential map for the Danish Agricultural Agency showing areas where mini-wetlands can be established (Børgesen et al., 2019). The potential map for mini-wetlands is overlaid with the map showing areas with phosphorus leaching to sinks and the map showing areas where phosphorus loss occurs via macropores to sinks. In the maximum scenario, it is assumed that all phosphorus loss with leaching and via macropores within the potential mini-wetland area can be treated in mini-wetlands with the above treatment effect. The potential for mini-wetlands amounts to approx. 31,000 ha in the catchments of Ringkøbing Fjord.

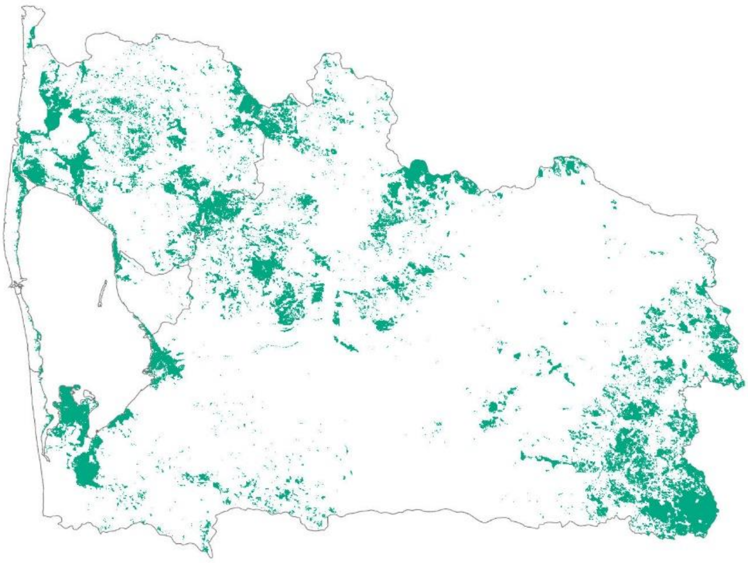


Figure 3.6. Potentially suitable areas for the establishment of mini-wetlands.

3.8 Integrated Buffer Zones (IBZ)

Integrated Buffer Zones (IBZ) are a drainage tool used in the riparian zone along ditches and streams and around lakes to intercept drainage water and any surface runoff from sloping fields. An IBZ consists of a deeper ditch and a shallow infiltration zone. The integrated buffer zone works by allowing the drainage water and any surface runoff from the field to pass through the open water part of the IBZ, extending the residence time of the water and allowing particle-bound phosphorus to be retained by sedimentation. In addition, dissolved phosphate can be taken up by plants and trees in the IBZ and adsorption of dissolved phosphate to free binding surfaces in the plant sediment can occur. Some of the drainage water from the open water part of the IBZ can infiltrate through a constructed infiltration zone, where the water seeps and flows through the soil in the edge zone behind the IBZ towards watercourses.

IBZ systems can be seen as a supplement to mini-wetlands, as they can typically be established on smaller drainage systems (<25 ha) and where there is a reasonably large slope on the field (>4) in the lower part towards streams and lakes. Kronvang et al. (2020) estimate that an IBZ system can retain 30-70% of the applied phosphorus. The potential for installing IBZ systems has been assessed by the Institute for Agroecology (Heckrath, G., pers. comm.) and amounts to approx. 100 ha in the catchment area of Ringkøbing Fjord.

3.9 GLM 5

With the implementation of the 2023-27 EU agricultural reform (CAP), new GAEC (Good Agricultural and Environmental Condition of Agricultural Land, 'GLM' in Danish) requirements apply, which are subject to conditionality (the current cross-compliance requirement). These requirements can help limit the erosion risk from agricultural land. GLM 5 includes a plowing ban from October 1 to February 15 on mapped, contiguous areas of at least 0.75 ha within a field block with an estimated erosion rate of more than 7.5 tons of soil per hectare per year. Ceasing plowing on erosion-prone areas is assumed to reduce phosphorus loss with erosion by 50% (Munkholm et al., 2020). In the project, the GLM 5 areas are mapped and overlaid on mapped erosion risk areas. The GLM5 areas in the Ringkøbing Fjord catchment only amount to approx. 5 ha.

3.10 Phosphorus wetlands (P-valleys)

Phosphorus wetlands or P-valleys are areas along watercourses that are established with the purpose of retaining suspended solids and particulate phosphorus via sedimentation when the areas are flooded by river water during large runoff events. The measure is primarily intended to be used upstream of lakes where there is a need to reduce phosphorus inputs to improve the ecological status of the lake. The criteria for the construction of P-valleys are first and foremost that there are periods of high water flows in the river system in question, and secondly that there is knowledge of the amount and concentration of suspended matter in the river.

Sedimentation in riparian areas and river valleys is controlled by several factors: topography, sediment concentration, flood duration, number of floods, water exchange between river and flooded area, flow pattern in the flooded area and river morphology (geometry, slope, sinuosity). Hoffmann et al. (2020) provide guideline deposition rates of particle-bound phosphorus of 0.5-1.5 kg P per flooded hectare per day.

Currently, there is no mapped potential for phosphorus wetlands. A calculation of the effect thus requires local information on the minimum size of the flooded area and the duration of flooding.

3.11 Ochre precipitation plant

Ochre precipitation plants are dug ponds with an open water table or shallow, gravel-filled basins that are established on small watercourses in order to oxygenate dissolved ferrous iron and retain particulate ferric iron. Ochre precipitation plants has been established with support from the 1985 Ochre Act, and more than 100 plants have been established in ochre-potential runoff areas in Western and Southern Jutland (DHI, 2014). The plants typically have an area of 0.5 - 2.5 ha. Phosphorus transported in the river system can be retained together with particulate iron (ferric oxyhydroxides) in the plants, and thus they also reduce the transport of total phosphorus to downstream recipients. Ochre precipitation systems are related to mini-wetlands and, like these, can be positioned to collect drainage runoff. The effect on phosphorus transport reduction is 140 kg P ha^{-1} $year^{-1}$ (Andersen et al., 2020). A review of published ochre removal systems shows an average size of a system of 1.0 ha. This size is used in the calculation of the phosphorus effect of ochre removal systems in this project.

Ochre precipitation systems are only established in ochre-potential areas such as low-lying soils in West and South Jutland. These areas are estimated at 300,000 ha, corresponding to 10% of Jutland's area (Kjærgaard and Forsmann 2014). The potential for establishing new ochre precipitation plants is based on the proposed measures in the river basin management plans for the third planning period, figure 3.7 (data downloaded from https://miljoegis.mim.dk/spatialmap?profile=vandrammedirektiv3-2022). In the catchment area of Ringkøbing Fjord, 15 ochre precipitation plants are planned.

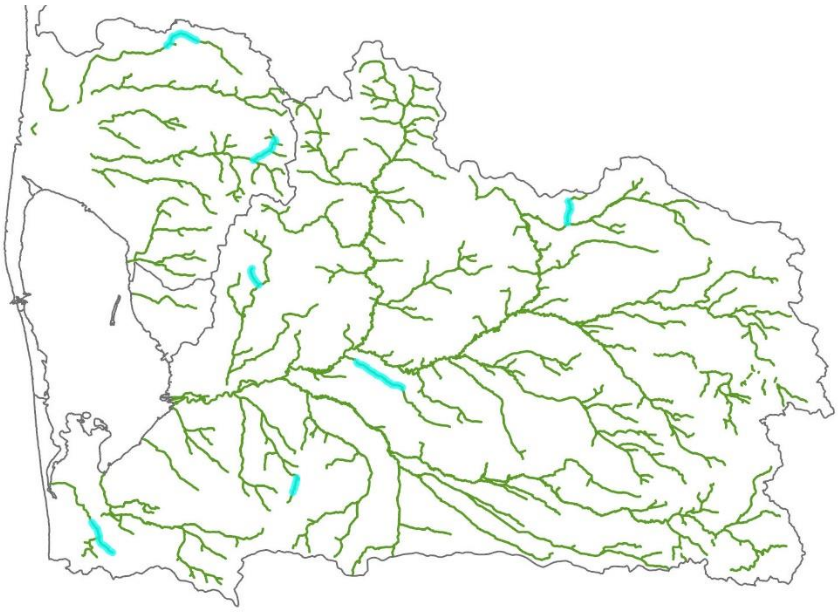


Figure 3.7. Planned location of ochre precipitation plants in the catchment area of Ringkøbing Fjord.

4 Calculation of effects of local policy scenario on wetlands, tree planting and mini-wetlands

4.1 Trees on river banks

A scenario has been set up with the placement of wetlands along some of the watercourses in the Ringkøbing Fjord catchment area (figure 4.1). The Coastal Water Council does not want trees planted along the watercourses within the wetlands. The scenario with wetlands and tree planting therefore includes tree planting on the small (type 1, width less than 2 m), medium-sized watercourses (type 2, width 2 - 10 m) and large watercourses (type 3, width greater than 10 m) outside the wetlands. Tree planting is assumed to occur on 10% of these streams, prioritizing the areas where bank erosion is highest.

The watercourses outside the scenario wetlands are found by an overlap analysis in GIS. Bank erosion in all Danish watercourses is mapped in Andersen & Heckrath (2020) on 100 m watercourse sections. Furthermore, the vegetation in a 2 m zone on each side of the watercourse is mapped and divided into low vegetation (grass, herbs, small shrubs) and high vegetation (trees). The potential for tree planting on riverbanks is thus made up of the river stretches where there is currently low vegetation. Calculation of the effect of tree planting follows Kronvang & Larsen (2023). The effect of trees is a reduction in bank erosion of 27-53%. The small, medium and large streams outside the wetlands are sorted by decreasing magnitude of bank erosion. The effect of trees is calculated for the 10% streams with the highest bank erosion.

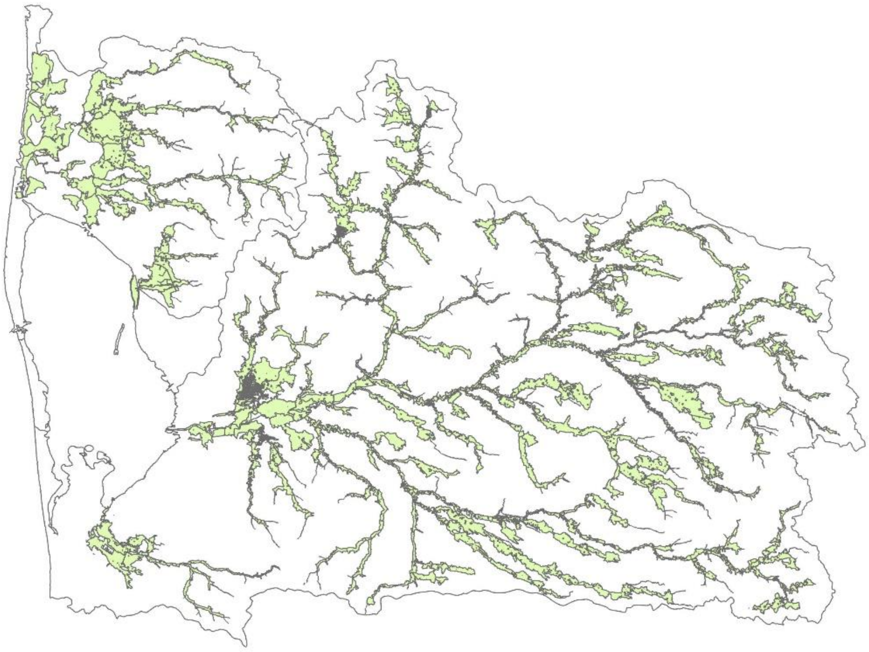


Figure 4.1. Location of the planned riparian wetlands in the catchment area of Ringkøbing Fjord.

4.2 Phosphorus wetlands (P-valleys)

It is assumed that 25% of the wetlands in the local scenario are constructed as phosphorus wetlands. That is, wetlands designed in such a way that the watercourse is allowed to periodically flood the areas close to the watercourse, thereby depositing sediment-bound phosphorus.

As mentioned above (section 3.10), calculating the effect requires local information on the minimum size of the flooded area and the duration of flooding. To calculate the effect, a number of assumptions have been made here:

Based on a mapping of the amount of suspended matter in Danish watercourses (Thodsen et al., 2019), a phosphorus sedimentation rate of 1.0 kg P ha^{-1} day^{-1} has been assumed. According to Hoffmann et al. (2020), the size of the flooded area close to the watercourse is assumed to be 25 m, 75 m and 100 m on each side of small, medium and large watercourses, respectively. However, based on empirical studies, these widths should be reduced by 25%, as there may be relatively higher areas adjacent to the watercourse that are not flooded (B. Kronvang, pers. comm.). The duration of flooding is set here to 15 days, which is a conservative estimate relative to Hoffmann et al. (2020).

The length of watercourses within the wetlands is found by an overlap analysis in GIS. The width of the streams is mapped in advance. The phosphorus retention by deposition during flooding is first calculated for all wetlands. The final effect is then found as 25% of the total effect, as it is not known which wetlands are constructed as phosphorus wetlands.

4.3 Sand traps and ochre precipitation systems

In a local scenario, 18 sand traps with a total area of 2640 m^2 and 14 ochre removal plants with a total area of 195,670 m^2 are planned.

5 Results

5.1 Source apportionment

The total phosphorus input to Ringkøbing Fjord averaged 112.1 tons P annually over the period 2016-2018, of which diffuse inputs account for 83.5 tons P or 74% (Table 5.1).

Table 5.1. Overall source breakdown of phosphorus input to Ringkøbing Fjord. Average for the period 2016-2018.

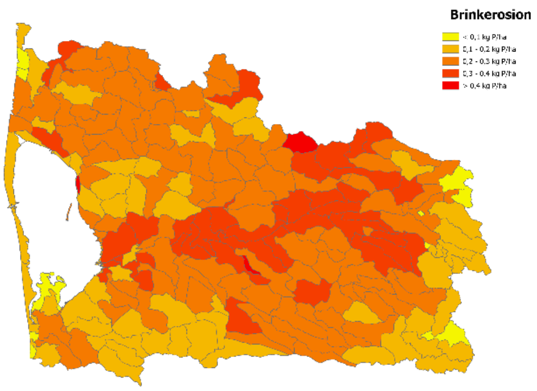
Total supply	112.1 tons P
Point sources	25.3 tons P
Contribution from sprawl	3.4 tons P
Diffuse contribution	83.5 tons P

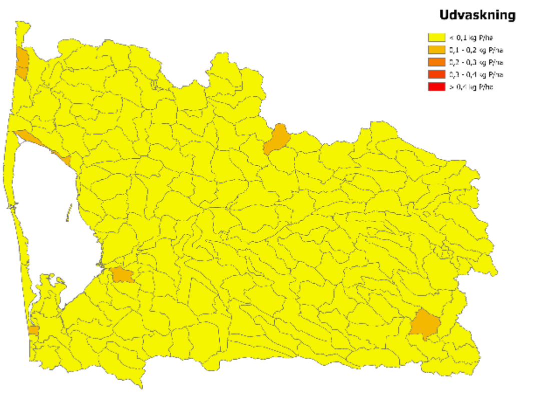
The diffuse input is further broken down into the five most significant transport pathways, which together account for 94% of the diffuse input (table 5.2).

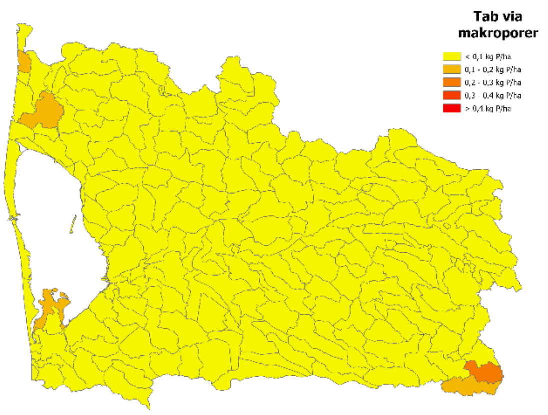
Table 5.2. Breakdown of the diffuse input to Ringkøbing Fjord in the period 2012-2021 on the most significant transport pathways.

		Share of total diffuse input
Loss via macropores to tile drains	1.6 tons P	2 %
Leaching to tile drains	4.4 tons P	5 %
Erosion	2.3 tons P	3 %
Losses from cultivated, drained organic soil	20.4 tons P	24 %
Bank erosion	49.7 tons P	60 %

Figure 5.1 shows the phosphorus losses along the five transport pathways at ID15 catchment level. The losses are area-weighted (kg P/ha) and shown with the same legend to facilitate comparison between transport pathways and catchments.


Brinkerosion
< 0,1 kg P/ha
0,1 - 0,2 kg P/ha
0,2 - 0,3 kg P/ha
0,3 - 0,4 kg P/ha
> 0,4 kg P/ha


Udvaskning
< 0,1 kg P/ha
0,1 - 0,2 kg P/ha
0,2 - 0,3 kg P/ha
0,3 - 0,4 kg P/ha
> 0,4 kg P/ha


Tab via makroporer
< 0,1 kg P/ha
0,1 - 0,2 kg P/ha
0,2 - 0,3 kg P/ha
0,3 - 0,4 kg P/ha
> 0,4 kg P/ha

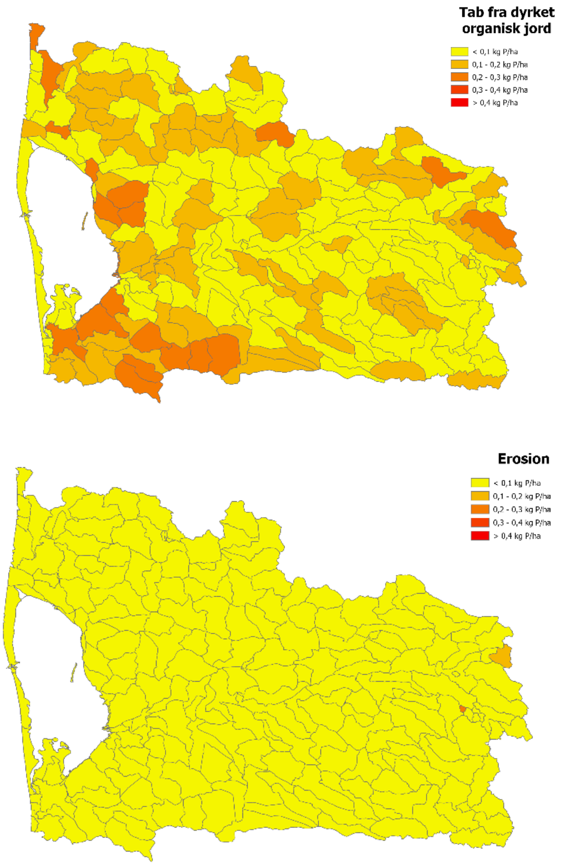


Figure 5.1. Area-weighted loss of phosphorus (kg P/ha) via bank erosion, leaching, macropores, cultivated organic soil and erosion at the ID15 catchment level.

5.2 Effects of measures against diffuse phosphorus loss when fully utilizing the potential of the measures

Reduction in diffuse phosphorus loss by full utilization of the potential for mitigations measures is calculated for all measures and calculated at ID15 level. This data is aggregated in Table 5.3 and shown at the Farvand 4 level. Figure 5.2 shows the division of the Ringkøbing Fjord catchment area into Farvand 4 catchments. The Ringkøbing Fjord catchment is subdivided into three Farvand 4 catchments: no. 1321, no. 1322 and no. 1323.

Table 5.3. Reduction in diffuse phosphorus loss by full utilization of potential remedies calculated at Farvand 4 level.

	1321	1322	1323
	P tons	*P tons*	*P tons*
Afforestation	0,02	0,01	0,5
20 m perimeter zones	0,02		0,05
GLM 5	-	-	-
Trees along watercourses < 2m	1,2	0,1	4,0
Trees along watercourses 2 - 10 m	4,3	0,3	22,0

Trees along watercourses > 10 m	0,3	-	2,7
IBZ	-	-	-
Mini wetlands	0,2	-	0,9
Raise the riverbed	0,4	-	2,4
Re-looping	-	-	0,4
Sand trap	0,02	-	0,1
Ochre precipitation plant	0,3	-	1,8

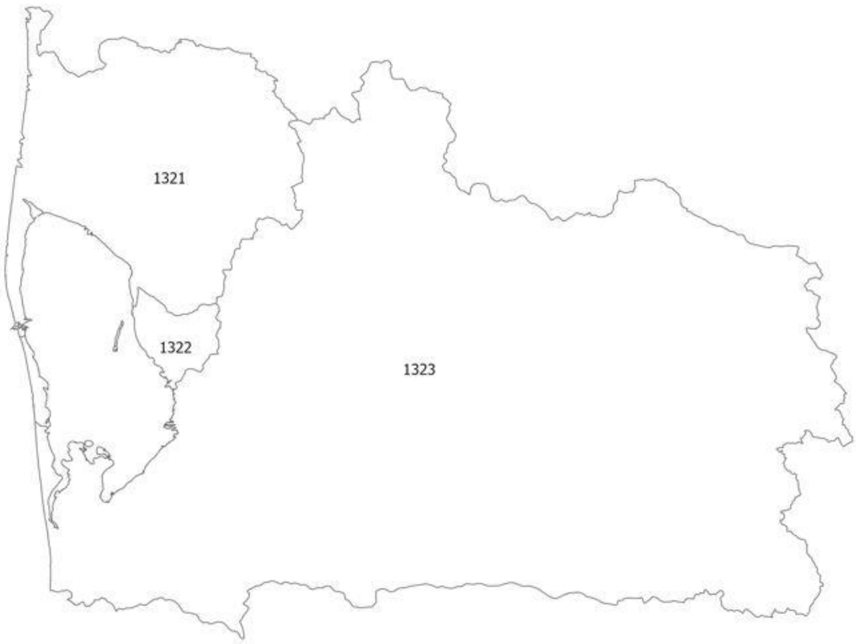


Figure 5.2. The catchment area of Ringkøbing Fjord subdivided into Farvand 4 catchments.

5.3 Effects of local policy scenarios

Table 5.4 contains the results of the calculation for the policy scenario with tree planting along 10% of the small, medium and large watercourses outside wetlands. In total, an effect of approximately 5.2 tons of P can be achieved.

Table 5.4. Results of calculations for local policy scenario with tree planting along all wa- the small, medium and large watercourses outside wetlands.

Watercourse type	Total length km	Length outside wetlands	Effect of trees along 10% of the watercourses outside wetlands
Type 1 (< 2 m)	1852 km	1237 km	1.4 tons P
Type 2 (2 - 10 m)	2404 km	1024 km	3.2 tons P
Type 3 (> 10 m)	269 km	42 km	0.6 tons P

Table 5.5 contains the results of the calculation for the local policy scenario, where it is assumed that 25% of the planned wetlands are constructed as phosphorus wetlands with periodic flooding of the areas close to the watercourse. In total, an effect of approx. 79.7 tons of P has been calculated. Two strong reservations about the effect calculation should be mentioned: Firstly, it should be noted that the effect is calculated on the assumption that the flooding is achieved by raising the riverbed. If river meandering is also included in the formation of the phosphorus wetlands, the effect of the phosphorus wetland is reduced. This is because bank erosion in meandering allluvial streams is significantly greater than in channelized streams (Kronvang & Larsen, 2023). If the phosphorus wetland is formed by a combination of meandering and raising the riverbed, the effect is therefore reduced to approx. 60% of the effect of the phosphorus wetland alone for type 1 streams. For type 2 and type 3 watercourses, 80 - 85% of the phosphorus wetland effect alone is achieved if re-meandering in combination with raising the riverbed is included in the formation of the wetland. Secondly, the large amount of phosphorus wetlands as planned here will 'shadow' each other, as the effect of phosphorus wetlands downstream of other phosphorus wetlands in the same river system will be smaller, as there is less phosphorus in transport in the river than there would be without the upstream phosphorus wetlands. In practice, a maximum effect of around 20 tons of P annually should probably be expected from the phosphorus wetlands in the Ringkøbing Fjord catchment area.

Table 5.5. Results of calculations for local policy scenario where it is assumed that 25% of the wetlands are constructed as phosphorus wetlands with periodic flooding of the areas close to the watercourse.

Watercourse size	Effect if 25% of the planned wetlands are established as phosphorus wetlands
Type 1 (< 2 m)	8.6 tons P
Type 2 (2 - 10 m)	58.2 tons P
Type 3 (> 10 m)	12.8 tons P

Table 5.6 contains the results of the calculation for the local policy scenario, where it is assumed that 18 sand traps and 14 ochre precipitation systems are installed. In total, an effect of approx. 3.2 tons of P is calculated.

Table 5.6. Results of the calculation of the local measure scenario where it is assumed that 18 sand traps and 14 ochre removal systems are installed.

	Total area	Overall effect
18 sand trap	2630 m^2	0.4 tons P
14 ochre plants	195.670 m^2	2.7 tons P

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